# London Atmospheric Emissions Inventory (LAEI) 2008

## Emissions Estimation Methodology Manual

London Atmospheric Emissions Inventory 2008

MAYOR OF LONDON

**London Atmospheric Emissions Inventory 2008**

Designed and compiled by

AEA

GREATER LONDON AUTHORITY

AEA

KING'S College LONDON

August 2010

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# Introduction

## 1.1. What is the London Atmospheric Emissions Inventory 2008 (LAEI 2008)?

The LAEI 2008 is a Microsoft® Access database of geographically referenced datasets of emissions sources and information about the location, rates of emissions and estimates of the quantity of specific pollutants emitted into the air within and around the Greater London area (i.e., within the M25 motorway[1] ring) in the 2008[2] base year, with forward and backward projections to 2011 & 2015 and 2006 & 2004, respectively.

The LAEI 2008 emission estimates are predominantly based Emission Factors and local activity data. Where insufficient local data existed, a combination of the "bottom up" and "top down" methodologies and datasets developed by the AEA Emissions Inventory Team for the compilation of the 2007 regional and sub-regional emissions inventories and the United Kingdom (UK) National Atmospheric Emissions Inventory (NAEI) 2007[3], were used. The NAEI is generally based on a combination of both "bottom up" and "top-down" source specific data and annually released "top down" energy data such as those presented in the Digest of United Kingdom Energy Statistics (DUKES), published by the UK Department of Business, Innovation and Skill (DBIS).

The LAEI 2008 is the latest version of the LAEI series released by the Greater London Authority (GLA). Since its establishment in 2000, the GLA has updated and released seven versions (i.e., including the current version, LAEI 2008) of the LAEI: LAEI 1999, released in October 2001 and February 2002; LAEI 2001, released in October 2003; LAEI 2002, released in February 2005; LAEI 2003, released in July 2006; LAEI 2004, released in February 2008; LAEI 2006, released in March 2009; and the current LAEI 2008, released in August 2010.

## 1.2. Uses of the LAEI 2008

The LAEI 2008 could be used for the following purposes:

- To assess the relative significance of the different emission sources in Greater London, including their spatial and temporal distributions, in order to identify the specific emission sources that could be targeted if reductions in atmospheric emissions are required.
- In conjunction with other air quality tools such as air quality monitoring data, modelled air quality data and maps, meteorological data, air quality targets and guidelines tools, to assist in assessing the effectiveness of the London Mayor's Air Quality Strategy (MAQS).

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[1] The M25 motorway is a 117 miles (188 km) orbital motorway which encircles Greater London, except for the tolled Dartford Crossing (A282) where it crosses the River Thames to the east of London.
[2] The 2008 base year (and in some cases 2007) is the most recent year for which adequate and reliable datasets were available at the time (September 2009-December 2009) the LAEI 2008 was compiled.
[3]The NAEI can be found at: http://www.naei.org - The NAEI is a "top down" inventory in which national data is allocated to smaller areas on the basis of the resident population and other appropriate indicators of regional activity. However, it contains some "bottom up" data such as on individual power stations and large industrial plants. The LAEI 2008 is a "bottom up" inventory in which local data is used to compile an inventory of local emissions. However, the LAEI and the NAEI are, to a certain degree, complementary.

- To provide an input to both UK and Greater London policy-making with respect to atmospheric pollution abatement and controls.
- To provide an input to atmospheric dispersion models and assist in the interpretation of ambient air quality measurements.
- For general public information.

## 1.3. Pollutants estimated in the LAEI 2008

The LAEI 2008 contains emission estimates for eight key and six subsidiary pollutants that largely correspond to those considered in the UK National Air Quality Strategy (NAQS). The eight key pollutants covered in the LAEI 2008 are:

- Oxides of nitrogen ($NO_X$)[4]
- Sulphur dioxide ($SO_2$)
- Carbon monoxide (CO)
- Non-methane volatile organic compounds (NMVOC)
- Carbon dioxide ($CO_2$)
- Benzene
- 1,3-butadiene
- Particulate matter less than 10 micrometres (μm) aerodynamic diameter ($PM_{10}$).

The subsidiary pollutants covered in the LAEI 2008 are:

- Methane ($CH_4$)
- Particulate matter less than 2.5 micrometres (μm) aerodynamic diameter ($PM_{2.5}$)
- Nitrous oxide ($N_2O$)
- Total suspended particulates (TSP)
- Black smoke
- Polycyclic aromatic hydrocarbons (PAH).

For the subsidiary pollutants, the quality of available information does not allow complete coverage of all possible emission sources. Therefore, estimates of these subsidiary pollutants are included in the LAEI 2008 only where appropriate data and information are available.

## 1.4. Spatial and temporal scopes of the LAEI 2008

Geographically, the **Greater London area** covers only the 32 London boroughs and the City of London, whilst the **LAEI area** covers the Greater London area and the area lying between the M25 motorway and the Greater London area boundary (see Figure 1). The total Greater London and the LAEI areas are approximately 1,604 km$^2$ and 2,466 km$^2$, respectively.

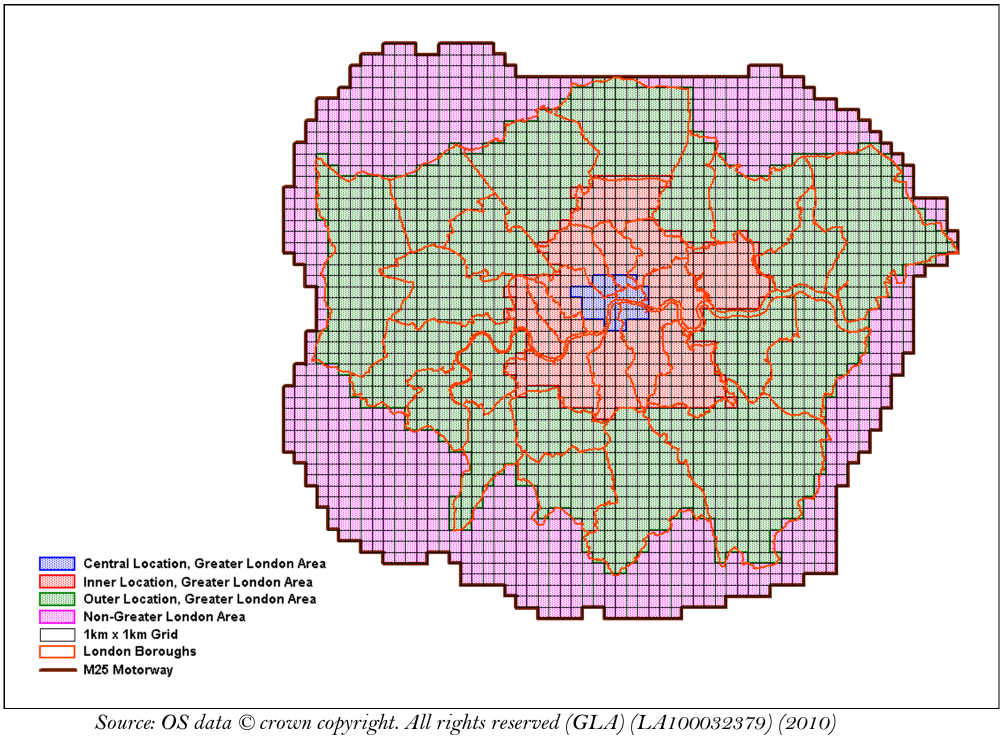
[4] Nitrogen dioxide ($NO_2$) and nitric oxide (NO) are both oxides of nitrogen and are collectively referred to as oxides of nitrogen ($NO_X$). All combustion processes produce some $NO_X$ emissions, largely in the form of nitric oxide, which is then converted to nitrogen dioxide, mainly as a result of reaction with ozone in the atmosphere. This reaction is thought to be responsible for the majority of $NO_2$ originating in London. Only nitrogen dioxide is associated with adverse effects upon human health.

The UK Ordnance Survey (OS) 1-kilometre squared (1-km$^2$) grids are used for spatially allocating the final emission estimates across the Greater London and LAEI areas. Final emission estimates are allocated to each 1-km$^2$ grid, therefore all details about emission variations from points, linear and polygon features (i.e., emission sources) within each 1-km$^2$ grid are lost through spatial aggregation. There are 2,466 and 1,604 1-km$^2$ grids covering the entire LAEI area and the Greater London area, respectively.

For reporting and presentation purposes, the LAEI 2008 area is geographically divided into two sub-areas:

- The **Greater London** area, which includes the 32 London boroughs and the City of London.
- The **Non-Greater London** area, which is the area that lies between the Greater London area boundary and the M25 motorway, including parts of 19 Districts in the Counties of Kent, Surrey, Berkshire, Buckinghamshire, Hertfordshire and Essex.

**Figure 1: London Atmospheric Emissions Inventory 2008 study area**




*Source: OS data © crown copyright. All rights reserved (GLA) (LA100032379) (2010)*

All geographical divisions and London borough boundaries within the LAEI 2008 are based on the "jagged" boundaries of the OS 1-km$^2$ grids. Therefore, the digital boundaries of the London borough referred to within this report do not exactly coincide with the actual OS administrative boundaries of the London boroughs. In other words, the digital boundaries of the London borough referred to within this report are the closest approximations to the geographically accurate OS administrative boundaries of the London boroughs.

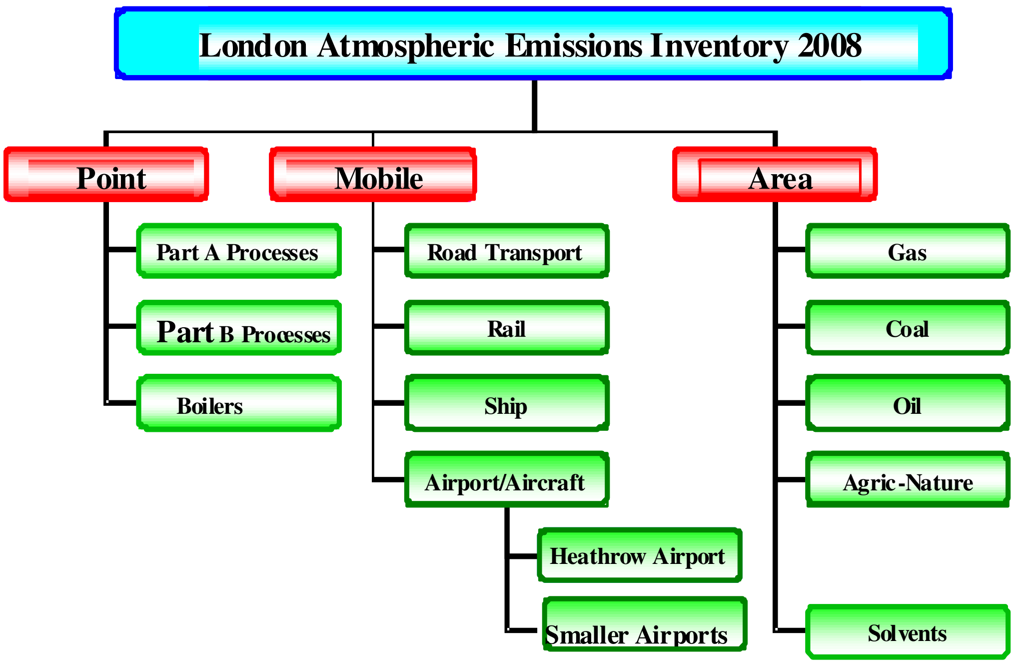
The 1-km$^2$ grids that make up the London boroughs are mutually exclusive (that is, each 1-km$^2$ grid belongs to no more than one London borough) and collectively exhaustive (that is, every 1-km$^2$ grid within the Greater London area belongs to a London borough). When a

1-km² grid falls in more than one London borough, the London borough with the largest share of the 1-km² grid's area gets the entire value of the 1-km² grid.

## 1.5. Emission sources categorisation in the LAEI 2008

The emission sources in the LAEI 2008 are grouped into three *main emission source categories* (see Figure 2), based on the characteristics of the emission sources. Each of the main emission source categories are further divided into various *emission source subcategories*, based on the nature of the emission sources.

**Figure 2: Categorisation of emission sources in the LAEI 2008**




**Point** emission source category includes stationary emission sources identified individually due to the quantity or nature of their atmospheric emissions. In the LAEI 2008, the point emission source category is divided into three *emission source subcategories*:

- Part A Processes (large industries regulated by the Environment Agency)
- Part B Processes (smaller industrial processes regulated by the local authorities)
- Boilers (large industrial boiler plants).

**Mobile** emission source category includes emission sources along a defined line. It includes all on-road mobile sources (these are vehicles operated on the streets and highways, such as motorcycles and cars) and non-road mobile sources (consisting of all vehicles and equipment not routinely operated on streets and highways, such as trains, ships and aircrafts). In the LAEI 2008, the mobile emission sources category is divided into four *emission source subcategories*:

- Road transport
- Rail traffic

- Ships
- Airports and aircrafts

**Area** emission source category encompasses a large number of diverse emission sources - everything from bakeries and breweries to domestic heating systems and degreasing operations. Area emission source category includes facilities whose individual emissions do not qualify them as point sources (individually they emit smaller quantities of pollutants. However, collectively they can release significant quantities of pollutants). This category also includes those emissions sources for which datasets do not exist to locate the emissions any more specifically. In the LAEI 2008, the area emission sources category is divided into five *emission source subcategories*:

- Gas (domestic, industrial-commercial consumption and gas leakage)
- Oil (domestic and commercial oil combustion)
- Coal (domestic and commercial combustion)
- Agriculture-nature (agricultural activities and natural occurrences)
- Solvents-buildings (solvents and solvent-processing buildings).

### 1.6. What is new in the LAEI 2008

The following significant improvements have been incorporated into the LAEI 2008 time:

- The LAEI 2008 now provides improved and integrated links to both MapInfo Professional files (i.e., *.tab) and ESRI ArcGIS®) shapefiles (i.e., *.shp) files to ensure users benefit from the mapping, visualisation and querying functionality offered by this GIS applications.
- *MS Excel PivotTable and PivotChart Reports functionality*: The LAEI 2008 now embeds interactive data analysis functionality (i.e., PivotTable and PivotChart reports from Microsoft Excel) for graphically summarising, displaying and analysing trends in total emissions estimates for 2004, 2006, 2008, 2011 and 2015. This functionality assists users in assessing the trend and magnitude of meaningful changes in emissions over the past years. Methodological changes and refinements to the LAEI 2008 estimation methodologies have been retrospectively applied ("back-calculation") to the LAEI 2006 and LAEI 2004 emission estimates (only $PM_{10}$ and $NO_X$) to enable consistent and meaningful comparisons over time.
- The Sewage emissions source subcategory (reported as an area source in the previous versions of the LAEI prior to the LAEI 2008) has now been removed from the Area Sources category and is now reported as a point source under the Part A Processes subcategory in the LAEI 2008. Sewage treatments emissions in the LAEI 2008 were obtained from the UK Environment Agency's Pollution Inventory for the 2007 base year.
- Air emissions from the Agricultural-Natural emission source subcategory have been expanded to encompass the following: Agricultural (i.e., soils, livestock, domestic gardens, animal incineration, agriculture and land use) and Natural-Other (i.e., forests, bonfire night, fireworks and accidental fires - dwellings and other buildings, forests, straw and vegetation) activities.

## 1.7. Availability of the LAEI 2008

The LAEI 2008 is available from the Air Quality Team, Environment Group, Greater London Authority (GLA), as a "zipped" (i.e., compressed) folder (LAEI_2008.zip) that contains all the necessary files and the actual LAEI 2008 Microsoft ® Access database that are needed to fully utilise the LAEI 2008. A user guide (**LAEI 2008 User Guide**) that provides clear and comprehensive information on how to copy and use the LAEI 2008 accompanies the LAEI.

The "unzipped" (decompressed) LAEI_2008 folder must be copied to a suitably named directory/folder on your PC or network and it contains all the necessary files (including the GIS maps in MapInfo® Professional, ESRI ArcGIS®, Microsoft® Excel, Microsoft® Word and Adobe Acrobat® Reader file formats) needed to fully utilise the LAEI 2008. The LAEI_2008 folder also contains the actual LAEI 2008 database (**LAEI_2008.mdb**), which was developed using the Microsoft® Access 2002 database management system (DBMS).

***Important!***
*Because the LAEI 2008 uses the Microsoft® Access 2002 application as its database management system (DBMS) you MUST have Microsoft® Access 2000 or later installed on your PC or else you will NOT be able to use the LAEI 2008 database (i.e., the LAEI_2008.mdb file) and its user-friendly interfaces to easily and quickly navigate and query the underlying LAEI 2008 emission datasets.*

*The LAEI 2008 was created using Access 2002 and do not need to be converted for use with Office Access 2007. You may open the LAEI 2008 (*.mdb file format) and modify data and object design in Office Access 2007 (*.accdb file format) - compatibility mode is automatically on when you open a file that was saved in the old file formats and most functionality in the LAEI 2008 is available in Office Access 2007, with some exceptions. When the Office 2007 program is in compatibility mode, it will be indicated in the document title bar. Please note that because of some inbuilt security functionality in Access 2007 and the way Access 2007 is installed, the LAEI 2008 may encounter some technical problems.*

## 1.8. Price of the LAEI 2008

The GLA provides the LAEI 2008 to London boroughs (as part of assisting London boroughs to implement their air quality works) and other users free of charge. Requests for the LAEI 2008 must be made to the Greater London Authority:

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City Hall
The Queen's Walk
London SE1 2AA
United Kingdom
Fax: 020 7983 4057
Email: mayor@london.gov.uk

# ESTIMATING EMISSIONS FROM RAIL TRAFFIC

## Summary

**Base Year: 2008**
Up-to-date 2008 rail traffic and energy consumption datasets were obtained from DeltaRail and were used to estimate emissions from rail traffic in the LAEI 2008.

**Projection Years: 2011 and 2015**
The up-to-date 2008 rail traffic and energy consumption datasets were obtained from DeltaRail and were used as the base year dataset to project rail traffic emissions to 2011 and 2015.

### 1.9. 2008 emission estimation methodology

This section presents the methodology for the estimation of atmospheric emissions ($CO_2$; CO; $NO_X$; HC; $PM_{10}$; and $SO_2$) from railway traffic in 2008 within the Greater London area.

Undoubtedly, estimating atmospheric emissions from railway traffic is a complicated task because several factors play significant roles in the definition of emission parameters, namely: type of train (electric or diesel); average train speed service; fuel (sulphur contents in diesel fuels); number of passengers per seat (0-100%); topography of the distance travelled, slopes and hills; wind speed; number of cold starts (for diesel powered trains); average distance between train stations; and degree of reuse of braking energy. In addition, the estimation of atmospheric emissions from railway traffic in the Greater London area is further complicated by the fact that London's rail traffic is characterised by diversity: a national railway system with a series of railways owned by private companies with a variety of applications; a passenger rail traffic that varies from smaller electric and diesel urban trains, with regular stops and starts, to high-speed passenger trains with infrequent stops; both diesel-powered passenger and freight trains operating on electrified lines used by electrically powered passenger and freight trains; both electrically powered passenger and freight trains operating on the same line, making it difficult to distinguish between electricity (kWh) used for a passenger train or that for a freight train on the same line at the same time; and the use of a given locomotive type for both freight traffic and for different types of passenger operation, making it difficult to attribute energy consumption to a given type of train traffic.

Railway traffic atmospheric emissions are dependent on the source of power (electricity or diesel fuel) used in the train. In the Greater London area, electrically powered trains undertake a significant proportion (about 70%) of high-speed journeys from London to regional cities. When electricity is used to power trains, their emissions are attributed to the power generation plants, and not to the location of the trains themselves as is the case for diesel-powered trains, where emissions are local as a result of the combustion. Therefore, the extensive use of electrically powered trains in London makes it difficult to attribute emissions directly to trains, further complicating the allocation of emissions to rail source in the LAEI. To do this, the distribution of electrical power generation sources and the fuel used (e.g., coal, gas, nuclear energy etc.) for the generation of the electric power in the Greater London area must be known. However, further difficulties arise because the electrical power used to operate most trains in London is actually produced by power stations located outside the Greater London area. Unfortunately, the type of fuel used by these power stations for the generation of the electric power is not known.

Prior to the LAEI 2002 (released in 2005), railway traffic emissions were estimated using a very simplified methodology – emission factors were multiplied by the total amount of passenger-kilometre regardless of the train speed service and average distances between stops. Variables such as occupancy and rail technology were implicitly incorporated into these emission factors, which were typically evaluated for one particular train speed and driving pattern, thus limiting the usefulness of this simplified methodology.

To overcome several of the difficulties highlighted in the preceding paragraphs, an improved methodology, largely based on the methods described in greater detail by Hickman (1999) and Jorgensen & Sorenson (1997), was used in estimating the atmospheric emissions generated by rail traffic in the Greater London area. A fundamental prerequisite in the improved methodology is the availability of the energy consumption (in particular, the specific energy consumptions, expressed as kWh/tonne-km[5]) of a given type of train. This energy consumption is the energy required to move the train and is for all extents and purposes independent of the type of locomotion used, allowing the same methodology to be used for both electric and diesel trains. Therefore, train weight is an important parameter in this improved methodology, since it is the most significant parameter determining the energy consumption and emission rates. However, there are some minor differences in train weights due to differences between the weights of electrical and diesel powered locomotive, but in general these differences are minute in relation to other uncertainties. The differences in emissions arise primarily through the differences in emissions factors for diesel engines and for electrical power generation.

In order to successfully use the improved methodology with a reasonable degree of confidence, the availability of actual up-to-date rail traffic and energy consumption information for the Greater London area and appropriate energy-specific emissions factor (expressed as g/kWh or kg/GJ) were imperative. In this study, actual rail traffic and energy consumption information were obtained from DeltaRail's "ACTRAFF" (Actual Traffic) database and "TRATIM" program respectively. ACTRAFF uses source data from Network Rail's BIFS (Billing Infrastructure for Freight System) and CCF systems. The results are therefore subject to the same limitations as the source data. Similarly the quality of the results is dependent on the quality of the raw data.

ACTRAFF assumes that passenger trains are fully occupied, and assumes an average passenger weight of 0.08 tonnes. This may therefore marginally overestimate the weight, and therefore the energy consumption, of passenger trains. DeltaRail holds large amount of data on actual train movement in the UK, compiled by taking historic train running data from TRUST (Train Running System on TOPS: A computer system which records actual train running times against scheduled times) and mapping this back to the rail network. At the end of each four-week period DeltaRail updates the ACTRAFF database, which holds information about the number of trains by type and weight of trains that have passed over each section of the Network Rail network. Furthermore, DeltaRail's Train Performance Service prepares energy consumption data for Network Rail (to assist the evolution of track access charging) and for train operators (for business costing purposes), which is used to produce basic energy consumption tables from its TRATIM program. The energy-specific emission factors for diesel engines per unit of power produced were obtained from

[5] Transportation of one tonne of goods over one kilometre including the weight of the rolling stock.

Jorgensen & Sorenson (1997) for $CO_2$, CO, HC and $SO_2$ and for $NO_X$ and $PM_{10}$ from National Transport Model (DfT). The emission factors for electric trains, are based on the averaged energy-specific emission factors of the electricity generation mix for the UK, were obtained from DUKES (2008).

Emission rates were determined according to the equation below.

$$E_p = EC \times EF_p * 10^{-6}$$

Where:

| | |
|---|---|
| $E_p$ | = Emission rate of pollutant *p*, tonne/annum |
| $EC$ | = Energy consumption, kWh |
| $EF_p$ | = Energy-specific emission factor for pollutant *p*, g/kWh |
| $10^{-6}$ | = Conversion factor, gramme to tonne |

For the purpose of spatially analysing and allocating rail traffic emission estimates across the study area at 1 km x 1km spatial resolutions, the UK Ordnance Survey National Grid Reference System was used as the geographical reference system. A digital geographic layer of the entire railway network (Figure 3) in the Greater London area was developed, with each railway link represented as a line feature and allocated a unique identification number, and both spatial and non-spatial attributes attached.

Undoubtedly, the finer the temporal resolution the greater becomes the volume of data required for estimating emissions (with mounting accuracy requirements as well). Taking into account the goal of this study, estimating only the average emission of the pertinent pollutants from railway traffic in the Greater London area over the year 2008 was considered sufficient. In terms of the rail traffic data from the ACTRAFF database, there are 13 railway periods every year, each (normally) consisting of four weeks (these do not coincide exactly with the calendar year).

### 1.10. Rail Traffic

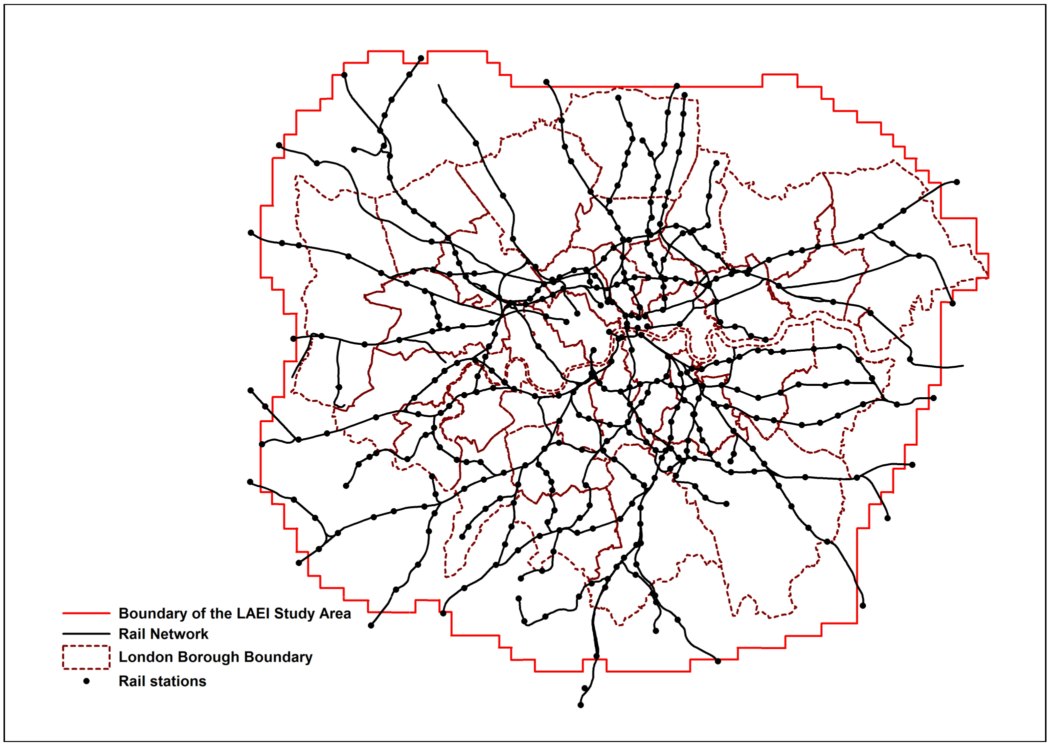
In order to obtain a proper spatial distribution, that is how many railway trains are operating within the Greater London area at a given time, proper rail traffic data was crucial. To keep the data collection and analytical process at reasonable levels, a sensible categorisation of train types (Table 1) was agreed.

Since 2005, a small number of changes have been made to London's railway infrastructure; these include:

- the opening of "High Speed 1" between St Pancras International and the Greater London boundary
- the introduction of services to Heathrow Terminal 5
- closure of the route between Stratford and North Woolwich;

ACTRAFF results are based on infrastructure existing at June 2006, therefore data relating to High Speed 1 and Heathrow Terminal 5 is very limited. Since the 2008 results are based on the same network as 2005, there is no GIS link data for new infrastructure.

**Figure 3. Spatial distribution of the rail network in the LAEI study area**




## 1.11. High Speed 1

Limited ACTRAFF data is available for services using High Speed 1, on the approaches to St Pancras International. This data has been used to generate results for train types and numbers over High Speed 1, based on the following assumptions:

- Eurostar trains operating in passenger service will run to or from the GLA boundary
- Eurostar trains operating out of service will run to or from the depot at Temple Mills
- Southeastern trains (operating for training or test purposes) will operate to or from the GLA boundary

- Although there is no GIS data against which to match these services, two additional links (998 High Speed 1 to/from Temple Mills depot, 999 High Speed 1 to/from GLA boundary) have been created in the data tables for train movements. Distances are assumed to be 12.50km (St Pancras International to Temple Mills Depot) or 31.75km (St Pancras International to the GLA boundary – this includes the section between the actual GLA boundary and the Thurrock river crossing).

**Table 1. Train categorisation used in the study**

| Train Category | Description |
|---|---|
| D1 | Intercity 125 2-Engine |
| D2 | Diesel Multiple Unit (DMU) type |
| 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 | Diesel Multiple Units - 5 coaches |
| E1 | 25kV Electric Locomotive & coaches |
| E2 | 25kV 8/12-coach Electric Multiple Unit |
| E3 | 25kV 4-coach Electric Multiple Unit |
| E4 | 750V Electric Multiple Unit (EMU) |
| E5 | 750V 8/12-coach Electric Multiple Unit |
| E6 | 750V 4-coach Electric Multiple Unit |
| E7 | 750V 3-coach Electric Multiple Unit |
| E8 | 750V 2-coach Electric Multiple Unit |
| E9 | 750V 6-coach Electric Multiple Unit |
| Ey | 750V 5-coach Electric Multiple Unit |
| F1 | Freight - other |
| M1/M2* | Unknown - missing from "CONSIST" |
| P1/P2* | Preserved-Locomotive |

*M1 and P1 for electric trains and M2 and P2 for diesel trains

The information in Table 2 was extracted from the ACTRAFF database for the calendar year 2008 across the LAEI study area on a link-by-link (a section of track) basis.

**Table 2. Rail traffic data extraction from the ACTRAFF database**

| | Information | Description |
|---|---|---|
| 1 | Year | 2008 – base year |
| 2 | Link | A unique ID for a section of track |
| 3 | Type | Passenger or Freight |
| 4 | Fuel Type | Electric or Diesel |
| 5 | Distance | Distance of link in kilometres |
| 6 | Number | Total number of passenger/freight trains |
| 7 | Tonnage | Total tonnage of passenger/freight trains |
| 8 | Seats | Average number of seats (passenger trains only) |
| 9 | Wagons | Average number of wagons (freight trains only) |
| 10 | Tare Weight | Average tare weight in tonnes (passenger and freight trains) |
| 11 | Gross Weight | Average gross weight in tonnes (passenger and freight trains) |

## 1.12. Rail Energy Consumption

In order to determine train energy consumption (i.e., both the average and specific energy consumption values) for a variety of situations, or in cases where it was necessary to make estimates, DeltaRail simulated TRATIM program runs over all the route sections with the identified train types from the ACTRAFF database. Specifically, the energy consumption of great interest is that energy (expressed in kWh/tonne-kilometre) which is required of a locomotive to move the train. By making the energy consumption mass specific, the key factor in determining the energy consumption, the train mass, was normalised out of the calculation. In these terms, energy consumption for different train types became more similar, and correlations based on mass specific energy consumption were applicable to a wider range of trains. Under acceleration, the energy consumption is directly related to the accelerated mass. Hence of great importance was the train weight dataset from the ACTRAFF database.

DeltaRail has substantial infrastructure and traction and rolling stock database that provides Network Rail with point-to-point train timing and energy consumption information via the suite of programs known as "TRATIM". Network Rail owns TRATIM but BR Research and subsequently DeltaRail have agreed exploitation rights. TRATIM calculates Sectional Running Times (SRTs) based on the Runge-Kutta Integration method. It is an event-based single train simulation and is used to compute the running times for single train operation to supply to Network Rail Operational Planning Units and the Train/Freight Operating Companies on request. It is currently recognised by Network Rail, the Train/Freight Operating Companies and other interested parties as the 'industry standard' method of calculating train timings and energy consumption.

The TRATIM simulations in this study utilised the latest railway geographical information comprising distances, station locations, gradients and speed restrictions. The train types and formations operating over the lines of route were identified from the on-line real running time 'TOPS' suite, of operational main frame computer programs, and then allocated train identifiers for evaluation purposes. The lines of route (broken down into route sections) under evaluation were based on the data extracted from ACTRAFF. These routes, uniquely identified as links, all emanated from London's main line terminus stations.

The TRATIM simulations were only carried out for passenger trains, since the freight movements in the central London area were low in number, comprising mainly very short formation trains, spasmodic in operating regularity when compared to the frequent vast numbers of passenger train movements. For this area, TOPS data was also very vague in detail, regarding freight movements and CONSIST makeup details.
Line voltages of 600v on the DC electrification system, and 22.5kV on the AC electrification system were used in the simulation to pre-defined inner suburban boundaries. These boundaries were agreed some thirty years by the Electrification Division of the then DM & EE, and subsequently agreed by Network Rail for use in Zonal routine operational timing.

The TRATIM simulations assumed the passenger trains were fully seated operating over the identified lines of route, stopping at the stations as specified. For each line of route, stopping pattern and train formation under evaluation, a forward and reverse direction, and minimum running time simulation were carried out. The average line energy consumption was then derived from the resultant two energy consumption values. A train auxiliary load, for an ambient temperature of 10 degrees C as declared by the manufacturer, was included in the simulation calculations for each traction type and train formation. Regarding the diesel traction units evaluated in the study, the above methodology was also applied, and the following conversion factors were used:

1 gallon of gas oil = 8.34lbs

Calorific value of 1 tonne of gas oil = 45.6GJ

To calculated line energy, the auxiliary energy consumption attributable to station dwell times (typically 30 seconds/station stop) was added and a total energy consumption figures derived. Thereafter, for each link of the route under evaluation, the value of *average energy consumption (kWh/train-km)* and *specific energy consumption (Wh/tonne-km)* were then calculated for each train type and formation. Table 3 shows the information from TRATIM.

**Table 3. Energy consumption information from the TRATIM program**

| Field Name | Description |
|---|---|
| Year | 2008 |
| Link | A unique ID for a section of track |
| Distance | Distance of link in km |
| Average Energy Consumption (kWh/train km) | |
| Specific Energy Consumption (Wh/tonne km) | |

### 1.13. Emission Factors

Table 4 below presents the energy-specific emission factors for diesel engines per unit of power produced and were extracted from Jorgensen & Sorenson (1997) and from DfT - Estimation of Rail Environmental Cost Report (2007). In the case of electric trains, emissions are not produced locally, but at remote power plants both within and outside the Greater London area, where the type of emissions is dependent on the fuel used (coal, gas, nuclear energy etc.) for the generation of the electric power. Even for one fuel type, there are variations in the emissions abatement technologies used at most of the power plants. Because the energy–specific emission factors for power generation from within and outside the Greater London area are unknown, we assumed that the electricity used to power electric trains in the Greater London area is supplied from the National Grid and have therefore used emission factors that are based on the averaged energy-specific emission factors of the electricity generation mix for the UK as provided in DUKES (2008). It should be noted that electrical generation and distribution are not uniform throughout the UK, so the emission factors in Table 4 may not be exactly equal to the general public electricity supply in Greater London. The energy-specific emission factors are given on the basis of primary energy consumption, that is, the energy consumed at the power stations, and not in terms of the amount of electrical energy sent over the electrical net. Ideally, the emission factors should have been divided by a power generation efficiency factor and a transmission loss factor, but the efficiencies of the various processes were not known.

The 2008 energy emission factors have been calculated using Sima Pro life cycle analysis software. This software uses the Ecoinvent data base and allows users to analyse and monitor the full range of environmental impacts of products or processes across the whole life cycle. The Ecoinvent database covers a huge array of pollutants which may be generated over the life cycle of a product or process and includes all the major sources of emissions to air, land and water. Consequently, electricity generation using the UK's generation mix from 2008, sourced from DUKES, has been modelled and the emission factors for CO, $NO_X$, HC, $SO_2$ and PM have been extracted.

**Table 4**. Energy–specific emission factors for diesel and electric trains, 2008

| | $CO_2$ | CO | NOx | HC | $SO_2$ | $PM_{10}$ |
|---|---|---|---|---|---|---|
| Diesel (g/kWh) | 640 | 3.9 | 8.4 | 2.0 | 0.8 | 0.32 |
| Electricity (g/kWh) | 455 | 0.126 | 1.04 | 0.0341 | 1.28 | 0.445 |

## 1.14. Estimating rail traffic emissions

The emission estimation methodology used the actual rail traffic and specific energy consumption data from DeltaRail's ACTRAFF database and TRATIM program respectively, and then applied appropriate energy-specific emissions factors in g/kWh of power produced to determine emission rates, as shown in Equation 1 below.

$$E_p = EC \times EF_p * 10^{-6} \qquad \text{Equation 1}$$

Where:

$E_p$ = Emission rate of pollutant *p*, tonne/annum

$EC$ = Energy consumption, kWh

$EF_p$ = Energy-specific emission factor for pollutant *p*, g/kWh

$10^{-6}$ = Conversion factor, gramme to tonne

The following steps were employed in estimating emissions generated by rail traffic:

1. Calculation of **total tonnage** for train category *t* on link *l*.

   $$TT_{t,l} = N_{t,l} * G_{t,l}W_{avg}$$

   Where;

   $TT_{t,l}$ = Total tonnage in tonnes for train category *t* on link *l*

   $N_{t,l}$ = Total number of trains in train category *t* on link *l*

   $G_{t,l}W_{avg}$ = Average gross weight in tonnes, for train category *t* on link *l*

2. Calculation of **gross tonne kilometre** (expressed in tonne-kilometre) for train category *t* on link *l*; i.e., the transportation of one tonne of goods over one kilometre by train category *t* on link *l*, including the weight of the rolling stock.

   $$GTK_{t,l} = D_l * TT_{t,l}$$

   Where;

   $GTK_{t,l}$ = Gross tonne kilometre (tonne-kilometre) for train category *t* on link *l*

   $D_l$ = Distance (km) travelled by train category *t* on link *l*

   $TT_{t,l}$ = Total tonnage in tonnes for train category *t* on link *l*

3. Calculation of **primary energy consumption** (kWh) by train category $t$ on link $l$, using the specific energy consumption (Wh/tonne-kilometre) data.

$$PEC_{t,l} = GTK_{t,l} * SEC * 10^{-3}$$

Where;

$PEC_{t,l}$ = Primary energy consumption (kWh) by train category $t$ on link $l$
$GTK_{t,l}$ = Gross tonne-kilometre for train category $t$ on link $l$
$SEC$ = Specific energy consumption (Wh/tonne-kilometre) from TRATIM
$10^{-3}$ = Conversion factor from Wh to kWh

4. Calculation of **emission rate** (tonne/annum) of pollutant $p$ by train category $t$ on link ***l***, using energy-specific emission factors (expressed in g/kWh).

$$EM_{p,t,l} = PEC_{t,l} * EF_p * 10^{-6}$$

Where;

$EM_{p,t,l}$ = Emission rate (tonne/annum) of pollutant $p$ by train category $t$ on link $l$
$PEC_{t,l}$ = Primary energy consumption (kWh) by train category $t$ on link $l$
$EF_p$ = Energy-specific emission factor (g/kWh) for pollutant $p$
$10^{-6}$ = Conversion factor from grammes (g) to tonne

Atmospheric emissions from rail traffic depend on the source of power used in the train, i.e., electricity or diesel fuel. Emissions from electric trains depend on two parameters – the energy consumption for the train and the emissions from the electricity generated to power the train. Hence, the atmospheric emissions from electric trains were attributed to the power generation plants that supply electricity to these electric trains. For diesel trains, atmospheric emissions were spatially and locally allocated because emissions from diesel engines are local as a result of combustion.

### 1.15. Emission projection

As explained in earlier paragraphs, emissions from rail traffic are estimated basically as the product of energy consumption by rail traffic and energy-specific emission factors. Therefore, to undertake any projection, future developments in parameters describing rail traffic activity, energy consumption and emission factors must be scrutinised to estimate what changes in rail transport are likely. Projecting future emissions from rail traffic must be based on several assumptions that cannot be easily authenticated, because changes in socio-political and economic climates can have profound effect on the makeup of rail traffic - passenger and freight trains, diesel and electric trains etc. Therefore, all projections in this study have been based on the assumptions that no calamitous scenarios and no spectacular technological breakthroughs affecting the railway system occur. This allowed future rail traffic emissions to be attributed to annual growth in the passenger and freight traffic, diesel and electric trains, improvements in train operating conditions, and improvements in the emission factors and the emissions characteristics of the power generating units.

To provide a foundation for establishing future developments in passenger and freight rail traffic, past rail traffic trends[6] (expressed as annual growth rates in passenger-kilometre and tonne-kilometre) between 2002 and 2008 were examined. After analysing the trends, a 3.57% and 2.9% annual growth rates were assumed for passenger and freight rail traffics respectively. For passenger traffic, the annual growth rate is based on the assumptions that there will be no change in train occupancy and no widespread restrictions on passenger rail traffic. For freight traffic, the annual growth rate is based on the assumption that there will be no major political incentives (e.g., the Government's 10 Year Plan for Transport sets the target of an 80 percent increase in rail freight over the next 10 years 2000-2010) to promote rail freight transport. These trends provided no indication of the share of rail traffic powered by electricity or diesel. However, it is expected that the share of rail traffic powered by electricity will be 85-90% in 2010.

Table 5 presents the energy-specific emission factors for electric and diesel engines per unit of power produced and were obtained from Bek & Sorenson (1997). To aid future decision-making, the energy-specific emission factors in Table 6 were obtained by statistical interpolation from the emissions factors for electrical power generation and diesel locomotive emissions provided by Bek & Sorenson (1997) for 1998 and 2020. Undoubtedly this approach unfortunately introduced significant uncertainty and provides an area to be targeted for future emission factor studies.

**Table 5. Energy–specific emission factors for diesel and electric trains, 2011 and 2015**

| | $CO_2$ | CO | $NO_x$ | HC | $SO_2$ | PM |
|---|---|---|---|---|---|---|
| Diesel (g/kWh) | 480 | 2.5 | 7.75 | 0.75 | 0.515 | 0.165 |
| Electricity (g/kWh) | 370 | 0.06 | 0.775 | 0.825 | 1.75 | 0.105 |

The emissions from electric trains will vary with the electricity generation mix and if operators decide to switch to renewable energy. Electricity generated by renewable energy has lower emissions than from the average generating mix. The exact emissions will vary with the renewable technology employed. Large changes in emissions from electric trains will occur by 2010 regardless of the use of renewable energy, because of the changes in the future UK electricity mix (Watkiss *et al*, 2002). Electricity generation emissions have been estimated for future years, based on forecasts from the DTI – the lower proportion of coal fired generation will have large effects on emissions of $CO_2$ and $SO_2$. It has been forecasted that emissions from electric rail journeys will decrease significantly in future years, especially for $NO_x$, $PM_{10}$ and $SO_2$, because of the lower proportion of coal in the electricity generation mix and because abatement technology is being fitted on remaining coal fired plants (Watkiss *et al*, 2002).

**Table 6: Train Class**

| Train Class / Powered Vehicle | Category |
|---|---|
| Class 43/0 (HST) | D1 |
| Class 47/4 | D2 |
| Class 47/7 | D2 |
| Class 57/0 | D2 |
| Class 57/3 | D2 |
| Class 57/6 | D2 |

[6] National Rail Trends Yearbook 2007-2008, Office of Rail Regulation.

| | |
|---|---|
| Class 67/0 | D2 |
| Class 73/1 | E4 |
| Class 86/2 | E1 |
| Class 87/0 | E1 |
| Class 90/0 | E1 |
| Class 91/0 (IC225) | E1 |
| Class 91/1 (IC225) | E1 |
| Class 150 - Sprinter | D6 |
| Class 158 - Express Unit | D5, D6 |
| Class 159 - Express Unit | D5 |
| Class 165 - Network Turbo | D5, D6 |
| Class 166 - Express Turbo | D5 |
| Class 168 - Chiltern Clubman | D4, D5, D6 |
| Class 170 - Turbostar | D4, D6 |
| Class 180 - Alstom Coradia | D3 |
| Class 205 | D5, D6 |
| Class 207 | D6 |
| Class 220 Voyager | D4 |
| Class 221 Voyager | D4, Dx |
| Class 312 | E3 |
| Class 313 | E7, E? |
| Class 315 | E3 |
| Class 317 | E3 |
| Class 319 | E3, E6 |
| Class 321 | E3 |
| Class 325 (Royal Mail) | E3, E6 |
| Class 332 EMU Motor Car | E3, Ex |
| Class 350 | E3 |
| Class 357 (Electrostar) | E3 |
| Class 365 (Networker) | E3, E6 |
| Class 373 'Loco' | E4 |
| Class 375 (Electrostar) | E6, E7 |
| Class 376 (Electrostar) | Ey |
| Class 377 (Electrostar) | E6, E7 |
| Class 390 (Pendelino) | E2 |
| Class 411 | E6 |
| Class 412 | E6 |
| Class 421 | E6 |
| Class 423 | E6 |
| Class 442 | Ey |
| Class 444 | Ey |
| Class 450 | E6 |
| Class 455 | E6 |
| Class 456 | E8 |
| Class 458 (Juniper) | E6 |
| Class 460 Juniper Motor Car | E5 |
| Class 465 (Networker) | E6 |
| Class 466 (Networker) | E8 |
| Class 508 | E7 |

| |
|---|
| Note 1: Classes shown in RED are new Classes recently introduced or will be in the coming year |
| Note 2: The following Classes do not have a code:<br>Class 221 - 5 car formation (Dx)<br>Class 332 - 5 car formation (Ey)<br>Class 376, 442 & 444 - 5 car formation (Ey) |

**Table 7: Train class formation and weight**

| Class | Formation | Mass Tonne |
|---|---|---|
| CLASS 357 | 8 CAR | 355.80 |
| CLASS 357 | 12 CAR | 533.70 |
| CLASS 321 | 4 CAR | 160.10 |
| CLASS 321 | 8 CAR | 320.20 |
| CLASS 321 | 12 CAR | 480.30 |
| CLASS 360 | 4 CAR | 190.66 |
| CLASS 360 | 8 CAR | 381.32 |
| CLASS 360 | 12 CAR | 571.98 |
| CLASS 315 | 4 CAR | 150.20 |
| CLASS 315 | 8 CAR | 300.40 |
| CLASS 315 | 12 CAR | 450.60 |
| CLASS 90 | 9mk2 + 1mk3 | 474.10 |
| CLASS 317 | 4 CAR | 157.90 |
| CLASS 317 | 8 CAR | 315.80 |
| CLASS 317 | 12 CAR | 473.70 |
| CLASS 91 | 9 MK4 + DVT | 539.60 |
| HST | 2+9 | 498.60 |
| CLASS 365 | 4 CAR | 171.00 |
| CLASS 365 | 8 CAR | 342.00 |
| CLASS 365 | 12 CAR | 513.00 |
| CLASS 317 | 4 CAR | 157.90 |
| CLASS 317 | 8 CAR | 315.80 |
| CLASS 317 | 12 CAR | 473.70 |
| CLASS 313 | 3 CAR | 121.00 |
| CLASS 319 | 4 CAR | 165.70 |
| CLASS 319 | 8 CAR | 331.40 |
| CLASS 319 | 12 CAR | 497.10 |
| HST | 2+8 | 458.44 |
| CLASS 319 | 4 CAR | 165.70 |
| CLASS 319 | 8 CAR | 331.40 |
| CLASS 319 | 12 CAR | 497.10 |
| CLASS 390 | 9 CAR | 501.12 |
| CLASS 90 | 16 SLEEPER | 842.18 |
| CLASS 90 | 9 MK3 + DVT | 494.00 |
| CLASS 221 | 5 CAR | 302.72 |
| CLASS 321 | 4 CAR | 160.10 |
| CLASS 321 | 8 CAR | 320.20 |
| CLASS 321 | 12 CAR | 480.30 |
| CLASS 350 | 4 CAR | 189.50 |
| CLASS 350 | 8 CAR | 379.00 |

| | | |
|---|---|---|
| CLASS 350 | 12 CAR | 568.50 |
| CLASS 313 | 3 CAR | 121.00 |
| CLASS 313 | 6 CAR | 242.00 |
| CLASS 165 | 4 CAR | 175.98 |
| CLASS 180 | 5 CAR | 284.00 |
| HST | 2+8 | 458.44 |
| CLASS 57 | 8 SLEEPER | 455.84 |
| CLASS 165 | 2 CAR | 87.99 |
| CLASS 165 | 4 CAR | 175.98 |
| CLASS 375 | 4 CAR | 182.60 |
| CLASS 375 | 8 CAR | 365.20 |
| CLASS 375 | 12 CAR | 547.80 |
| CLASS 460 | 8 CAR | 347.40 |
| CLASS 170 | 6 CAR | 295.40 |
| CLASS 377 | 4 CAR | 182.60 |
| CLASS 377 | 8 CAR | 365.20 |
| CLASS 377 | 12 CAR | 547.80 |
| CLASS 456 | 2 CAR | 81.89 |
| CLASS 450 | 4 CAR | 189.70 |
| CLASS 450 | 8 CAR | 379.40 |
| CLASS 450 | 12 CAR | 569.10 |
| CLASS 455 | 4 CAR | 159.52 |
| CLASS 455 | 8 CAR | 319.04 |
| CLASS 455 | 12 CAR | 478.56 |
| CLASS 159 | 6 CAR | 259.09 |
| CLASS 170 | 6 CAR | 295.40 |
| CLASS 377 | 4 CAR | 182.60 |
| CLASS 377 | 8 CAR | 365.20 |
| CLASS 377 | 12 CAR | 547.80 |
| CLASS 456 | 2 CAR | 81.89 |
| CLASS 375 | 4 CAR | 182.60 |
| CLASS 375 | 8 CAR | 365.20 |
| CLASS 375 | 12 CAR | 547.80 |
| CLASS 465/466 | 4 CAR | 158.50 |
| CLASS 465/466 | 8 CAR | 317.00 |
| CLASS 465/466 | 10 CAR | 401.00 |
| CLASS 466 | 2 CAR | 84.00 |
| CLASS 313 | 3 CAR | 121.00 |
| CLASS 313 | 3 CAR | 242.00 |
| CLASS 150 | 2 CAR | 83.82 |

## References

Bek, B. H., & Sorenson, S. C (1998) Future Emissions from Railway Traffic. Deliverable 17a of the MEET project. *Report ET-EO-98-02*, Technical University of Denmark, Lyngby, Denmark.

Hickman, A. J. (1999) Methodology for Calculating Transport Emissions and Energy Consumption. Deliverable 22 for the MEET project. *Report SE/491/98*, Transport Research Laboratory, UK.

Jorgensen, M. W., & Sorenson, S. C. (1997) Estimating Emissions from Railway Traffic. Deliverable 17 of the MEET project. *Report ET-EO-97-03*, Technical University of Denmark, Lyngby, Denmark.

Lewis, C. A. (1997) Fuel and Energy Production Emission Factors. *Deliverable 20 of the MEET project.* ESTU, AEA Technology, Harwell, UK.

Watkiss, P., Jones, R., Rhodes, D., Hardy, A., Handley, C., & Walker, C., (2001) A Comparative Study of the Environmental effects of Rail and Short-haul Air Travel. A report produced for Commission for Integrated Transport, ED50021, AEA Technology Environment, UK.

Estimation of Rail Environmental Costs (2007), A report produced by AEA Energy & Environment (AEA), DeltaRail, and Paul Watkiss Associates, UK.

## ESTIMATING EMISSIONS FROM SHIPS/MARINE VESSELS

### Summary

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

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

### 1.16. Emission estimation methodology: (Same as the LAEI 2006 methodology)

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

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

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

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

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

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

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

Equation 1

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

Where:

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

$VC_{port}$ =Number of vessel calls at ports

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

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

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

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

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

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

For the purpose of estimating emissions from marine vessels in this study, only the 33 ports and terminals (see Table 8) on the Thames and within the LAEI area were considered - starting from the breakwater at the M25 Motorway eastern boundary and then 43 km westward along the River Thames towards Teddington.

**Table 8: Ports and terminal within the LAEI area**

| Ports | Approximate distance (km) from the LAEI boundary* |
|---|---|
| Thames Europort | 0.5 |
| Vopak Terminal London | 0.5 |
| Thurrock Marine Jetty/Lafarge Jetty | 0.7 |
| Civil & Marine/Purfleet Aggregates | 1.4 |
| Jurgens | 1.9 |
| Purfleet Thames Terminal | 2.2 |
| European Metal Recycling | 7 |
| British Gypsum | 7.5 |
| ADM Erith Ltd | 8.2 |
| Pioneer | 8.5 |
| Mulberry Wharf | 9.2 |

| | |
|---|---|
| Fords | 10.8 |
| Hanson Aggregates | 11.3 |
| No.1 Western Extension | 12.1 |
| TDG European Chemicals | 12.4 |
| RMC Dagenham | 12.7 |
| Docklands Wharf | 14.5 |
| Kierbeck | 16 |
| Welbeck | 16.3 |
| Pinns | 16.4 |
| Thames Refinery | 19.3 |
| Tay Wharf | 19.6 |
| Riverside Wharf | 20.3 |
| Murphy's Wharf | 21.8 |
| Angersteins | 22.4 |
| Thames Wharf | 22.8 |
| Brunswick Wharf | 23 |
| Delta | 24.1 |
| Victoria Deep | 24.9 |
| Brewery | 26.6 |
| RMC Vauxhall | 38.6 |
| Cringle Wharf | 39.4 |
| RMC Fulham | 42.7 |

Source: GLA 2005

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

## 1.17. Vessel characteristics and movement

The primary source of information in terms of vessel characteristics and movements was a comprehensive database[7] maintained by LMIU. The database maintains information about ship details, including owner, operator, ship name, ship type, registry number, cargo handling equipment, flag of registry and, significantly, ship engine details such as maximum horsepower and sometimes number of auxiliary engines. The LMIU provided a spreadsheet of vessel characteristics and vessel movements to and from the Port of London for the full calendar year 2004. Due to the large number of vessel types and vessel movements to and from the Port of London on an annual basis and the complexities of data analysis required for this project, all vessels were classified and limited to the following categories:

- Liquified Gas Carrier - *Liquefied natural gas/Liquified petroleum gas*
- Specialised Cargo - *Chemical tank, chemical/oil carrier*
- Tanker - *Acid tanker, asphalt tanker, bunkering tanker, crude oil tanker, edible oil tanker, fruit juice tanker, fish oil tanker, floating production& storage, molasses tanker, naval auxiliary, product tanker, wine tank, water tanker*
- Bulk Carrier - *Bulk, cement, aggregates, ore, wood-chip*

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

- General Cargo - *Cargo, general cargo, barge carrier, container/unitised carrier*
- Pallet Carrier - *Container, barge carrier, vehicles*
- Ro-Ro Cargo - *Ro/Ro, container Ro/Ro, Passenger Ro/Ro*
- Tug/Dredger - *Tugs/dredgers*

**Table 9: Vessel characteristics: average speed, power and tonnage**

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

*Source: LMIU, 2004*

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

**Table 10: Vessel movements: number and types of vessels and vessel calls in 2004**

| Ports of Arrival and Departure | Number of Vessels | Type of Vessel | Number of Vessel Calls |
|---|---|---|---|
| ADM Erith Ltd | 99 | General Cargo | 163 |
| ADM Erith Ltd | 16 | Tanker | 32 |
| Angersteins | 5 | Dredger | 93 |
| Brewery | 6 | General Cargo | 249 |
| British Gypsum | 9 | General Cargo | 59 |
| Brunswick Wharf | 9 | Tanker | 72 |
| Civil & Marine/Purfleet Aggregates | 11 | Dredger | 57 |
| Civil & Marine/Purfleet Aggregates | 4 | General Cargo | 108 |
| Cringle Wharf | 7 | General Cargo | 13 |
| Cringle Wharf | 1 | Tug | 1 |
| Delta | 6 | Dredger | 70 |
| Delta | 1 | Tug | 1 |
| Docklands Wharf | 30 | General Cargo | 49 |
| Docklands Wharf | 1 | Specialised Cargo | 2 |
| European Metal Recycling | 9 | General Cargo | 9 |
| European Metal Recycling | 1 | Ro/Ro | 1 |
| Fords | 10 | Ro/Ro | 693 |
| Fords | 1 | Tug | 1 |
| Hanson Aggregates | 4 | Dredger | 184 |
| Jurgens | 1 | Specialised Vessels | 1 |
| Jurgens | 23 | Tanker | 129 |
| Kierbeck | 28 | General Cargo | 32 |

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

Source: Port of London Authority, 2004

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

- Information on the times that each type of vessel spent "at sea" and "in port";
- A GIS representation of the ports and terminals within the Port of London; and

- Emission factors for the air pollutants: oxides of nitrogen ($NO_X$), sulphur dioxide ($SO_2$), hydrocarbons (HC), carbon dioxide ($CO_2$) and particulate matters ($PM_{10}$) form the Entec Report (Entec UK Ltd, 2000).

## 1.18. Durations of vessel operations "in port" and "at sea"

The LMIU and PLA databases recorded only the dates when vessels arrived at and departed from the Port of London. Undoubtedly, actual arrival and departure times to and from each port would have assisted greatly in estimating durations of "in port" activities with confidence. "In port" activities include time spent manoeuvring, hotelling, loading, and unloading. Hotelling denotes the time a vessel spends in port that is neither loading nor unloading time, at berth and consuming minimum power. Manoeuvring is associated with arrival at and departure from a port, i.e. when a ship decreases main engine load at the end of a period "at sea", up to the point when the ship is stationary in port and vice versa.
In the absence of reliable arrival and departure times to and from each port in the Port of London, the average time (in hours) spent "in port" per call by each vessel type was estimated from the LMIU and PLA ship activity datasets and augmented by information gained through personal conversations with port operators. For example, a typical tanker can take 24 to 40 hours to unload, with the vessel using its own pumps to unload liquid material. Due to various conditions on vessel movements in the Port of London, after loading, a vessel may stay an additional 12-18 hours at berth. Discharge rates for product ships vary considerably with the loading rate dependent on the diameter of the pipeline, the distance to the tank, pump used, and capacity.

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

Equation 2

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

Where:

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

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

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

**Table 11: Estimates of durations of vessel "in port" in Port of London**

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

*Source: LMIU 2004*

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

Equation 3

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

Where:

$AvgT_{at-sea,vc,j}$ =Average time "at sea" per vessel call *vc* by vessel type *j*, *(hours)*
$D_{PL}$ = Distance from breakwater to a port in the Port of London, (km)
$AvgS_{PL,j}$ =Average speed of vessel type *j* in the Port of London, (km/hour)

**Table 12: Durations (in hours) of vessel "at sea" in Port of London**

| Port | Distance km | Vessel Type | Average Speed km/h | Average Time "at sea" hours |
|---|---|---|---|---|
| Thames Europort | 0.5 | Ro/Ro | 30 | 0.02 |
| Thames Europort | 0.5 | Tug | 22 | 0.02 |
| Vopak Terminal London | 0.5 | Liquified Gas Carriers | 24 | 0.02 |
| Vopak Terminal London | 0.5 | Tanker | 22 | 0.02 |
| Thurrock Marine/Lafarge Jetty | 0.7 | Bulk Carrier | 26 | 0.03 |
| Thurrock Marine/Lafarge Jetty | 0.7 | Dredger | 22 | 0.03 |
| Thurrock Marine/Lafarge Jetty | 0.7 | General Cargo | 20 | 0.04 |
| Civil & Marine/Purfleet Aggregates | 1.4 | Dredger | 22 | 0.06 |
| Civil & Marine/Purfleet Aggregates | 1.4 | General Cargo | 20 | 0.07 |
| Jurgens | 1.9 | Specialised Vessels | 24 | 0.08 |
| Jurgens | 1.9 | Tanker | 22 | 0.09 |
| Purfleet Thames Terminal | 2.2 | Ro/Ro | 30 | 0.07 |
| European Metal Recycling | 7 | General Cargo | 20 | 0.35 |
| European Metal Recycling | 7 | Ro/Ro | 30 | 0.23 |
| British Gypsum | 7.5 | General Cargo | 20 | 0.38 |
| ADM Erith Ltd | 8.2 | General Cargo | 20 | 0.41 |
| ADM Erith Ltd | 8.2 | Tanker | 22 | 0.37 |
| Pioneer | 8.5 | Dredger | 22 | 0.39 |
| Mulberry Wharf | 9.2 | General Cargo | 20 | 0.46 |
| Fords | 10.8 | Ro/Ro | 30 | 0.36 |
| Fords | 10.8 | Tug | 22 | 0.49 |
| Hanson Aggregates | 11.3 | Dredger | 22 | 0.51 |
| No.1 Western Extension | 12.1 | General Cargo | 20 | 0.61 |
| TDG European Chemicals | 12.4 | Tanker | 22 | 0.56 |
| RMC Dagenham | 12.7 | Dredger | 22 | 0.58 |
| RMC Dagenham | 12.7 | General Cargo | 20 | 0.63 |
| RMC Dagenham | 12.7 | Specialised Cargo | 24 | 0.53 |
| Docklands Wharf | 14.5 | General Cargo | 20 | 0.73 |
| Docklands Wharf | 14.5 | Specialised Cargo | 24 | 0.60 |
| Kierbeck | 16 | General Cargo | 20 | 0.80 |
| Welbeck | 16.3 | General Cargo | 20 | 0.81 |

| | | | | |
|---|---|---|---|---|
| Pinns | 16.4 | General Cargo | 20 | 0.82 |
| Thames Refinery | 19.3 | Bulk Carrier | 26 | 0.74 |
| Thames Refinery | 19.3 | General Cargo | 20 | 0.96 |
| Thames Refinery | 19.3 | Pallet Carrier | 30 | 0.64 |
| Tay Wharf | 19.6 | General Cargo | 20 | 0.98 |
| Riverside Wharf | 20.3 | General Cargo | 20 | 1.01 |
| Murphy's Wharf | 21.8 | Dredger | 22 | 0.99 |
| Murphy's Wharf | 21.8 | General Cargo | 20 | 1.09 |
| Murphy's Wharf | 21.8 | Specialised Cargo | 24 | 0.91 |
| Murphy's Wharf | 21.8 | Tanker | 22 | 0.99 |
| Angersteins | 22.4 | Dredger | 22 | 1.02 |
| Thames Wharf | 22.8 | General Cargo | 20 | 1.14 |
| Brunswick Wharf | 23 | Tanker | 22 | 1.05 |
| Delta | 24.1 | Dredger | 22 | 1.10 |
| Delta | 24.1 | Tug | 22 | 1.10 |
| Victoria Deep | 24.9 | Dredger | 22 | 1.13 |
| Victoria Deep | 24.9 | General Cargo | 20 | 1.25 |
| Victoria Deep | 24.9 | Specialised Cargo | 24 | 1.04 |
| Brewery | 26.6 | General Cargo | 20 | 1.33 |
| RMC Vauxhall | 38.6 | General Cargo | 20 | 1.93 |
| Cringle Wharf | 39.4 | General Cargo | 20 | 1.97 |
| Cringle Wharf | 39.4 | Tug | 22 | 1.79 |
| RMC Fulham | 42.7 | General Cargo | 20 | 2.13 |

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

1. Where a vessel arrived and departed on the next day, the time in port (see Table 11) were assumed to be one day or 24 hours. Where arrival and/or departure dates were estimated from the LMIU databases, times "in port" were assumed to be two days or 48 hours.

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

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

4. The Average Time "at sea" in Table 12 is considered the time taken to travel to the designated port (in one direction only) after entering the breakwater (entrance at the Port of London at the LAEI boundary).

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

### 1.19. Average and rated average vessel (engine) power

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

The LMIU database did not hold data for auxiliary engines on vessels so a decision was taken to use only the average vessel power (kW) of the main engine power (see Table 13) based on the assumption that most of the emissions "at sea" and "in port" come from the main engine, which realistically is not true and introduces significant uncertainty. The greatest contribution to uncertainty arises from the estimation of emissions from vessels whilst undertaking "in port" operations, as the exact engine power and load levels are subject to an unknown degree of variation. Nonetheless, this assumption provides a "rational estimate" within the context and constraints of this study.

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

**Table 13: Average vessel power (kW) by vessel type**

| Type of Vessel | Average Vessel Power ,kW[8] |
|---|---|
| Bulk Carrier | 5,464 |
| Pallet Carrier | 7,803 |
| General Cargo | 1,362 |
| Specialised Cargo | 1,982 |
| Tug/Dredger | 2,544 |
| Liquified Gas Carrier | 1,982 |
| Tanker | 3,116 |
| Ro/Ro | 5,411 |

*Source: LMIU 2004*

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

For the purpose of this study, the load on the main engines during navigation "at sea" and "in port" was assumed to be 80% and 20% of the main engine respectively, irrespective of the vessel type. This assumption has been made as an attempt to obtain a "reasonable approximation" of emissions from ships within the constraints of this study. The assumed

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

load factors and the average vessel power (average power of the main engine) by vessel type were used to calculate the **rated average engine power** (kW) by mode ("at sea" and "in port") and vessel type according to Equation 4.

Equation 4

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

Where:

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

**Table 14: Rated average vessel power (kW)**

| Type of Ship | "At sea" 80% of average vessel power, kW | "In port" 20% of average vessel power, kW |
|---|---|---|
| Bulk Carrier | 4,371 | 1,093 |
| Pallet Carrier | 6,242 | 1,561 |
| General Cargo | 1,090 | 272 |
| Specialised Cargo | 1,586 | 396 |
| Tug/Dredger | 2,035 | 509 |
| Liquified Gas Carrier | 1,586 | 396 |
| Tanker | 2,493 | 623 |
| Ro/Ro | 4,329 | 1,082 |

## 1.20. Average Energy Consumption

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

***Average energy consumption (kWh) "at sea"***

Equation 5

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

Where:

$EC_{avg.k.sea}$ =Average energy consumption for vessel category *k* "at sea", kWh
$2 * T_{sea}$ =Total time "at sea" during arrival at and departure from a port, h

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

***Average energy consumption (kWh) "in port"***

Equation 6

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

Where:

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

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

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

Emission factors: The installed engine type on board a vessel and the fuel used largely dictates the ship's emissions. Since the emission factors for individual engines on vessels in this study were not known, a decision was taken to use the emission factors from the Entec UK Ltd 2000 Report. While the Entec UK Ltd 2000 study was geared towards estimating emissions for the European Union, it provides an insightful analysis of the worldwide commercial marine vessel fleet, even including a statistical analysis of variance in emission factors. The Entec UK Ltd 2000 study estimated emission factors for $NO_X$, HC, CO and $PM_{10}$ and $SO_2$ for "at sea" and "in port" activities as shown in Table 15 and Table 16[9]. The emission factors for main engines "at sea" and "in port" were assumed to be operating at 80% and 20% maximum continuous rating respectively. Entec used the LMIS database for the ships entering the EU study area to derive weighted emission factors for each vessel type for "at sea" and "in port" activities. Assignment of "engine size" emission factors with any great significance was doubtful. Consequently the emission factors were only derived for engine types and valid for all engine sizes.

**Table 15: Emission factors for "at sea" operation regarding vessel type, 2004**

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

Source: Entec UK Ltd, 2000

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

**Table 16: Emission factors for "in port" operation regarding vessel type, 2004**

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

Source: Entec UK Ltd, 2000

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

**Table 17: Estimated uncertainties at the 95% confidence interval**

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

Source: Entec UK Ltd, 2000

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

As can be noted form Table 17, the "in port" emission factors have an increased uncertainty compared to emission factors "at sea", for two reasons. Firstly, some main engine operation will be from starts with a cold engine, which will give significantly different emissions (especially HC and PM), compared to starts with relatively warm engines. Secondly, because engine loads can change rapidly during "in port" operations, the variability in emissions are increased.

## 1.21. Estimating emissions

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

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

**"At sea" emission calculation**

Equation 7

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

Where:

| | |
|---|---|
| $E_{k,sea}$ | =Emissions from vessel category $k$ "at sea", tonnes |
| $VC_{port}$ | =Number of vessel calls at port |
| $EF_{k,sea}$ | =Emission factor for vessel category $k$ "at sea", g/kWh |
| $EC_{avg.k,sea}$ | =Average energy consumption for vessel category $k$ "at sea", kWh |
| $10^{-6}$ | =Unit conversion factor from grammes to tonne |

**"In port" emission calculation**

Equation 8

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

Where:

| | |
|---|---|
| $E_{k,port}$ | =Emissions from vessel category $k$ "at sea", tonnes |
| $VC_{port}$ | =Number of vessel calls at port |
| $EF_{k,port}$ | =Emission factor for vessel category $k$ "at sea", g/kWh |
| $EC_{avg.k,port}$ | =Average energy consumption for vessel category $k$ "at sea", kWh |
| $10^{-6}$ | =Unit conversion factor from grammes to tonne |

A GIS presentation of the study area and a large spreadsheet were constructed to apportion and spatially represent "at sea" and "in port" emissions for each vessel type. "At sea" emissions were uniformly and linearly represented as channel segments (lines) along the River Thames using the linear referencing functionality in ArcGIS. "In port" emissions were allocated to the appropriate ports as point features. Both the "at sea" and "in port" emissions, represented as channel segments and points respectively, were overlaid with a digital layer of the generic LAEI 1km² grid cells and their corresponding emission values "proportion summed" to the 1km² grid cell that they intersected.

### 1.22. 2011 and 2015 emission projections

In the future, it is expected that there will be changes in the atmospheric emissions from marine vessels operating in the Port of London as a result of legal requirements regarding ship engines and the fuel they use, improved technologies and emission control systems.

The European Union intends to propose legislation aimed to reduce marine emissions, especially legislation capping fuel sulphur content[10] and restriction of fuel type use. Consequently, a high degree of uncertainty will be introduced in any future projections (specifically, 2011 and 2015 projections) of air emissions from marine vessels operating in the Port of London.

Though a steady course of investment and expansion is set to create a number of high-profile new facilities[11], which will confirm London's status as the major gateway to UK market, most of these expansions lie outside the LAEI area. Quantitative estimates of future emissions have been based on a review of literature on ship transport and emissions. Annual growth in number of vessel calls to the Port of London (that lies within the LAEI area) for future years was estimated from the "Port of London Handbook 2004" and "PLA Annual Review 2003", which was assumed at 1% growth per annum in number of vessel calls for the period 2003 – 2010. To project 2010 (assumed in this report to remain the same as for 2011 and 2015) emissions, the estimated emission factors for future scenarios (i.e., 2008) for "at sea" and "in port" activities (shown in Table 18 and Table 19) were derived from the Entec UK Ltd Report. Entec's estimated emission factors for 2008 years were used to project 2010 emissions in this study.

**Table 18: Emission factors for "at sea" operation regarding vessel type, 2011 and 2015**

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

Source: Entec UK Ltd, 2000

**Table 19: Emission factors for "in port" operation regarding vessel type, 2011 and 2015**

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

Source: Entec UK Ltd, 2000

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

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

## References

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

Lloyds Register (1995) Marine Exhaust Emissions Research Programme. Lloyds Register Engineering services, London, UK.

PLA (2004) Port of London Handbook 2004, PLA 2004, UK.

PLA (2004) Annual Review 2003, PLA 2003, UK.

Trozzi C and R Vaccaro (1998) Methodology for estimating air pollutants emissions from ships. Deliverable 19 of the MEET project. Techne report MEET RF98.

## ESTIMATING EMISSIONS FROM HEATHROW AIRPORTS

### Summary

**Base Year: 2008**
Because of lack of recent, representative and reliable activity datasets for the 2008 base year, emission estimates for $NO_X$, $PM_{10}$, CO, $CO_2$, $SO_2$, benzene and 1,3-butadiene from the 2002 Heathrow Emissions Inventory (HEI), which were originally provided by AEA in combination with recent aircraft movements statistics from DfT[12], were used. These emission estimates for the base year 2008 were spatially analysed and integrated into the LAEI 2008. Emissions from Heathrow's road traffic were excluded from the HEI dataset used to compile the LAEI 2008 in order to avoid double counting as these were already estimated under the Road Transport sector of the LAEI 2008.

**Projection Years: 2011 and 2015**
AEA provided projected (2010) emission estimates for $NO_X$, $PM_{10}$, CO, $CO_2$, $SO_2$, benzene and 1,3-butadiene from the 2010 Heathrow Emissions Inventory, which were then spatially analysed and integrated into the LAEI 2008. Again, emissions from Heathrow's road traffic were also excluded from the HEI dataset used in compiling the LAEI 2008.

Because of lack of recent, representative and reliable activity datasets, projection of atmospheric emissions from Heathrow airport to 2010 and 2015 were not undertaken; instead projections of atmospheric emissions from Heathrow airport to 2011 and 2015 were basically assumed to be the same as those in the 2010 Heathrow Emissions Inventory (same as the 2010 projection in the LAEI 2006).

### 1.23. 2008 emission estimation methodology: (Same as the LAEI 2006 methodology)

### Base Year

The trends in aircrafts movement data from DfT statistics[12] spreadsheet for "Aircraft Movements 1998 – 2008" at Heathrow Airport were analysed. It was calculated that there was 0.6% increase between 2004 and 2008 in the aircraft movements at Heathrow Airport. This % increase was used to upscale the original datasets.

AEA Technology provided the entire emission estimates for $NO_X$, $PM_{10}$, CO, $CO_2$, $SO_2$, benzene and 1,3-butadiene from the 2002 Heathrow Emissions Inventory. The methodologies for the 2002 Heathrow Emissions Inventory are commercially restricted documents (i.e., *Heathrow Emission inventory 2003: Part 1 – A report produced for BAA Heathrow; BY Underwood, C T Walker and M J Pierce. Netcen/AEAT/ENV/R/1657/Issue 4; August 2004* and *Heathrow Emission inventory 2003: Part 2 – A report produced for BAA Heathrow; BY Underwood, C T Walker and M J Pierce. Netcen/AEAT/ENV/R/1728/Issue 1; November 2004*). Therefore only the executive summaries are provided in this document.

[12] http://www.dft.gov.uk/pgr/aviation/airports

The report describes the compilation of an inventory of atmospheric emissions from London Heathrow airport (LHR) for the base year 2002. The report describes the methodologies and datasets used to compile an inventory of the pollutants $NO_X$ (nitrogen oxides) and $PM_{10}$ (particulate matter of aerodynamic diameter less than 10 microns), CO (carbon monoxide), $CO_2$ (carbon dioxide), $SO_2$ (sulphur dioxide), benzene and 1,3-butadiene.

The inventory includes emissions from the following source categories:

- Aircraft in the landing and take-off (LTO) flight phases up to 1,000m, including Auxiliary Power Unit (APU) emissions and emissions from engine testing;
- Airside vehicles/plant;
- Road vehicles on airport landside roads and on the road network around the airport;
- Car parks and taxi queues;
- Airport heating plant; and
- Fire-training ground.

For $PM_{10}$, the inventory also includes fugitive emissions from brake and tyre wear (for aircraft and road-vehicles).

Aircraft emissions are included in the inventory for the LTO flight phases up to 1,000m height, but the contribution from aircraft on the ground is separately identified. Road vehicle emissions are included for a road network within a 12km x 9km rectangle enclosing the airport. This choice relates to the modelling study presented in a separate report and allows a measure of comparability with the emissions presented previously on the near-Heathrow network.

One of the principal functions of the inventory is to provide essential inputs to a dispersion modelling study that identifies the airport contribution to the ground-level concentrations of key pollutants around the airport. Thus, besides quantifying total annual emissions, this report specifies the spatial distribution of the emissions on the horizontal plane.

For those source categories included in the 2000 inventory, the methodology for the 2002 inventory is largely unchanged from that used for 2000, but the following differences can be noted:

(a) the methodology for taking account of reduced-thrust aircraft take-off has been revised, particularly to refine assumptions that are now judged to be over-conservative; and

(b) the classification of vehicles as road or off-road vehicles in the airside-vehicle emissions methodology has been updated on the basis of more detailed information.

The estimate of total ground-level aircraft $NO_x$ emissions is 9% lower for 2002 than it was for 2000, principally as a result of changes to the reduced-thrust methodology. There is about 3% reduction in emissions per movement for those flight phases unaffected by the reduced-thrust changes, reflecting evolution in the aircraft fleet between 2000 and 2002. The corresponding change in emissions per passenger for this component of the inventory is smaller (a decrease of 1.7%). The estimate of total aircraft $PM_{10}$ emissions per movement has fallen by 3%, principally reflecting the evolution of the aircraft fleet.

For $NO_x$ and $PM_{10}$, aircraft provide the dominant contribution to ground-level airport-related emissions. The estimate for ground-level aircraft $NO_x$ ($PM_{10}$) emissions is 7.5 (4.5) times larger than the estimate for airside vehicle emissions and 2.0 (2.1) times larger than the estimate for landside (airport-related) road vehicle emissions on the designated network. For $NO_x$, take-off roll is the LTO mode giving the largest contribution to ground level emissions, whereas for $PM_{10}$ landing is the flight phase generating the largest fraction of total ground level aircraft emissions, as a result of current estimates of the contribution from brake and tyre wear.

The estimate of total $NO_x$ emissions from airside vehicles/plant for 2002 is similar to that for 2000. The similarity in the total masks a significant change in the relative contributions from off-road and road vehicles due to extensive re-classification of vehicles on the basis of more detailed data. However, typical $NO_x$ emission factors (in g/kg fuel) for road and off-road vehicles are not very different for the current fleet. The estimate of total $PM_{10}$ emissions from airside vehicles/plant for 2002 is 38% smaller than that for 2000 principally as a result of the vehicle re-classification.

For ground-level airport-related emissions, landside road vehicles are the source category giving the second largest $NO_x$ and $PM_{10}$ contribution after aircraft: within this category, airport-related emissions on the designated network give the dominant contribution. For this component, the contribution from Heavy Goods Vehicles (HGVs) is larger than that from Light Duty Vehicles (LDVs) for both $NO_x$ and $PM_{10}$, but there may be some overestimation of the HGV traffic fraction as a result of specific assumptions in the traffic modelling, which would in turn lead to an overestimation of the total emissions from road vehicles on the network.

For 2002, the estimated $NO_x$ ($PM_{10}$) emissions from non-airport traffic on the designated network are 3.0 (3.2) times higher than the estimated $NO_x$ ($PM_{10}$) emissions from airport related traffic. For the non-airport traffic, the contribution to annual emissions from HGVs is comparable to that from LDVs for $NO_x$ and less than that from LDVs for $PM_{10}$.

Compared to the values in the 1998 inventory, estimated airport-related $NO_x$ ($PM_{10}$) emissions on the network have fallen by 9% (30%), whereas estimated non-airport emissions have fallen by 41% (53%), although the networks used are not exactly the same. The smaller decrease for the airport contribution indicates a faster rate of growth of airport-related traffic compared to non-airport traffic between 1998 and 2002.

The 2002 emissions from heating plant do not correspond to quite the same list of plant as in the 2000 inventory, although the differences relate to minor contributions to the total. Using a common list of plant in the two years, the $NO_x$ emissions have fallen by 9% from 2000 to 2002 for a 5% fall in fuel energy input. Similarly, for the common list of plant, $PM_{10}$ emissions have fallen by 3% for the 5% fall in fuel energy input. The emissions decreases are not exactly pro rata with the fuel energy decrease because emission factors for different types of plant are different. Heating plants are not expected to make a major contribution to ground-level annual-mean concentrations beyond the airport perimeter.

In terms of recommendations for operational data improvements, more detailed information on reduced-thrust operation for airlines other than British Airways would be beneficial and also statistical information on reverse-thrust usage on landing for the whole LHR fleet. Similarly, more information on the variables influencing APU running times may be beneficial. For airside vehicle emissions, the recommendations made in the 2000 inventory report regarding fuel usage surveys or plant duty-cycle surveys are still relevant. The available activity data for airside vehicles/plant still do not allow a robust assessment of associated emissions, so changes from one inventory update to the next continue to be dominated by changes to the methodology, as the assumptions used to fill gaps in the activity data are gradually refined.

In relation to emission factors, the key uncertainties relate to aircraft $PM_{10}$ emission factors (exhaust and fugitive) and emission factors for off-road/specialist airside vehicles/plant. Additional information is also required on the emissions performance of in-service aircraft engines compared to the factors in the ICAO databank.

### 1.24. Projection Years

AEA Technology provided the entire emission estimates for $NO_X$, $PM_{10}$, CO, $CO_2$, $SO_2$, benzene and 1,3-butadiene from the Heathrow Emissions Inventory 2010. The methodologies for the Heathrow Emissions Inventory 2010 are commercially restricted documents (i.e., *Heathrow 2010 Baseline Emission Inventory: Part 1 – A report produced for BAA Heathrow; BY Underwood, C T Walker and M J Pierce. Netcen/AEAT/ENV/R/1660/ Issue 3, August 2004* and *Heathrow 2010 Baseline Emission Inventory: Part 2 – A report produced for BAA Heathrow; BY Underwood, C T Walker and M J Pierce. Netcen/AEAT/ENV/R/1729/ Issue 1, November 2004*). Therefore only the executive summaries have been provided below.

The report describes the methodology and data used to forecast the inventory of atmospheric emissions from London Heathrow airport (LHR) in the year 2010[13]. This is an important year from an air quality perspective, in that 1 January 2010 marks the date by which agreed European Union (EU) limit values for $NO_2$ concentration must be met in Member States. It is also the specified date by which the EU Stage 2 (indicative) limit values for particulate matter are to be met.

The recent White Paper on the future of air transport in the UK supports a third runway at Heathrow in the 2015-2020 period provided the Government is confident that compliance with mandatory air quality limits can be maintained. Thus, there is significant stakeholder interest in forecasting the air quality situation in residential areas around the airport in 2010. The inventory presented in this report is intended to serve as the basis for calculating the 'baseline' air quality in 2010, i.e., the air quality under the assumption that the airport evolves without forcing measures introduced specifically to mitigate air quality impacts.

The reports describe the methodology and data used to compile an inventory of the pollutants $NO_X$ (nitrogen oxides) and $PM_{10}$ (particulate matter of aerodynamic diameter less than 10 microns), CO (carbon monoxide), $CO_2$ (carbon dioxide), $SO_2$ (sulphur dioxide), benzene and 1,3-butadiene.

The inventory includes emissions from the following source categories:
(a) Aircraft in the Landing and Take-Off (LTO) flight phases, including Auxiliary Power Unit (APU) emissions and emissions from engine testing;
(b) Airside vehicles/plant;
(c) Road vehicles on airport landside roads and on the road network around the airport;
(d) Car parks and taxi queues;
(e) Airport heating plant; and
(f) Fire-training ground.

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[13] The inventory is based on the most current information on 2010 available at the end of 2003.

For $PM_{10}$, the inventory also includes fugitive emissions from brake and tyre wear (for aircraft and road-vehicles), but excludes any contribution from construction activities.

Aircraft emissions are included in the inventory for the LTO flight phases up to 1,000m height, but the contribution from aircraft on the ground is separately identified. Road-vehicle emissions are included for a road network within a 12km x 9km rectangle enclosing the airport. This choice allows comparability with the emissions presented for the 2002 inventory. For heating plant, emissions associated only with on-airport energy requirements (including those for T5) are included in the inventory.

The methodology for estimating emissions is largely the same as that used for the 2002 inventory, although for aircraft it was modified to reflect the lower level of detail available in the forecast aircraft movement data compared with that for current movement data. For aircraft times-in-mode, the assumption was made that at the highest level of detail available, the time-in-mode data used for the 2002 inventory are still applicable in 2010. Of course, this may still lead to differences in average times-in-mode, for example as a result of fleet evolution and differences in the pattern of terminal usage. Similarly, the average take-off thrust settings for specific aircraft types were assumed to be the same in 2010 as in current operations.

For road traffic emissions, 2010 baseline forecast data were provided by W S Atkins on behalf of BAA Heathrow for a similar network to that used for the 2002 inventory but taking account of anticipated network developments associated with T5. The airport-related component of the traffic was based on passenger and mode share forecasts consistent with those used in the aircraft movement predictions and with the data provided on car parking on the airport. Airside vehicle activity on the airport was assumed to grow in proportion to total passenger throughput. For the baseline estimate, the relative age distribution of the airside vehicle fleet was assumed to be the same as in 2002 apart from constraints on maximum age imposed by Operational Safety Instructions. Heat energy use on the airport was assumed to grow to meet the needs of the T5 development; in the baseline it was assumed that conventional boilers would meet these needs.

The number of movements is predicted to increase by 4% from 466,554 in 2002 to a total of 485,500 movements in 2010 (including non-ATMs[14]), with a forecast 28% increase in passengers, from 63.0mppa in 2002 to 80.9mppa in 2010. The baseline aircraft fleet is expected to evolve such that the B737 (all series) will account for a much smaller fraction of the movements in 2010, with the A320/A321 and the B777 accounting for a much larger fraction than in 2002. In the baseline 2010 fleet, the future A380 is expected to account for around 4% of the total movements.

For both $NO_x$ and $PM_{10}$, ground-level aircraft emissions represent the largest contribution to airport-related ground-level emissions. For $NO_x$, this contribution is 13.6 times larger than the contribution from airside vehicles/plant and 3.0 times larger than the contribution from airport-related traffic on the designated road network. For $PM_{10}$, the estimate of ground-level aircraft emissions is 8.2 times that for airside vehicles/plant and 2.6 times that from airport-related road traffic on the designated road network.

[14] Non-ATMs are movements not counted as Air Transport Movements, for example positioning movements. ATMs are limited to 480,000.

For ground-level aircraft $NO_x$ emissions, take-off roll gives the largest contribution, accounting for nearly half of the total, in spite of the fact that roll times are substantially shorter than taxiing times. This results from the relatively high thrust setting on take-off, even after taking account of reduced-thrust take-off. For ground-level aircraft $PM_{10}$ emissions, brake and tyre wear is the dominant contributor, accounting for around two thirds of the ground-level $PM_{10}$ emissions from aircraft. However, there are large uncertainties associated with this contribution, which results from generalisation from a single item of data.

The forecast total aircraft $NO_x$ emissions in 2010 are 31% higher than in 2002. This is a larger fractional increase than the fractional increase in the number of movements, as would be expected given that the average size of aircraft increases as the airport develops. It is also a larger fractional increase than the fractional increase in the number of passengers, reflecting a trend in the $NO_x$ performance (in the LTO flight phases) of the current generation of large jet engines. Engine designs are now entering the fleet that are aimed at addressing this trend.

On the other hand, ground-level aircraft $PM_{10}$ emissions are predicted to be almost the same in 2010 as in 2002, despite an increase in the numbers of movements and passengers. This results from a cancellation of the forecast increase in the contribution from brake and tyre wear by a forecast decrease in the exhaust contribution, although both contributions are subject to large uncertainties. For ground-level airport-related emissions, airport-related traffic on the designated network is the source category giving the second largest contribution after aircraft for both pollutants. These emissions are more spread out spatially than those from aircraft on the ground and from airside vehicles. The contribution from car parking and taxis is a small fraction of the total ground-level emissions for either pollutant. The $NO_x$ emissions from non-airport traffic on the network are about 2.1 times the emissions from airport-related traffic; for $PM_{10}$, emissions from non-airport traffic on the network are about 2.5 times the emissions from airport-related traffic.

The 2010 baseline forecast for airport-related landside road-vehicle $NO_x$ ($PM_{10}$) emissions on the road network (within the defined 12km x 9km rectangle) is lower by 15% (12%) than the 2002 estimate for the same network area. The predicted increase in airport-related traffic is more than offset by the lower average emissions per vehicle-km for the national fleet in 2010. The non-airport traffic $NO_x$ ($PM_{10}$) emissions on the network are predicted to fall by 41% (31%) between 2003 and 2010, with this larger reduction reflecting the lower expected rate of increase of background traffic on the network compared to LHR-related traffic in the near vicinity of the airport. The airport-related traffic on the network is forecast to increase by a greater fraction than the fractional increase in passenger numbers because transfer passengers are a smaller fraction of the total in 2010.

The 2010 baseline forecast for airside-vehicle $NO_x$ emissions is 29% lower than the 2002 estimate: the predicted increase in airside vehicle activity (assumed to be broadly in line with passenger throughput) is more than offset by the lower average $NO_x$ emission factors for the baseline vehicle fleet in 2010. The decrease is greater for road vehicles because of the impact of Euro IV and IV+ standards whereas for off-road vehicles no standards beyond Stage 2 have been included. Similarly, the 2010 baseline forecast for airside-vehicle $PM_{10}$ emissions is 41% lower than the 2003 estimate, for the similar reasons. However, for $PM_{10}$, the decrease is greater for off-road vehicles than for road vehicles, but this is the result of adding in a contribution from fugitive (brake and tyre wear) $PM_{10}$ emissions for the road-vehicle but not for the off-road category.

For both $NO_x$ and $PM_{10}$, the contribution to near ground emissions arising from on-airport heating plant is not insignificant, but the contribution to annual-mean ground-level concentrations is expected to be small, after taking account of boiler-house stack height. The predicted emissions are higher in 2010 than in 2003, in line with an anticipated (small) increase in the heat energy use on the airport.

It is clear from the above that some emissions contributions are predicted to be higher in 2010 than in 2002 and some lower. Given the different spatial distributions associated with the different source categories (and the important background contribution to concentrations), it is difficult to predict the net impact of these changes in emissions on the total annual-mean airborne concentrations without undertaking a dispersion modelling exercise.

## ESTIMATING EMISSIONS FROM SMALLER AIRPORTS

### Summary

**Base Year: 2008**
Because of lack of recent activity datasets for the 2008 base year, estimate of airside emissions (provided by AEA Technology) for the 2008 base year (from the LAEI 2006) from minor Greater London airports and airfields (London City, Stapleford , Elstree , Northolt, Battersea , Kenley, Biggin Hill , Lippits Hill Heliport, Denham and Metro London Heliport), undertaken on behalf of the Greater London Authority were used.

**Projection Years: 2011 and 2015**
Because of lack of recent, representative and reliable activity datasets, projection of atmospheric emissions from the smaller airports to 2011 and 2015 were not undertaken; instead projections of atmospheric emissions from the smaller airport to 2011 and 2015 were basically assumed to be the same as those in the LAEI 2006 (using 2010 projection).

### 1.25. 2008 emission estimation methodology: (Same as the LAEI 2006 methodology)

This section describes the LAEI 2008 methodology, data used and results obtained from the calculation of airside emissions from minor Greater London airports and airfields (see Figure 8), undertaken by AEA Technology on behalf of the Greater London Authority (GLA). Airside emissions are those emissions that occur airside and include emissions from aircraft, airside vehicles and plant (i.e. those operating on the apron areas) and refuelling. The report summarises the methodology and present summarised result for each airport/airfield:

- London City
- Stapleford
- Elstree
- Northolt
- Battersea
- Kenley
- Biggin Hill
- Lippits Hill Heliport
- Denham
- Metro London Heliport

The historic data was only available for City Airport. The trends in aircrafts movement data from DfT statistics spreadsheet for Aircraft Movements 1998 – 2008 at City Airport were analysed. It was calculated that there was 55% increase in the aircraft movements at City Airport. The % increase was used to upscale the original data for City Airport. The data for the other small airport remained the same as in LAEI 2006.

It should be noted that this study did not undertake emission estimation for large airports such as Heathrow and only included those airports or airfield as listed above within the M25 orbital, with the exception of Kenley, which was assumed to have negligable impact due to the assumption that all aircraft operating from Kenley are gliders.

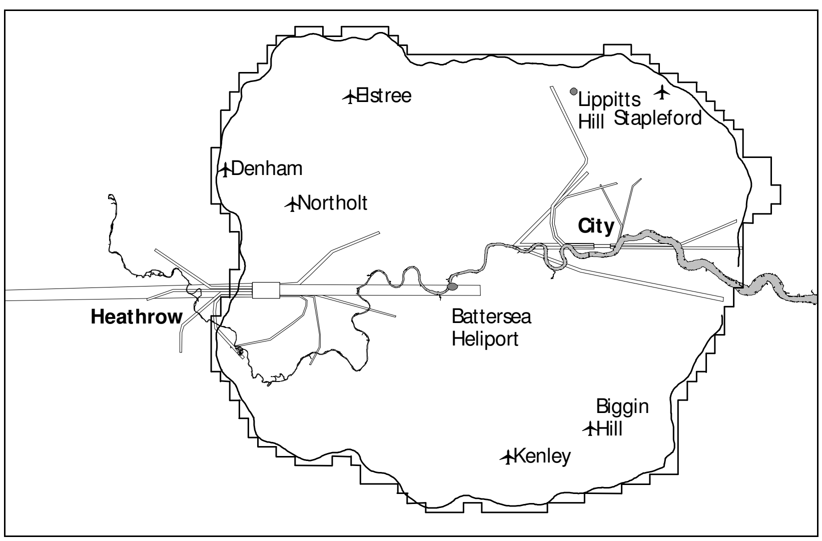
Additionally, only airside emissions have been estimated, no emissions have been calculated for landside road traffic (i.e. those on public access roads), heating plants or car parking.

Therefore the sources for which emissions have been calculated are: the aircraft landing and take-off cycle (LTO), auxiliary power units (APU), refuelling and airside vehicles and plant equipment (i.e. baggage loaders and other aircraft support equipment).

Emissions have been calculated for the following pollutants: oxides of nitrogen; sulphur dioxide; carbon monoxide; non-methane volatile organic compounds; carbon dioxide; benzene; 1,3-butadiene, methane and particulate matter ($PM_{10}$).

The Greater London Authority provided the initial contact details for all airports/airfields and AEA Technology liased with the operators to obtain suitable data. It should be noted that the airports/airfields were under no obligation to provide the data and as such a considerable amount of time elapsed before sufficient data was gathered for the airports/airfield, with the exception of Denham who have, to date, supplied no data. After considerable effort it was decided to assume Denham had 30,000 movements (all twin-engined propeller) based on Elstree. Denham were informed of the assumption of 30,000 movements and given time to respond, but to date have not responded.

**Figure 4: Location of airports in the Greater London area**




Usually, an emissions inventory relates to a specific spatial domain, for example a given city, region or country. The aim in the current work, however, is to quantify airport-related emissions to the extent that they impact on local air quality.

For aircraft, emissions at cruise altitude are best considered in relation to the total demand for air travel and the inventory considers emissions only in the Landing and Take-Off (LTO) cycle, which conventionally extends up to 1,000m. In practice, the impact on ground-level concentrations per unit emission decreases rapidly with the height of emissions, such that the total aircraft emissions above ground level have a much smaller impact on local air quality than those at ground level on the airport.

The following sources are included in the inventory:

- aircraft in the LTO cycle, including APU emissions;
- airside vehicles/plant;
- Fuel storage and aircraft refuelling.

For $PM_{10}$, the inventory includes exhaust emissions and fugitive emissions from brake and tyre wear (for aircraft).

### 1.26. Estimating emissions

The usual approach to calculate emissions from specific sources is to multiply an activity statistic, for example fuel usage or distance travelled, by an emission factor (expressed as mass of pollutant emitted per kg of fuel burned or per km travelled respectively). Emission factors are usually derived from measurement data but are often calculated from a limited sample of measurements. Specific emission factors for individual sources are not always available, in these cases a representative emission factor is usually used, this is however often subject to some educated judgement. The aim of the current work is to quantify the airport and airfield emissions within the M25, excluding Heathrow Airport, to a height of 1000m.

### 1.27. LTO Cycle aircraft exhaust emissions

The dominant aircraft source of emissions is main-engine exhaust during the LTO cycle, and this will be the principal focus of the discussion below. However, separate consideration is also given to emissions from Auxiliary Power Units (APU's).

The following 'modes' (phases) of the LTO cycle are distinguished for purposes of emissionsestimation:

(1) taxi-out;
(2) take-off roll (from start-of-roll to wheels-off);
(3) initial climb (i.e., wheels-off to throttle-back, assumed to occur at 450m);
(4) climb-out (from 450m to 1,000m);
(6) approach (from 1,000m to touchdown);
(7) landing roll (from touchdown to runway exit);
(8) taxi-in.

It was assumed that emissions from the holding of aircraft ready to depart would be minimal at small airports and would be encompassed by the taxiing emissions.

'Taxi-out' commences at stand or apron and ends when the aircraft reaches the end of the runway where take-off begins. The 'taxi-in' commences when the aircraft completes its landing and leaves the runway and ends when the aircraft reaches the stand or apron. Taxi times were based on mapped taxi distances between runways and aprons and an assumed 10mph speed based on data from other studies. Thrust was assumed to be at 7% for taxi.

Take-off roll and initial-climb emissions are estimated from emission rate at take-off thrust multiplied by the take-off roll time (time from start of roll to wheels-off) and initial-climb time (time from wheels-off to 450 m altitude) respectively. Initial climb and take-off had an assumed thrust of 100%, for smaller aircraft. However, reduced thrust for some larger aircraft operating at London City, Biggin Hill and Northolt was assumed for take-off and initial climb, with estimates of take-off thrust taken from a study undertaken at Gatwick (Underwood et al, 2004a).
Once aircraft reach approximately 450 m altitude they will reduce their thrust setting from take-off thrust to climb-out thrust this is termed "throttle back". Climb-out emissions are estimated from the time to climb to 450 m 1000 m multiplied by the emission rate at climb-out thrust (typically 85%).

Approach emissions are estimated from the time in approach from 1000 m multiplied by the emission rate at 30% thrust. In line with the airport studies, the time in approach was assumed to be 286 s for large, medium and small aircraft, 312 s for light aircraft and 390 s for helicopters.

In general, aircraft will land at idle thrust (7%). However, most aircraft make use of reverse thrust (usually 30%) for some of the time. Data from Gatwick study (Underwood et al, 2004a) gave the percentage of aircraft that use reverse thrust for each specific aircraft type. The total time in landing-roll and the time in reverse thrust as well as the reverse thrust settings by aircraft types were taken from the Gatwick study (Underwood et al, 2004a). Some aircraft have periods of reverse thrust during landing roll, in place of braking. Where information is available for specific aircraft types emissions for reverse thrust have been included. Where it is not available it has been assumed that no reverse thrust is used during landing roll.

*Times-in-mode*

The times-in-mode for take-off roll, initial climb, climb-out, approach and landing roll were base on survey data used in the 2002/3 Gatwick emission inventory report (Underwood et al, 2004a). Take-off roll, initial climb, climb-out, approach and landing roll are not as airport specific as taxiing times. The taxiing times in mode have been estimated using mapped data as described above.

*Movement data*

Movement data was provided by each airport, with the exception of Denham. The CAA also supplied the movement data for both Biggin Hill and London City. This was supplemented with data from London City airport.

*Engine assignment*

The movement data provided did not provide engine type directly nor did it include details of each aircraft registration number. Therefore weighted average emissions, based on Gatwick data for the mix of engine types used per aircraft, were calculated and applied to the relevant aircraft.

*Engine exhaust emission factors*

Emissions from aircraft originate from the fuel burned in the main aircraft engines, and the engines powering the auxiliary power units. The combustion products from the engines include greenhouse gases and other pollutants. Carbon dioxide and oxides of nitrogen are emitted in the greatest quantities per tonne of fuel consumed, but methane, nitrous oxide, other by-product gases, and trace amounts of metals are emitted also. The fuel use and emissions will be dependent on the fuel type, aircraft type, engine type, engine load and flying altitude. The chief source of emission factors (and fuel flow rates) used in the present work is the ICAO databank (CAA, 2006), which gives certification test results for most of the engines in service, at four thrust settings (7%, 30%, 85% and 100%). It is a key assumption of the methodology that these engine test results are representative of the emissions performance of in-service engines. Data for some engines not listed in the ICAO databank (usually turboprops) were obtained from the FAA Aircraft Engine Emission Database (FAA). A significant proportion of aircraft engines were identified from the databanks. In a few cases surrogate engines of similar size were used.

**Table 20: Emission factors for aviation fuels (kg/t)**

| Fuel | $CO_2$ | $SO_2$ |
|---|---|---|
| | (kt / tonne) | (kg / tonne) |
| Aviation Turbine Fuel | 859 | 0.82 |
| Aviation Spirit | 865 | 0.82 |

The ICAO databank only contains emission factors for NOx, HC, and CO. It does not include emission factors for $PM_{10}$ directly, but does include 'smoke number' (SN), an indirect measure of particulate emissions calculated from the reflectance of a filter paper measured before and after the passage of a known quantity of smoke-bearing gas. A method developed as part of the Project Sustainable Development Heathrow Project (DfT, 2006) to derive an emission factor (g pollutant per kg of fuel consumed) from SN was used. The core of the method depends on generalising from a sparse data set relating SN to a gravimetric measure (from example, $g/m^3$ of exhaust gas). This method of emission factor estimation has been used in similar airport emission estimation for airports such as Gatwick, Birmingham, Manchester and Heathrow. Emissions of carbon dioxide and sulphur dioxide were calculated by assumed amounts of the particular pollutant per tonne of fuel consumed.

In general there are three fuels that are used to power aircraft: aviation gasoline, jet gasoline, and jet kerosene. Aviation Gasoline is motor spirit prepared especially for aviation piston engines, with an octane number suited to the engine, a freezing point of -60°C and a distillation range usually within the limits of 30°C and 180°C. Jet Gasoline (Naphtha type Jet Fuel or JPA) is a light hydrocarbon oil distilling between 100°C and 250°C for use in aviation turbine power units. It is obtained by blending kerosenes and gasoline or naphthas in such a way that the aromatic content does not exceed 25 per cent in volume, and the vapour pressure is between 13.7 kPa and 20.6 kPa. Jet Kerosene is a distillate also used for aviation turbine power units. It has the same distillation characteristics between 150°C and 300°C (generally not above 250°C) and flash point as kerosene. In addition, it has particular specifications (such as freezing point) which are established by the International Air Transport Association (IATA).

Emissions of carbon dioxide and sulphur dioxide are derived from the carbon and sulphur contents in the fuels. The sulphur contents are updated annually from data provided by UKPIA. The carbon contents of the fuels are currently under review.

Emissions of benzene, 1, 3-butadiene, methane were calculated from the hydrocarbon emissions calculated using the ICAO emission factors. The methodology described in Memorandum from R. Cook to R. Wilcox. .'Exhaust THC to VOC Correction Factors for Aircraft," July, 1992 was used to first convert hydrocarbons to methane and NMVOC. The NMVOC was then converted to benzene and 1,3 butadiene using 1.97 and 1.8 factors respectively.

In terms of spatial apportionment, all airports and airfields, except Biggin Hill, were assumed to use the main runway only, with the operation direction split based on Heathrow meteorological data for 2004. For Biggin Hill only a small percentage of the light aircraft were apportioned to the short runway (based on analysis of meteorological wind direction data), others were apportioned to the main runway. Take-off and landing were apportioned to runways and assumptions made concerning length of take off and landing typical to the aircraft size. Similarly, approach was assumed to be a straight line from 1000m to touch down. Initial climbout assumed to be a straight line from wheels of up to 450m, climbout a straight line from 450m to 1000m. Taxi emissions were apportioned to the most obvious route between runway end and apron. APU emissions were apportioned to aprons. Brake and tyre wear were assumed to be apportioned to landing.

***APU emissions***

Data from Heathrow and Gatwick studies (Underwood et al, 2004a) enabled aircraft types and APU types to be matched. Stansted data gave one average APU running times prior to departure and after arrival for all aircraft and this was used in conjunction with the typical APU types per aircraft taken from the Gatwick and Heathrow studies.

APU emissions (kg) from an aircraft movement were estimated from the product of the APU running time (s), the fuel consumption (kg/s) and the emission factor (kg pollutant per kg fuel consumed).

There are limited source of emission factors for APUs, emission factors have been taken from the Heathrow and Gatwick studies (Underwood et al, 2004 and 2004a).

The APU emission factor dataset does not contain $PM_{10}$ emission factors. However, total APU fuel used can be calculated, and an estimate of APU $PM_{10}$ emissions was derived by taking a representative emission factor of 0.1g/kg fuel. This value is approximately equal to the ratio of total $PM_{10}$ emissions in the LTO cycle to total fuel used in the LTO cycle found in the current work and in past airport emission inventories such as those for Gatwick and Heathrow.

***Engine testing emissions***

It was decided from past experience that the emission from this source would be insignificant for small airports and they were therefore not calculated.

*Aircraft-related fugitive emissions*

It was assumed for this air quality assessment based on previous assessments for Heathrow and Gatwick that the quantity of eroded material per landing should be scale with the size of aircraft. The most suitable way of scaling by size was thought to be by the maximum take-off weight. The estimate of the contribution of tyre and brake wear to emissions should be treated with caution, the method used is the same as used in the PSDH project (Dft, 2006).

***Airside support vehicle/plant emissions***

For the purposes of this report it has been assumed that the fuel consumption of aircraft (excluding helicopters) during the approach mode can be used as a surrogate statistic to scale emissions from other airport studies, in this case for Belfast City Airport, where airside fuel consumption for support vehicles and plant were available. Approach fuel use has been used as a surrogate as approach time is normally assumed to be fairly consistent from one airport to another. Fuel at Belfast City Airport was estimated in 2005 to be 110, 5547kg for aircraft approach and 206047 litres of airside fuel (assumed diesel).

Emission factors from the National Atmospheric Emission Inventory (NAEI, 2005) have been used for diesel fuelled support vehicles and plant. The emissions calculated should be treated with caution due to the assumed fuel use. Estimated emissions are detailed below and have been apportioned to the aprons:

***Aircraft fuel storage and handling***

There will be emissions of hydrocarbons due to evaporation of aircraft fuel from storage, tank filling and from any spillages. It has been reported in previous air quality assessments for airports (Underwood et al, 2004 and 2004a) that these sources are not thought to be major contributors to the overall emissions of hydrocarbons.

It has been assumed that the fuel use is related to the estimated approach fuel burn and a similar methodology to that used to estimate airside vehicle/plant emissions has been used. The aviation fuel related evaporative emissions at Belfast City Airport have been used and factored using approach fuel use. Evaporative emissions have been apportioned to the apron areas. Benzene, 1,3 butadiene and methane have been estimated from the ratio of aircraft hydrocarbon emissions to these pollutant as the emissions of these pollutants is related to the relative proportions of different types of fuel used at different airports.

Breathing losses at the fuel farms consist of vapour expelled due to pressure changes arising from diurnal temperature cycling. Working losses from fixed-roof tanks are the sum of the loading losses (vapour expelled on filling) and unloading losses (saturation of new air intake with vapour). These losses are normally calculated using the methodology in 5$^{th}$ Edition of AP-42 (USEPA, 1995) for fixed-roof tanks. The principal data required for calculating total vapour loss are the dimensions of the tanks and the total annual throughput of fuel. These data were not available for the airports under consideration at the time of this study. It was also assumed that refuelling losses are the same as the working loses from the tanks. The emissions calculated should be treated with caution due to the assumed fuel use. The total emissions from aircraft fuel storage and handling are below and have been apportioned to the aprons.

## References

Civil Aviation Authority (2006) ICAO Aircraft Emissions Databank, http://www.caa.co.uk/default.aspx?categoryid=702&pagetype=90, Accessed 23/05/2006

Dft (2006) Project for the Sustainable Development of Heathrow:Air Quality Technical Report http://www.dft.gov.uk/stellent/groups/dft_aviation/documents/divisionhomepage/612123.hcsp, accessed 31/7/06.

FAA Aircraft Engine Emissions Database. AEE-110. Developed by the FAA Office of Environment and Energy.

Heathrow Emissions Inventory 2002: Part 1. A report produced for BAA Heathrow (2004), BY Underwood, CT Walker and M J Peirce. netcen /AEAT/ENV/R/1657/Issue 4. August 2004.

Gatwick Emissions Inventory 2002/3. A report produced for BAA Gatwick (2004a), BY Underwood, CT Walker and M J Peirce. netcen/AEAT/ENV/R/1569/Issue 2. October 2004

NAEI (2005) Emission Factors Database. http://www.naei.org.uk/emissions/selection.php (Accessed 15/12/2005)

USEPA (1995) Compilation of air pollutant emission factors. AP-42. Volume 1: stationary point sources and area sources. 5th Edition.

# ESTIMATING EMISSIONS FROM ROAD TRAFFIC

## Summary

**Base Year: 2008**
Environmental Research Group (ERG)/King's College London, on behalf of the GLA provided estimates of road traffic emissions for the 2008 base year.

**Projection Years: 2011 and 2015**
ERG projected road transport emissions to 2011 and 2015 and these projections include the effects of the Congestion Charge Scheme (CCS); and a Low Emissions Zone (LEZ).

### 1.28. Emission estimation methodology: 2008

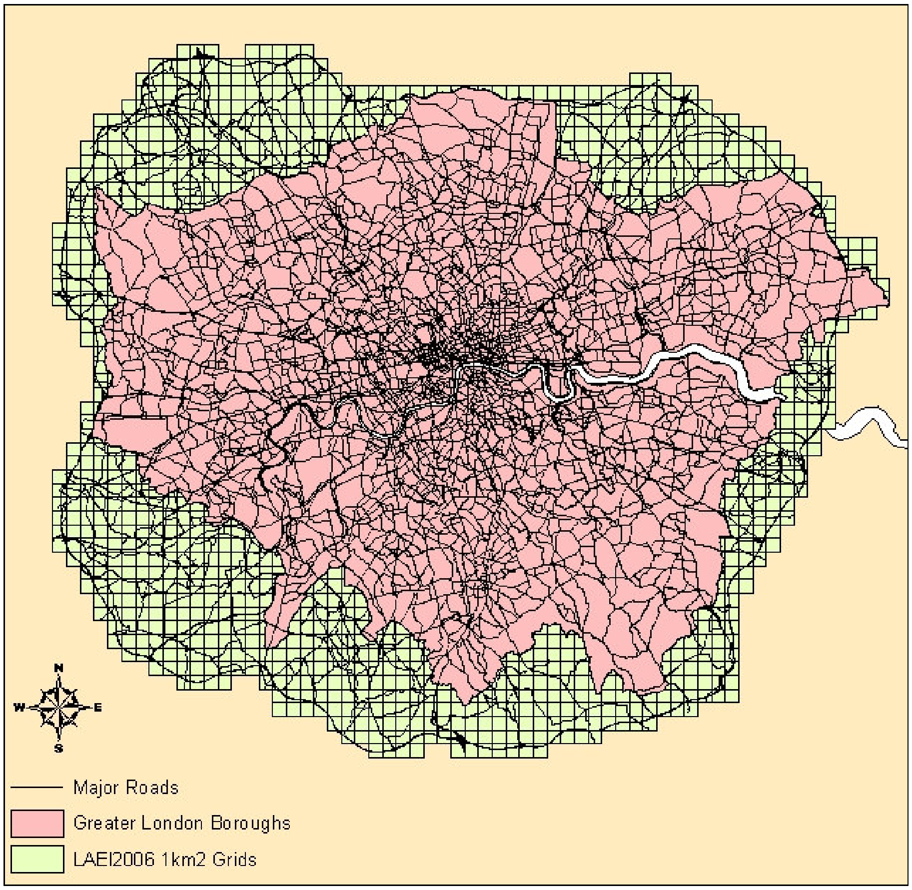
Emissions for the following pollutants have been calculated:

1. Benzene ($C_6H_6$)
2. 1,3-Butadiene ($C_4H_6$)
3. Carbon Dioxide ($CO_2$)
4. Carbon Monoxide (CO)
5. Non-Methane Volatile Organic Compounds or Hydrocarbons (NMVOC) [15]
6. Oxides of Nitrogen ($NO_X$)
7. Primary Nitrogen Dioxide ($NO_2$)
8. Particles $PM_{10}$ (Exhaust and Tyre and Brake wear);
9. Particles $PM_{2.5}$ (Exhaust and Tyre and Brake wear);
10. Sulphur Dioxide ($SO_2$)
11. Methane ($CH_4$)
12. Polycyclic Aromatic Hydrocarbons (PAH) (Benzo(a)pyrene)
13. Nitrous Oxide ($N_2O$)

The LAEI covers the entire Greater London Authority area as well as the area extending up to and including the M25 motorway (see Figure 5). This report describes the methodology used to estimate road transport emissions in 2004, 2006, 2008, 2011 and 2015.

[15] Note – any reference to hydrocarbons excludes methane.

**Figure 5: The extent of the LAEI 2008 illustrated by the 1km2 grid cells. (The Greater London Boroughs and all major roads in the area are superimposed on the top of the grid cells.)**




The methodology used to create the traffic emissions for the LAEI 2008 has undergone significant changes compared with the previous version and these include:

- A complete revision of the methods used to estimate traffic flow on the road network;
- A new set of emissions factors for all vehicle types, provided by Department for Transport;
- Revisions to the vehicle stock model, provided by AEA;
- An updated trip starts matrix used in estimating cold starts, provided by TfL;
- New London specific vehicle stock, also provided by TfL.

## 1.29. Updating London Traffic data

A completely new method has been developed by ERG to calculate the traffic flow on roads in London. The method was first used in the recent report to DEFRA, which compared trends in emissions with measurements in London (Beevers et al, 2009[16]). The reasons for developing the new methods include:

[16] Beevers SD, Carslaw DC, Westmoreland E and Mittal H. 2009. Air pollution and emissions trends in London. Report produced for DEFRA by King's College London, Environmental Research Group and Leeds University, Institute for Transport studies

- To incorporate the traffic information not only from the most recent year but for all years from 1999 to the present day through use of a smooth function applied to all data, road by road. This analysis goes some way to resolving uncertainties associated with traffic counts, which are taken infrequently;
- The traffic is generated for each hour of the year, prior to being summarised as an AADT equivalent value and thus transport strategies, affecting certain periods or times of the day, can be more appropriately assessed;
- The traffic data will ultimately lead to the development of hourly emissions estimates from road traffic and that this will in turn allow more appropriate comparisons with air pollution data and ultimately lead to a robust evaluation of the traffic emissions in London.

The following description of the methods used to generate traffic data is taken from the DEFRA report (Beevers et al, 2009):

The approach to develop an hourly emissions estimate for road traffic used a combination of data. The basis of the calculation was a 'London averaged' hourly traffic file based upon an average of Automatic Traffic Count (ATC) sites in central London, running between March 2003 and the end of 2008. The London average ATC data was assessed using GAM modelling techniques to estimate whether a long term trend existed in the data. The GAM modelling established that total hourly traffic counts could be described using smooth functions of hour of day, day of week, season and trend and that on average these factors could account for $R^2$ values ~ 0.9. Furthermore, there was no significant long-term trend, thus avoiding any problems associated with introducing an artificial trend into the data.

To calculate total traffic flows along individual roads the 'London averaged' data was scaled using manual count (MCC) data taken during weekday periods (7am to 7pm). Unlike the ATC data, manual counts are widespread and cover all of the major roads in London. This means that where a MCC count exists a specific hourly traffic file can be calculated. Since the manual count data is taken infrequently a number of tests were undertaken to compare col-located MCC and ATC data taken over the same 12 hour period as well as for longer periods of the year. Furthermore, since manual count measurements may be highly variable due to specific local events the time series of these data was smoothed using a LOESS smoothing function or where few measurements were taken an average of the data was used. Finally, when rescaling the ATC data care was taken to maintain daytime and night time differences in vehicle flow as well as weekend totals.

The MCC data are classified into 11 vehicle types and these were used to split the total vehicle counts for each hour of the day. Less data was available during weekday overnight periods, Saturdays and Sundays. Here a combination of datasets were used, including a set of MCC counts taken over a complete 24 hour period and Automatic Number Plate Recognition (ANPR) camera data. The former provided average proportions by vehicle type during the overnight minimum traffic periods and a combination of ANPR and weekday MCC data was used to apportion the weekend periods.

The results of the total vehicle counts was tested against a separate data set of ATC data recorded by DfT during 2006 and 2007 and not used in the model development. These tests were made for a combination of 16 site years and are presented as a predicted and measured profile, averaged over all sites and by day of the week (Figure 6). Alongside these results a summary of bias and the RMS error has also been presented (Table 21). Comparison of the predicted total (red), measured ATC total (blue) and the residual, (predicted-measured in light green) across an average of all sites show that the methods for creating vehicle totals are robust and provide good results across all days of the week.

The results in Table 21 show that over a 24 hour period very little bias exists in the predictions and in all cases is below 7%. Lack of data during weekends is apparent and as a consequence the method has the poorest performance during Saturdays. Because manual count data is specific to each site the 12 hour weekday periods should have the lowest uncertainty and for these separate results are presented. Here too modest bias estimates are apparent with average values of the order of -5%. Furthermore, Sunday, is well predicted for total vehicles and is widely understood to have small proportions of HGVs so is also a period where the traffic and emissions data is relatively robust. Overall the predicted average data has a RMS error of ~ ±10%.

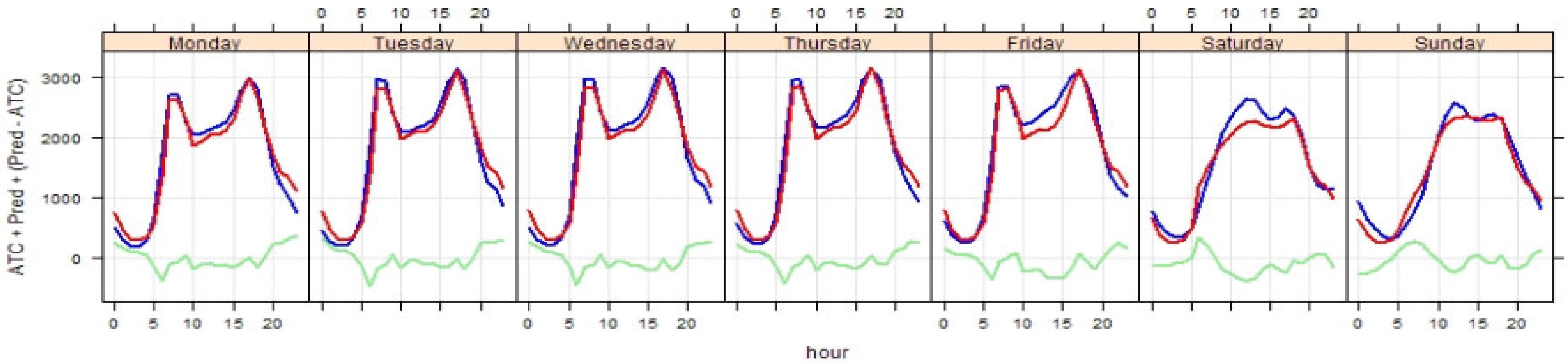



**Figure 6: Comparison of predicted (red), measured (blue) and predicted-measured (light green) hourly total traffic flows. 16 site and year combinations for 2006 and 2007.**

**Table 21: Summary statistics from** Error! Reference source not found.

| | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Sunday | All days (RMS error) |
|---|---|---|---|---|---|---|---|---|
| Predicted | 1659 | 1741 | 1753 | 1770 | 1753 | 1466 | 1419 | **10.7%** |
| Measured | 1657 | 1740 | 1773 | 1792 | 1820 | 1569 | 1461 | (% of mean |
| **Bias (%) (pred-measured/meas)** | **0.1%** | **0.1%** | **-1.1%** | **-1.2%** | **-3.6%** | **-6.6%** | **-2.9%** | (measured)) |
| Predicted (12 hrs) | 2339 | 2455 | 2472 | 2495 | 2471 | 2066 | 2023 | **6.7%** |
| Measured (12 hrs) | 2438 | 2553 | 2588 | 2597 | 2625 | 2243 | 2036 | (% of mean |
| **Bias (%) (pred-measured/meas)** | **-4.1%** | **-3.9%** | **-4.5%** | **-3.9%** | **-5.8%** | **-7.9%** | **-0.6%** | (measured)) |

## 1.30. Including vehicle km changes in London between 2003 and 2008

As a consequence of the new methods used to process the traffic data many of the changes associated with traffic interventions are inherent within the counts used in each of the year 2003, 2004, 2006 and 2008. Where they are not additional changes have been assumed such as those described for WEZ in section 6.16.

## 1.31. Vehicle kms travelled by road type

The vehicle kms travelled on minor roads have been re-calculated (Table 22), based on the latest estimates provided by TfL[17] which in Greater London is estimated to be 31.19 billion vehicle km (bvkm) in 2008. Of this total the vehicle kms on major DfT and LTS roads have been calculated at 21.52 and 5.29 bvkm in 2008, respectively. This was calculated using the following equation[18]

Vehicle kms = (road traffic flow (24 hours) * 365 * (road link length (m) * multiplier)/ $1*10^{12}$

Other changes include the number of DfT roads, which has increased compared to the LAEI 2006 as a result of around 400 LTS links being replaced with DfT counts. This partly explains an overall decline of ~15% in LTS vehicle kms in the Greater London Area for the LAEI 2008 compared with the LAEI 2006. It should be noted that the TfL estimate of vehicle km for 2006 supersedes the figure of 31.15 bn used in the previous release of the LAEI. Indeed a direct comparison between the LAEI2008 and LAEI2006 shows that the vehicle km associated to minor roads has increased by about 20%.

**Table 22: Vehicle km corrected for minor roads**

| Year | MINOR | TOTAL GLA |
|---|---|---|
| 2003 | 5.44 | 32.47 |
| 2004 | 4.91 | 31.99 |
| 2006 | 4.71 | 31.78 |
| 2008 | 4.38 | 31.19 |

## 1.32. AADT comparisons

The vehicle kms travelled, by vehicle type, between 2003 and 2008 has been calculated and is displayed in Table 23. Note, Table 23 is concerned with the LAEI area and not the GLA area.

The results show that the total vehicle kms for all vehicle types (save motorcycles and cars) is greater than that of the LAEI 2006, for example, the vehicle km of buses and LGVs has increased by 6% for the year 2006.

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[17] Charles Buckingham personal communication.

[18] Note: The road link length and multiplier is held within the traffic flow tables for each road link. Slip roads in this case are given a value of 0, dual carriageways and roundabouts a value of 0.5 and all other roads a value of 1. Note that some of the more complex road junctions may be assigned manually.

**Table 23: Vehicle km (billion) for each vehicle type for the LAEI area.**

| LAEI Year | Motor cycles | Taxis | Cars | Buses | LGVs | Rigid HGVs | Artic HGVs | Total |
|---|---|---|---|---|---|---|---|---|
| 2003 | 0.78 | 1.10 | 36.68 | 0.70 | 5.05 | 1.58 | 0.95 | 46.84 |
| | | | | | | | | |
| 2004 | 0.76 | 1.09 | 36.11 | 0.70 | 5.05 | 1.56 | 0.95 | 46.22 |
| | | | | | | | | |
| 2006 | 0.74 | 1.07 | 35.88 | 0.71 | 5.13 | 1.56 | 0.96 | 46.07 |
| | | | | | | | | |
| 2008 | 0.73 | 1.06 | 35.43 | 0.71 | 5.09 | 1.59 | 0.97 | 45.58 |

## 1.33. Including taxis within London traffic data

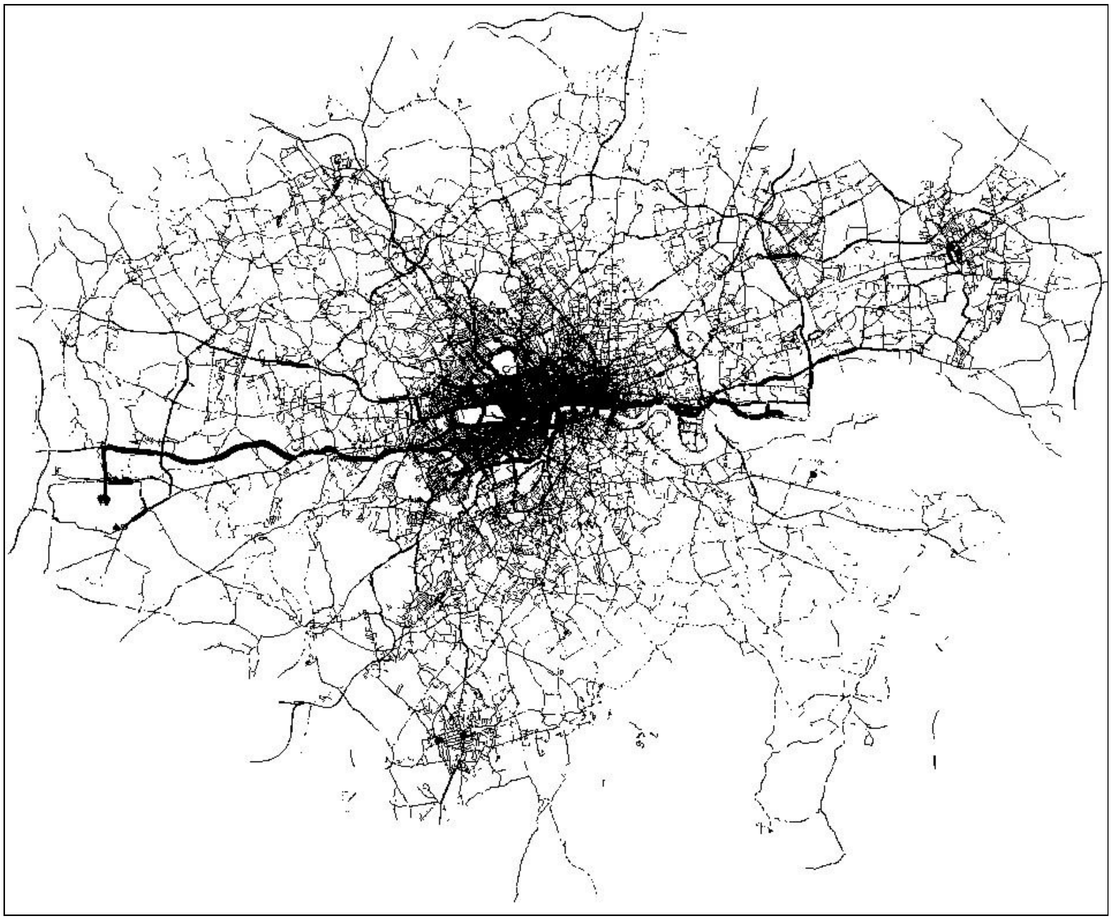
**Traffic count data for taxis are very limited; they are generally counted as cars. Some TfL manual classified data have separate counts for cars and taxis. These data have been used to calculate a revised set of proportions of taxis by area of London. The zones within which these proportions are applied have also been changed to a single zone, which includes the WEZ and CZ area's combined, the inner zone, which includes the IRR and an outer/external zone. The reason for a change to the central zone is that it better reflects the area where taxis operate (**

Figure 7).

**Table 24: Proportion of taxis (taxis/(taxis+cars)) by area of London**

| Hour | Central | Inner | Outer/External |
|---|---|---|---|
| 0 | 28.73 | 12.27 | 4.28 |
| 1 | 30.11 | 16.00 | 8.36 |
| 2 | 21.83 | 11.07 | 5.41 |
| 3 | 18.31 | 9.65 | 3.78 |
| 4 | 16.52 | 7.29 | 3.78 |
| 5 | 12.24 | 8.56 | 2.79 |
| 6 | 11.79 | 5.99 | 1.46 |
| 7 | 15.58 | 3.70 | 1.01 |
| 8 | 16.26 | 2.55 | 1.07 |
| 9 | 18.94 | 3.17 | 0.94 |
| 10 | 20.42 | 4.80 | 1.33 |
| 11 | 21.55 | 4.83 | 1.83 |
| 12 | 19.20 | 4.89 | 1.59 |
| 13 | 20.95 | 5.00 | 1.59 |
| 14 | 26.61 | 5.60 | 1.84 |
| 15 | 21.97 | 4.34 | 1.61 |
| 16 | 21.70 | 4.79 | 1.72 |
| 17 | 20.70 | 4.51 | 1.63 |
| 18 | 19.98 | 4.24 | 1.33 |
| 19 | 20.47 | 5.17 | 1.63 |
| 20 | 22.69 | 7.00 | 2.03 |
| 21 | 24.96 | 7.23 | 2.29 |
| 22 | 25.92 | 7.04 | 2.17 |
| 23 | 29.18 | 8.74 | 2.67 |

**Figure 7: An estimate of taxi operation in London using GPS vehicle tracking (taken from the LAEI 2001)**



## 1.34. Vehicle Speed Data

Vehicle speeds on the major road network have been updated using an average of all traffic speed data taken by the TfL floating car from 2003 to 2008. These measurements cover the entire major road network with additional measurements being taken in inner and central London (Figure 8). These speeds separately consider three intervals throughout the day (am, inter-peak and pm), with the CCS speed survey covering six periods of the day in the CCS area and four periods in Inner London. Overnight speeds are also taken periodically and all speed data has been carefully matched with the road network. Speeds in the area outside the Greater London boundary have also been updated. Minor road vehicle speeds have been kept the same as in LAEI 2006 and are as follows: central and IRR = 18.1 km $h^{-1}$, inner = 25 to 30 km $h^{-1}$ and outer = 30 to 35 km $h^{-1}$.

Figures 9 and 10 illustrate the comparison of speeds used in the LAEI2006 and the LAEI2008. It can be seen that on the whole there is good agreement between the two LAEI versions, suggesting that speed has changed little over time. There is however a pronounced region of discrepancy in speeds on the DfT referenced links and further analysis of these speeds (Figure 11) illustrates that this is concentrated in the external zone of the LAEI area. Further investigation revealed that the links in question have not had a speed update for a number of years and that the speeds were not based on site-specific data but instead set to an average speed for the external zone. Since the new speeds are based on site-specific data this update is considered an improvement to the LAEI.

**Figure 8: The CCS speed network used in compiling central and inner London speeds**

**Figure 9: Comparison of hourly speed for DfT referenced links between the LAEI2006 and the LAEI2008.**

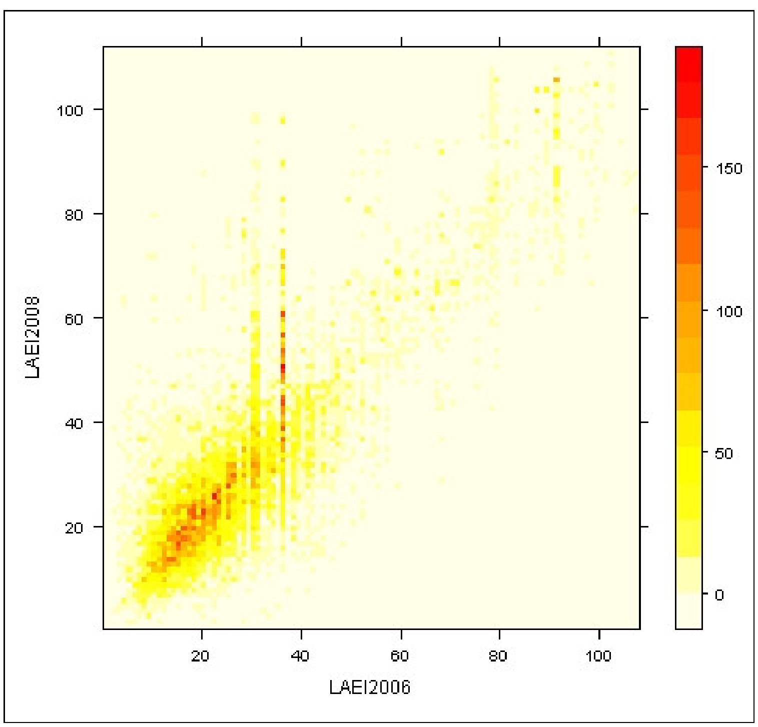


**Figure 10: Comparison of hourly speed for LTS referenced links between the LAEI2006 and the LAEI2008.**

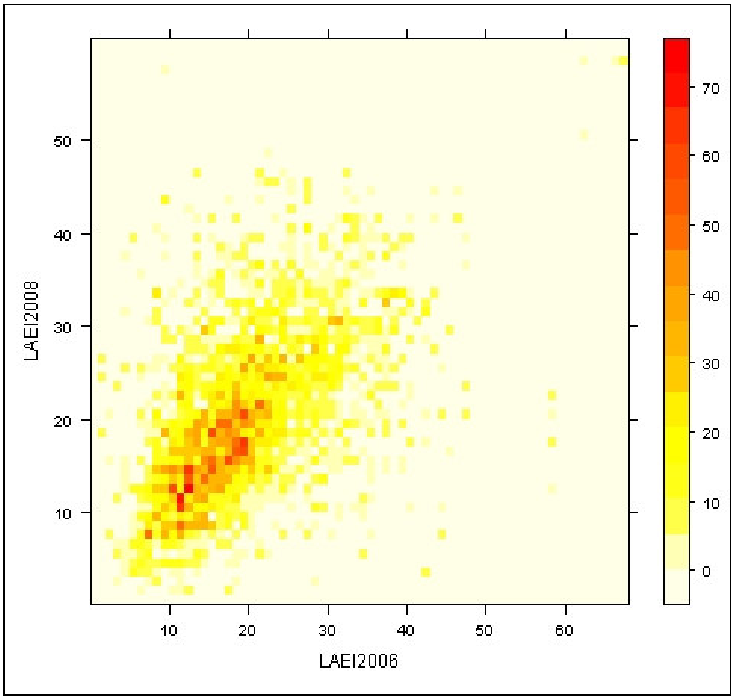
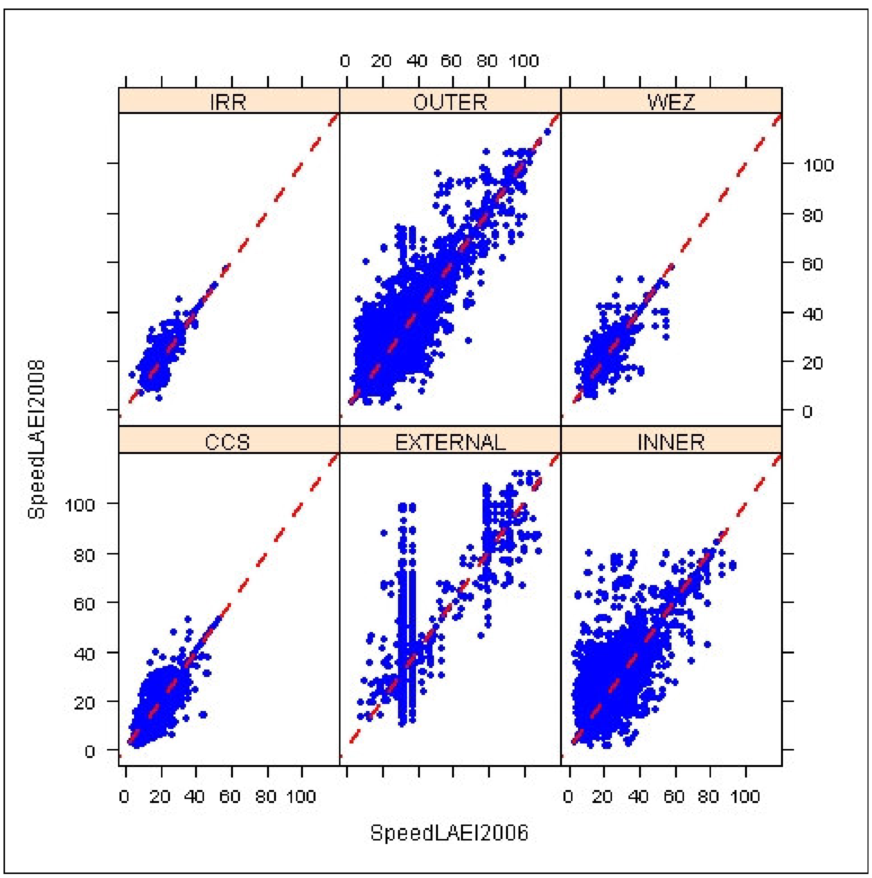



**Figure 11: Comparison of hourly speed for DfT referenced links split by location between the LAEI2006 and the LAEI2008.**



## 1.35. Vehicle Stock Data

### Changes to the national stock model

The vehicle stock in London has been updated since the LAEI 2006 and is based on the UK National Atmospheric Emissions Inventory (NAEI) fleet composition data[19]. One of the most significant of these changes is the proportion of failed catalysts in petrol cars, which has increased by about 12% until 2009 (from 1% to 13% in 2008). The consequence of this change is that up to 2009 the proportion of pre Euro equivalent vehicles within the fleet has increase significantly and has increased the emissions of all pollutants from cars. This effect is short lived and after 2009 the catalyst failure rate returns to a very low level, 5% in 2009 and 2% by 2015. The proportion of failed catalysts in petrol LGV's has also increased by about 15% for all the years until 2025 (from 2% to 15% in 2008). Unlike cars, LGVs catalyst failure rates remain at about 11% after 2009 until 2025.

### Changes made to taxi stock information

Taxi stock has been updated based on information from the Public Carriage Office (PCO) for 2003, 2004, 2006, 2008, 2011 and 2015 [20] (Table 25) Stock estimates up to and including 2008 are based on the actual fleet, whereas the 2011 to 2015 information is based on forecast data, which reflects the GLA's taxi strategy. Additionally, it has been assumed that 7.5% of retro-fitted taxis (Euro 3 equivalent) fail and so for the years 2008, 2011 and 2015 the taxi stock has been readjusted to reflect this[21].

**Table 25: Taxi Stock data (%) for the years 2004, 2006, 2010 and 2015.**

| Euro Class | 2003 | 2004 | 2006 | 2008 | 2011 | 2015 |
|---|---|---|---|---|---|---|
| Pre Euro | 16 | 12 | 4 | 4.5 | 2.8 | 1.3 |
| Euro 1 | 48 | 42 | 21 | 0.7 | - | - |
| Euro 2 | 26 | 26 | 12 | 3.2 | - | - |
| Euro 3 | 11 | 19 | 60 | 70.1 | 58.2 | 38.1 |
| Euro 4 | - | - | 2 | 20.4 | 38 | 39.3 |
| Euro 5 | - | - | - | - | - | 16.2 |
| Euro 6 | - | - | - | - | - | 4.1 |
| LPG | - | 1 | 1 | 1 | 1 | 1 |

### Estimates of LT Buses stock

The LT bus stock has also been revised according to the latest information[22] (Table 26). In common with Taxi's, bus stock up to 2008 is based on the actual fleet, whereas the 2010 to 2015 information is based on forecast data.

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[19] Personal communication with Tim Murrells at AEAT; NAEI Department for Transport (DfT) forecast dated April 2008.
[20] Personal communication with Finn Coyle at TfL.
[21] TfL personal communication. Claire and Yvonne Brown (Feb 4th 2010)
[22] Personal communication with Finn Coyle at TfL.

**Table 26: TfL Bus Stock data (%) for the years 2004, 2006, 2010, 2015, 2020 and 2025[23]**

| Euro Class | 2003 | 2004 | 2006 | 2008 | 2011 | 2015 |
|---|---|---|---|---|---|---|
| Pre-Euro | 15 | 7 | - | - | - | - |
| Euro 1 | 2 | 1 | - | - | - | - |
| Euro 2 | 20 | 6 | - | - | - | - |
| Euro 2 + CATa | 1 | 1 | - | - | - | - |
| Euro 2 + Trap | 24 | 36 | 37 | 31 | 13.5 | - |
| Euro 2 + Trap + SCRb | - | 0.1 | - | - | - | - |
| Euro 3 + Trap | 37 | 48 | 60 | 56 | 53.6 | 41.8 |
| Euro 3 + Trap + SCR | - | 0.1 | - | - | - | - |
| Euro 4 | - | - | 2 | 12 | 21.4 | 21.4 |
| Euro 5 | - | - | - | 1 | 8.4 | 33.7 |
| E4 Hybrid | - | 0.03 | 0.1 | 0.4 | 1.9 | 1.9 |
| E5 Hybrid | - | - | | | 1.2 | 1.2 |

a: Oxidation Catalyst; b: Selective Catalytic Reduction

## 1.36. Emission Factors

### Assumptions and Data

A complete revision of the emissions factors, available from DfT and compiled by TRL, were used in the calculation of traffic emissions in the LAEI 2008. The emissions factors follow a similar format to previous versions in that they use polynomial expressions to express emissions in g/km vs. vehicle speed, for different pollutant types[24]. However, the number of vehicle types has increased due in the main to the disaggregation of vehicle size or weight. A more detailed note of the headline changes due to the adoption of the new vehicle stock and emissions factors will be given as part of the MAQS 2 work currently being undertaken by King's, however some notable changes to $NO_X$ and $PM_{10}$ based on the year 2006 are summarised below and in Table 27:

- Total $PM_{10}$ emissions are 12 % lower
- Total $NO_X$ emissions are 10% higher ($NO_2$ 16% higher)
- The largest changes from new emission factors are for buses, which have more than 60% higher $NO_X$, $NO_2$ and $PM_{10}$ emissions. Emissions from HGVs, on the other hand, are lower for all pollutants e.g. $NO_X$ emissions for articulated HGVs have fallen by 14%.
- Emissions from cars have not changed significantly and although motorcycle emissions show some large changes, they contribute only a small proportion of total vehicle emissions.
- As a consequence of the changes across vehicle types, there is substantial spatial variation across London. These largely depend on the varying proportions of different

[23] Source: TfL buses.
[24] See http://www.naei.org.uk/emissions/index.php for details.

vehicle types in different areas of the city. For example, the increase in taxi and bus emissions is more important for central London than outer London where the decrease in HGV emissions has more impact.

**Table 27: Emission factors sensitivity of new DfT emission factors. (Percentage change compared to old emission factors) – Year 2006**

| Pollutant | MC | Taxis | Cars | Buses | LGV | Rigid | Artic | Total |
|---|---|---|---|---|---|---|---|---|
| $CO_2$ | 0% | 11% | -2% | 28% | -21% | -29% | -5% | -5% |
| Exhaust $PM_{10}$ | -54% | 29% | -5% | 65% | -17% | -11% | -32% | -12% |
| $NO_X$ | 32% | 41% | 6% | 63% | 0% | 0% | -14% | 10% |
| $NO_2$ | 32% | 22% | 3% | 60% | -2% | 0% | -14% | 16% |

## 1.37. Cold start emissions

The emission factors described above do not include the effect of cold starts, which is included as an additional emission, dependent on the number of trips a vehicle makes and the mean length of each trip. The methodology that has been used in the LAEI is the same as that used in the COPERT IV methodology. (For more details, see http://lat.eng.auth.gr/copert/)

Cold start emissions have been calculated using revised data from a recent LTS model forecast. This has made a large change in the number of total trip starts within the LAEI, an increase of around a factor of 4. The cold start emissions are calculated for cars and LGVs for CO, NMVOCs, $NO_X$ and $PM_{10}$ on a $km^2$ basis and are expressed in terms of annual emission rates.

$PM_{2.5}$ emissions from cold starts have also been included and these are based on the assumption that approximately 90% of the $PM_{10}$ cold start emissions are emitted as $PM_{2.5}$.

However the change in actual cold start emissions is a combination of both the change in trip starts and the new emission factors and have resulted in the following emissions changes:

*CO cold start emissions have increased by ~12 times.*
Emission factors for CO have changed substantially and in combination with the factor of 4 increase in trips starts has increased CO significantly.

*$PM_{10}$ cold start emissions have decreased by ~20%*
The $PM_{10}$ emission factors for both pre Euro and Euro 1 cars are lower than previously assumed. Therefore the reduction in g/km released by pre Euro vehicles will go some way to explain the overall reduction in cold start $PM_{10}$ emissions. The difference in pre Euro and Euro 1 LGVs between the new and old emission factors is similar to that of cars.

*$NO_X$ cold start emissions have increased by ~2.4 times.*
The combination of a change in $NO_X$ emission factors alongside the increase in trip starts has contributed to the increase in cold start emissions, although the increase is smaller than would have been the case using the new trip start data alone.

*NMVOC cold start emissions have increased by ~12 times*

The new DfT emission factors for NMVOC for all types of petrol cars and LGVs are greater than previously assumed. This increase, alongside the increase in trip starts has lead to an overall increase in cold start NMVOC emissions and is similar to CO.

## 1.38. Evaporative Emissions

Evaporative emissions of NMVOCs for petrol vehicles arise from a number of different sources. The methodology that has been used in their calculation is consistent with the COPERT IV methodologies. The three principal sources of emissions are diurnal losses, hot soak losses and running losses. Diurnal losses arise because of changes in temperature throughout each day through "tank breathing". Hot soak losses arise when evaporation occurs from the fuel delivery system when a vehicle is stationary but with a hot engine. Finally, running losses are those that occur when a vehicle is in motion. The calculations take account of fuel volatility, changes in ambient temperature and the vehicle technology used to control such losses. The change in trip start data has also affected the evaporative emissions and since the methods used have not changed the emissions of NMVOC and Benzene from this source has increased considerably.

## 1.39. Assumptions for the 2011 to 2015 emissions inventories

This section provides details of the assumptions that have been used in the calculation of emissions for forecast years 2010, 2011, 2015, 2020 and 2025 in the LAEI 2008.

## 1.40. Vehicle km and speed changes from 2011 to 2015

For traffic data, post 2008, forecast traffic changes were provided by TfL and were consistent with the TfL Business Plan. Between 2006 and 2026 average traffic growth was assumed to be 0.36% per year and was applied to the 2008 traffic data by location and time of day (Table 28). To account for changes in speed for future years, speed reduction was assumed to be in the same proportion as the growth in traffic (Table 28).

**Table 28: Growth factors, expressed as a % change between 2008 and the forecast year, by period and location**

| Peak Periods | Location | 2010 | 2011 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| AM | central | 0.64 | 0.95 | 2.22 | 3.81 | 5.40 |
| AM | inner | 0.63 | 0.95 | 2.22 | 3.81 | 5.39 |
| AM | outer | 0.65 | 0.98 | 2.28 | 3.90 | 5.53 |
| AM | external | 0.65 | 0.97 | 2.26 | 3.88 | 5.49 |
| INTER | central | 0.78 | 1.17 | 2.74 | 4.70 | 6.66 |
| INTER | inner | 0.77 | 1.16 | 2.70 | 4.63 | 6.56 |
| INTER | outer | 0.76 | 1.15 | 2.67 | 4.58 | 6.49 |
| INTER | external | 0.77 | 1.15 | 2.68 | 4.60 | 6.52 |
| PM | central | 0.86 | 1.28 | 2.99 | 5.13 | 7.27 |
| PM | inner | 0.73 | 1.09 | 2.55 | 4.38 | 6.20 |
| PM | outer | 0.72 | 1.08 | 2.53 | 4.33 | 6.13 |
| PM | external | 0.73 | 1.09 | 2.55 | 4.37 | 6.19 |
| Overnight | central | 0.77 | 1.15 | 2.68 | 4.59 | 6.50 |
| Overnight | inner | 0.72 | 1.09 | 2.54 | 4.35 | 6.16 |
| Overnight | outer | 0.72 | 1.08 | 2.52 | 4.33 | 6.13 |
| Overnight | external | 0.72 | 1.09 | 2.53 | 4.34 | 6.15 |

**Table 29: Speed change post 2008: a 1% change in total flow leads to a 1% change in speed**

| Peak Periods | Location | Speed change (%) |
|---|---|---|
| AM | central | 1 |
| AM | inner | 1 |
| AM | outer | 0.9 |
| AM | external | 0.9 |
| INTER and 7.00 pm to 10.00 pm | central | 1 |
| 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 |
| PM | inner | 1 |
| PM | outer | 0.8 |
| PM | external | 0.8 |
| Overnight | All location | No change |

## 1.41. Effect of the LEZ on vehicle stock in 2008-2015

The effect of the LEZ has been applied to vehicle stock projections for all years, using part 5 of the LEZ impacts analysis work[25]. The LEZ phase 3 and the impact of the recession have been applied to LGV diesel stock as with the latest MAQS. The LEZ affects the composition of HGVs, coaches, heavier diesel LGVs and minibuses and the assumptions for these vehicle types are given in Table 30 to Table 33.

**Table 30: LEZ Articulated HGV stock composition (%)**

| Euro class | Articulated HGV | | |
|---|---|---|---|
| | 2008 | 2011 | 2015 |
| Pre Euro | 0 | 0 | 0 |
| Euro 1 | 0.3 | 0 | 0 |
| Euro 2 | 4.5 | 0.2 | 0 |
| Euro 2 + Trap | 1.7 | 1.1 | 0 |
| Euro 3 | 55.3 | 26.9 | 0 |
| Euro 3 (PM) + Euro2 ($NO_x$) | 2.8 | 0.8 | 0 |
| Euro 4 (PM) + Euro3 ($NO_x$) | 0 | 0 | 7.2 |
| Euro 4 | 32.3 | 30.2 | 7.9 |
| Euro 5 | 3.0 | 40.8 | 50.5 |
| Euro 6 | 0 | 0 | 34.5 |

[25] Air Pollution Modelling of the London Low Emission Zone, (Phase 5 update), November 2006.

**Table 31: LEZ Rigid HGV stock composition (%)**

| Euro class | Rigid HGV | | |
|---|---|---|---|
| | 2008 | 2011 | 2015 |
| Pre Euro | 0 | 0 | 0 |
| Euro 1 | 1.1 | 0 | 0 |
| Euro 2 | 7.0 | 0.6 | 0 |
| Euro 2 + Trap | 1.8 | 0.9 | 0 |
| Euro 3 | 57.3 | 36.0 | 0 |
| Euro 3 (PM) + Euro2 ($NO_X$) | 3.9 | 1.2 | 0 |
| Euro 4 (PM) + Euro3 ($NO_X$) | 0 | 0 | 7.4 |
| Euro 4 | 26.0 | 22.4 | 6.4 |
| Euro 5 | 2.9 | 38.9 | 53.8 |
| Euro 6 | 0 | 0 | 32.4 |

**Table 32: LEZ Coach stock composition (%)**

| | 2008 | 2011 | 2015 |
|---|---|---|---|
| Pre Euro | 1.1 | 0.0 | 0 |
| Euro 1 | 1.4 | 0.1 | 0 |
| Euro 2 | 9.0 | 0.7 | 0 |
| Euro 2 + Trap | 5.7 | 6.1 | 0 |
| Euro 4 (PM) + Euro 2 + Trap ($NO_X$) | 0 | 0 | 2.4 |
| Euro 3 | 48.9 | 35.8 | 0 |
| Euro 3 (PM) + Euro2 ($NO_X$) | 5.9 | 2.2 | 0 |
| Euro 4 (PM) + Euro3 ($NO_X$) | 0 | 0 | 14.6 |
| Euro 4 | 25.4 | 23.0 | 16.6 |
| Euro 5 | 2.7 | 32.2 | 40.8 |
| Euro 6 | 0 | 0 | 25.5 |

**Table 33: LEZ diesel LGVs and minibus stock composition (%)**

| Euro class | Diesel LGVs and Minibuses | |
|---|---|---|
| | 2011 | 2015 |
| Pre Euro | 1.2 | 0 |
| Euro 1 | 3.1 | 0 |
| Euro 2 | 6.5 | 0.1 |
| Euro 2 + rpc | 1 | 0.3 |
| Euro 3 | 44.8 | 17.4 |
| Euro 4 | 40.5 | 22.2 |
| Euro 5 | 2.9 | 59.9 |
| Euro 6 | 0 | 0 |

## 1.42. WEZ assumptions

**2008**

Since for major roads the LAEI 2008 uses traffic data up to and including traffic counts in 2008, the impact of changes to traffic strategies such as WEZ are implicit within these data. As such no additional change has been applied. However, for the major roads not updated since the WEZ introduction in February 2007 and for LTS and minor roads the WEZ effects, provided by TfL, have been applied. These are summarised in Table 34.

**Table 34:Western Extension traffic change during charging hours (07.00am to 06.00 pm)**

| Vehicle Type | MC | Taxis | Cars | Buses | LGV | HGV |
|---|---|---|---|---|---|---|
| Traffic change | -1.31% | -7.05% | -26.34% | +4.52% | -12.93% | +2.81 |

**2011 and 2015**

For the years 2011 and 2015 the WEZ is assumed to be removed. The removal was achieved by applying a set of factors provided in Table 35 to both traffic flow and speed for the appropriate hours charging hours[26].

**Table 35: Extension traffic change during charging hours (07.00am to 06.00 pm)**

| | Calculated 50% Capacity Return % Change | | | | | |
|---|---|---|---|---|---|---|
| Location | Cars | LGV | HGV | Taxis | Buses | Speed |
| CCS | -0.4 | -2.9 | -6.2 | 5.0 | -0.4 | 2% |
| Inside Free Area | 8.7 | -13.6 | -11.6 | 2.2 | -2.3 | -2% |
| Inside WEZ | 27.3 | 13.2 | 0.0 | 5.0 | -3.5 | -5% |
| Eastern Boundary | 3.7 | 1.8 | -2.5 | -5.5 | -0.6 | 1 |
| Western Boundary | -1.7 | -4.7 | -9.3 | 0.4 | -4.9 | 1 |
| Inner | 2.3 | 0.3 | -0.8 | 1.6 | -0.4 | 0 |
| NSC | 0.8 | 0.2 | 0.3 | 1.0 | -0.2 | 0 |
| Outer | 0.8 | 0.0 | -0.4 | 2.3 | -0.1 | 0 |

## 1.43. Particle traps, SCR and other emissions control assumptions

Within the LEZ scenarios used in the LAEI, vehicles that fit particle traps are commonplace. The assumptions used to factor Euro class vehicle emissions to simulate the introduction of such particle traps are given in Table 35. In addition a 50% reduction in $NO_X$ has also been assumed for buses using a combination of exhaust gas recirculation (EGR) and selective catalytic reduction (SCR). Finally, the assumption for Hybrid buses is that they have 30% less $CO_2$ and 20% less $NO_X$ emissions than a standard Euro 4 bus.

[26] TfL personal communication

**Table 36: Particle trap assumptions for pollutant emissions**

| $NO_X$ | $PM_{10}$[27] | CO | HC[28] | $SO_2$ | $CO_2$ |
|---|---|---|---|---|---|
| 0.95 | 0.05 | 0.1 | 0.1 | 1.008 | 1.008 |

## 1.44. Estimating uncertainty in LAEI emissions

Previous versions of the LAEI have been accompanied by a comprehensive estimate of vehicle emissions uncertainty. This resulted in typical values for $PM_{10}$ exhaust, $NO_X$, CO and NMVOC of 22 to 27% ($2\sigma$). However, a key component of the uncertainty estimate was the uncertainty associated with the emissions factors, by vehicle type. As described above these have change considerably since the LAEI 2006 and so it may not be reasonable to assume a similar level of uncertainty in the new factors. Estimates of uncertainty cannot be undertaken using the information provided with the new emission factors and it is not possible therefore to calculate the uncertainty of the emissions for the LAEI 2008.

It is recommended that estimates of uncertainty for each of the emissions factors be established for future versions of the inventory.

[27] Also applied to PaH and $PM_{2.5}$
[28] Also applied to $CH_4$, Benzene and 1-3 Butadiene

## ESTIMATING EMISSIONS FROM PART 'A' PROCESSES

### Summary


**Base Year: 2008**
Emission estimates for Part A Processes in the LAEI 2008 were directly obtained from NAEI database and the Environment Agency (EA) database. The EA provided the initial emission estimates of the key pollutants for Part A processes from its 2007 Pollution Inventory (PI) database. The 2007 PI datasets were incorporated into the LAEI 2008 Part A Processes worksheet templates and updated accordingly.

**Projection Years: 2011 and 2015**
Projection of atmospheric emissions from Part A Processes to 2011 and 2015 were not undertaken; instead projections of atmospheric emissions to 2011 and 2015 were basically assumed to be the same as the 2008 emissions.


### 1.45. 2008 emission estimation methodology

2008 base year emissions (expressed as kg/annum) from Part A Processes for the LAEI 2008 were obtained from the Environmental Agency database. The pollutants from Part A Processes included in the LAEI 2008 are as follows:

- Sulphur dioxide ($SO_2$)
- Oxides of nitrogen ($NO_x$)
- Carbon monoxide (CO)
- Carbon dioxide ($CO_2$)
- Non-methane volatile organic compounds (NMVOC)
- Benzene
- Butadiene
- Total particulate matter (PM)
- Particulate matter with a diameter of less than 10 mm ($PM_{10}$)
- Methane ($CH_4$)
- Nitrous Oxide ($N_2O$)

This inventory does not include all pollutants that may be of concern for health or other reasons (e.g. lead). However, information for other pollutants (such as $NH_3$, HBr, $H_2S$ and dioxins) has been included where possible.

The Excel workbooks include individual worksheets for each Part A Authorisation and a summary worksheet for all the Part A authorisations.

UK NAEI data sets were used to estimate atmospheric emissions from fuel used by Part A processes. Data and information provided on the individual installations (usually in conjunction with data on location, operating conditions, fuel type and throughput) from the Environment Agency's (EA) databases of installations that participate in the EU Emissions Trading Scheme (EU-ETS) and data from the EA Pollution Inventory (PI) were also used.

In order to provide fuel use information for those installations not captured in the EU-ETS databases, the emissions data given in the EA PI was used.

### 1.46. Authorisation, process & stack parameters details

Where possible, details on the authorisations, processes and stacks were obtained from the public register and the Environment Agency. The most common data gap was the operating hours of the Part A processes; these were often assumed.

### 1.47. Annual Emissions

Annual emissions were taken from either the Environment Agency's Pollution Inventory (PI) or the public register. The Pollution Inventory is published on the Environment Agency's website.

## ESTIMATING EMISSIONS FROM PART 'B' PROCESSES

### Summary

**Base Year: 2008**
Because of lack of recent, representative and reliable activity datasets, atmospheric emissions from Part B Processes for the 2008 base year were not estimated; they were simply assumed to be the same as those in the LAEI 2006. In the LAEI 2006, most of the London boroughs provided updated versions of their activity data for the Part B Processes, which were updated accordingly and integrated into the LAEI 2008.

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

### 1.48. 2008 emission estimation methodology: (Same as the LAEI 2006 methodology)

The 2008 methodology used to estimate atmospheric emissions from Part B processes mirrors the LAEI 2004 methodology. Where monitoring data from the Part B Processes have been made available, this has been included in the LAEI 2008. However, in the majority of cases no monitoring data was supplied. In these cases, two techniques were applied to estimate emissions.

### 1.49. Emission factors

US EPA emission factors (*Document AP42: Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources*)[29] were used to update the LAEI 2004 because these were used in the compilation of the previous inventories. In most cases, the emissions factors are simply averages of all available data of acceptable quality, and were generally assumed to be representative of long-term averages for all facilities in the source category. Where possible, the activity rate for a given process has been obtained. When this has not been available, a process average has been used. For each process, the method of deriving the emission has been noted.

### 1.50. Weight percentages

For processes where volatile organic compounds (VOCs) are considered to be the major air pollutant, a different approach was used to derive the emission. Here, the total amount of VOC consumed annually is assumed to have been vented into the atmosphere. From this unspeciated emission, the proportion of different organic compounds within the total emission was derived using a document titled *Emissions of Volatile Organic Compounds from Stationary Sources in the UK* by N R Passant. From this data, it is therefore possible to derive

[29] It is recommended that in future inventory updates the emissions should be converted into UK emission factors to enable comparison between other inventories.

speciated emissions from the annual VOC consumption of a process. When the total VOC consumption has not been available, a process average has been used. Again, for each process, the method of deriving the emission has been noted.

The scope of this work dictated that the Part B processes and their associated throughput that existed in the LAEI 2006 were crudely assumed to remain unchanged in the base year 2008, unless otherwise specified by the local authority. The same applies to incidences where a company name change has been carried out, but the site details and process description remain the same. The limitation being that processes, which have altered their throughput within the last three years, will not be adequately reflected in the LAEI 2008.

Process averages were used to calculate the throughput of processes where data was not provided. There are obvious limitations associated with using this calculation and so it is recommended in order to increase the accuracy and ease of production for future updates of the LAEI that each local authority should be sent a copy of a spreadsheet template for them to fill in and return, either on disk or via Email. The spreadsheet should include the following columns for each process in order to obtain the essential information required to produce an inventory:

- Name of process
- Type of process
- Address
- Postcode
- Eastings
- Northings
- Total Annual Throughput of process

Concerning the throughput of the process, it should be relatively straightforward for each local authority to provide. For example, the total throughput for vehicle re-sprayers would equal the total annual VOC usage in tonnes per annum. In the case of cement batchers, the throughput would correspond to the amount of cement produced per year given as tonnes per annum. Finally, in the case of petrol stations these would need to specify whether they are above 500, 1000 or 2000 cubic metres of petrol delivered per annum.

### 1.51. Process types

- Adhesive coating process
- Aluminium and aluminium alloy processes
- Animal by product rendering
- Asbestos process
- Bitumen
- Blending, packing, batching and/or loading of bulk cement
- Cadmium plating and associated activities
- Cement and lime production
- Ceramic production
- Clinical waste incineration
- Coating in drum reconditioning

- Coating of metals, plastics and wood products
- Combustion
- Concrete crushing
- Cremation
- Di-isocyanate Process
- Drum Manufacturing and Reconditioning
- Dry cleaning
- Fat and oil refining
- Ferrous and non-ferrous metal production and processing
- Foundry process
- Haulage/demolition
- Hot dip galvanising processes
- Incineration
- Industrial
- Manufacture of concrete products
- Manufacture of printing inks
- Manufacture of timber and wood based products
- Melting and casting of non-ferrous metals
- Metal decontamination
- Mobile concrete batching, crushing and screening
- Mobile conrete crushing process
- Oil refinery
- Other coating processes
- Other mineral activities
- Painting and enamelling
- Powder coating
- Printing works
- Quarry processes
- Respraying of road vehicles
- Road stone coating process
- Rubber process
- Timber processing
- Unloading of petrol and/or vapour recovery at storage terminal/service station
- Waste oil burner
- Wood coating
- Wood combustion

*Blending, packing, batching and/or loading of bulk cement (PG3/1)*

An average throughput of 100,000 tonnes per annum was used for cement works within the M25. This average was derived from calculations submitted by RMC London, a major chain of cement producers. For this process, particulate matter, including $PM_{10}$, is taken as the only pollutant of concern. Using AP 42, Section 11.12 the total particulate emissions of each cement works was calculated. Calculations were based on a pneumatic conveying of cement to a truck mix facility, and did not include vehicle traffic or wind erosion from storage piles. According to Appendix B.2 (Generalised Particle Size Distributions) of document AP 42, 51% of particulate matter generated through the action of cement batching may be assumed to be PM less than or equal to 10μm, in other words, $PM_{10}$. The $PM_{10}$ value has therefore been assumed to be 51% of total suspended particulate.

*Waste oil burners*

An average throughput has been calculated as $5m^3$ waste oil per annum. AP 42, Section 1.11 – Space heaters (vaporizing/atomising burners) emission factors were used for the calculation of emissions for waste oil burners. Using this data, PM, $PM_{10}$, $NO_X$, $SO_2$, CO and $CO_2$ emissions where calculated.

*Mobile concrete batching, crushing and screening (PG3/16)*

A process average throughput of 160 tonnes/annum has been calculated for the mobile crushing processes. An average of 325 tonnes/annum was used for static concrete crushing processes. AP 42, Section 1.3 emission factors were used for the calculation of emissions.

*Wood combustion*

A process average throughput of 102 tonnes/annum has been used for the amount of wood combusted. AP 42, Section 1.6 (Wood Waste Combustion in Boilers) emission factors were used for the calculation of emissions for wood combustion processes.

*Manufacture of timber and wood based products (PG6/2)*

A process average of $5{,}000m^3$ wood per annum has been used. Particulate was derived using Appendix B.2 (Generalised Particle Size Distributions) of document AP42.

*Powder coating (PG6/31)*

Where no monitoring data was available, a process average has been used. This average was established in the original inventory.

*Incineration (PG5/1-4)*

Where no monitoring data was available, a process average has been used. This average was established in the original inventory.

*Unloading of petrol and/or vapour recovery at storage terminal/service stations (PGs 1/13 & 1/14)*

There is no emission associated with the normal running of these processes. The London Research Centre (LRC) calculated the saving in emissions that petrol vapour recovery represents. Data was supplied for service stations that have a throughput over 1,000 tonnes per annum, as these are the only sites that are presently required to have vapour recovery systems installed.

*Ferrous and non-ferrous metal production and processing (PG2/4)*

A process average throughput of 350 tonnes/annum has been calculated and applied in some instances where a value for the throughput has not been available. AP42, Section 12.5 (Iron & Steel Production) emission factors were used for the calculation of emissions.

*Respraying of road vehicles (PG 6/34)*

Data from the *Emissions of Volatile Organic Compounds from Stationary Sources in the UK* by N R Passant has been used to derive values for speciated VOCs. In section 1.1 of the document, the weight percent of different compounds within paint solvents is given, as supplied by the paint industry. Multiplying the amount of annual VOC consumption by the corresponding weight percentage then derived a value for the emission of each compound. Where the annual VOC consumption for a given process was not readily available, a process average value has been used. A value for particulate from respraying processes was derived from the AP 42 document, Appendix B.1: 'Particle Size Distribution Data and Sized Emission Factors for Selected Sources'.

*Printing works (PG 6/16)*

Data from the *'Emissions of Volatile Organic Compounds from Stationary Sources in the UK'* by N R Passant has been used to derive values for speciated VOCs. In section 1.2 of the document, the weight percent of different compounds within printing solvents is given. Multiplying the amount of annual VOC consumption by the corresponding weight percentage then derived a value for the emission of each speciated compound. Where the annual VOC consumption for a given process was not readily available, a process average value has been used. A value for particulate from printing processes was derived from the AP 42 document, 'Generalized Particle Size Distributions'.

*Coating of metals, plastics and wood products (PG6/23)*

Data from the 'Emissions of Volatile Organic Compounds from Stationary Sources in the UK' by N R Passant has been used to derive values for speciated VOCs. In section 1.1 of the document, the weight percent of different compounds within paint solvents is given, as supplied by the paint industry. Multiplying the amount of annual VOC consumption by the corresponding weight percentage then derived a value for the emission of each speciated compound. Where the annual VOC consumption for a given process was not readily available, a process average value has been used.

## References

*Emissions of Volatile Organic Compounds from Stationary Sources in the United Kingdom: A Review of Emission Factors by Species and Process*, N R Passant, Warren Spring Laboratory Publications, 1993

AP 42: Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, United States Environmental Protection Agency, 1995.

## ESTIMATING EMISSIONS FROM BOILERS

### Summary

**Base Year: 2008**
Because of lack of recent, representative and reliable activity datasets, atmospheric emissions from industrial and commercial boilers for the 2008 base year were not estimated; they were simply assumed to be the same as those in the LAEI 2006 (which were based on 1997 activity datasets).

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

### 1.52. 2008 emission estimation methodology: (Same as the LAEI 2006 methodology)

The original atmospheric emissions from industrial and commercial boilers were estimated using the methodology employed by Warren Spring Laboratory and NETCEN in their original boiler survey in 1997. The methodology entailed phoning boiler sites/operators to find out whether the sites/operators were still using oil; and if yes, ascertaining the types and volumes of oil used. The information from sites/operators was then augmented with other pertinent proxy datasets, where appropriate. For the completion of the LAEI 2008, 39 new sites/operators were added to the original list. These sites and their emissions were provided by the 2007 Pollution Inventory (PI) database. Atmospheric emissions for the industrial and commercial boilers were then estimated from the fuel throughput using emissions factors obtained from the UK Emissions Factor Database (UK EFD).

During the original boiler survey conducted by Warren Spring Laboratory and NETCEN, the following information was obtained for each site/operator:

1. Type of fuel used (*ft*)
2. Amount of fuel used (*FU)*, L $yr^{-1}$

Atmospheric emissions from boiler – expressed in tonnes $yr^{-1}$ - were then estimated from the amount of fuel used (FU) by applying the emissions factors (see Table 1 below) obtained from AP-42 and the UK EFD in accordance with Equation 1 below.

$$BE_{p,ft} \text{ (tonnes yr}^{-1}) = FU * EF_{p,ft} * 10^{-3} \qquad \text{Equation 1}$$

Where

$BE_{p,ft}$ = Emissions from boiler for pollutant *p* from fuel type *ft*[30] , (tonnes $yr^{-1}$)
FU = Fuel used, L $yr^{-1}$

[30] *ft* is either Residual Oils or Distillates

$EF_{p,ft}$ = Emission factor for pollutant *p* from using fuel type *ft* , (tonnes $m^{-3}$)
$10^{-3}$ = Conversion factor[31] from litre (L) to cubic metre ($m^{-3}$)

**Table 37: Emission factors for boilers**

| | **Residual Oils**[32] (tonnes $m^{-3}$) | **Distillates**[33] (tonnes $m^{-3}$) | **4.3.1.1. Source** |
|---|---|---|---|
| $SO_2$[34] | 0.00047 | 0.000034 | AP-42 1.3 |
| $NO_x$ | 0.0066 | 0.0024 | AP-42 1.3 |
| CO | 0.0006 | 0.0006 | AP-42 1.3 |
| NMVOC | 0.000136 | 0.000041 | AP-42 1.3 |
| PM | 0.00347 | 0.00024 | AP-42 1.3 |
| $PM_{10}$ | 0.0021514 | 0.000132 | AP-42 1.3 |
| Benzene | 0.000000026 | 0.000000026 | AP-42 1.3 |
| Methane | 0.000057 | 0.000026 | AP-42 1.3 |
| $CO_2$ | 3.11667 | 3.14233 | UK EFD |

Notes:

1. 1 $m^3$ = 1,000 litres

2. Tonnes $m^{-3}$ = tonnes of pollutant per $m^3$ fuel oil

[31] See Conversion factors at the end of next page
[32] Residual Oils include heavy and medium fuel oils
[33] Distillates include paraffin, kerosene and gas oil.
[34] The percentage by weight of sulphur in fuel (i.e., the sulphur content) was assumed to be 2.5-3% for Residual Oils and 0.2-0.4 % for Distillates). The lower values (2.5% and 0.2% for Residual Oils and Distillates respectively) were assumed in determining the emission factors.

## ESTIMATING EMISSIONS FROM GAS USE AND LEAKAGE

### Summary

**Base Year: 2008**
Atmospheric emissions from gas consumption and gas leakage for the 2008 base year were estimated from the 2007 Middle Layer Super Output Area (MLSOA) level Electricity and Gas Consumption datasets (i.e.,. Gas Consumption Data at Regional and Local Authority Level) produced by Department for Energy and Climate Change (DECC).

**Projection Years: 2011 and 2015**
The projection factors were derived from a statistical analysis of historical trends (gas consumption data at regional and local authority level from 2001 to 2008) in gas sales from the domestic and industrial-commercial sectors in the Greater London area (using 2008 as the base year).

### 1.53. 2008 gas emission estimation methodology

The 2007 gas sales and numbers of customers by region and local authority workbooks were obtained from the Department for Energy and Climate Change (DECC) website: (http://www.berr.gov.uk/energy/statistics/regional/regional-local-gas/page36200.html). DBERR collects and compiles estimates of gas consumption at regional (NUTS1) and local authority levels (NUTS4) using base data at meter point level from the re-structured gas distribution network.

Within each workbook, several worksheets provided details of electricity and gas consumption down to MLSOA level for each LA in the UK. The 2007 datasheets showed electricity and gas consumption data (given in kWh for the entire year) for the Greater London area regarding total consumption, number of meters and average consumption levels for domestic and non-domestic users. Details about how the information on electricity and gas consumption has been collected and collated can be found in "DECC, Guidance Note for Regional Energy Data PUBLICATION URN 09D/608" at http://www.berr.gov.uk/files/file42994.pdf.

DECC's sub local authority gas consumption estimates at MLSOA level in the Greater London area for 2007 were used to estimate atmospheric emissions from gas consumption in the LAEI 2008. In order to produce local gas consumption statistics for 2008 at the 1-$km^2$ spatial resolution, the gas consumption statistics for each MLSOA was first cleansed, formated and then aggregated to the 1$km^2$ grid cells using GIS algorithms (i.e., spatial analysis by overlaying the MLSOAs' electricity consumption data with the 2,466 1-$km^2$ grid cells).Where a MLSOA covered more than one 1-km2 grid cell area, the gas consumption was divided between the relevant grid cells based on the proportion of the area covered by the MLSOA. There were also some circumstances where for confidentiality or other reasons, BERR combined MLSOA data, and each MLSOA was given an equal share of the gas data when deriving statistics. Furthermore, due to data disclosure issues, gas consumption relating to larger commercial/industrial consumers could not be disaggregated below local authority level, and in some cases data relating to a particular area have been merged with data for nearby areas.

The summarised gas demand data were entered into an Excel spreadsheet containing emission factors for the various sectors (domestic, industrial & commercial and gas leakage). All data entered into the spreadsheet were double checked to ensure data accuracy. Atmospheric emissions are dependent on emission factors, the amounts of gas used and also the temperature and efficiency of combustion, but these latter influencing factors were not directly considered in the LAEI 2008 estimation methodology. The updated 2008 emissions factors (see Tables 1-3), obtained from the UK Emissions Factor Database and maintained by AEA, were used in estimating emissions from the gas demand data.

Below is the formula used for estimating annual atmospheric emissions of a pollutant from gas consumption data in a 1-km² grid cell.

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

Where;

$AE_{p,j}$ = Annual Emission of pollutant *p* in grid cell *j*, tonne $yr^{-1}$

$EF_{s,p}$ = Sector *s* Emission Factor for pollutant *p*, kg $kWh^{-1}$

$GC_{s,j}$ = Sector *s* Gas Consumption in grid cell *j*, kWh $yr^{-1}$

$10^{-3}$ = Conversion factor; kg to tonne

Grid cell *j* =1km x 1km grid cell

Sector *s* = Domestic or Industrial-commercial

Pollutant *p* = $CO_2$, Methane, $NO_X$, Hydrocarbons (HC) as NMVOC, CO, Black smoke, Benzene or $PM_{10}$

## 1.54. Emission factors

**Table 38: Industrial-Commercial gas emission factors – 2008**

| Pollutant | Emission factors | |
|---|---|---|
| | Kt $mth^{-1}$ fuel consumed | Kg $kWh^{-1}$ |
| $CO_2$ | 5.41E+00 | 1.85E-01 |
| Methane | 5.27E-05 | 1.80E-06 |
| $SO_2$ | | |
| NOx | 5.60E-03 | 1.91E-04 |
| NMVOC | 2.34E-04 | 7.95E-06 |
| CO | 1.11E-03 | 3.79E-05 |
| Black smoke | 1.06E-05 | 3.60E-07 |
| Benzene | 2.13E-05 | 7.28E-07 |
| 1,3-Butadiene | | |
| $PM_{10}$ | 8.06E-05 | 2.75E-06 |

Source: AEA, NAEI Emission Factors Database 2007

**Table 39: Domestic gas emission factors - 2008**

| Pollutant | Emission factors | |
|---|---|---|
| | Kt mth$^{-1}$ fuel consumed | Kg kWh$^{-1}$ |
| $CO_2$ | 5.41E-00 | 1.85E-01 |
| Methane | 5.27E-04 | 1.80E-05 |
| $SO_2$ | | |
| NOx | 7.30E-03 | 2.49E-04 |
| NMVOC | 2.34E-04 | 7.97E-06 |
| CO | 3.25E-03 | 1.11E-04 |
| Black smoke | 1.05E-05 | 3.58E-07 |
| Benzene | 2.10E-05 | 7.18E-07 |
| 1,3-Butadiene | | |
| $PM_{10}$ | 5.27E-05 | 1.80E-06 |

Source: AEA, NAEI Emission Factors Database 2007

**Table 40: Gas Leakage emission factors – 2008**

| Pollutant | Emission factors | |
|---|---|---|
| | Kt mth$^{-1}$ fuel consumed | Kg kWh$^{-1}$ |
| $CO_2$ | | |
| Methane | 7.70E-01 | 2.63E-02 |
| $SO_2$ | | |
| NOx | | |
| NMVOC | 1.50E-01 | 5.12E-03 |
| CO | | |
| Black smoke | | |
| Benzene | 1.67E-03 | 5.70E-05 |
| 1,3-Butadiene | | |
| $PM_{10}$ | | |

Source: AEA, NAEI Emission Factors Database 2007

All the 2008 emission factors (with the exception of black smoke[35] and Methane[36]) used in estimating and projecting gas demand, gas leakage and their associated emissions were obtained from AEA. These emission factors were also used for the 2008 UK estimates in the NAEI. The emission factors for $SO_2$ and 1,3-butadiene are currently not available; thus, the emissions of $SO_2$ and 1,3-butadiene form gas consumption are currently not available in the LAEI 2008. Most of the gas emission factors used in the LAEI 2008 are considered to be of high reliability as they are based on NAEI/AEA's data.

## 1.55. Emission estimation methodology: 2008 Gas leakage

Gas leakage covers emissions of 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;

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[35] Emission factors are from the AEA Report, "UK emissions of air pollution 1970-1994".
[36] Source: UK Emission Factor Database, 2000

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

In the Greater London area, the level of gas leakage from the Local Distribution Network (before the gas reaches customer meters) is around 0.65%. Therefore, to calculate the amount of gas leakage (in kWh) in 2008, we simply took each MLSOA that was within the LAEI study area and multiplied its corresponding gas demand (i.e., annual quantities in kWh) value by 0.0065 (i.e., 0.65% of annual quantities in kWh). However, 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 (in KWh) after the gas has reached 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 will be different to the actual amount of gas leaked from the distribution network before the gas reached 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 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 that 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 adsorbed 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.

### 1.56. Projection Years: 2011 and 2015

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 – Gas Consumption Data at Regional and Local Authority Level, http://www.berr.gov.uk/energy/statistics/regional/regional-local-gas/page36200.html

The % per annum growth/decay rates in gas demand from the domestic and industrial-commercial sectors in the Greater London area (using 2007 as the base year) were calculated as follows (based on the data in Table 41):

| | |
|---|---|
| For Domestic gas projections to 2011 | = -1.64% |
| For Industrial-Commercial gas projections to 2011 | = -4.88% |

| | |
|---|---|
| For Domestic gas projections to 2015 | = -1.59% |
| For Industrial-Commercial gas projections to 2015 | = -4.40% |

**Table 41: Trends in gas sales (GWh) in Greater London**

| Years | Domestic consumers | Commercial and Industrial consumers |
|---|---|---|
| | Gas Sales (GWh) | |
| 2001 | 55,279.14 | 33,836.01 |
| 2002 | 55,749.34 | 33,812.69 |
| 2003 | 56,073.73 | 34,385.62 |
| 2004 | 53,463.09 | 29,261.52 |
| 2005 | 52,635.33 | 27,213.85 |
| 2006 | 50,943.40 | 26,006.73 |
| **2007** | **49,920.59** | **24,428.74** |

## ESTIMATING EMISSIONS FROM SOLVENTS-BUILDINGS

### Summary

**Base Year: 2008**
Because of lack of recent, representative and reliable activity datasets, atmospheric emissions from solvents for the 2006 base year were not estimated; they were simply assumed to be the same as those in the LAEI 2006 (which were based on 1997 activity datasets).

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

### 1.57. 2008 emission estimation methodology: Same as the LAEI 2006 methodology

The LAEI 2008 emission estimation method for the solvents-building source was based on the 1996 methodology and datasets used by the London Research Centre in the compilation of the first LAEI.

The solvents-building emission source category includes NMVOCs not accounted for elsewhere and it emission estimation is entirely based on the methodology and datasets used by the LRC in the compilation of the LAEI 1999, mainly from solvent use.[37] The NMVOC emissions were taken from the Passant Report, "*Emissions of Volatile Organic Compounds from Stationary Sources in the UK*". Double counting in terms of Part A and Part B processes were taken out as far as possible, and the forecasts in the Passant report were used to bring the data to 1996 level. These emissions were apportioned to residential and/or employment census as appropriate. For London, as the employment is mainly service based, the manufacturing employment data was used. As many manufacturing companies also have their head offices in London, as service industry, this was seen to be reasonable. The speciation of VOCs and how they were apportioned to residential and employment population is given on a separate worksheet in the Area Sources Excel spreadsheet in the LAEI 2008.

[37] There is a worksheet in the LAEI 2008 with speciation of the NMVOCs, which gives the proportions of emissions from each source.

## ESTIMATING EMISSIONS FROM COAL CONSUMPTION

### Summary

**Base Year: 2008**
Because of lack of recent, representative and reliable activity datasets, atmospheric emissions from coal consumption for the 2008 base year were not estimated; they were simply assumed to be the same as those in the LAEI 2006.

**Projection Years: 2011 and 2015**
Because of lack of recent, representative and reliable activity datasets for the 2008 base year, projection of atmospheric emissions from coal consumption to 2011 and 2015 were not undertaken; instead projections of atmospheric emissions from coal consumption to 2011 and 2015 were basically assumed to be the same as those in the LAEI 2006.

### 1.58. 2008 emission estimation methodology: Same as the LAEI 2006 methodology

Estimates of atmospheric emissions from coal consumption were based on the methodology used by the London Research Centre (LRC). The LRC obtained 1996 coal sales data by postcode area (for the entire LAEI study area) from RJB Mining and Celtic Energy and emissions factors for smokeless solid fuel (SSF)[38] from the AEA Report, "*UK Emissions of Air Pollutants 1970-1994*".

Although the LRC had rough figures of the market shares of RJB Mining and Celtic Energy, it did not factor up the figures as there were no regional figures for total coal use/supply, only coal production data was available. National market shares figures were approximated and coal sale datasets (by postcode area) were apportioned by 1-km$^2$ grids. Imported coal, mainly for power stations, was covered under the Part A Processes.

**Table 42: Emission factors for coal**

| Pollutants | Domestic | Industrial |
|---|---|---|
| | *Tonne/tonne* | *Tonne/tonne* |
| $CO_2$ | 2.83873 | 2.80977 |
| Methane | 0.0064 | 0.000264 |
| $NO_X$ | 0.00132 | 0.00396 |
| NMVOC | 0.0012 | 0.000528 |
| CO | 0.045 | 0.0041 |
| Black Smoke | 0.0056 | 0.00023 |
| $SO_2$ | 0.016 | 0.019 |
| Benzene | 3.47% of NMVOC | 3.47% of NMVOC |
| TSP | 0.003894 | 0.003894 |
| $PM_{10}$ | 0.00275 | 0.00275 |

[38] The urban areas covered by the LAEI are covered by smoke control legislation, so it will be SSF that is burnt rather than coal.

# ESTIMATING EMISSIONS FROM AGRICULTURE AND NATURE

## Summary

**Base Year: 2008**
Estimated and aggregated (at 1-km$^2$ spatial resolution) 2008 datasets for atmospheric emissions from agricultural and natural sources were obtained from the 2007 National Atmospheric Emissions Inventory data and then reclassified (as Agricultural and Natural Emissions sources) and integrated into the LAEI 2008.

**Projection Years: 2011 and 2015**
Because of the lack of representative and reliable projection factors, projection of atmospheric emissions from agricultural and natural sources to 2011 and 2015 were not undertaken; instead projections of atmospheric emissions from agricultural and natural sources to 2011 and 2015 were basically assumed to be the same as those in the LAEI 2008.

### 1.59. 2008 emission estimation methodology: (Same as the LAEI 2006 methodology)

Estimated and aggregated (at 1-km$^2$ spatial resolution, covering the entire LAEI study area) 2008 datasets for atmospheric emissions from agricultural soils, agricultural livestock, agricultural power units, agricultural stationary, domestic-house gardens, incineration animals, wood impregnation, forests and landfill sources were obtained from the 2007 NAEI, which is maintained by AEA.

For the purpose of the LAEI 2008, the various agricultural and natural emission estimates obtained from the 2007 NAEI were then reclassified into two major categories: Agricultural (i.e., agricultural soils, agricultural livestock, agricultural power units, agricultural stationary, domestic-house gardens, incineration animals and wood impregnation) and Natural (i.e., forests and landfills). Atmospheric emissions of specific pollutants from each sector were then analysed, aggregated and integrated into the LAEI 2008.

## CONVERSION FACTORS

| | |
|---|---|
| 1 GigaJoule (GJ) | = 1,000 MegaJoule (MJ) |
| | = 1,000,000,000 Joule (J) |
| | = 277.8 kilowatt-hours (kWh) |
| | = 9.48 Therms (Th) |
| 1 kilowatt-hour | = 1,000 Watt-hours (Wh) |
| | = 3.6 MJ |
| | = 0.0036 GJ |
| | = 0.03414 Therms (Th) |
| 1 $m^3$ | = 1,000 litres (L) |
| 1 tonne | = 1,000 kg |
| 1 kg | = $10^{-3}$ tonne |
| 1 L | = $10^{-3}$ |