CLEANER AIR FOR LONDON

London Atmospheric Emissions Inventory 2010

Methodology Document

MAYOR OF LONDON

Transport for London

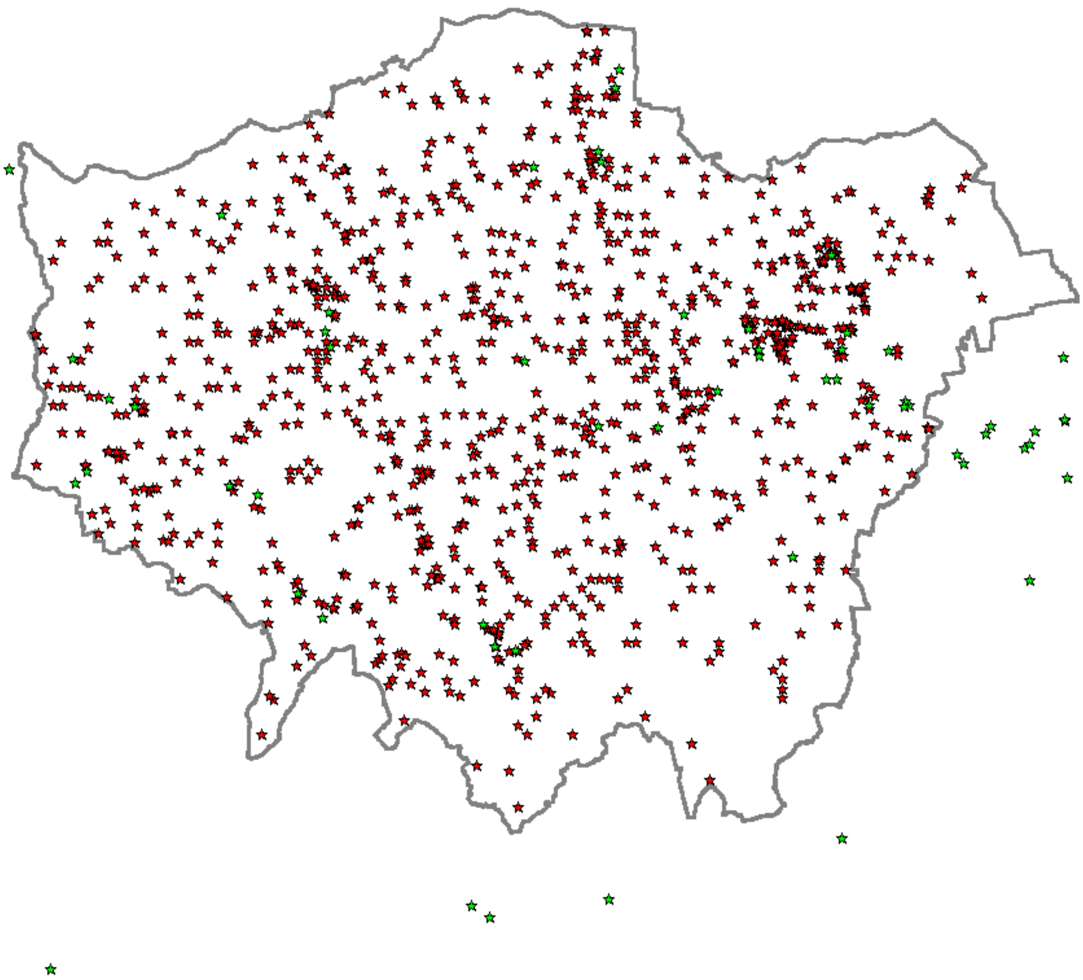
Contents

The LAEI Methodology

The LAEI is a database of geographically referenced datasets of pollutant emissions and sources in Greater London and up to the M25 motorway ring. The base year for the current LAEI is 2010, with a back projection to 2008 and forward projections to 2012, 2015 and 2020. This document sets out the methodology for calculating the emissions in the inventory. Detail has only been given where there has been a change in methodology compared to the LAEI 2008. Where the method remains unchanged this has been stated.

Methodology for Calculating Point Sources Emissions

Figure 1 Map showing Part A (Green) and Part B (Red) Industrial Point Source emissions in the LAEI



Part 'A' Processes Emission Calculation Methodology

Base Year 2010

- Emissions estimates for Part A processes in the LAEI 2010 were obtained from the Environment Agency 2010 Pollution Inventory (PI 2010).

Projections Years 2012, 2015, 2020

- Future years are assumed to be the same as 2010.

Emissions estimates for Part A processes in the LAEI 2010 were obtained from the Environment Agency 2010 Pollution Inventory (PI 2010). As was the case with the LAEI 2008 (that made use of PI 2007), a small number of sites have closed or been removed from the inventory, many have been retained with the same data, some new sites have been included and there were several sites for which information was no longer available in PI 2010. The latter group were assumed to have the same emissions and supporting data as in PI 2007.

Part 'B' Processes Emission Calculation Methodology

Base Year 2010

- London Boroughs provided an updated list of the location and number of processes for 2010. Throughput information however remains at the same levels as in the LAEI 2008.

Projection years 2012, 2015 and 2020

- Future years are assumed to be the same as 2010. Back calculations for 2008 used an appropriate list of processes and locations from the updated borough information.

London Boroughs provided an updated list of the location and number of processes in their areas for 2010, but not throughput information. Throughput data from LAEI 2008 was used, however some of this information dates back to LAEI 2006. New processes in LAEI 2010 were assumed to have the same annual emissions as comparable processes that pre-existed in the LAEI.

Two process methodologies were reviewed in light of new available data

- Blending, packing, batching and /or loading of bulk cement (PM_{10})
- Waste Oil Burners

Blending, Packing, Loading, Unloading and Use of Bulk Cement, (PG 3/01)
The previous method used in the LAEI 2008 was based on US EPA (United States Environmental Protection Agency) AP42 reference material. This included emission factors for a number of different activities within this source: silo loading/unloading, hopper loading and truck loading. There are emissions factors for controlled and uncontrolled activities. There are also emissions factors for aggregate handling.

The drawback of using the US EPA data is that there is limited information on the sources, and consequently it is difficult to decide between controlled/uncontrolled emission factors or truck/mixer loading. Both of these decisions make a large impact on the resulting emission estimate.

Given the levels of uncertainty associated with the throughput input data, the US EPA methodology is considered overly detailed. Therefore LAEI 2010 uses information from the EMEP/EEA Emissions Inventory Guidebook[12]. This is the central reference for air quality emission inventories in Europe.

This method gives lower emissions for the LAEI 2010 compared to the LAEI 2008 based on US EPA methods (see **Table 1**), but has the advantage of being more consistent with other calculations in European emission inventories.

This method does not consider emissions from storage of materials, or emissions from transportation.

Table 1 - Blending, Packing, Batching and /or Loading of Bulk Cement – Comparison LAEI 2010 / LAEI 2008 Emissions (tonnes per annum)

	PM_{10}	PM	NMVOC
LAEI 2008	2.50	5.00	0.16
LAEI 2010	1.22	2.44	0.16

Waste Oil and Recovered Oil Burners less than 0.4MW, (PG1/01)
As in LAEI 2008, an average throughput of $5m^3$ waste oil per annum has been assumed for the LAEI 2010. US EPA AP42 Section 1.11 – Space Heater (vaporizing burner) emissions factors only were used with A and S factors of 1 and 2 respectively. Changes in overall emissions are provided in **Table 2** below.

Table 2 – Waste Oil and Recovered Oil Burners - Comparison LAEI 2010 / LAEI 2008 (kg per annum)

	SO_2	NOx	CO	CO_2	PM_{10}
LAEI 2008	0.40	10.00	1.00	14,800	0.30
LAEI 2010	120.00	6.60	1.02	13,200	1.68

Boiler Emission Calculation Methodology

Base Year 2010

- Because of lack of new information on activity, this source sector was assumed to be the same as in the LAEI 2008, which originally relates back to 1997 datasets. However, more recent information on pollutant emissions (i.e. new emissions factors from EMEP/EEA) have been employed, which generally give higher pollutant emissions for the boilers compared to the LAEI 2008.

Projections Years 2012, 2015, 2020

- Future years are assumed to be the same as 2010.

Activity data (i.e. fuel type, and fuel usage expressed as litres/year) is the same as in the LAEI 2006 and the LAEI 2008. However, the LAEI 2008 contained 39 additional boilers compared to the LAEI 2006. These contained no fuel type or usage data but had an annual tonnage for CO_2 emissions attributed to them.

The Emission Factors in the LAEI 2008 were from the UK Emission Factor Database (EFD), and expressed as tonnes pollutant/m^3 of fuel. The LAEI 2008 uses a 'Tier 1' approach, as follows:

tonnes pollutant emitted / year = (Litres of fuel /year x tonnes pollutant /fuel m^3) / 1000

For the LAEI 2010, the latest pollutants Emission Factors were derived from EMEP/EEA Emissions Inventory Guidebook[12]. These are not expressed as tonnes pollutant/m^3 fuel. Instead, they are expressed as g pollutant/GJ of energy. In modern emission inventories, it is useful to know the kW or MW of the combustion plant as a definition of the activity. However, the LAEI 2008 did not contain this information. Therefore, a slightly different calculation is necessary to get the total tonnes pollutant/year emitted when using the Emission Factors from EMEP/EEA.

For the LAEI 2010, firstly, further details on the different fuel types listed in the LAEI 2008 were collated i.e. their densities and net (inferior) calorific values (Table A. 1. In the Appendix). If density/calorific value were unavailable, the fuel was assumed to have the same characteristics as for gas oil.

The EMEP/EEA does not distinguish between residual oils Heavy Fuel Oil (HFO) and Medium Fuel Oil (MFO), nor between the various distillates oils, each is given the same g pollutant/GJ of energy Emission Factor (Table 3). Differences in the total, annual tonnes pollutant/annum emitted arise because of different assumptions on calorific value of the different fuels i.e. amount (mass or volume) of fuel burnt to generate 1 GJ of energy.

Table 3 - EMEP/EEAEFs (as g pollutant/GJ of energy) used in LAEI 2010– Residual and Distillate Oils

SO_2	NO_X	CO	NMVOC	PM/TSP	PM_{10}	$PM_{2.5}$
140	100	40	10	140	21.5	16.5

Also noteworthy is that S (sulphur) content of fuels assumed in the LAEI 2008, and EMEP/EEA are different, as shown in Table 4 below.

Table 4 - Sulphur Content of Fuels

	Residual oils	**Distillates**
S content assumed in LAEI 2008	2.5%	0.2%
EMEP/EEA assumption, used in LAEI 2010	0.3 - 1%	0.1% Red diesel 0.001%

From g pollutant/GJ of energy, there is a need to derive the g pollutant/m^3 of fuel used.

The method is as follows:

g pollutant/m^3 of fuel = (g pollutant/GJ energy) x net inferior calorific value of the fuel (as GJ/m^3 of fuel)

The calorific value of the fuel is usually given as GJ/tonne of fuel. The density of the fuel is required to convert GJ/tonnes of fuel to GJ/m^3 of fuel.

It is then possible to compare the newly-derived Emission Factors for various fuels (as tonne pollutant /m^3 fuel) against those assumed in the LAEI 2008 inventory (see Table 5 and Table 6 below). The new emission factors are used in the LAEI 2010, coupled with the old LAEI 2008 activity data (litres fuel/annum). The new LAEI 2010 emission factors for Residual Oils are higher for all pollutants aside from NOx and PM10. For Distillate Oils the new LAEI 2010 emissions factors are higher for all pollutants.

Table 5 - Residual Oils: Tonnes pollutant/m³ of Fuel

Residual oils	Inventory	SO_2	NO_X	CO	NMVOC	PM/TSP	PM_{10}	$PM_{2.5}$	Benzene	Methane	CO_2
Heavy fuel oil HFO, heavy oil	LAEI 2010	0.00537	0.0038	0.0015	0.00038	0.0054	0.0008	0.00063	-	-	-
	LAEI 2008	0.00047	0.0066	0.0006	0.000136	0.00347	0.0021514	-	0.000000026	0.000057	3.11667
Medium fuel oil	LAEI 2010	0.00589	0.0042	0.0015	0.00042	0.0059	0.0009	0.00069	-	-	-
	LAEI 2008	0.00047	0.0066	0.0006	0.000136	0.00347	0.0021514	-	0.000000026	0.000057	3.11667

Table 6 - Distillate Oils: Tonnes pollutant/m³ of Fuel

Distillates	Inventory	**SO_2**	**NO_X**	**CO**	**NMVOC**	**PM**	**PM_{10}**	**$PM_{2.5}$**	**benzene**	**methane**	**CO_2**
Kerosene	LAEI 2010	0.00484	0.00346	0.00138	0.000346	0.00484	0.000743	0.00057	-	-	-
	LAEI 2008	0.000034	0.0024	0.0006	0.000041	0.00024	0.000132	-	0.000000026	0.000026	3.14233
Gas oil	LAEI 2010	0.00507	0.0036	0.00145	0.000362	0.00507	0.00078	0.00059	-	-	-
	LAEI 2008	0.000034	0.0024	0.0006	0.000041	0.00024	0.000132	-	0.000000026	0.000026	3.14233
Diesel	LAEI 2010	0.00498	0.00356	0.00142	0.000356	0.00498	0.000765	0.000587	-	-	-
	LAEI 2008	0.000034	0.0024	0.0006	0.000041	0.00024	0.000132	-	0.000000026	0.000026	3.14233
Red diesel	LAEI 2010	0.004168	0.00298	0.00119	0.000298	0.004168	0.00064	0.000491	-	-	-
	LAEI 2008	0.000034	0.0024	0.0006	0 .000041	0.00024	0.000132	-	0.000000026	0.000026	3.14233
Marine gas oil	LAEI 2010	0.00514	0.00376	0.00147	0.000367	0.00514	0.000789	0.000606	-	-	-
	LAEI 2008	0.000034	0.0024	0.0006	0.000041	0.00024	0.000132	-	0.000000026	0.000026	3.14233

Methodology for Calculating Emissions from Area Sources

Figure 2 Map showing Area Source emissions in the LAEI

Gas Usage and Leakage

Base Year 2010

- Atmospheric emissions from gas consumption and gas leakage for the 2010 base year were calculated from the 2010 MLSOA level Electricity and Gas Consumption datasets (gas consumption data at regional and LA level) produced by DECC.

Projection Years: 2012, 2015 and 2020

- The 2010 gas consumption and leakage was calculated based on the reported MLSOA datasets produced by DECC. The projection factors for future years were derived from a statistical analysis of historical trends (gas consumption data at regional and LA level from 2005 to 2010) in gas sales from the domestic and industrial-commercial sectors in the Greater London area (using 2010 as the base year).

Gas Usage Emission Calculation Methodology

The 2010 gas sales and numbers of customers by region and Local Authority (LA) workbooks were obtained from the DECC website[1]. The Department for Business Innovation and Skills (DBIS) collects and compiles estimates of gas consumption at regional (NUTS1) and LA level (NUTS4) using base data at meter point level from the re-structured gas distribution network.

Separate workbooks are provided by DECC for gas consumption divided between domestic consumption and industrial-commercial consumption. Each workbook contains information for every Middle Layer Super Output Area (MLSOA) on the total gas consumption (given in kWh for the entire year), the number of meters and the average consumption levels. Details about how the information on electricity and gas consumption has been collected and collated can be found in DECC's Guidance note for the DECC MLSOA/IGZ and LLSOA electricity and gas consumption data[2].

DECC's sub LA gas consumption estimates at MLSOA level in the Greater London area for 2010 were used to calculate atmospheric emissions from gas consumption in the LAEI 2010. In order to produce local gas consumption statistics for 2010 at the $1km^2$ spatial resolution the data was first entered into an excel spreadsheet. There were some circumstances where for confidentiality or other reasons the data for some MLSOA's data was combined. On these occasions the data for the combined MLSOAs was divided between the individual MLSOA's based on the area ratio of each MLSOA within its LA.

Atmospheric emissions from gas use are dependent on emission factors, the amounts of gas used and also the temperature and efficiency of combustion. The latter factors of temperature and efficiency of combustion have not been directly considered in the LAEI 2010 emission methodology. The updated 2010 emission factors shown below were obtained from the UK Emissions Factor Database[3] and were used in calculating the emissions from the gas demand data. In order to see at a glance the changes between the emission factors in the LAEI 2008 and the LAEI 2010 both sets of data have been provided. The user should note the large difference between the NOx emission factors used in the LAEI 2008 and the LAEI 2010. These differences are due to a change in methodology used by the National Atmospheric Emissions Inventory (NAEI)[4] to calculate NOx therefore they should not be used to develop a time-series. The NAEI 2008 NOx emission factor for domestic combustion of natural gas was based primarily on the EMEP/CORINAIR factor for boilers <50KWth of 70 g/GJ, adjusted slightly to account for non-boiler technologies in the sector. However the NAEI 2009 methodology was revised to account for newer boiler technologies and an emission factor of 23 g/GJ was estimated for the domestic boiler population in 2008, based on factors derived from emission limit values set out in the EuP (Energy-using Products Directive) and EN 483 standard. The NAEI 2010 factor quoted below uses the improved methodology developed, and therefore should be used in preference to the NAEI 2008 factor.

Below is the formula used for calculating annual atmospheric emissions of a pollutant from gas consumption data in each MLSOA:

$$AE_{p,j} = EF_{s,p} * GC_{s,j} * 10^{-3}$$

[1] http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/regional/gas/gas.aspx

[2] http://www.decc.gov.uk/assets/decc/statistics/regional/mlsoa2008/1_20100325121429_e_@@_mlsoallsoaguidance.pdf

3 http://naei.defra.gov.uk/emissions/

[4] http://naei.defra.gov.uk/

Where:

AEp,j = Annual Emission of pollutant p in MLSOA j (tonne/yr)

EFs,p = Sector s Emission Factor for pollutant p (kg/kWh)

GCs,j = Gas Consumption for sector s in MLSOA j (kWh/yr)

10^{-3} = Conversion factor (kg to tonne)

MLSOA j = MLSOA area

Sector s = Domestic or Industrial- commercial

Pollutant p = CO_2, Methane, NOx, NMVOC, CO, Benzene and PM_{10}.

All the 2010 emission factors used in calculating and projecting gas demand, gas leakage and their associated emissions were obtained from the NAEI database. Where 2010 pollutant emission factors are not currently available it has not been possible to include them in the LAEI 2010. Details of the NAEI emission factors chosen are given below;

Domestic gas emission factors – NAEI 2010 selection was "Domestic combustion: Natural Gas", natural gas is taken as the main source of domestic gas as "town gas" (gas from coal) was more commonly used prior to 1960.

Industrial- commercial emission factors – NAEI 2010 selection was "Miscellaneous industrial/commercial combustion: Natural Gas"

Gas leakage emission factors – NAEI 2010 selection was "Gas leakage: Natural Gas Supply"

Table 7 – Comparison of Gas Emission Factors in LAEI 2008 and LAEI 2010 (from NAEI 2010)

Industrial- Commercial				
	LAEI 2008		LAEI 2010	
Pollutant	Kt mth-1 fuel consumed	Kg kWh-1	Kt mth-1 fuel consumed	Kg kWh-1
CO_2	5.41E+00	1.85E-01	5.50E+00	1.88E-01
Methane	5.27E-05	1.80E-06	5.30E-04	1.81E-05
NOx	5.60E-03	1.91E-04	5.70E-03	1.94E-04
NMVOC	2.34E-04	7.95E-06	2.40E-04	8.19E-06
CO	1.11E-03	3.79E-05	1.20E-03	4.09E-05
Black smoke	1.06E-05	3.60E-07		
Benzene	2.13E-05	7.28E-07	2.10E-05	7.17E-07
PM10	8.06E-05	2.75E-06	9.20E-05	3.14E-06
Domestic 2008				
	LAEI 2008		LAEI 2010	
Pollutant	Kt mth-1 fuel consumed	Kg kWh-1	Kt mth-1 fuel consumed	Kg kWh-1
CO_2	5.41E+00	1.85E-01	5.50E+00	1.88E-01

Methane	5.27E-04	1.80E-05	5.30E-04	1.81E-05
NOx	7.30E-03	2.49E-04	2.30E-03	7.85E-05
NMVOC	2.34E-04	7.97E-06	2.40E-04	8.19E-06
CO	3.25E-03	1.11E-04	3.20E-03	1.09E-04
Black smoke	1.05E-05	3.58E-07		
Benzene	2.10E-05	7.18E-07	2.10E-05	7.17E-07
PM_{10}	5.27E-05	1.80E-06	5.30E-05	1.81E-06
Gas Leakage 2008				
	LAEI 2008		LAEI 2010	
Pollutant	Kt mth-1 fuel consumed	Kg kWh-1	Kt mth-1 fuel consumed	Kg kWh-1
CO_2			3.01E-02	1.03E-03
Methane	7.70E-01	2.63E-02	8.00E-01	2.73E-02
NMVOC	1.50E-01	5.12E-03	1.40E-01	4.78E-03
Benzene	1.67E-03	5.70E-05	1.60E-03	5.46E-05

Gas Leakage Emission Calculation Methodology

Gas leakage covers emission of CO_2, methane, benzene, and NMVOC from the local distribution network in the LAEI study area. Gas leakage to air from a distribution network is dependent on a number of factors including:

- Type and condition of the gas pipeline;
- Pressure in the network;
- Soil permeability;
- Number of service customers; and
- Accidental pipe ruptures by contractors and excavation work

There has not been an update regarding the level of gas leakage from the Local Distribution Network in the Greater London area since the LAEI 2008, therefore the same gas leakage level of around 0.65% of the gas demand figures for each MLSOA is assumed in the LAEI 2010. Care should be exercised in using and interpreting the amount of gas leakage (in kWh) estimated by this simplified methodology since the gas demand dataset contained gas demand after the gas has reached the customers' meters (when most gas leakage from the distribution network would have already taken place at several points along the supply chain). Consequently, the amount of gas leakage estimated by using the aforementioned methodology would be different to the actual amount of gas leaked from the distribution network before the gas reached the customers' meters. Furthermore, the inherent limitations in the accuracy of meters used at various points of the chain supply; differences in the methods used to calculate flow of gas in energy terms; differences in the temperature and pressure between the various points at which gas is measured; differences in the timing of reading meters; and other losses from the distribution network means the actual amount of gas leakage in the LAEI area is inevitably subject to large uncertainties.

It was assumed that all natural gas lost from the distribution network would enter the atmosphere. It was also assumed that some gas lost underground might be partially or completely absorbed by the soil and consumed by bacterial action. However, there were no reliable estimates of the significance of such a process for the distribution network, so it was assumed negligible.

Projection Years: 2012, 2015, 2020

Projections of atmospheric emissions from gas demand and gas leakage were based on an analysis of historical trends in gas sales obtained from DECC's website[5].

To calculate the reduction rates in gas demand from the domestic and industrial sectors in the Greater London area using a 2010 base, the linear yearly reduction between 2005 and 2010 was calculated based on the information in Table 8 below. This gave an annual reduction of 3.2% for domestic use and 3.5% for industrial-commercial use. This reduction was applied to all future years 2010 to 2020 and the ratio of the change between the future year and the 2010 baseline was used to calculate the future gas use in GWh (see Table 9).

Table 8 - Historical Gas Consumption Data

Years	Domestic Consumers	Commercial and Industrial consumers	Domestic Change %	Commercial Change %
	Gas Sales (GWh)			
2005	52,635	27,214	-	-
2006	50,943	26,007	-3.2%	-4.4%
2007	49,921	24,429	-2.0%	-6.1%
2008	48,528	24,272	-2.8%	-0.6%
2009	44,939	22,448	-7.4%	-7.5%
2010	44,701	22,722	-0.5%	1.2%

[5] http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/regional/gas/gas.aspx

Table 9 - Future Year Gas Use Predictions based on a 2010 Baseline

Years	Domestic Consumers	Commercial and Industrial consumers
	Gas Sales (GWh)	
2010 baseline	44,701	22,722
2011	43,268	21,928
2012	41,880	21,161
2013	40,537	20,422
2014	39,237	19,708
2015	37,979	19,019
2016	36,761	18,354
2017	35,582	17,713
2018	34,441	17,093
2019	33,337	16,496
2020	32,268	15,919

Coal and Oil

Base Year 2010

- Atmospheric emissions from coal consumption the 2010 base year were calculated from the 2009 DECC data on the sub-national consumption of other fuels.

Projection Years: 2012, 2015 and 2020

- Due to the small contribution to total emissions from this sources and the lack of reliable information for forecasting these sources were assumed to be the same as those in the base year.

Coal Emission Calculation Methodology

Coal and petroleum consumption from DECC's 2009 sub-national dataset[6] has been used at the LA level and distributed across the grid. Only the domestic sector petroleum consumption has been used in order to avoid double counting with the industrial and commercial Boiler sources.

Emissions factors from the NAEI 2010 have been used for Coal, Solid Smokeless Fuel (SSF) and Gas Oil. Different factors have been used for industrial & commercial combustion and domestic combustion. Where sources are in London, emissions factors for SSF have been used due to smoke control areas. The Gas Oil factors have been used for the oil calculations.

[6] http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/regional/other/other.aspx

Table 10 – Emissions Factors (Kt mth^{-1} fuel consumed) for Gas Oil and Solid Smokeless Fuel used in the LAEI 2010 (from NAEI 2010)

	Domestic combustion		Miscellaneous industrial/commercial combustion		
Pollutant	Gas Oil	Solid Smokeless Fuel	Gas Oil	Solid Smokeless Fuel	Coal
CO_2	870	770	870	770	610
Methane	0.45	5.8	0.45	0.011	0.011
SO_2	1.4	16	1.4	19	17
NOx	3.2	3.3	1.2	4.9	5.6
NMVOC	0.047	4.90	0.047	0.05	0.05
CO	1.8	130	0.16	49	8.6
Benzene	0.0024	0.22	0.0024	0.002	0.002
NO	0.027	0.12	0.027	0.15	0.15
PM_{10}	0.14	3.1	0.086	2.4	3.8

NRMM, Agriculture & Other Sources

Base Year 2010

- Various methods have been used, however generally 2010 data has been calculated as a fraction of the NAEI emission for that sub-sector based on the fraction of a relevant proxy for activity in the sub-sector.

Projection Years 2012, 2015, 2020

- Various methods have been used. Either base year data is considered not to change or suitable scaling factors have been obtained from national projections.

The Non-Road Mobile Machinery (NRMM), Agriculture & Other category (formally Agriculture and Nature) has been updated using revised methodologies and now includes emissions from NRMM as the primary sub-sector. The sub-sectors are as follows:

- Agriculture (Stationary and Machinery)
- Agriculture (Animals and General)
- Waste
- Natural (Forests)
- Household and Garden
- Construction and Demolition
- Fires

- NRMM Construction
- NRMM Industry

Agriculture (Stationary and Machinery)

Stationary Combustion and Off-road Machinery. Emissions from stationary combustion in agriculture arise from the need to heat buildings and greenhouses. Emissions from off-road machinery in the agriculture sector are caused by the use of portable or mobile equipment powered by diesel or petrol engines such as tractors, combine harvesters and chain saws. Centre for Ecology and Hydrology (CEH) land cover data[7] provides 1km resolution data for land cover which is classified as arable and improved grassland. This is used as a proxy for the spatial distribution of emissions from both stationary combustion in agriculture and off-road machinery. The latest available land cover data is for 2007 (released in July 2011).

The spatial pattern of emissions is assumed to be the same in all years for these sectors and it is also assumed that there will be no change in the amount of emissions in years after 2010. The total amount of emission in 2008 and 2010 is calculated as a fraction of the NAEI emission based on the fraction of UK arable and improved grassland land cover that is found within the LAEI boundary.

Agriculture (Animals and General)

Emissions from Animal Husbandry and Manure Management. Emissions of methane from enteric fermentation and particulate matter from housed livestock are mapped within the LAEI area using a combination of agricultural census data from Defra and CEH 1 km resolution land cover maps. The population of each animal type within the LAEI area is estimated based on Local Authority (LA) level agricultural census data8. For those LAs with partial coverage by the LAEI area, around the LAEI area boundary, a fraction of the total animal population is estimated based on the fraction of relevant CEH land cover type within the LAEI area for that LA. The land cover types that are matched with each of the livestock types are listed in

Table 11 below:

Table 11 – Land Cover Types

Animal type	CEH land cover type
Cattle	Improved grassland
Sheep	Improved grassland
Pigs	Arable & improved grassland
Poultry	Arable & improved grassland

The total emissions in 2008 and 2010 is calculated as a fraction of the NAEI emissions for that sub-sector (animal type), based on the fraction of UK animal population estimated for the LAEI

[7] http://www.ceh.ac.uk/LandCoverMap2007.html

[8] Local Authority level key land areas / livestock numbers / labour force: 2010 http://www.defra.gov.uk/statistics/files/defra-stats-foodfarm-landuselivestock-june-results-localauthority2010-120608.xls

area. The emissions within the LAEI area are divided between LA areas by animal population and at the 1km resolution within LA areas using the land cover distribution.

Emissions from horses are distributed using a different approach, because no animal population numbers are available at the LA level. Emissions are distributed using the CEH improved grassland distribution.

Emissions of ammonia (NH_3), methane (CH_4) and nitrous oxide (N_2O) from manure management are distributed using the maps generated for emissions from cattle (see above).

Emissions for years after 2010 are calculated based on published national emissions projections for detailed sub-sectors for agriculture[9] (Fapri data). Emission projection factors derived from the national data are applied to the detailed sub-sectors before aggregation.

Emissions from Fertilizer Use
Emissions from fertilizers arise from the use of both synthetic fertilisers and manure based fertilisers. Synthetic fertilizer emissions are mapped using the CEH land cover data for arable land. Manure based emissions are mapped by using the CEH land cover data for improved grassland.

The total amount of emission in 2008 and 2010 is calculated as a fraction of the NAEI emission based on the fraction of UK for the relevant land cover that is found within the LAEI boundary. It is assumed that there is no change in the amount or distribution of emissions after 2010.

Waste
Landfill Sites. A top-down methodology has been used to map fugitive emissions from landfills. This does not include emissions arising from landfill gas combustion, because this source is allocated to the power generation sector. NAEI emissions data at the national level is rescaled by population to give an emission estimate for London which is then be assigned to individual landfill sites.

A bottom-up approach was not possible because this would require very detailed information for each of the landfill locations – a long time series of the amount of waste gong to each site, the composition of the waste, management practices, the type of landfill site, and importantly the extent of methane recovery (which can reduce emissions to air by more than an order of magnitude). It would be a very lengthy process to obtain these data (if they exist), and also a substantial task to ensure consistency with the data that is used as input into the national scale calculations.

For the top-down approach, population is a good proxy for waste arising and emissions from landfill sites (when considered across a large geographical extent). So the UK emission totals from landfill were scaled by population (the LAEI area population as a fraction of the UK) to give an emission total that is considered to be representative of the total emission in the LAEI area.

This total emission is distributed across all landfill sites (active as well as closed) that had taken biodegradable waste, with emissions allocated in proportion to the area covered by the landfill site. This method assumes that the emission per square metre of landfill is the same irrespective of the age of the landfill. Importantly this approach ensures that emissions are not assigned to landfill that have only taken inert waste – which would not produce methane.

[9] http://archive.defra.gov.uk/evidence/economics/foodfarm/reports/fapri/GHG%20Paper%20(Dec%202010).pdf

Emissions for future years have been projected using population growth rates for London.[10]

Waste-Water Handling (Sewage Treatment Works). Sewage Treatment Works are Part A processes regulated by the Environment Agency with emissions reported in the Pollution Inventory. However, reported emissions for the sites are limited to only NH_3 for most sites, with most other pollutant emissions at levels below reporting thresholds. For consistency with the national inventory for this sector, emissions of CH_4 and N_2O are also presented for the LAEI2010. These estimates are based on the reported emissions of NH_3.

An estimate of total CH_4 and N_2O emissions for the sector within the LAEI are made by using NH_3 emissions data as a proxy. The fraction that the NH_3 emissions in the LAEI areas represent of the national total is calculated. This is then used to scale the national emission totals for CH_4 and N_2O to estimates for the LAEI geographical area. The total emissions of CH_4 and N_2O for the LAEI are then distributed to individual sewage works point sources, by again using the NH_3 emissions as a proxy.

Waste Transfer Stations. A bottom-up approach has been used to estimate emissions of particulate matter from waste transfer stations (N.B emissions from this source are not currently included in the UK national inventory). Data on the locations of the waste transfer stations and the type and throughput volumes of waste were obtained from the London Waste Map[11].

There is no standard methodology included in the guidance for this source (EMEP/EEA Emissions Inventory Guidebook[12]). So methodologies reported for similar sources are adapted using expert judgement.

Estimated emission factors for the different waste types are derived from emission factors for sites where there is “Storage, handling and transport” of mineral products (from the EMEP/EEA Emissions Inventory Guidebook[12]) on the basis that this is a similar type of activity. These emission factors are then applied to the waste volumes for each site. The estimates are very approximate but provide an indication of the levels of particular matter emissions from these sites.

Natural (Forests)

Forest vegetation naturally emits VOCs. These emissions are mapped for the LAEI area using CEH 1km resolution land cover maps of broadleaf and coniferous woodland, which are combined to produce a total woodland distribution.

The total amount of emission in 2008 is calculated as a fraction of the NAEI emission based on the fraction of UK woodland land cover that is found within the LAEI boundary. Emissions for this source are very nearly constant between 2008 and 2010 in the NAEI and it has been assumed that there is no change in the amount or distribution of emissions after 2010.

Household and Garden

Emissions from the use of machinery in the domestic sector are distributed the using land cover data from CEH. The suburban land cover class has been used as a proxy spatial distribution for this source because this is more representative of the locations of houses with gardens and prevents emissions from being located in high density areas of the city. The spatial pattern of

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10 Travel in London report 4 (TfL 2011) http://www.tfl.gov.uk/assets/downloads/travel-in-london-report-4.pdf
11 http://www.londonwastemap.org/
12 http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009

emissions is the same in all years. The total amount of emission in 2008 and 2010 is calculated as a fraction of the NAEI emission based on the fraction of UK suburban land cover that is found within the LAEI boundary. Emissions totals for 2012, 2015 and 2020 have been projected using estimates of the change in number of households at ward level for future years[13].

Construction and Demolition

Emissions of particulate matter from construction and demolition have been mapped for 2008, 2012 and 2012 using data on the locations and sizes of new developments from the London Employment Sites Database[14]. For future years (2015 and 2020) a different map was produced based on both the Brownfield Sites database[15] and development sites in the London Employment Sites Database (removing any duplicate locations).

The estimate of total emissions is derived from a top-down calculation using the fraction of total monetary value of developments in London compared to the UK as a whole, from ONS data[16]. This fraction in 2010 is 13% of the UK. However, expert judgement has been applied to reduce the resulting estimate of London construction emissions by 25% assuming that half of sites will have half the national average emissions rates due to stricter emission controls in London and to take some account of high land values and building costs in London.

The development sites and brownfield sites maps used in the method described above only covered Local Authorities within the GLA area. Therefore emissions from this sector occurring outside the GLA boundary have been estimated based on urban land cover maps (CEH). A rate of development (floor area) per urban land cover unit has been calculated within the outer LAEI area (outside the GLA area). This rate has been applied to urban land cover within the M25 zone outside the GLA area. This resulted in a 3% increase in total development area and hence a 3% addition of emissions for this area. These additional emissions have been distributed in proportion to urban land cover where more than 10% of a 1km grid was defined as urban.

Future emissions from this sector are estimated using employment growth factors at ward level.

Fires

Accidental Fires (Vegetation). Accidental fires in which vegetation is burnt are not officially included as a source within the official UK emissions inventory but are calculated and reported for completeness. Separate emissions estimates are available for straw burning, forests and other vegetation. These are mapped using CEH land cover data for arable land, woodland and improved grassland respectively. The improved grassland land cover in the LAEI area has a very similar distribution to 'other types of grassland' within the LAEI area and is therefore a good proxy for 'other vegetation'.

The total amount of emission in 2008 for the different sub-sectors is calculated as a fraction of the NAEI emission based on the fraction of the UK for each relevant land cover that is found within the LAEI boundary. Emissions for this source are constant between 2008 and 2010 in the NAEI and it has been assumed that there is no change in the amount or distribution of emissions after 2010.

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[13] Greater London Authority – London Datastore http://data.london.gov.uk/

[14] https://www.london.gov.uk/archive/mayor/economic_unit/docs/emp-proj-techpaper1.pdf

[15] http://data.london.gov.uk/datastore/package/london-brownfield-sites-review

[16] http://www.ons.gov.uk/ons/rel/construction/output-in-the-construction-industry/index.html

Accidental Fires (Not Vegetation). Emissions from accidental fires involving vehicles, dwellings and other buildings have been distributed using CEH land cover data for both sub-urban and urban land use types.

The total amount of emission in 2008 for the sector is calculated as a fraction of the NAEI emission based on the fraction of the UK of sub-urban and urban land that is within the LAEI boundary. Emissions for this source are constant between 2008 and 2010 in the NAEI and it has been assumed that there is no change in the amount or distribution of emissions after 2010.

Small Scale Waste Burning (Bonfires). Small scale waste burning consists of bonfires in gardens or other open areas. The emissions are mapped based on the 1km resolution CEH land cover dataset for suburban land. These fires are less likely to occur in central city locations and are therefore have not simply been mapped in proportion to population numbers.

The total amount of emission in 2008 and 2010 is calculated as a fraction of the NAEI emission based on the fraction of UK for suburban land that is found within the LAEI boundary. It has been assumed that emissions will increase in future in proportion to population growth data at ward level[17].

Non-Road Mobile Machinery (NRMM)
Emissions from NRMM in the industrial sector (not including agriculture) have been mapped using two different distributions because it is best to split the sector into construction based emissions and other industrial activities. The split of emissions between these two sources has been calculated using data from the national inventory and a recent report by AEA[18]. In 2010, emissions from construction NRMM were estimated to account for 58% of the sector. The London portion of the UK total has been calculated for the construction NRMM, based on the same data as used for PM_{10} emissions from construction activities, at 13%. This is the fraction of total monetary value of developments in London compared to the UK as a whole, from ONS data. The London fraction of industrial NRMM has been calculated as the fraction of UK emissions in the LAEI area as shown in the NAEI industrial CO_2 emissions map for 2009[19] (the latest available at the time). This is 3.4%.

The geographic distribution of emissions within London for the construction NRMM is based on floor area of developments listed within the London Employment Sites Database[20] plus additional development estimated in urban areas outside the GLA. The industrial NRMM distribution within London is equivalent to the NAEI industrial CO_2 map mentioned above.

Future emissions have been calculated by applying reduction factors based on projected emission estimates presented in the AEA report. These are calculated based on assumptions about the implementation of the European Standards for this type of machinery.

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[17] Greater London Authority – London Datastore http://data.london.gov.uk/

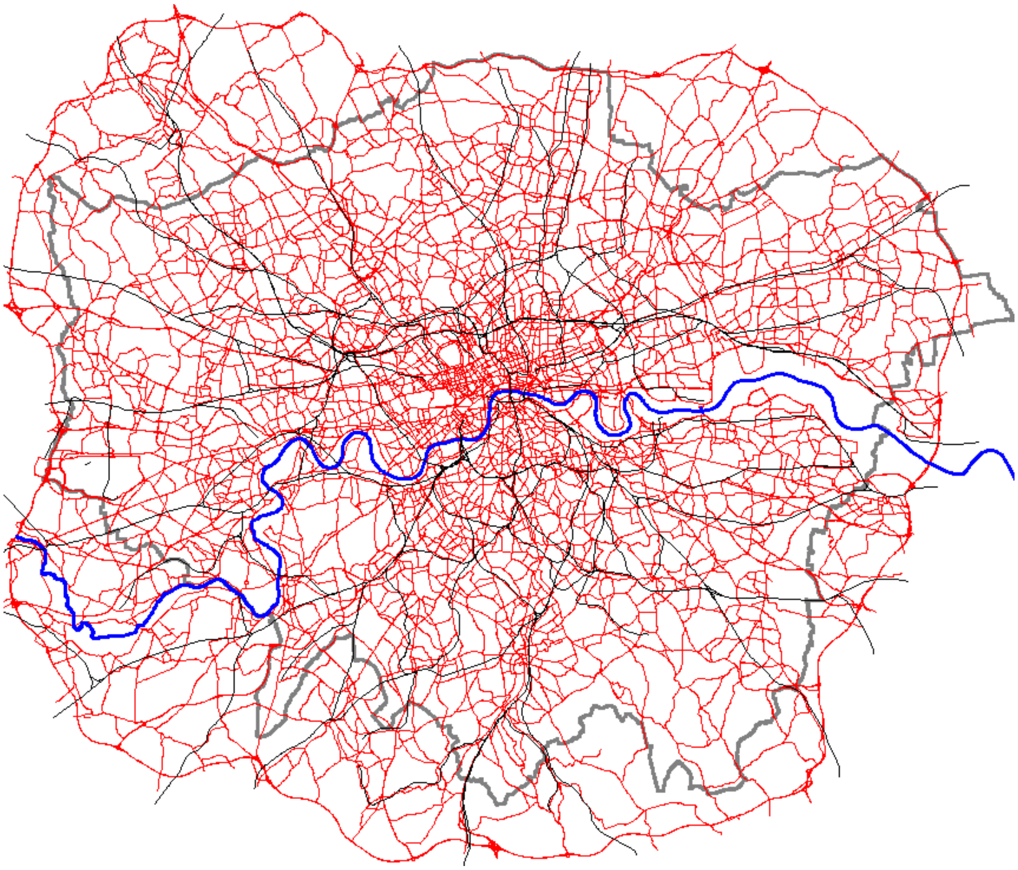
[18] Norris, J (2012) Assessment of emissions impact of GLA NRMM LEZ proposed scheme Report for Defra, AEA/R/ED57423115, October 2012

[19] NAEI Maps of CO_2 emissions 2009 http://naei.defra.gov.uk/mapping/mapping_2009/co2_by_pointofrelease.zip

[20] https://www.london.gov.uk/archive/mayor/economic_unit/docs/emp-proj-techpaper1.pdf

Methodology for Calculating Emissions from Mobile Sources

Figure 3 Map showing Mobile Source emissions in the LAEI



Aviation

Base Year 2010

- Aircraft emissions have been calculated using International Civil Aviation Organization (ICAO) emissions factors linked to aircraft activity provided by the CAA (Civil Aviation Authority) for Heathrow, and from the APR (Annual Performance Report) for London City Airport. Other sources (Airside/landside vehicles and stationary sources) have been obtained from the HAEI report for Heathrow and from an Air Quality Consultants (AQC) report for London City. For the other smaller airports, revised activity data were not available so the LAEI 2008 emissions have been used.

Projection Years 2012, 2015, 2020

- Future scaling factors were derived for all aircraft emissions modes using forward projections of aircraft emissions from the HAEI report and forward projections of aircraft movements from the London City Airport Action Plan. Smaller airport forward projections were kept constant due to a lack of information and the small contribution to total emissions from these sources.

Emissions at Heathrow airport were calculated using the methodology described in the latest HAEI (Heathrow Airport Emission Inventory Report). This is consistent with the PSDH (Project for the Sustainable Development at Heathrow) and with the air quality work undertaken for the British Airports Authority (BAA)[21]. Heathrow's methodology has been simplified and adapted to include, for the first time in the LAEI, a detailed and up to date emissions estimate from London City Airport. The aviation emission inventory quantifies airport and heliport emissions within the M25 and up to a height of 1000m. Emissions of NO_X from aircraft main-engine exhaust are the dominant source of airport emissions.

Heathrow Airport

Aviation emissions in the LAEI 2010 are based upon the methodology described in the HAEI report[22] and include the following sources:

- Aircraft emissions (LTO (landing and take off) cycle up to 1000m height, APU (Auxiliary Power Unit), engine testing and aircraft refuelling);
- Airside vehicle emissions (road and off-road vehicles associated with aircraft turn-around);
- Landside vehicles emissions (cars parks and taxis);
- Stationary emissions (heating plant and fire-training ground).

However, the HAEI report is commercially restricted and as such, only a brief methodology can be provided.

Aircraft Emissions Methodology

Aircraft exhaust emissions are calculated by multiplying aircraft activity (from a given mode of aircraft operation) by the engine fuel flow rate, the emission factor for the pollutant of interest and the duration of the operation (times–in-mode). Total emissions are then simply calculated by summing the contributions from all the aircraft movements in a given year.

The aircraft LTO modes considered in the inventory include:

- Taxi out (commences at stand and ends when the aircraft joins the departure queue)
- Hold at runway head
- Take off roll (from start of roll to wheels off)
- Initial climb (wheels off to throttle back - normally 305 m (1000 ft) or 457 m (1500 ft))
- Climb out (from throttle back to 1000 m altitude)

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[21] BAA (2007). Project for the Sustainable Development of Heathrow: Surface Access Report. http://www.dft.gov.uk/consultations/archive/2008/heathrowconsultation/technicalreports/surfaceaccess.pdf

[22] Underwood, B.Y., Walker, C.T. and Peirce, M.J. July 2010. Heathrow Airport Emission Inventory 2008/9. Made by AEA to BAA. Restricted Commercial. AEAT/ENV/R/2906 Issue 1

- Approach (from 1000 m altitude to runway threshold)
- Landing roll (from runway threshold to runway exit)
- Taxi in (commences when the aircraft leaves the runway and ends when the aircraft reaches the stand)

Aircraft Movement Data
Heathrow activity data for the base years 2008 and 2010 were compiled by Kings College London Environmental Research Group using aircraft movements from 1st January to 31st December 2008 and 2010, made available by the UK CCA[23]. The aircraft activity data included each aircraft movement by time and date, disaggregated by plane and engine type, number of engines, call sign, tail number, origin of the flight destination, operation type (arrival or departure) and runway used. The aircraft movement database is very large (>1 million records) and shows an overall reduction of aircraft movements from 472,083 to 450,735 (i.e. a drop of 4.5 %) and total passenger movements from 65.93 to 65.88 million (i.e. a drop of 0.08 %) between 2008 and 2010, respectively.

Emission Factors
To calculate aircraft emissions, the ICAO emissions factors databank (issue 17A released December 2010[24]) was linked to the CAA aircraft movement database by engine type. The ICAO database provides jet engines certification test results of emission factors (referred to as 'emission index' in the ICAO database), smoke number and fuel factors for every aircraft engine type. Adjustments were made to account for speed effect on stationary engine tests and engine deterioration using forward speed effect factors and degradation factors in line with PSDH recommendations. The pollutants in the ICAO database include: oxides of nitrogen, carbon monoxide and hydrocarbons by thrust setting (7 %, 30 %, 85 % and 100 %), and these have been used to represent idle, approach, climb out and take off operations. The ICAO database provides other information used in the aircraft emission calculations e.g. engine category split between TF (TurboFan) and MTF (Mixed TurboFan), bypass ratios (both used in the PM calculations) and the engine maximum rated thrust (in kilo Newtons) used to estimate aircraft start-up emissions.

Thrust settings by mode
As a consequence of the high variability in the fuel flow rate and emission factors between different engine types and thrust settings, specific estimates were used for each aircraft. The thrust setting varied by vehicle type within each mode, ranging between: 4.5 to 6 % for taxi out, hold and taxi in modes; 70 to 100 % for take off and initial climb; 70 to 85 % for climb out; 15 to 30 % for approach and 7 to 30 % for landing roll.

Times-in-mode
Aircraft times-in-mode have been derived from NTK (Noise and Track-Keeping) radar data and NATS (National Air Traffic Services) ground radar data and have been provided by aircraft type, NATS group, wake vortex category or runway type, and for the various LTO and APU running times. Spool up time was taken into account at the start of the take off roll, as recommended by

[23] Civil Aviation Authority, personal communication
[24] http://easa.europa.eu/environment/edb/aircraft-engine-emissions.php

PSDH, to include a period during which fuel flow rates and thrust levels are significantly less than the take off values.

Additional aircraft emissions

APU (Auxiliary Power Unit) Emissions: APU emissions factors are not included in the ICAO test results, thus emission rates were taken from the HAEI report and processed by aircraft type. Total APU emissions were calculated as the product of the aircraft activity, APU running time, the fuel consumption and the emission factor for each APU, characterised into three operating modes: no load; ECS (Environmental Control System) for air conditioning plus electrical power; and MES (main engine start) for main engine start plus electrical power.

Engine Testing Emissions: Engine testing represents a very small contribution thus the total engine testing emissions were taken directly from the HAEI report.

Refuelling Emissions: The total amount of fuel delivered to aircraft through an underground pipeline system and from individual fuel tankers was used to calculate aircraft refuelling emissions. Only fuel vapours emitted during the fuelling process and when the tankers are filled with fuel at the storage facility have been considered in the calculations. The total hydrocarbon emissions have been calculated using an estimated 6 millions tonnes per annum of fuel used at Heathrow and an emission factor of 0.01 g/kg for refuelling with kerosene (or aviation turbine fuel)[25].

Start-up emissions: During the starting sequence, due to very low engine temperatures and pressures, very few NO_X emissions are produced compared to the LTO cycle and so only hydrocarbon emissions have been considered. The ICCAIA (International Coordinating Council of Aerospace Industries Associations) have performed a detailed analysis of engine starting data and recommends a simple first order linear relationship between total hydrocarbons and the take-off engine thrust rating taken from the ICAO database[26]. Start-up emissions were calculated by multiplying the number of aircraft departing with the start-up hydrocarbon emissions.

Emission calculation summary for all pollutants

NO_X, CO, total hydrocarbon emissions and fuel use were calculated directly using ICAO emission factors and fuel factors. The NO_2/NO_X ratio was assumed to be 5 %[27]. CO_2 and SO_2 were derived from the fuel use, using assumed amounts of pollutant contained in aviation fuel, as given in Table 12, alongside a list of fuel types used (by aircraft type)[28]. The fractions of total hydrocarbons used for estimating NMVOC and methane emissions were 90.43 % and 9.57 %, respectively. NMVOC was then used to calculate benzene and 1,3-butadiene emissions using factors of 0.0197 and 0.018, respectively (as given in LAEI 2008).

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[25] https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/digest-of-uk-energy-statistics-dukes

[26] ICAO, First Edition 2011. Airport Air Quality Manual. Order Number: 9889, ISBN 978-92-9231-862-8

[27] AEA (June 2007). Emissions of Nitrogen Dioxide and Nitrous Acid from Road Transport and Other Sources, Report to The Department for Environment, Food and Rural Affairs, Welsh Assembly Government, the Scottish Executive and the Department of the Environment for Northern Ireland, ED05450007, Issue 1, June 2007)

[28] Watterson, J., Walker, C. and Eggleston, S. (July 2004) Revision to the Method of Estimating Emissions from Aircraft in the UK Greenhouse Gas Inventory Report to Global Atmosphere Division, DEFRA netcen/ED47052. http://naei.defra.gov.uk/reports/reports?report_id=316

PM_{10} was calculated using the PSDH methodology and the ICAO smoke number, estimated by aircraft and engine type. This method is described in the LAEI 2008. All of the aircraft exhaust PM mass was assumed to be in the $PM_{2.5}$ fraction and thus $PM_{2.5}$ and PM_{10} exhaust emissions were the same for this source. PM_{10} non-exhaust emissions were also included as:

- PM_{10} brake wear emissions, estimated for each landing, using the emission factor; 2.53 X 10-7 kg PM_{10} per kg MTOW (Maximum Take Off Weight).
- PM_{10} tyre wear emissions, calculated as the amount of weight lost per landing using the emission factor; 2.23 X 10-6 kg PM_{10} per kg MRW (Maximum Ramp Weight) – 0.0874.
- $PM_{2.5}$ non-exhaust emissions were apportioned directly from PM_{10} non-exhaust totals using brake wear and tyre wear $PM_{2.5}/PM_{10}$ mass ratios of 0.4 and 0.7, respectively.

Table 12 CO_2 and SO_2 emission factors in kg tonne-1

Fuel type	CO_2 (kg tonne^{-1})	SO_2 (kg tonne^{-1})
ATF (aviation turbine fuel)	3150	0.87
AS (aviation spirit)	3172	0.87

Projected emissions

All Heathrow aircraft emissions in 2012 and 2015, except refuelling and start up, were calculated by scaling the LAEI 2010 base year 2010 data by the percentage change in HAEI emissions from 2010 to 2012 and 2015[29]. 2020 emissions were assumed to be the same as 2015 emissions.

Refuelling and start-up projected emissions in 2012 and 2015 were scaled to Heathrow's CO_2 aircraft emissions change between 2010 and 2015/2020. 2020 emissions were assumed to be the same as 2015 emissions.

Non-aircraft emissions methodology

Additional methodology details for airside vehicles, landside vehicles and stationary sources can be found in the HAEI report.

Airside vehicle sources

Airside vehicle emissions were estimated based on fuel use data combined with emission factors for all road and off-road vehicles and plant associated with aircraft turn-around (e.g. caterers, cleaners, fuel handlers and buses) and runway maintenance. Fuel use and associated emission factors were broken down by fuel type (gasoil, diesel, petrol and LPG) and by airside vehicle categories such as road vehicles (car, LGV, HGV, bus) and off-road vehicles (37-75 kW, 75-13 kW and 130-560 kW). Additional airside vehicle operation data such as the fraction of time idling and average speed when moving were also taken into account.

[29] D. Vowles (BAA) and H. Peace (AEA), personal communication

Landside vehicle sources
Landside vehicle emissions from staff car parks, taxi queues, car rental and public car parks have been estimated by combining cold-start and exhaust emissions derived from vehicle parking transaction data, total distance travelled and the emission factor by vehicle category. Emissions from taxis queuing at the terminal forecourts were estimated using the total number of taxis passing through the TFP (Taxi Feeder Park) combined with the average time spent queuing at each terminal.

Stationary sources
Heating plant emissions have been calculated by combining fuel consumption by fuel type (gas and gasoil) for each heating plant (e.g. CHP, 448, T4, T5, BA Cargo, 1157 ASU) and their specific emission factors.

Fire-training ground emissions are very small and were estimated using the total LPG fuel consumed by the fire service at Heathrow combined with emission factors from commercial boilers.

Base case and projected non-aircraft emissions
For airside vehicles, landside vehicles and stationary sources, NO_X and PM emissions in 2008 were taken from the HAEI report and CO_2 from the LAEI 2008. All the other pollutants for airside and landside vehicles were scaled to their CO_2 emissions and for stationary sources were taken from the LAEI 2008. Emissions data were not available for non-aircraft sources in 2010. In the case of airside vehicles and landside vehicles, emissions in 2010 were extrapolated from 2008 using the change in aircraft movements (i.e. a drop of 4.5 %) and the change in total passenger numbers (i.e. a drop of 0.08 %) between 2008 and 2010. For stationary sources, it was assumed that there was no change between 2008 and 2010.

All non-aircraft Heathrow emissions in 2015 were taken from the HAEI 2015 projection. 2012 emissions were derived by interpolating between 2010 and 2015[30]. 2020 non-aircraft emissions were kept the same as in 2015.

London City Airport
The Heathrow Airport emissions methodology has been adapted for use at London City Airport. Some simplifications had to be made however, as most datasets available for London City (e.g. activity and times-in-mode) are less detailed than those available for Heathrow. As a consequence, only a brief overview of the assumptions used at London City airport has been provided.

Aircraft Emissions
Aircraft activity data from London City airport have been compiled using information from the 2009 and 2010 London City Airport Annual Performance Report (APR)31. Aircraft movements in 2010, by aircraft type, are summarised in Table 13.

[30] D. Vowles (BAA) and H. Peace (AEA), personal communication

[31] London City Airport APR (Annual Performance Report) 2009 and 2010 released in 1 July 2010 and 1 August 2011, respectively

Table 13 Aircraft movements (in numbers) and fraction (in percentage) in 2010 by aircraft type

Aircraft type	Movements	Fraction (%)
Airbus A318	1,046	1.5
ATR-42/72	2,296	3.4
Avro RJ1H	8,696	12.8
Avro RJ85	13,683	20.2
Cessna C25A/B C510 C525 C550 C560 C56X C680	3,651	5.4
Dash DH8C DH8D	2,883	4.2
Dassault Falcon F900 FA10 FA50 FA7X	945	1.4
Dornier D328	5,077	7.5
Embraer E135	648	1.0
Embraer E170	7,943	11.7
Embraer E190	4,991	7.4
Fokker F50	13,115	19.3
Hawker H25B	1,750	2.6
Others	1,147	1.7
Totals	**67,871**	**100**

The ICAO emission and fuel factor database has been linked to aircraft movements from the APR report using the most common engine for each aircraft type and based upon knowledge gained at Heathrow. The aircraft movements were split equally between arrival and departure (London City, personal communication).

Assumptions for aircraft times-in-mode (**Table 14**) were extracted from London City Airport's Planning Application report from 2007[32].

[32] http://www.londoncityairport.com/AboutAndCorporate/page/PlanningApplication

Table 14 Aircraft times-in-mode for the LTO cycle stages

Mode	Time (s)
Taxi out/Taxi in/Hold	150
Take off	18.5
Initial Climb	52
Climb out	68
Cruising out/Cruising in	113
Approach	200
Landing	41
APU narrow bodied	1974

Realistic emissions estimates for the LTO cycles (taxi out, hold at runway head, take off roll, initial climb, climb out, approach, landing roll and taxi in) and APU's have been made using a similar approach to that used in the Heathrow Airport calculations.

At London City Airport, aircraft departing towards the west stop ascending below 1000 m altitude (near London Bridge) and maintain this altitude until clear of the London Heathrow inbound flight path, i.e. up to the LAEI boundary. When landing from the west, aircraft are not on a continuous descent profile but stay below 1000 m until commencing their final descent near London Bridge. This additional source of emissions was calculated using a low thrust of 15 %, by assuming a steady cruise-out mode (following climb out toward the west) and cruise-in mode operation (before landing from the west).

Non-aircraft emissions
All other city airport sources are considered to be small, and due to a lack of more specific information, have been given as a total emission provided by AQC

Projected emissions
London City airport projected emissions were scaled backward to 2008 and forward to 2020 based on London City Airport monthly statistics of total aircraft movements from 1998 to 2011[33] and the London City Airport Air Quality Action Plan[34], assuming full capacity of 120,000 aircraft movements by 2020. A summary of the total aircraft movements for all the years covered can be found in **Table 15**

[33] www.lcacc.org/statistics/lcystat2.pdf
[34] www.londoncityairport.com/content/pdf/LCY43435_PLANAP_Air%20Quality%20Action%20Plan_2011_fv_sm.pdf

Table 15 London City total aircraft movements by year

Year	2008	2010	2012	2015	2020
Total aircraft movements	94,763	67,871	73,867	91,167	120,000

Other smaller airports
Because of a lack of new and reliable activity datasets for Stapleford, Denham, Elstree, Northolt, Biggin Hill, Battersea Heliport and Lippits Hill Heliport, and the relatively small contribution to total emissions from these sources, estimates of emissions for 2008 were taken directly from the LAEI 2008.

Since no published data exists for 2010 and beyond, emissions for years beyond 2008 were kept constant.

The spatial representation of London airports
The spatial representation of all the London airports has been based upon the LAEI 2008. Emission estimates were spatially analysed by source type to create geographically accurate emissions source locations for use with dispersion modelling. The source locations include:

- Point sources: hold, start up, APU, engine testing, airside vehicles, stationary sources and refuelling of aircraft;
- Line sources: taxi out, take off, initial climb, climb out, cruise-in, cruise-out, approach, landing roll and taxi in;
- Area sources: landside vehicles.

When judged appropriate, the spatial representation was improved to give a more accurate representation of the various sources. At London city, the climb out length was reduced (to reach London Bridge at 1000 m altitude) to represent the steep glide slope and the stringent rules imposed to limit the noise impact from aircraft operations due to the airport's proximity to Central London. A new mode, cruising-in/cruising-out was plotted at km2 grid level, to represent the aircraft maintaining altitude just below 1000 m until clear of the London Heathrow inbound flight path (between London Bridge and the LAEI boundary), Emissions at London City were assumed to be spatially represented using 60 % of all arrivals approaching from the east side of the airport and 60 % of all departures taking off toward the west (both taking advantage of westerly wind).

Rail

Base Year 2010

- Updated based on rail movements data provided by Delta Rail Ltd, with updates to the structure of the rail networks to reflect recent developments such as the development of the London Overground network and re-location of Eurostar services to London St Pancras.

Projection Years 2012, 2015, 2020

- Rail vehicle-kilometre data for future years has been scaled using the recent historical trend, based on data from the Office of the Rail Regulator (ORR). For 2020, the electrification of the Great Western Main Line has been assumed, with transfer of local services to Crossrail and operation of the majority of longer-distance services by either electric multiple units or electric Inter City Express Passenger (IEP) trains. Small amounts of diesel operation are expected to remain at this point – mostly longer-distance services to the West of England.

The rail networks in London fall into three broad categories:

- The National Rail network, with both passenger and freight trains powered by electric or diesel traction. TfL's London Overground network is considered to be part of the National Rail network for this purpose.
- The London Underground network – exclusively electric traction.
- Light rail systems (Docklands Light Railway and London Tramlink), operated on behalf of TfL – exclusively electric traction.

Air quality pollutants arise at the 'point of use' from diesel traction on the National Rail network. CO_2 arises from both diesel and electric traction. Energy use for electric traction and for non-traction purposes on the rail networks are not included in this part of the inventory.

National Rail Network (including London Overground)
Delta Rail, on behalf of Network Rail, maintains a database of train movements used primarily for operator billing purposes. This consists of a set of discrete rail links, typically lengths of track between junctions or major stations, with annual total (actual) movements allocated to each link. This allows spatial mapping of the rail network and rail traffic for the base year.

The movements on each link are apportioned to a number of generic train categories representing the traction type. The categories relating to diesel traction are:

- D1 Intercity 125 2-Engine
- D2 Diesel locomotive and coaches

- D3 Diesel Multiple Units – 6 coaches
- D4 Diesel Multiple Units – 4 coaches
- D5 Diesel Multiple Units – 3 coaches
- D6 Diesel Multiple Units – 2 coaches
- D7 High Speed Diesel Multiple Units – 5 coaches
- F1 Freight – other
- P1 Preserved – Locomotive

In addition to these train movements, Delta Rail also provides the following details for each link:

- Passenger Trains
- Train type (see above)
- Total number of trains per year per link
- Average number of seats, for this train type, per year per link
- Average tare weight in tonnes, for this train type, per year per link
- Average gross weight in tonnes, for this train type, in this period, per year per link
- Total energy consumption in kWh
- Average energy consumption in kWh per train km
- Specific energy consumption in kWh per tonne-km

The data assumes that passenger trains are fully laden, and assume an average passenger weight of 0.08 tonnes. This may marginally overestimate the weight, and therefore the energy consumption, of passenger trains.

- Freight Trains
- Number of trains per year per link
- Average number of wagons, for this train type, per year per link
- Average tare weight in tonnes, for this train type, per year per link
- Average gross weight in tonnes, for this train type, per year per link
- Total energy consumption in kWh
- Average energy consumption in kWh per train km

- Specific energy consumption in kWh per tonne-km

Estimating emissions from trains

Aggregate emissions factors for the main pollutants are shown below.

Table 16 Diesel emissions factors (g/kwh)

	CO_2	CO	NO_x	HC	SO_2	PM_{10}
2008 and 2010	640	3.9	8.4	2	0.8	0.32
2012, 2015 and 2020	480	2.5	7.75	0.75	0.515	0.165

Infrastructure changes since the previous update to the LAEI

A small number of changes have been made to London's railway infrastructure since the previous update to the LAEI (which used rail network data based on 2006). These have included: the opening of High Speed One between St Pancras International and the Greater London boundary, and the related diversion of Eurostar trains away from London Waterloo; the introduction of services to Heathrow Terminal 5; the closure of the route between Stratford and North Woolwich and various changes reflecting the development of the London Overground network.

Road Transport

Base Year 2010

- The LAEI 2010 road network is based upon the OS Integrated Transport Network (ITN). There has been a comprehensive update of traffic flow on the road network.
- A major revision of the use of vehicle speeds has been implemented, and includes sub-link level data derived from GPS vehicle tracking (TrafficMaster). There has been a commensurate development in the emissions model to incorporate these speed data.
- There has been an update to the London vehicle stock model to include the latest ANPR based vehicle ages, as well as a revision to the proportion of petrol/diesel light duty vehicles (LGV).
- A new set of NO_x emission factors and emission degradation correction factors (from COPERT 4 v8.1) has been implemented for all vehicle types into the LAEI emissions model.
- A complete revision has been undertaken of the non-exhaust particulate matter emissions, derived from observational data collected at Marylebone Rd by Harrison *et al.*. As part of the non-exhaust update, the introduction of a road dust resuspension source has been included for the first time.

Projection Years 2012, 2015, 2020

- In the LAEI 2010 the growth in traffic flow between 2010 and 2012, 2015 and 2020 has been simulated using scaling factors underlying the TfL Business Plan, with speed data adjusted accordingly. Fleet composition data, used in the emissions calculations, have been taken from the London vehicle stock model.

Road network update using OS ITN data
Major Road Network

The LAEI 2008 road network (OS road centreline OSCAR data) has been replaced in the LAEI 2010 using the current OS MasterMap Integrated Transport Network (ITN) Layer[35]. Road links in the new ITN network are identified using a unique Ordnance Survey topographic identifier (TOID), a 16 digit reference number that is used widely across Ordnance Survey data products. ArcGIS v10.0 was used to spatially join the LAEI 2008 Oscar-based road centreline network with the ITN network. This joining method enabled the traffic meta-data (e.g. DfT link ID, flow and speed) to be assigned to the ITN network. Where the road network had changed, was complex (e.g. motorway junctions) or dense (e.g. central London), the automatic spatial join function introduced

[35] ITN Road Network Theme - www.ordnancesurvey.co.uk/oswebsite/support/products/os-mastermap/itn-layer-technical-specification/road-network-theme.html

errors into the network. This necessitated a large number of "manual network checks" to identify: links without traffic meta-data, inconsistencies in the assignment of traffic flows/DfT link ID's, and checks on the accuracy of known problem areas of the network. While this substantial piece of work resulted in relatively little geographic variation between the LAEI 2008 and ITN networks, there has been a large increase in the number of base road links used to calculate emissions (78,603 total ITN links). In addition, the network is now directly compatible with the TrafficMaster speed data, discussed below.

Road traffic update

Emissions calculations for links in the LAEI2010 road network have been made using annual averaged daily traffic (AADT) data. The AADT data for each link has been calculated using two separate methods, one for major roads and one for LTS roads (Figure 4). Major roads are defined as those where traffic flow is determined using manual classified count (MCC) data from the Department of Transport, while LTS road traffic is derived from TfL's LTS model.

The methodology used to update major road traffic data is in accordance with that used in the LAEI 2008, and is described in Beevers *et al.*[36]. There are a total of 2028 MCC traffic count sites within the LAEI area used to allocate traffic to the network. Not all sites are counted each year, and of the 2,028, 690 were counted in 2010 (indicated in green Figure 4. The MCC data are based upon only one day of observations, so to minimise the effect of specific local events introducing outliers into the dataset, the 2010 data were added to a series of MCC data (extending back to 1999). For each site separately, and using all traffic counts from 1999 to 2010, the MCC data has been smoothed using a LOESS smoothing function. Furthermore, as the MCC data only cover a 12 hour weekday period (7am to 7pm), these data were then expanded to provide counts for each hour of each day in 2010 (including weekends and overnight hours), using hourly average automatic traffic count (ATC) and automatic number plate recognition (ANPR) data. The resulting annual hourly dataset was then averaged by link to provide the AADT data (by 11 vehicle types) for each major road. For the LTS links, traffic flow has been based upon TfL's LTS model for 2008. These data were scaled to 2010 using a series of correction factors provided by TfL (Table 2.1). Finally, minor road traffic was expressed as annual vehicle km travelled in each of the 2,466 km^2 grids of the LAEI, with the calculation method described in the following section.

[36] Beevers, S., Carslaw, D., Westmoreland, E. and Mittal, H. (2009).Air pollution and emissions trends in London - http://uk-air.defra.gov.uk/reports/cat05/1004010934_MeasurementvsEmissionsTrends.pdf

Figure 4. The LAEI 2010 road network. Major road links are indicated in black, LTS road links are indicated in red. Circles represent the manual classified count (MCC) sites used to determine major road traffic. Sites with 2010 count data are coloured green.

Table 17 Percent change in traffic flow between 2008 and 2010 on LTS roads

Vehicle Category	LTS road traffic scaling factor
Motorcycles	0.838
Taxis	0.964
Cars	0.964
Buses	0.996
LGVs	0.929
Rigid HGVs	0.928
Articulated HGVs	0.928

Vehicle km travelled in London

TfL estimates that 31.4 and 30.3 billion vehicle km (bvkm) were driven on all roads in Greater London in 2008 and 2010, respectively. The bvkm travelled on major and LTS roads were calculated (Table 18), and the remaining vehicle km were attributed to minor roads, at 1km^2 grid resolution. Equation (1) was used for this calculation:

$$bvkm = \frac{(flow \times 365 \times L_{road} \times M)}{1 \times 10^{12}} \qquad (1)$$

where: bvkm = billion vehicle km; flow = 24 hour road traffic flow; Lroad = road link length (m) and M = a link specific multiplier – typically M = 0 for slip roads, 0.5 for dual carriageways and roundabouts, and 1 for single roads. Complex road junctions are assigned M values manually. The vehicle km driven in Greater London, split by vehicle type, are provided in Table 19.

Table 18. Billion vehicle km driven in Greater London in 2008 and 2010, by road type. Note that rounding of raw data means that the sum of the road types does not equal the 'All roads' value in this table.

	Billion vehicle km driven in Greater London			
Year	**Major roads**	**LTS roads**	**Minor roads**	**All roads**
2008	21.4	5.2	4.8	31.4
2010	21.6	5.0	3.8	30.3

Table 19. Billion vehicle km driven in Greater London in 2008 and 2010, by vehicle type.

	Billion vehicle km driven in Greater London							
Year	**Motorcycles**	**Taxis**	**Cars**	**Buses**	**LGVs**	**Rigid HGVs**	**Articulated HGVs**	**Total**
2008	0.7	0.9	24.5	0.6	3.4	1.0	0.3	31.4
2010	0.6	0.8	23.8	0.6	3.2	1.0	0.3	30.3

Speed update using TrafficMaster GPS speed

While the spatial resolution of the vehicle traffic flows in the LAEI 2010 is still based upon DfT's numbering system, and has not changed since the LAEI 2008, vehicle speed data has. Vehicle speeds for the major road network in the LAEI 2010 are now based upon a combination of TrafficMaster GPS derived and Moving Car Observer (MCO) speeds, rather than solely on MCO data. The 'TrafficMaster' speed is derived from a GPS-based vehicle tracking system operated by the company TrafficMaster . These speed data are derived from 2009/2010 observations, and are averaged by overnight (22:00 – 06:00), AM (07:00 – 09:00), inter (10:00 – 15:00), PM (16:00 – 18:00) and evening (19:00 – 21:00) periods. Data are averaged at TOID link level, and are available for approximately 62 % of the LAEI 2010 major road links. For the remaining road links, where TrafficMaster data are not available, the LAEI 2008 MCO data have been retained. The reader is referred to the LAEI 2008 methodology report for further details on the MCO dataset.

Traffic and speed scaling for projection years

TfL forecasts of traffic changes beyond 2010, by location and time of day, have been used to calculate traffic flows for 2012, 2015 and 2020 (**Table 20**). The traffic change data are consistent with the TfL Business Plan, and it is assumed that between 2006 and 2026 traffic growth is, on average, 0.36 % per year. Traffic increases in future years are assumed to result in a reduction in speed, which varies by location and time of day, and is expressed as % speed reduction per 1 % traffic increase (**Table 21**).

Table 20 Traffic growth expressed as a percentage change between 2010 and the forecast year, by period and location.

		Traffic change (%)		
Peak period	**Location**	**2012**	**2015**	**2020**
AM	central	0.64	1.59	3.18
AM	inner	0.63	1.59	3.17
AM	outer	0.65	1.63	3.25
AM	external	0.65	1.61	3.23
Inter peak	central	0.78	1.96	3.92
Inter peak	inner	0.77	1.93	3.86
Inter peak	outer	0.76	1.91	3.82
Inter peak	external	0.77	1.92	3.83
PM	central	0.86	2.14	4.28
PM	inner	0.73	1.82	3.65
PM	outer	0.72	1.80	3.61
PM	external	0.73	1.82	3.64
Overnight	central	0.77	1.91	3.83
Overnight	inner	0.72	1.81	3.62
Overnight	outer	0.72	1.80	3.61
Overnight	external	0.72	1.81	3.62

Table 21 Percent speed change per 1 % increase in traffic flow, by period and location

Peak period	Location	Speed change (%)
AM	Central	-1.0
AM	Inner	-1.0
AM	Outer	-0.9
AM	External	-0.9
Inter and 7.00 pm to 10.00 pm	Central	-1.0
Inter and 7.00 pm to 10.00 pm	Inner	-0.9
Inter and 7.00 pm to 10.00 pm	Outer	-0.7
Inter and 7.00 pm to 10.00 pm	External	-0.7
PM	Central	-1.0
PM	Inner	-1.0
PM	Outer	-0.8
PM	External	-0.8
Overnight	All locations	No change

Vehicle stock and petrol/diesel proportions using ANPR data

The vehicle stock data used in the LAEI 2010[37] and are based upon a combination of UK NAEI data as contained within the Emissions Factors Toolkit (v5.2)[38]and TfL's London specific fleet composition data. These data fully incorporate the effects of the Mayor's Air Quality Strategy. In addition, a revision has been made to the petrol/diesel split of the car and LGV fleets[39], with an increase in the proportion of diesel fuelled vehicles relative to previous estimates in LAEI 2008 e.g. diesel cars represent 34 % of the car fleet in 2010 rather than 30 %, and by 2020 this share has increased to 55 %, rather than 41 %.

To establish the implication of these changes on emissions calculations, a sensitivity analysis has been carried out to investigate the impact of both the stock and the petrol/diesel changes, the results of which are summarised in Table 22, Table 23 and Table 24. The revised stock data resulted in a fleet emissions reduction for CO_2, PM and NO_x of between 0.2 and 6.9 %, but increased primary NO_2 emissions by 0.9 %. The revised higher proportion of diesel vehicles in the fleet resulted in slightly lower total CO_2 emissions (0.2 %), but caused a 1.1 – 5.9 % increase in total PM, NO_x and

[37] Provided in the road transport fleet composition file within the supporting data folder of the LAEI http://data.london.gov.uk/datastore/package/london-atmospheric-emissions-inventory-2010

38 http://laqm.defra.gov.uk/review-and-assessment/tools/emissions.html

[39] T. Murrells at AEA, personal communication

primary NO_2.emissions. The combined effect of both dataset revisions resulted in reductions in CO_2, PM and NO_x emissions of between 0.4 – 5.3 %, while increasing primary NO_2 emissions by 6.8 %

Table 22 Percent emission change as a result of LAEI 2010 petrol and diesel vehicle proportion changes for the 2010 base year

Pollutant	Cars	Petrol cars	Diesel cars	LGVs	Petrol LGVs	Diesel LGVs	All Vehicles
CO_2	-0.4	-5.7	13.3	-0.2	-60.0	6.7	-0.2
PM_{10}	1.7	-5.7	13.3	3.0	-60.0	6.7	1.1
PM_{25}	3.2	-5.7	13.3	4.2	-60.0	6.7	2.5
NO_2	11.5	-5.7	13.3	6.3	-60.0	6.7	5.9
NO_x	2.9	-5.7	13.3	3.6	-60.0	6.7	1.7

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Table 23 Percent emission change as a result of LAEI 2010 vehicle stock changes for the 2010 base year

Pollutant	Motorcycles	Taxis	Cars	Petrol cars	Diesel cars	LGVs	Petrol LGVs	Diesel LGVs	Buses & Coaches	TfL buses	Coaches	Rigid HGVs	Articulated HGVs	All Vehicles
CO_2	13.4	0.6	0.8	1.1	0.0	-7.4	0.5	-7.8	-0.4	-1.0	1.3	-1.7	3.3	-0.2
PM_{10}	-23.4	-4.9	0.1	-0.3	0.7	-18.3	0.7	-18.7	0.7	-0.1	3.2	-0.1	-1.9	-2.9
PM_{25}	-29.4	-6.5	0.3	-0.6	1.1	-25.4	1.5	-25.7	1.8	-0.6	7.3	-2.3	-7.0	-6.5
NO_2	7.8	-0.3	-3.8	-38.9	-0.6	13.0	51.5	12.9	-0.2	1.5	-11.8	-1.8	4.7	0.9
NO_x	7.8	-2.2	-17.1	-34.8	0.7	-16.3	51.2	-17.6	5.6	4.2	10.6	6.1	8.2	-6.9

Table 24 Percent emission change as a result of the combined LAEI 2010 vehicle stock and petrol and diesel vehicle proportion changes for the 2010 base year

Pollutant	Motorcycles	Taxis	Cars	Petrol cars	Diesel cars	LGVs	Petrol LGVs	Diesel LGVs	Buses & Coaches	TfL buses	Coaches	Rigid HGVs	Articulated HGVs	All Vehicles
CO_2	13.4	0.6	0.4	-4.7	13.3	-7.6	-59.8	-1.6	-0.4	-1.0	1.3	-1.7	3.3	-0.4
PM_{10}	-23.4	-4.9	1.8	-6.0	14.1	-15.9	-59.7	-13.3	0.7	-0.1	3.2	-0.1	-1.9	-1.8
PM_{25}	-29.4	-6.5	3.5	-6.3	14.6	-22.2	-59.4	-20.8	1.8	-0.6	7.3	-2.3	-7.0	-4.2
NO_2	7.8	-0.3	7.3	-42.4	12.6	20.1	-39.4	20.5	-0.2	1.5	-11.8	-1.8	4.7	6.8
NO_x	7.8	-2.2	-14.8	-38.5	14.1	-13.3	-39.5	-12.1	5.6	4.2	10.6	6.1	8.2	-5.3

Emissions control technology assumptions

A range of assumptions have been used in the LAEI to simulate emissions from: vehicles with diesel particulate filters (DPFs); vehicles using selective catalytic reduction (SCR) and hybrid TfL buses. These have been revised for the LAEI 2010 based upon new TfL technology test results, and are provided in Table 25 below. The key changes relate to DPF technology. DPFs are now assumed to reduce PM emissions by 90 % for pre-Euro IV vehicles (was typically 95 % reduction in LAEI 2008) and not to effect NO_x emissions (LAEI 2008 assumed a 5 % reduction).

Table 25 Scaling factors for emissions from Euro class vehicles fitted with emissions control technologies and hybrid TfL buses.

Pollutant	Full DPF fitted diesel cars, HGVs, coaches, LGVs and TfL buses (Euro II and III)	SCR fitted LGVs, HGVs and Coaches	SCR fitted TfL Buses	Hybrid TfL Buses
Benzene	0.1	1	1	1
1,3 -Butadiene	0.1	1	1	1
CH_4	0.1	1	1	1
CO	0.1	1	1	1
CO_2	1.01	1	1	0.7
Exhaust PM_{10}	0.1	1	1	1
Exhaust PM_{25}	0.1	1	1	1
NMVOCs	0.1	1	1	1
NO_2	1	1	0.5[40]	0.79
NO_x	1	0.5	0.3	0.79[41]
PaH	0.1	1	1	1
SO_2	1.01	1	1	0.7

Changes to NO_x emission factors and emission degradation factors

NO_x emissions in the LAEI 2010 have been calculated using COPERT 4 v8.1 emission factors, as recommended by Defra[42]. These data were also used to derive primary NO_2. Additionally, emission degradation factors have been updated to reflect the relationship between accumulated mileage and the emission factors used in the COPERT methodology. These relationships assume that NO_x emissions for Euro 1 – 4 petrol cars and LGVs increase linearly with mileage, until 120,000 km

[40] The NO_2 reduction figure for SCR fitted TfL buses is specific to London as it is TfL's performance requirement for SCR systems. Other authorities may not be requiring these same standards.

[41] Evidence (after the LAEI 2010 was produced) indicates that this level of reduction may not be applicable to Euro VI buses

[42] Defra, National Atmospheric Emissions Inventory – Emission factors for transport. - http://naei.defra.gov.uk/data/ef-transport

(Euro 1 and 2 vehicles) or 160,000 km (Euro 3 and 4 vehicles) is reached. No degradation is assumed for Euro 5 or 6 petrol vehicles or for diesel vehicles. The mileage correction factors are speed dependant; different coefficients are used in the calculation for speeds below 19 km h^{-1} and speeds above 63 km h^{-1}, and data are interpolated for speeds within this range. UK vehicle fleet accumulated mileage data has been taken from TRL/Defra fleet estimates[43].

Adoption of the new emission and degradation factors has had a significant impact upon NO_x and NO_2 emissions. The percentage difference in total NO_x/NO_2 emissions between the LAEI 2010 and LAEI 2008 methodologies, by vehicle type, is provided in **Table 26**. The key changes are:

- Overall, the change in methodology has led to a large increase in NOx (22 %) and NO_2 (35 %) emissions from road transport.
- Light duty vehicle emissions have greatly increased with the new methodology. NO_x emissions have increased for taxis by 75 %; for cars by 50 %; and for LGVs by 77 %. NO_2 emissions increased for taxis by 78 %; for cars by 58 %; and for LGVs by 85 %.
- There has been a small increase in emissions with the new methodology from TFL buses (7 % NO_x, 1 % NO_2) and coaches (7 % NO_x, 6 % NO_2).
- There has been a small decrease in emissions from rigid HGVs wqith the new methodology (-2 % NO_x, -4 % NO_2) and a slightly larger decrease in articulated HGV emissions (-11 % NO_x, -13 % NO_2).

Table 26 The percent change in total emissions for NO_X and NO_2 as a result of using COPERT 4 v8.1 NO_x emission factors and accumulated mileage correction factors in the LAEI 2010.

Pollutant	Motorcycles	Taxis	Cars	Petrol cars	Diesel cars	LGVs	Petrol LGVs	Diesel LGVs	Buses & Coaches	TfL Buses	Coaches	Rigid HGVs	Articulated HGVs	Total
NO_2	0	78	58	43	59	85	35	86	2	1	6	-4	-13	35
NOx	0	75	50	45	53	77	36	79	7	7	7	-2	-11	22

Non-exhaust particulate matter emissions update

Recent scientific evidence[44] has indicated that non-exhaust sources of road transport PM_{10} are of more importance to total road transport emissions than was previously thought. This evidence suggests that the methodology adopted for previous inventories underestimated total PM_{10} (and $PM_{2.5}$) emissions from the road

[43] TRL/Defra. Mileage fuel scaling factors MS Excel spreadsheet - https://www.gov.uk/government/publications/road-vehicle-emission-factors-2009

[44] Harrison, R.M.; Jones, A. M.; Gietl, J. and J. Yin. 2012. Estimation of the contributions of brake dust, tyre wear and resuspension to non-exhaust traffic particles derived from atmospheric measurements. *Environmental Science and Technology*, 46, 6523−6529.

transport sector. This section describes the methodology applied in the LAEI 2010 to improve estimates of non-exhaust PM emissions, based upon measurement data.

Source apportionment of PM from measurement data

Harrison et al. studied the chemical composition of size-segregated airborne PM at Marylebone Road and nearby urban background sites during a series of month long sampling campaigns conducted in 2007, 2009, 2010 and 2011. The roadside increment (i.e. kerbside minus background concentration) of the chemical tracer species zinc, barium and silicon were scaled to calculate the total mass of tyre, brake and resuspended PM, respectively. The combined mass from these sources accounted for 104.1 % of the mass measured in the 0.9-11.5 μm size fraction, of which 10.7 ± 2.3 % was derived from tyre sources, 55.3 ± 7.0 % from brake wear and 38.1 ± 9.7 % from resuspension of road dust. This resulted in 77 % of the road traffic increment being attributed to non-exhaust emissions. The road emissions at Marylebone Road, by source type, are summarised in.

Table 27 Source apportionment of PM11.5 calculated by Harrison et al. (2012).

Source	% of $PM_{11.5}$	% of non-exhaust $PM_{11.5}$	% Standard error
Exhaust	23		
Non-exhaust	77		
Tyre		10.7	2.3
Brake		55.3	7.0
Resuspension		38.1	9.7

Revision of existing LAEI emission factors

Using the London Emissions Toolkit (LET)[45], average PM_{10} emissions were calculated for the years 2007-10 using an LAEI 2008 comparable methodology, to correspond to the time period of the Harrison et al. measurement campaigns. An initial estimate of resuspension emissions was also included using emission factors from Boulter et al.[46]. Based on the assumption that the LAEI exhaust emissions were correct, a new 'expected' non-exhaust emissions total at Marylebone Road was calculated assuming a non-exhaust contribution of 77 % (Table 27). Scaling factors were then applied to each of the tyre, brake and resuspension sources separately to account for this non-exhaust proportion, taking care to ensure that the emissions ratios between each component remained consistent with those found by Harrison et al. The scaling factors were applied to all vehicle types in the same way, maintaining any existing relationships, such as the relationship between tyre and brake wear emissions and speed, as well as the relative difference in non-exhaust emissions between vehicle types. The resulting PM_{10} emissions, using the base methodology (comparable to the LAEI 2008) and the new methodology, are provided in Table 28 for Marylebone Road in 2010. The scaling factors used to create the new emissions are also included.

[45] Kings College London Environmental Research Group

[46] Boulter, P.G.; Thorpe, A.J.; Harrison, R.M. and Allen, A.G. 2007. Road vehicle non-exhaust particulate matter: final report on emission modelling, prepared for DEFRA - http://uk-air.defra.gov.uk/library/reports?section_id=15

Table 28 Marylebone Road 2010 PM_{10} g/km/s from emission runs using base and new methodologies, with scaling (or change in emission) factors.

	Base method emissions g/km/s	**Base method proportion**	**New method emissions g/km/s**	**New method proportion**	**Scaling factor (or emission change)**
Exhaust	0.0227	0.54	0.0227	0.22	1.00
Tyre wear	0.0077	0.18	0.0084	0.08	1.09
Brake wear	0.0119	0.28	0.0431	0.42	3.63
Resuspension	-	-	0.0290	0.28	-
Total (no resuspension)	0.0423		0.0742		1.75
Total (with resuspension)	0.0423		0.1032		2.44

Using this methodology, total PM_{10} emissions for the full LAEI area have increased by ~158 %, tyre wear emissions increased by ~9 % and brake wear emissions increased by ~262 % relative to the LAEI 2008 methodology. The proportions of LAEI road transport PM_{10} emissions by source type in the LAEI 2010 for 2010 are: exhaust = 18 %; tyre = 10 %; brake wear = 38 % and resuspension = 34 %. This is in sharp contrast with the LAEI 2008 method proportions, which are: exhaust = 51 %; tyre = 22 % and brake wear = 27 %. In 2010, the LAEI 2010 $PM_{2.5}$ proportions are: exhaust = 41 %; tyre = 17 %; brake = 39 % and resuspension = 3 %, compared to the LAEI 2008 method proportions of: exhaust = 64 %; tyre = 22 % and brake = 15 %.

Limitations

There are several limitations associated with the development and application of the methodology described above:

- The conclusions of Harrison et al. are derived from several month long sampling campaigns at one roadside site. As a consequence, there is a large degree of uncertainty in extrapolating these findings and applying them universally across all roads in London;
- King's College London Environmental Research Group have made the assumption that the results obtained by Harrison et al. for the $PM_{0.9-11.5}$ size fraction are applicable to PM_{10} modelling due to the large overlap between the two fractions;
- Given that PM derived from surface wear is likely to be accounted for in the measured roadside increment, this source is not modelled explicitly.

Shipping

Base Year 2010

- A new passenger shipping methodology has been developed for the LAEI 2010, a source not included in previous iterations of the LAEI. Emissions from passenger shipping for the 2010 base year were calculated using spatially disaggregated and vessel specific fuel consumption data - developed by combining annual fuel consumption data with timetabled movements and engine specifications. Emissions from commercial shipping for the base year 2010 were calculated by scaling the 2008 emissions (in LAEI 2008) by the change in cargo tonnage transported on the Thames between 2008 and 2010.

Projection Years 2012, 2015, 2020

- Emissions for both passenger and commercial shipping in future years were assumed to be the same as in 2010 due to uncertainty surrounding future activity on the river.

Passenger shipping emissions calculation
In order to represent 2010 passenger shipping emissions, two methodologies were developed:

- A Detailed Methodology was used to calculate the emissions of the largest passenger shipping operators - Thames Clippers, City Cruises, Woolwich Ferry and Bateaux London - for which detailed activity and/or fuel use data were available. These operators accounted for > 90 % of total fuel use in 2010.
- A Simple Methodology was used to calculate the emissions from all other operators – LRS, WPSA, Crown River, Westminster Party Boats, Thames River Services, Thames Executive Charters and Campion Launches – where limited activity data are available.

In both cases, emissions were spatially represented by a Thames centre line extending from Hampton Court in the west to Woolwich Arsenal in the east and split into a series of links based upon those piers used by the largest operators. Cross-river ferry services were accounted for by straight line paths between ferry terminals.

Detailed methodology
Activity data; For each main operator - Thames Clippers, City Cruises, Woolwich Ferry and Bateaux London, two estimates of main engine operating hours per annum were made:

The first method used a top down estimate of the vessel operating hours in 2008 taken from a TRL report[47], and scaled to 2010 using operator fuel consumption data (Table 29). Note that for Bateaux London no fuel use data were available, so it was assumed that their total operating hours in 2010 remained the same as in 2008.

The second method used a bottom up estimate derived from timetable data. This estimate incorporates detailed variations in activity e.g. as a result of specific weekday, weekend, and public holiday schedules, and was spatially disaggregated at the river link level.

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[47] TRL, 2010. Client Project Report CPR475: Reducing emissions from Thames river passenger services in London.

Table 29 Annual fuel consumption by operator. 2010 calendar year usage calculated assuming ¼ from financial year 2009/10 and ¾ from financial year 2010/11. Note: Bateaux London fuel consumption data is not available.

Operator	Fuel type	Fuel Consumption (l)		
		2009/10	2010/11	2010
Thames Clippers	Ultra Low Sulphur Fuel	3,607,671	3,535,800	3,553,768
City Cruises	Gas Oil	1,084,430	1,056,482	1,063,469
Woolwich Ferries	Gas Oil	743,640	887,110	851,243
LRS (Lord Ashfield)	Gas Oil	381	449	432
WPSA (Upriver)	Gas Oil	94,000	95,000	94,750
Scheduled services: Crown River Cruises, Westminster Party Boats, Thames River Services	Gas Oil	337,830	327,270	329,910
Charter services: Crown River Cruises, Westminster Party Boats, Thames River Services	Gas Oil	66,350	60,950	62,300
Thames Executive Charters	Gas Oil	54,204	123,059	105,845
Campion Launches	Gas Oil	11,768	12,000	11,942
Total		6,000,274	6,098,120	6,073,658

The bottom-up estimates gave a good indication of the spatial and temporal distribution of shipping activity, but underestimated the top down fuel consumption derived operating hours by 6 - 35 %. We assumed that this underestimation occurred because the timetabled ship movements did not account for chartered usage, in-port activity, and other off timetable movements. As a result, the two datasets were combined by scaling the bottom up operating hour totals to the top down totals in order to retain both the correct fuel consumption totals by vessel and the spatial disaggregation. It was also assumed that all of an operator's vessels are used equally along the extent of the operator's route, with the exception of the Thames Clippers vessel 'Twinstar', which only operates on the Canary Wharf ferry route. Details of the scaled main engine operating hours by river link for each operator are given in Table 30. For each vessel, auxiliary engine operating hours have been determined using the auxiliary engine to main engine operating hour ratio provided in the appendix Table A. 2 and

.

Table 30 Passenger shipping river links with annual main engine operating hours split by major operator, 2010.

Link	Link Length (m)	Total annual operating hours (h yr^{-1})			
		Thames Clippers	City Cruises	Bateaux London	Woolwich Ferry
Hampton Court – Putney	25,554	-	-	-	-
Putney – Wandsworth	1,209	303	-	-	-
Wandsworth – Chelsea Harbour	2,002	471	-	-	-
Chelsea Harbour – Cadogan	1,418	539	-	-	-
Cadogan – Millbank	3,406	1,143	-	-	-
Millbank – Westminster	1,139	1,850	-	-	-
Westminster – London Eye	187	270	694	50	-
London Eye – Embankment	359	6,270	1,331	164	-
Embankment – Blackfriars	1,036	5,798	3,839	137	-
Blackfriars – Bankside	698	3,450	2,588	92	-
Bankside – London Bridge City	872	3,117	3,233	115	-
London Bridge City – Tower	368	3,117	1,366	49	-
Tower – Canary Wharf	3,948	7,013	6,306	523	-
Canary Wharf – Greenland	1,117	3,102	1,784	148	-
Greenland – Masthouse Terrace	1,042	2,347	1,665	138	-
Masthouse Terrace – Greenwich	1,011	2,676	1,615	134	-
Greenwich – North Greenwich	3,869	6,180	257	-	-
North Greenwich – Woolwich Arsenal	4,428	3,311	295	-	-
Canary Wharf Ferry	211	5,819	-	-	-
Woolwich Ferry	305	-	-	-	8,680
Total	**54,180**	**56,775**	**24,972**	**1,549**	**8,680**

Fuel consumption calculation

Vessel fuel consumption was calculated according to equation (2), using link activity data (Table 30) and vessel specification data (appendix Tables A1(a)-(d)):

$$FC_T = (FCR_M.T_M.LF_M.N_M + FCR_A.T_A.LF_A.N_A).FD \qquad (2)$$

where: FCT = total fuel consumption (tonnes annum^{-1}), FCRM = main engine fuel consumption rate (lh^{-1}), TM = main engine activity data (h annum^{-1}), LFM = main engine load factor, NM = number of main engines, FCRA = auxiliary engine fuel consumption rate (lh^{-1}), TA = auxiliary engine activity data (h annum^{-1}), LFA = auxiliary engine load factor, NA = number of auxiliary engines and FD = fuel density (kg l^{-1}). TM for a given vessel is calculated by multiplying link operating hours by the main engine operating hour proportion, and TA is calculated by multiplying TM by the auxiliary engine: main engine ratio. For some vessels, no fuel consumption rate factors were available and these were obtained by King's College London using a combination of: engine specifications found in the literature; calculation from an average vessel passenger capacity to engine size ratio; or back calculation from total fuel consumption. Fuel consumption data were converted to tonnes annum^{-1} using fuel density values of 0.831 and 0.867 for ultra low sulphur fuel and gas oil, respectively, taken from DUKES 2009[48].

Simple methodology

Little information was available regarding the activity and vessel specifications of the smaller passenger shipping operators. As such, total fuel consumption figures (Table 29) were allocated to the river links within the geographic range of each operator's timetabled services, based upon link length (Table 30).

Emissions calculation

Emissions were calculated as tonnes annum^{-1} using the fuel consumption data, calculated above, in conjunction with the emission factors (g/kg) in appendix Table A. 2 to Table A. 5. For all vessels we have used the same emissions factors, except for the six newest "River Runner 200 Mark 2B" Thames Clippers vessels; Typhoon, Aurora, Cyclone, Meteor, Monsoon and Tornado. These vessels were constructed in 2007, with a swept volume of 2.23 l cylinder^{-1} and net power of 900kW. As such, they are assumed to comply with category V1:3 emission standards for inland waterway vessels under Directive 2004/26/EC Stage III A[49], for which the associated emissions factors are summarised in Table 31.

[48] DECC - https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/digest-of-uk-energy-statistics-dukes

[49] EU, 2004. Directive 2004/26/EC of the European Parliament and of the Council. Official Journal of the European Union L146 of 30 April 2004.

Table 31 Passenger shipping, minor operator fuel use by river link.

River Link	Fuel use (l yr^{-1})					
	LRS (Lord Ashfield)	WPSA (Upriver)	Scheduled: Westminster party boats, Crown Cruises, Thames River Services	Chartered: Westminster party boats, Crown Cruises, Thames River Services	Thames Executive Charters	Campion Launches
Hampton Court – Putney	0	69,720	0	29,667	50,403	5,687
Putney – Wandsworth	22	3,299	0	1,404	2,385	269
Wandsworth - Chelsea Harbour	37	5,462	0	2,324	3,949	446
Chelsea Harbour – Cadogan	26	3,869	0	1,646	2,797	316
Cadogan – Millbank	62	9,294	0	3,954	6,719	758
Millbank – Westminster	21	3,106	18,711	1,322	2,246	253
Westminster - London Eye	3	0	3,075	217	369	42
London Eye - Embankment	7	0	5,901	417	708	80
Embankment - Blackfriars	19	0	17,019	1,202	2,043	230
Blackfriars - Bankside	13	0	11,473	810	1,377	155
Bankside - London Bridge City	16	0	14,334	1,013	1,720	194
London Bridge City - Tower	7	0	6,055	428	727	82
Tower - Canary Wharf	72	0	64,884	4,583	7,787	879
Canary Wharf - Greenland	20	0	18,351	1,296	2,202	248
Greenland - Masthouse Terrace	19	0	17,132	1,210	2,056	232
Masthouse Terrace - Greenwich	18	0	16,619	1,174	1,994	225
Greenwich - North Greenwich	71	0	63,578	4,491	7,630	861
North Greenwich - Woolwich Arsenal		0	72,777	5,141	8,734	985
Total	**432**	**94,750**	**329,910**	**62,300**	**105,845**	**11,942**

Table 32 Stage III A emission standards for inland waterway vessel engines (Cat. V1:3).

Category: swept volume / net power (SV/P) (l cylinder^{-1}/kW)	CO	NOx + HC (g kWh^{-1})	PM
V1:3 1.2 ≤ SV <2.5 and P ≥ 37	5.0	7.2	0.20

Commercial shipping emissions calculation
For the LAEI 2010, the only change from the LAEI 2008 methodology for commercial shipping is the inclusion of emissions for hydrocarbons, methane, benzene, 1,3-butadiene, carbon monoxide, ammonia and nitrous oxide. Emissions of carbon monoxide, ammonia and nitrous oxide were scaled from CO_2 emissions using the pollutant: CO_2 ratios of major passenger shipping operators. Similarly, hydrocarbon, methane, benzene and 1,3-butadiene were scaled from NMVOC emissions, using pollutant: NMVOC ratios from passenger shipping, or in the case of 1,3-butadiene, from the national navigation category of the NAEI[50].

Emissions in 2008 were assumed to be identical to those in the LAEI 2008. The reduction in cargo transported on the river Thames between 2008 and 2010, of 17.7 % (, was used to scale the data between 2008 and 2010. Emissions from 2010 were held constant for years 2012, 2015 and 2020.

[50] DEFRA, 2012. National Atmospheric Emissions Inventory - http://naei.defra.gov.uk/data

Geographical definitions

The LAEI 2010 has a more refined geographical representation of emissions and roads. Previous inventories aggregated emissions across all sources at a 1km grid square level. Grid squares were then assigned to boroughs and area (e.g. central, inner, outer London). Where a grid square spanned more than one borough the entire grid square was assigned to just one borough.

In the LAEI 2010 the original 1km grid squares have been split at borough and location boundaries to give more precise borough and location totals.

Figure 5 Location and borough boundaries under old 1 km grid square split

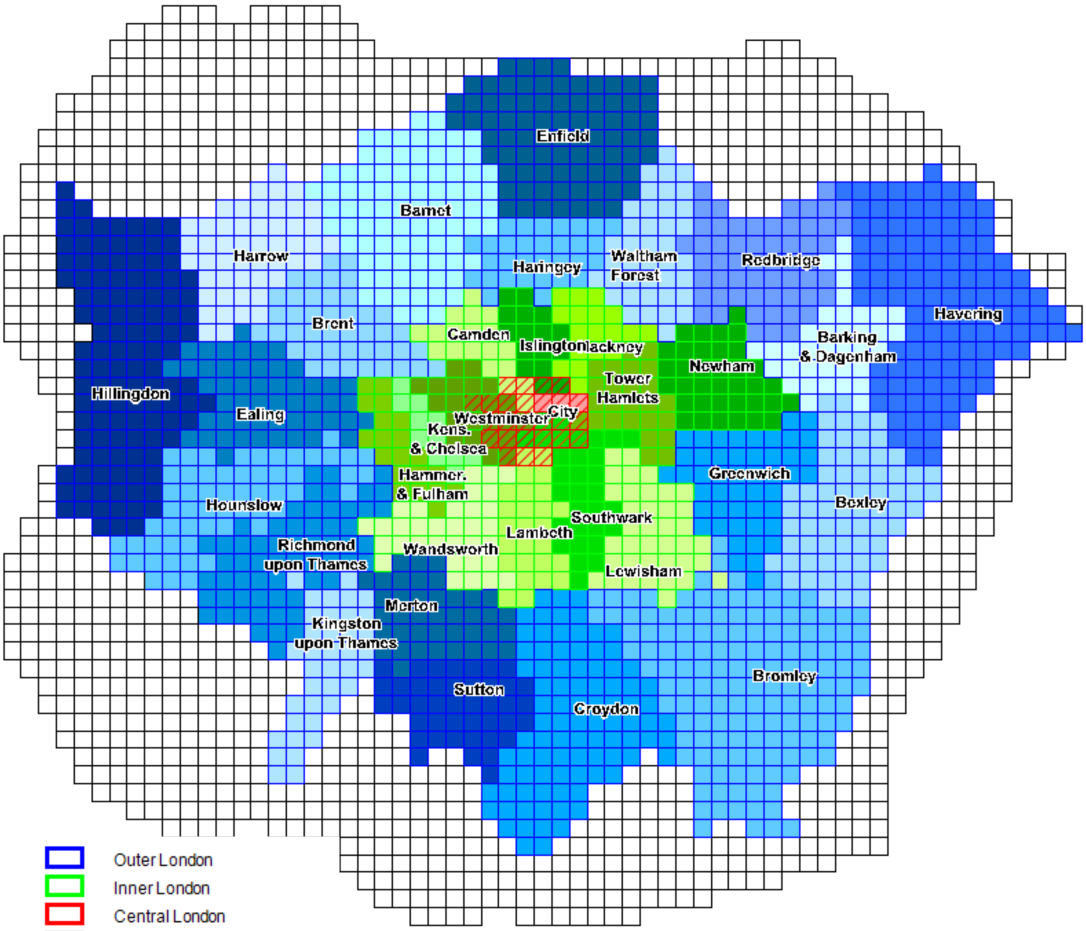
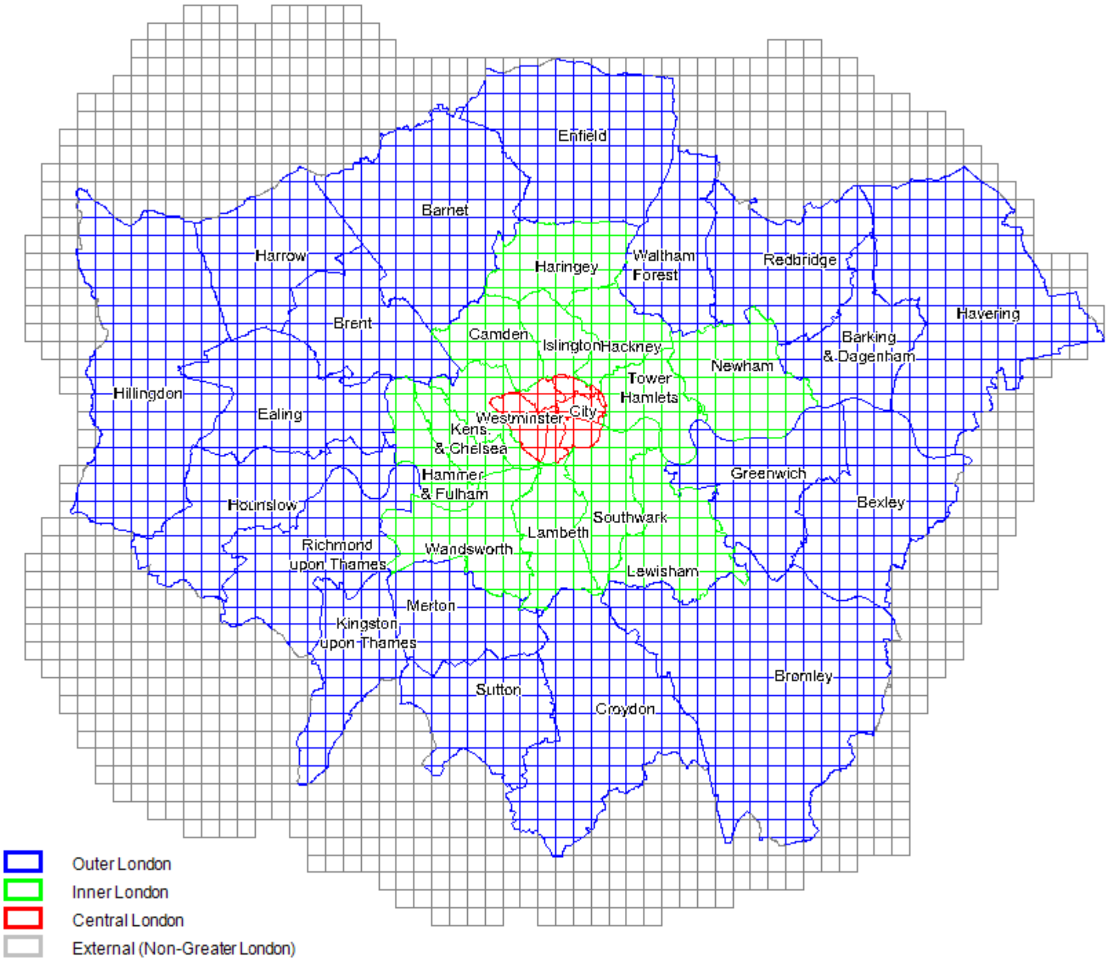


Figure 6 Location and borough boundaries under new grid split



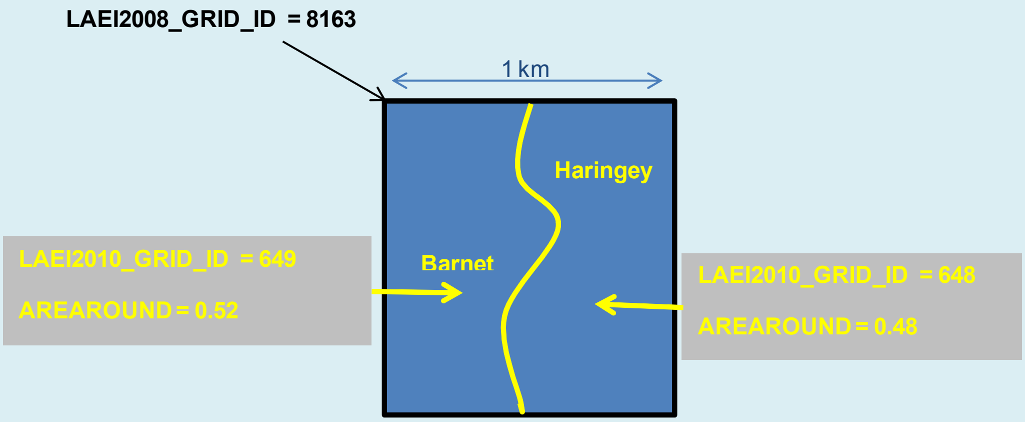
In the grid based emissions outputs, each record corresponds to one of the new split grid IDs (referred to as **LAEI2010_GRID_ID**). Each record has also been assigned to the previous 1 km grid square ID (**LAEI2008_GRID_ID**) as well as the split-grid and 1km-grid defined location and borough. Where a 1km grid square has been split into two along a borough boundary the old grid ID will appear twice. The column **AREAROUND** gives the proportion of the 1km-grid **LAEI2008_GRID_ID** that the record contributes to.

An extract of the location data within each of the output sheets is shown as an example along with an illustration of how the 1km grid square with ID 8163 is now made up of two split grids – 649 and 648.

LAEI2010_GRID_ID	648	649
LAEI2008_GRID_ID	8163	8163
AREAROUND	0.48	0.52
BOROUGHNAME_1KM_GRID	Haringey	Haringey
BOROUGHNAME	Haringey	Barnet
LOCATION_1KM_GRID	Inner	Inner
LOCATION_REFINED	Inner	Outer

Area Round Example

AREAROUND = Proportion of LAEI2008_GRID_ID that the corresponding LAEI2010_GRID_ID makes up



Appendix

Table A. 1.- Fuel Characteristics for Fuels Fired in Boilers

Residual oils			
Type	**Density (tonnes fuel /m³)**	**Net inferior calorific value (GJ/tonne fuel)**	**Net inferior calorific value (GJ/m³ fuel)**
Heavy fuel oil HFO	0.930 – 0.970	41.2	38.32
Medium fuel oil MFO	0.990	42.5	42.08
Distillates			
Paraffin	0.804	41.5	33.34
Kerosene (aka 28 s oil?)	0.804	43.0	34.57
Gas oil (aka red diesel?)	0.835	43.4	36.24
30 second oil	No data	No data	-
32 s (aka diesel?)	No data	No data	-
35 s (aka gas oil?)	No data	No data	-
Diesel	0.82	43.4	35.59
Red diesel	0.82	36.3	29.77
Gas oil class D (aka 35 s heating oil?)	No data	No data	-
Marine gas oil	0.86	42.7	36.72
Light oil	0.91	42.1	38.31
3000 Redwood gas oil	No data	No data	-
Light gas oil	0.94	No data	-
35 second diesel	No data	No data	-
35 second gas oil	No data	No data	-
38 second diesel	No data	No data	-
Standard heating oil	No data	No data	-

Table A. 2 Passenger shipping vessel specifications for Thames Clippers. Used in conjunction with link activity data (Table 29) to calculate main and auxiliary engine fuel consumption by link and vessel. Data derived from TRL report[51] unless otherwise stated.

Operator	Vessel Name	Main engine operating hour proportion	# of main engines, N_M	Main engine fuel consumption rate, FCR_M (l/hour)	Main engine load factor, LF_M	Auxiliary engine : main engine ratio	# of auxiliary engines, N_A	Auxiliary engine fuel consumption rate, FCR_A (l/hour)	Auxiliary engine load factor, LF_A	Fuel Density, *FD* (kg/l)	Notes
Thames Clippers	Typhoon	0.1177	2	233	0.163	1.1557	1	5	0.5	0.831	-
	Aurora	0.0764	2	233	0.163	1.5542	1	5	0.5	0.831	-
	Cyclone	0.1142	2	233	0.163	1.1288	1	5	0.5	0.831	-
	Meteor	0.0880	2	233	0.163	1.1709	1	5	0.5	0.831	-
	Monsoon	0.1033	2	233	0.163	1.1873	1	5	0.5	0.831	-
	Tornado	0.1095	2	233	0.163	1.1557	1	5	0.5	0.831	-
	Hurricane	0.1377	2	184	0.163	0.9433	1	5	0.5	0.831	Main engine fuel consumption source: http://marine.cat.com/cat-3412E
	Moon	0.0740	2	135	0.163	0.9524	1	5	0.5	0.831	Main engine fuel consumption source: http://marine.cat.com/cat-3406E
	Sun	0.0497	2	135	0.163	1.4185	1	5	0.5	0.831	
	Sky	0.0514	2	70	0.163	1.4757	1	5	0.5	0.831	Main engine fuel consumption for a Scania DSI 11 R82, website source accessed April 2012, no longer available.
	Star	0.0382	2	70	0.163					0.831	
	Storm	0.0399	2	70	0.163					0.831	
	Twinstar	1.0000	2	110	0.163					0.831	Fuel consumption estimated through back calculation from total Thames Clippers fuel consumption.

[51] TRL, 2010. Client Project Report CPR475: Reducing emissions from Thames river passenger services in London. Available from TfL.

Table A. 3 Passenger shipping vessel specifications for City Cruises. Used in conjunction with link activity data (Table 29) to calculate main and auxiliary engine fuel consumption by link and vessel. Data derived from TRL report unless otherwise stated.

Operator	Vessel Name	Main engine operating hour proportion	# of main engines, N_M	Main engine fuel consumption rate, FCR_M (l/hour)	Main engine load factor, LF_M	Auxiliary engine : main engine ratio	# of auxiliary engines, N_A	Auxiliary engine fuel consumption rate, FCR_A (l/hour)	Auxiliary engine load factor, LF_A	Fuel Density, *FD* (kg/l)	Notes
City Cruises	Millenium City	0.1313	2	79	0.282	0.6692	2	5	0.5	0.867	-
	Millenium Dawn	0.1313	2	79	0.282	0.6692	2	5	0.5	0.867	-
	Millenium Peace	0.1313	2	79	0.282	0.6692	2	5	0.5	0.867	-
	Millenium Time	0.1313	2	79	0.282	0.6692	2	5	0.5	0.867	-
	Millenium London	0.0615	2	79	0.282	0.8608	2	5	0.5	0.867	-
	Mayflower Garden	0.1276	1	55	0.282	0.6741	2	5	0.5	0.867	Main engine fuel consumption calculated from average vessel passenger capacity to fuel consumption ratio from vessels where both values are available.
	Eltham	0.0106	1	44	0.282	1.5385	1	5	0.5	0.867	
	Westminster	0.0053	1	44	0.282	1.5385	1	5	0.5	0.867	
	Princess Rose	0.0061	1	36	0.282	0.5000	1	5	0.5	0.867	
	City Alpha	0.0871	2	70	0.282	1.5100	1	5	0.5	0.867	
	City Gamma	0.0871	2	70	0.282	1.5100	1	5	0.5	0.867	
	City Delta	0.0871	2	70	0.282	1.5100	2	5	0.5	0.867	
	Eleanor Rose	0.0012	1	40	0.282	0.0000				0.867	
	Witheycombe	0.0012	1	55	0.282	0.0000				0.867	

Table A. 4 Passenger shipping vessel specifications for Woolwich Ferry and Bateaux London. Used in conjunction with link activity data (Table 29) to calculate main and auxiliary engine fuel consumption by link and vessel. Data derived from TRL report unless otherwise stated.

Operator	Vessel Name	Main engine operating hour proportion	# of main engines, N_M	Main engine fuel consumption rate, FCR_M (l/hour)	Main engine load factor, LF_M	Auxiliary engine : main engine ratio	# of auxiliary engines, N_A	Auxiliary engine fuel consumption rate, FCR_A (l/hour)	Auxiliary engine load factor, LF_A	Fuel Density, FD (kg/l)	Notes
Woolwich Ferry	**John Burns**	**0.3333**	**2**	**40**	**0.976**	**1.0000**	**2**	**20**	**0.5**	**0.867**	**Auxiliary engine fuel consumption back calculated from total fuel consumption**
	Ernist Bevin	**0.3333**	**2**	**40**	**0.976**	**1.0000**	**2**	**20**	**0.5**	**0.867**	
	James Newman	**0.3333**	**2**	**40**	**0.976**	**1.0000**	**2**	**20**	**0.5**	**0.867**	
Bateaux London	**Symphony**	**0.6998**	**2**	**75**	**0.470**	**1.0000**	**2**	**5**	**0.5**	**0.867**	**-**
	Naticia	**0.3002**	**2**	**90**	**0.470**	**1.0000**	**2**	**5**	**0.5**	**0.867**	**-**

Table A. 5 Emission factors used for passenger shipping

Pollutant	Gas Oil		Ultra low sulphur fuel		River Runner 200 Mark 2B vessels	
	Emission Factor (g kg^{-1})	Source	Emission Factor (g kg^{-1})	Source	Emission Factor (g kg^{-1})	Source
NO_x	55.00	TRL (2010)[52]	55.00	TRL (2010)	30.76	Directive 2004/26/EC NO_x+HC limit value (EU, 2004)[53] x 0.94 (NO_x: NO_x+HC ratio)
NO_2	8.25	NO_x x 0.15 (AEA, 2007)[54]	8.25	NO_x x 0.15 (AEA, 2007)	4.61	NO_x x 0.15 (AEA, 2007)
CO_2	3190.00	TRL (2010)	3164.00	TRL (2010)	3164.00	TRL (2010)
PM_{10}	2.00	TRL (2010)	1.80	90 % of gas oil (TRL, 2010)	0.91	Directive 2004/26/EC PM limit value (EU, 2004)
SO_2	2.00	TRL (2010)	0.02	TRL (2010)	0.02	TRL (2010)
CO	11.76	Average value from King's literature search.	11.76	Average value from King's literature search.	11.76	Average value from King's literature search (lower value than EU limit).
N_2O	0.26	Average value from King's literature search.	0.26	Average value from King's literature search.	0.26	Average value from King's literature search.
hydrocarbons	3.55	Average value from King's literature search.	3.55	Average value from King's literature search.	1.96	Directive 2004/26/EC NO_x+HC limit value (EU, 2004) x 0.06 (HC: NOx+HC ratio).
CH_4	0.07	2 % of hydrocarbons (EEA/EMEP2009)[55]	0.07	2 % of hydrocarbons (EEA/EMEP2009)	0.04	2 % of hydrocarbons (EEA/EMEP2009)
NMVOC	3.48	98 % of hydrocarbons (EEA/EMEP2009)	3.48	98 % of hydrocarbons (EEA/EMEP2009)	1.92	98 % of hydrocarbons (EEA/EMEP2009)

[52] TRL, 2010. Client Project Report CPR475: Reducing emissions from Thames river passenger services in London. Available from TfL.

[53] EU, 2004. Directive 2004/26/EC of the European Parliament and of the Council. Official Journal of the European Union L 146 of 30 April 2004.

[54] AEA, 2007. Emissions of Nitrogen Dioxide and Nitrous Acid from Road Transport and Other Sources. DEFRA. Reference no. ED05450007.

[55] EEA/EMEP, 2009. Air Pollutant Emissions Inventory Guidebook - http://eea.europa.eu/emep-eea-guidebook

Pollutant	Gas Oil		Ultra low sulphur fuel		River Runner 200 Mark 2B vessels	
	Emission Factor (g kg^{-1})	Source	Emission Factor (g kg^{-1})	Source	Emission Factor (g kg^{-1})	Source
PM_{25}	1.24	Average value from King's literature search.	1.12	Assumed 90 % of gas oil value, based on PM_{10} from TRL (2010)	0.91	Directive 2004/26/EC PM limit value (EU, 2004)
Benzene	0.70	20 % of NMVOC (EEA/EMEP2009)	0.70	20 % of NMVOC (EEA/EMEP2009)	0.38	20 % of NMVOC (EEA/EMEP2009)
NH_3	0.01	Average value from King's literature search.	0.01	Average value from King's literature search.	0.01	Average value from King's literature search.
1,3 Butadiene	-	Assumed 1 % of NMVOC. Based on NAEI VOC: 1,3 Butadiene ratio from national navigation (DEFRA, 2012)[56]	-	Assumed 1 % of NMVOC. Based on NAEI VOC: 1,3 Butadiene ratio from national navigation (DEFRA, 2012)	-	Assumed 1 % of NMVOC. Based on NAEI VOC: 1,3 Butadiene ratio from national navigation (DEFRA, 2012)

[56] DEFRA, 2012. National Atmospheric Emissions Inventory - http://naei.defra.gov.uk/data