London Energy and Greenhouse Gas Inventory (LEGGI) 2008

Methodology Manual

London Energy and Greenhouse Gas Inventory (LEGGI) 2008

MAYOR OF LONDON

London Energy and Greenhouse Gas Inventory 2008

Designed and compiled by AEA

GREATER LONDON AUTHORITY

AEA

KING'S College LONDON

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1. INTRODUCTION

This Manual provides an overview of the LEGGI 2008, including descriptions of the activity data; data sources, emission factors, methodologies and assumptions used in quantifying energy consumption and greenhouse gas (GHG) emissions in the LEGGI 2008. The Manual also highlights the key improvements in the LEGGI 2008 that have been undertaken to accommodate improved scientific information, changing priorities and new legislative requirements. To ensure that the LEGGI remains relevant and responsive to the needs of the energy community, the Greater London Authority (GLA) has undertaken a continuous improvement programme that entails a comprehensive review, assessment and update of previous energy consumption and GHG emission estimates, activity data, data sources, emission factors and estimation methodologies.

The LEGGI 2008 is compiled using extensive combinations of "top-down" and "bottom-up" methodologies, which are based predominantly on emission factors (e.g., a known amount of carbon dioxide is emitted from a given type of vehicle exhaust at a given speed per kilometre travelled) and activity data (e.g., vehicle kilometre travelled and fuel consumption) estimated or measured in the base year. These emission factors, activity data and energy consumption and greenhouse gas emission estimates have been derived from the following sources:

- The London Atmospheric Emissions Inventory (LAEI)[1] 2008, which is a comprehensive database of geographically referenced datasets of atmospheric emission sources and information about the location, rates of emissions and estimates of the quantity of specific pollutants emitted into the air within and around Greater London.
- Department for Energy and Climate Change (DECC) – formerly Department for Business, Enterprise & Regulatory Reform (BERR) - Middle Layer Super Output Area (MLSOA)[2] level electricity and gas consumption datasets and UK local and regional estimates of non-gas, non-electricity and non-transport energy consumption.
- Department for Environment, Food and Rural Affairs' (DEFRA) experimental and national statistics on carbon dioxide (CO2) emissions at local authority and regional levels datasets[3].
- National Atmospheric Emissions Inventory (NAEI)[4] and the UK Emission Factor Database (UK EFD): The UK EFD is based on emissions data used to derive the

[1] The LAEI 2008 is maintained by the GLA Air Quality Team as part of the Mayor's commitment to the promotion, provision and sharing of strategic data on issues concerning air emissions and air quality in Greater London.

[2] MLSOAs are a new geographical hierarchy that was first introduced in the 2001 census and are expected to
eventually become the standard across National Statistics and beyond. For further information see the link below: http://www.statistics.gov.uk/geography/soa.asp

[3] For further information see:
http://www.defra.gov.uk/evidence/statistics/environment/airqual/index.htm

[4] The UK Greenhouse Gas Inventory (GHGI) is compiled using the same database as the UK NAEI, which is used for reporting under other international agreements and includes emission estimates for greenhouse gases, regional pollutants leading to acid deposition and

NAEI, which is maintained by AEA on behalf of DEFRA. The emission factors in this database are UK average factors for a large number of different source sectors including industrial processes, combustion, transport and commercial combustion.

- DECC's Digest of United Kingdom's Energy Statistics (DUKES)[5] 2008. The DUKES contain extensive tables, charts and commentary covering all the major aspects of energy, including separate sections on petroleum, gas, coal and electricity.
- EEA, Air Pollutant Emission Inventory Guidebook – 2009 (prepared by the UNECE/EMEP Task Force on Emissions Inventories and Projections)[6], which provides a comprehensive guide to state-of-the-art atmospheric emissions inventory methodology.
- UK and European energy consumption and greenhouse emission studies and literature.

Because the LAEI 2008 provides detailed London-specific activity data and atmospheric emissions estimates, a key tenet in estimating fuel/energy consumption and greenhouse emissions in the LEGGI 2008 is the use of the LAEI 2008 data as much as possible in order to gain a more consistent and realistic picture of energy consumption and greenhouse emissions in Greater London. However, where limitations (e.g., estimates of nitrous oxide[7] for some relevant emission sources are incomplete in the LAEI 2008 while estimates of hydroflourocarbons, perflourocarbons and sulphur hexaflouride are virtually non-existent) in the LAEI 2008 prevent the use of the LAEI 2008 datasets, DECC's and DEFRA's datasets on energy consumption and CO_2 emission statistics are used instead. Therefore, we have updated most of the activity data, emission factors and the energy consumption and GHG emissions estimates for road transports, railway traffic, domestic shipping and domestic aviation using data, information and methodologies from the LAEI 2008, where appropriate. On the other hand, the activity data, emission factors and the energy consumption and GHG emissions estimates for Electricity[8], Coal, Oil and Wastes & Renewable have been derived from the updated local energy consumption data from DECC's Energy Statistics and DEFRA's local authority CO_2 emissions datasets[9].

The six greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O),

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photochemical pollution, persistent organic pollutants and other toxic pollutants such as heavy metals. For further information see: http://www.naei.org.uk.

5 http://www.berr.gov.uk/whatwedo/energy/statistics/publications/dukes/page45537.html

6 http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009 (formerly referred to as EMEP CORINAIR Guidebook).

7 Nitrous oxide (N_2O) is emitted in London from anthropogenic sources. However, most of the key sources (e.g. agriculture and adipic and nitric acid manufacture) are absent from the capital.

8 This significantly contrasts with the methodology used in the London Atmospheric Emissions Inventory (LAEI) 2008 where CO_2 emissions from electricity generation are allocated to the location of the power stations rather than to the location of the customers. This re-allocation of energy consumption and GHG emissions from power stations to place of consumption is one of the major features of the LEGGI 2008.

9 DECC commissioned AEA to provide regional estimates of fuel and energy consumption from various sectors at the Government Office and local authority levels for 2005, 2006 and 2007. The project used 2007 data from the National Atmospheric Emissions Inventory (NAEI), which is also maintained by AEA.

hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulphur hexafluoride (SF_6), considered in the LEGGI 2008 comprise the "basket of emissions" against which reduction targets were agreed at the Third Conference of the Parties of the United Nations Framework Convention on Climate Change (UNFCCC) in Kyoto, Japan in December 1997. Of the "basket of emissions", the major greenhouse gases are CO_2, CH_4 and N_2O, all of which have both natural and anthropogenic sources. In contrast, the other flourinated industrial gases: HFC, PFC and sulphur SF_6, are potent greenhouse gases that do not occur in nature, and hence only originate from anthropogenic sources. The non-CO_2 GHG gases play an important role in the effort to understand and address global climate change. The non-CO_2 greenhouse gases are more potent than CO_2 (per unit weight) at trapping heat within the atmosphere and, once emitted, can remain in the atmosphere for either shorter or longer periods of time than CO_2.

HFCs[10], PFCs[11] and SF_6[12] gases are all used in highly specialised cases and it is not currently possible to give reliable emission estimates for individual HFCs, PFCs and SF_6 in the LEGGI 2008 because most of the activity data concerning these gases are considered commercially sensitive data within the industries involved. Furthermore, most major industrial applications of these gases occur outside London and the quantities emitted to the atmosphere within Greater London are assumed to be negligible and far smaller than the emissions of CO_2, CH_4 and N_2O.

During the compilation of the LEGGI 2008, the non-CO_2 GHG gas emission estimates were converted to Carbon dioxide equivalent (CO_2eq or CO_2e)[13] using the Second Assessments Report's Global Warming Potentials (GWP) published by the Intergovernmental Panel on Climate Change (IPCC) and recognised by the UNFCCC (see Table 27). CO_2eq is a more correct/broad measure of total GHG contribution. GWPs are used to compare the abilities of different GHGs to trap heat in the atmosphere and are based on the radiative efficiency (heat-absorbing ability) of each gas relative to that of CO_2, as well as on the decay rate of each gas (the amount removed from the atmosphere over a given number of years) relative to that of CO_2. The GWPs provide a construct for

[10] HFCs are being increasingly used as substitutes for CFCs and HCFCs in domestic, commercial and industrial refrigeration and air conditioning; substitutes for CFCs in plastic foam blowing; substitutes for CFCs for some medical aerosols; substitutes for CFCs for industrial and specialist aerosols; and fire fighting fluids.

[11] PFCs are used mainly in etching processes in the semiconductor industry; chemical vapour deposition in the electronics industry; soldering processes; leak testing of electrical components; cooling electrical components, for example in some computers and radar systems; refrigerant blended with HFC; fire fighting in specialist applications; and cushioning in the soles of training shoes.

[12] SF_6 is used in for insulation medium in high voltage applications such as switchgear and circuit breakers; cushioning in soles of training shoes; insulating gas in double glazing applications, replacing vacuum as an insulation medium; and plasma etching of poly-silicon and nitrite surfaces

[13] CO_2eq or CO_2e is an internationally accepted metric measure that expresses the amount of global warming of greenhouse gases (GHGs) in terms of the amount of carbon dioxide (CO_2) that would have the same global warming potential (GWP), measured over a specified timescale (generally, 100 years).

converting emissions of various greenhouse gases into a common measure, which allows climate analysts to aggregate the radiative impacts of various GHGs into a uniform measure denominated in CO2eq. For example, the GWP used in the LEGGI 2008 for CH_4 is 21 and for N_2O it is 310. This means that emissions of 1 metric tonne of CH_4 and N_2O are equivalent to emissions of 21 and 310 metric tonnes of CO_2, respectively[14].

All aspects of energy use by the domestic sector, the principal industrial and commercial sectors, public services as well as private and public transportation have been considered. For the purpose of the LEGGI 2008, energy consumption (and its associated GHG emissions) has been broadly split into three sectors:

- Domestic
- Industrial & Commercial
- Transport

All energy or fuel consumptions, which are not clearly industrial or commercial, have been included into the Industrial & Commercial sector. This simplified split has been necessary in
order to provide energy consumption and GHG emission estimates in a format that can be reliably and meaningfully compared to the figures in DECC's Energy Statistics and DEFRA's Statistics on CO_2 Emissions at Local Authority and Regional Level.

In comparison with the LEGGI 2006, the presentational layout of the LEGGI 2008 has not significantly changed, especially in terms of database structure and content. Like the LEGGI 2006, the LEGGI 2008 incorporates features that provide users with functionality that facilitate the querying, displaying, reporting and direct exporting of the underlying energy consumption and GHG datasets through graphical user interfaces (GUI) to a Microsoft® Excel workbook (with various Excel formats already applied to facilitate filtering by London boroughs and other geographical units). Furthermore, the LEGGI 2008 also provides improved and integrated links to the most common Geographic Information Systems (GIS) applications (i.e., MapInfo® Professional and ArcGIS®), ensuring that LEGGI 2008 users benefit from the mapping, visualisation and querying functionality offered by these GIS applications.

The LEGGI 2008 has been developed using a wide range of assumptions, emission factors and activity datasets that have some uncertainties associated with them. Such uncertainties are inherent within any kind of estimation of complex and highly variable sources of energy use and greenhouse gas emissions over space and time. Therefore, it must also be noted that the estimation methodologies in this Manual and the energy/fuel consumption and greenhouse gas estimates presented in the LEGGI 2008 may be different from those reported by DECC, DEFRA, independent organisations and researchers, whose estimates might be based on inventories developed using different datasets, emission factors, assumptions or methods. Therefore, whilst making interpretations, deductions, conclusions or actions based on the LEGGI 2008, it is prudent that its contents are interpreted in conjunction with other reliable publications on Greater London's energy/fuel use and greenhouse gas emissions.

[14] The CO_2eq for a gas is derived by multiplying the tonnes of the gas by the associated GWP.

Although this Manual is envisaged to promote transparency and consistency in compiling and reporting London's energy/fuel use and greenhouse gas emissions, AEA does not accept responsibility for the accuracy or completeness of the contents of this Manual and shall not be liable for any loss or damage that may be occasioned directly or indirectly through the use of, or inferences from the material contained in this Manual, or for any actions as a result of any person's or group's interpretations, deductions, conclusions or actions in reliance on this Manual. Nonetheless, reasonable efforts have been made to ensure the methods presented in this Manual are correct as far as possible.

1.1. What is London Energy and Greenhouse Gas Inventory (LEGGI) 2008?

The LEGGI 2008 is a database of geographically referenced datasets of fuel/energy consumption within the Greater London area and estimates of the quantity of resulting greenhouse gases (GHGs) - carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydroflourocarbons (HFCs), perflourocarbons (PFCs) and sulphur hexafluoride (SF_6) - emitted into the air.

1.2. Uses of the LEGGI 2008

The LEGGI is used for assessing the spatial distributions and relative significance of the various fuel/energy consumption sources and sectors and greenhouse gases emissions to reach informed opinions when formulating, monitoring and evaluating energy policies and preparing energy and climate change reports. The LEGGI plays a major role in the development and implementation of the Mayor's Climate Change Mitigation and Energy Strategy (CCMES).

1.3. Background of the LEGGI 2008

The LEGGI 2008 emission estimates are predominantly based on the "bottom up" methods outlined in the LEGGI 2008 Emissions Estimation Methodology Manual, which can be found on the LEGGI 2008 CD. Where insufficient local data existed, a combination of some 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 greenhouse gas emissions inventories and the United Kingdom (UK) Greenhouse Gas Inventory GHGI) and National Atmospheric Emissions Inventory (NAEI) 2007[15], have be used. The NAEI and GHGI are generally based on a combination of both "bottom up" and "top-down" source specific data from the UK Department of Energy and Climate Change (DECC), Department for Environment, Food and Rural Affairs (DEFRA) and the annually released "top down" energy data such as those presented in the Digest of United Kingdom Energy Statistics (DUKES), published by DECC.

The LEGGI 2008 is the latest version of the LEGGI series released by the Greater London Authority (GLA). Since its establishment in 2000, the GLA has updated and released five versions (i.e., including the current version, LEGGI 2008) of the LEGGI: London Energy Database (LED) 2000, released in April 2003; London Energy and Carbon dioxide Inventory (LECI) 2003, released in April 2006; LEGGI 2004-2005, released in December 2008; LEGGI 2006, released in April 2009; and the current LEGGI, 2008, released in August 2010.

1.4. Spatial scope of the LEGGI 2008

The geographical area covered by the LEGGI includes the 32 London boroughs and the City of London (see Figure 1). The total area covered by the LEGGI is approximately 1,604 km^2. For reporting and analytical purposes, the LEGGI study area is geographically

[15]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.

divided into three sub-areas: *Central*, *Inner* and *Outer Greater London areas.* To spatially analyse and allocate emission estimates across the LEGGI study area, the UK Ordnance Survey's 1km² National Grid is used as the geographical framework for data output and presentation in the LEGGI. Each 1-km² grid cell (1,604 1-km² grid cells cover the entire LEGGI area) has a unique identification number and is assigned a value for the level of energy consumption and greenhouse gas emissions occurring within that 1-km² grid cell. The 1-km² grid cells that make up the London boroughs are mutually exclusive (i.e., each 1-km² grid cell belongs to no more than one London borough) and collectively exhaustive (i.e., every 1-km² grid cell belongs to a London borough). The rule applied when one 1-km² grid cell falls in more than one London borough is that of simple plurality: the London borough with the *largest share* of the 1-km² grid cell's area gets the 1-km² grid cell.

For reporting and analytical purposes, the LEGGI area is geographically divided into:

- **Central Greater London -** roughly corresponds to the boundary of the old (2003) Central London Congestion Charging Zone (CCZ) and is made up of some of the 1-km² grid cells in the boroughs of Camden, City of London, Islington, Lambeth, Southwark, Tower Hamlets, and Westminster (Figure 2).

- **Inner Greater London -** consists of some 1-km² grid cells in the boroughs of Camden, Greenwich, Hackney, Hammersmith and Fulham, Haringey, Barnet, Islington, Kensington and Chelsea, Lambeth, Lewisham, Newham, Southwark, Tower Hamlets, Wandsworth, Westminster, Waltham Forest and Redbridge (Figure 3).

- **Outer Greater London -** consists of some 1-km² grid cells in the boroughs of Enfield, Barking and Dagenham, Barnet, Bexley, Brent, Bromley, Croydon, Ealing, Harrow, Havering, Hillingdon, Hounslow, Kingston-upon-Thames, Merton, Richmond-upon-Thames, Redbridge, Sutton and Waltham Forest (Figure 4).

Figure 1: LEGGI area

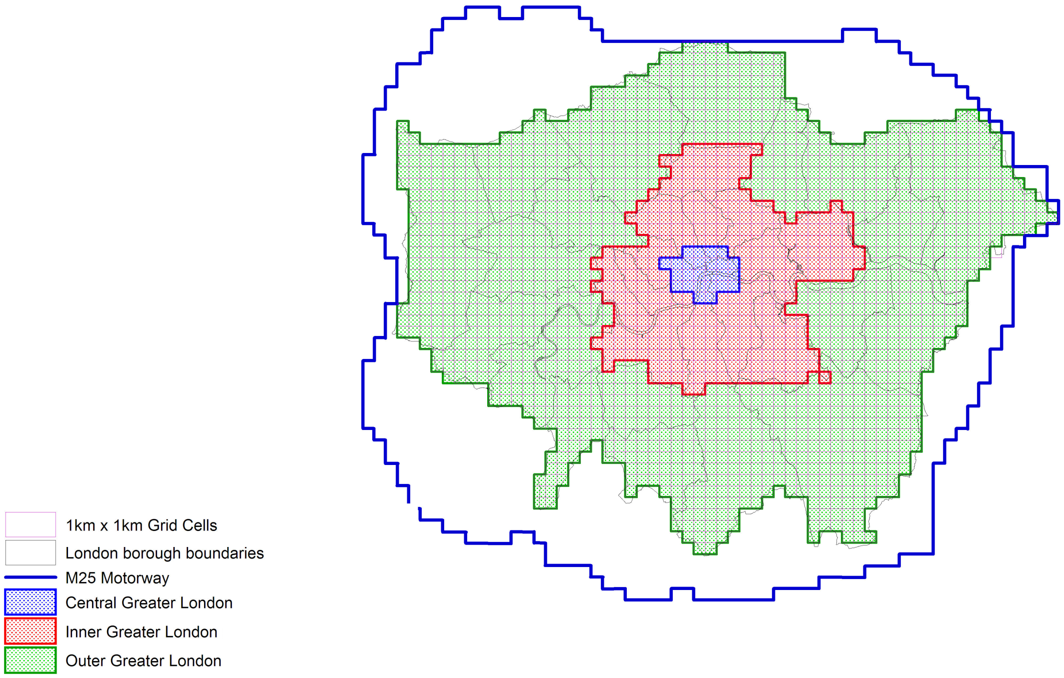


Figure 2: Central Greater London area

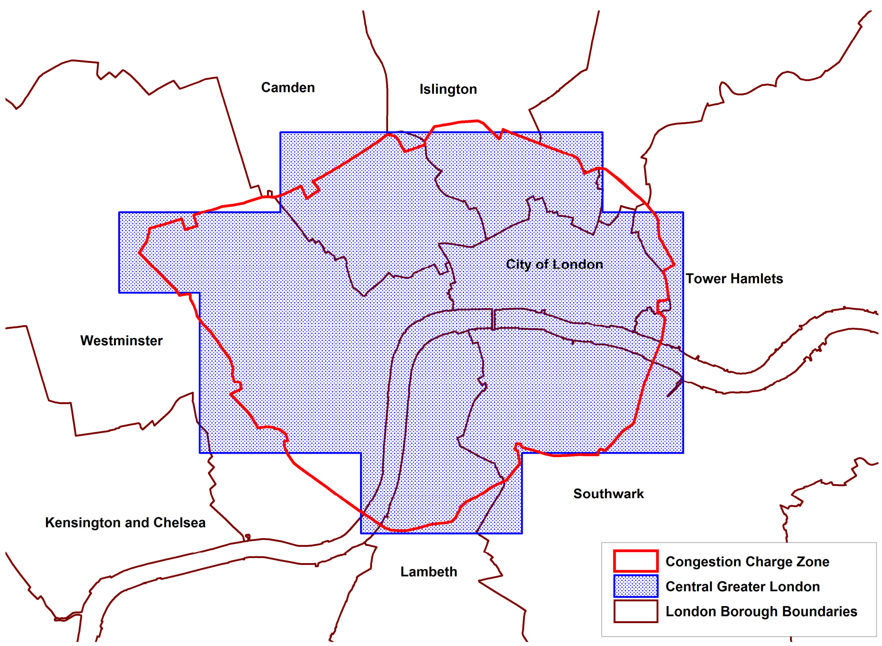


Figure 3: Inner Greater London area

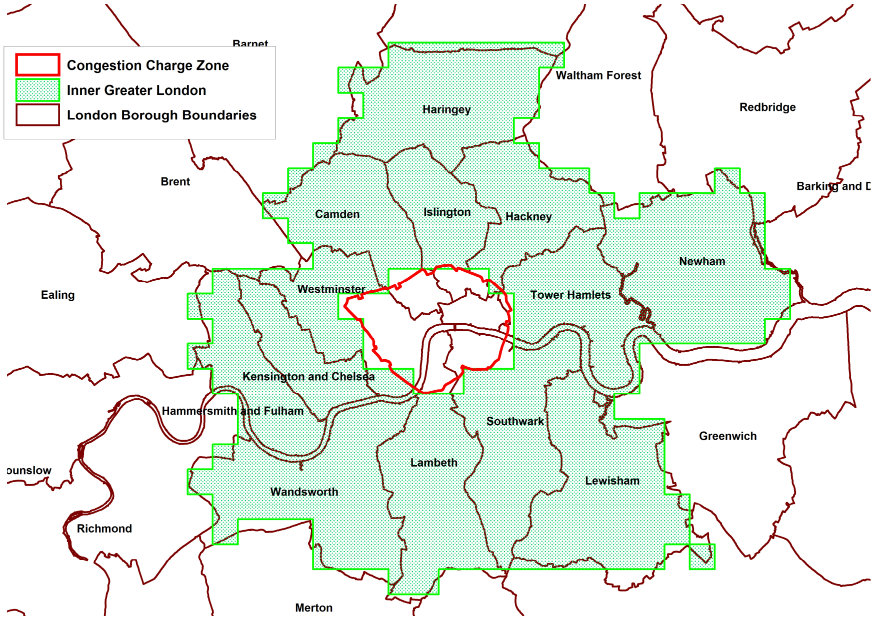
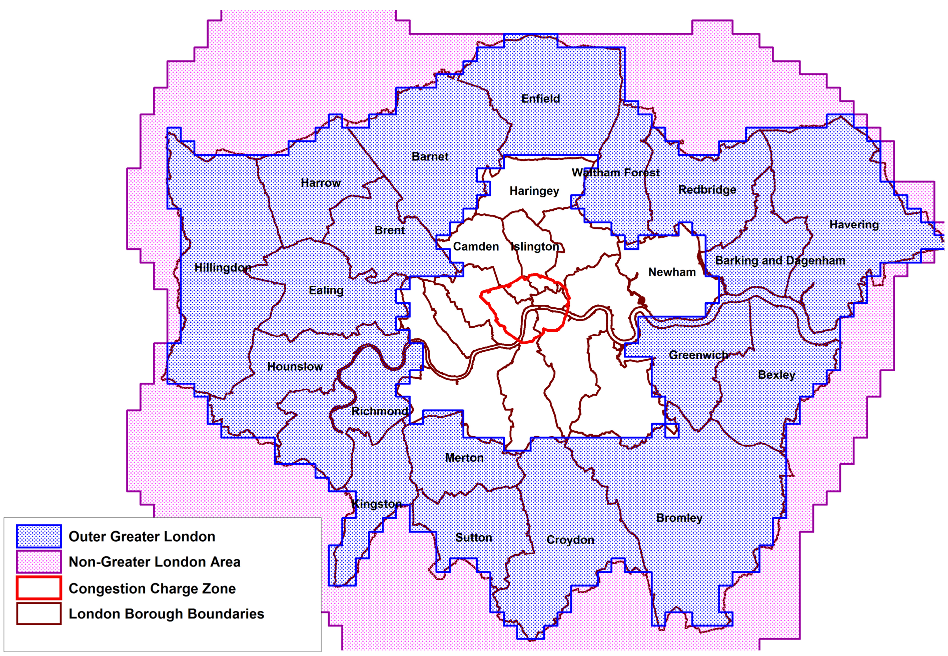


Figure 4: Outer Greater London area



1.5. Temporal scope of the LEGGI 2008

The base year for the LEGGI 2008 is the 2008[16] calendar year with forward and backward projections to 2011 & 2015 and 2006 and 2004, respectively. The LEGGI contains average fuel/energy consumption and greenhouse gas emission estimates for the base years and these averages are not necessarily indicative of energy use and greenhouse gas emissions for a given day.

Energy consumption is expressed in kilowatt-hours per year (kWh/yr) and greenhouse gases emissions in carbon dioxide equivalent-tonnes per year (CO_2eq tonnes/year)[17].

1.6. Simplified energy/fuel source and sector split in the LEGGI 2008

Energy/fuel consumption estimates (and the corresponding greenhouse gas emissions) in the LEGGI 2008 have been grouped into the following sources:

- Road Transport
- Domestic Aviation
- Rail Traffic
- Shipping
- Electricity
- Gas
- Oil
- Coal
- Wastes & Renewables

The aforementioned energy/fuel consumption estimates (and greenhouse gas emissions) have been further grouped into the following three broad sectors:

- Domestic
- Industrial & Commercial
- Transport

All fuel/energy consumption estimates that cannot be separately, easily and reliably classified as industrial[18] or commercial[19] have been grouped into the Industrial & Commercial sector. This simplified grouping is necessary in order to provide fuel/energy

[16] 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 LEGGI 2008 was compiled.
[17] Carbon dioxide equivalent (CO_2eq) is an internationally accepted metric measure that expresses the amount of global warming of greenhouse gases (GHGs) in terms of the amount of carbon dioxide (CO_2) that would have the same global warming potential (GWP), measured over a specified timescale (generally, 100 years).
[18] The Industrial sector includes power stations, plants regulated as combustion processes under Integrated Pollution Control (IPC), refineries, integrated steelworks, coke ovens, cement clinker manufacture, lime manufacture and other plants regulated under IPC, etc.
[19] The Commercial sector includes commercial offices, communication and transport, hotel and catering, retail, sport and leisure, warehouses, education, Government and health sub-sectors, etc.

consumption and greenhouse gas emission estimates in a format that is meaningfully comparable to the energy consumption and greenhouse gas emission estimates in the UK Department for Energy and Climate Change (DECC) Energy Statistics and Department for Environment, Food and Rural Affairs (DEFRA) Statistics on CO_2 Emissions at Local Authority and Regional Level, respectively.

The energy use and greenhouse gases estimates in the LEGGI 2008 are disaggregated by fuel/energy consumption sources (i.e., aviation, coal, electricity, gas, oil, rails, roads, shipping, wastes and renewable), sectors (i.e., domestic, transport, commercial and industrial) and location (i.e., London borough and 1-km^2 grid levels).

Table 1: Simplified energy/fuel source and sector split in the LEGGI 2008

Energy/Fuel	Use Source	Energy/Fuel Use
Road Transport	Transport	Energy use and greenhouse gas emissions from petrol and diesel (DERV) consumption by various road vehicles (i.e., cars, taxis, motorcycles, buses and coaches, light goods vehicles, rigid heavy goods vehicles and articulated heavy goods vehicles) in the Greater London area.
Domestic Aviation	Transport	Energy use and greenhouse gas emissions from fuel use in civil aviation (i.e., domestic and international flights and aircrafts in the landing and take-off flight phases up to 1,000m) and management of airports (including airside support vehicles, stationary heating and auxiliary power units, etc) at London Heathrow, London City, Battersea, Biggin Hill, Denham, Elstree, Lippits Hill, Northolt and Stapleford airports.
Rail	Transport	Energy use and greenhouse gas emissions from gas oil/diesel consumption by over ground diesel trains (emissions from diesel trains/engines are local as a result of combustion). Energy use and emissions by over ground electric trains and London Underground trains and stationary combustion in the rail sector (all accounted for in the Industrial & Commercial Electricity sector) are excluded.
Domestic Shipping	Transport	Energy use and greenhouse gas emissions from domestic and international shipping/marine vessels operating on the River Thames (i.e., including the 33 ports and terminals on the River Thames, starting from the breakwater at the M25 Motorway eastern boundary and then about 43 km westward towards Teddington) in Greater London.
Electricity[20]	Domestic	Electricity use and greenhouse gas emissions calculated from actual or estimated meter reading at domestic premises.
	Industrial &	Energy use and greenhouse gas emissions

[20] Greater London is an overall importer of electrical energy so the actual emissions of greenhouse gases in the
LEGGI 2008 due to consumption of electricity in the Greater London area (i.e., consumption-based entity) would be much higher than those reported in the LAEI 2008.

Energy/Fuel	Use Source	Energy/Fuel Use
	Commercial	associated with industrial and commercial electricity consumption, including electricity consumption by over ground electric trains and the London Underground trains.
Gas	Domestic	Energy use and greenhouse gas emissions from natural gas supplied to homes, where it is used for cooking in natural gas-powered ranges and ovens, natural gas-heated clothes dryers, water and central heating, and domestic boilers, etc.
	Industrial & Commercial	Energy use and greenhouse gas emissions from industrial (excluding gas-fired electricity generation and power stations), commercial (e.g., hotel and catering, warehouses, retail, sport and leisure, etc) and public services (e.g., education, Government, health, etc) gas use.
Oil	Domestic	Energy use and greenhouse gas emissions from domestic oil (e.g., heating oil, gas oils, kerosene, etc) used for oil- fired central heating in residential homes.
	Industrial & Commercial	Energy use and greenhouse gas emissions from oil (e.g., heavy, medium and light fuel oil) used in general industrial and commercial applications, including boiler firing for hot water and steam raising, furnaces and large air heater and dryers but excluding petrol and gas oil/diesel (DERV) used by road and rail transport as well as oil used for electricity generation at power stations.
Coal	Domestic	Energy use and greenhouse gas emissions from smokeless solid fuels (SSF) - coke and anthracite - burnt exclusively within Smoke Control Areas and used for room heaters, cookers, boilers, open fires and stoves.
	Industrial & Commercial	Energy use and greenhouse gas emissions from industrial (e.g., iron and steel production, excluding coal-fired electricity generation at power stations) and commercial/ public (e.g., as feedstock for boilers providing heating and hot water in public buildings such as hospitals and schools) coal consumption.
Wastes & Renewables	Industrial & Commercial	Energy use and greenhouse gas emissions from wastes (excluding greenhouse gases from waste incinerated and/or used to generate energy) and renewables (including, landfill gas, sewage gas, wood, municipal solid waste, scrap tyres, waste oils, clinical waste, waste solvents, etc,). CO_2 emissions from biomass are excluded but non-carbon dioxide greenhouse gases (methane and nitrous oxide) are included.

1.7. Availability of the LEGGI 2008

The LEGGI 2008 is available from the Environment Team, Greater London Authority (GLA), as a "zipped" (i.e., compressed) folder (**LEGGI_2008.zip**) that contains all the necessary files and the actual LEGGI 2008 Microsoft ® Access database that are needed to fully utilise the LEGGI 2008. A user guide (**LEGGI 2008 User Guide**) that provides clear and comprehensive information on how to copy and use the LEGGI 2008.

The "unzipped" (decompressed) LEGGI_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 LEGGI 2008. The LEGGI_2008 folder also contains the actual LEGGI 2008 database (**LEGGI_2008.mdb**), which was developed using the Microsoft® Access 2002 database management system (DBMS).

Important!

Because the LEGGI 2008 uses the Microsoft® Access 2002 application as its database management system (DBMS) you MUST have Microsoft® Access 2002 or later installed on your PC or else you will NOT be able to use the LEGGI 2008 database (i.e., the LEGGI_2008.mdb file) and its user-friendly interfaces to easily and quickly navigate and query the underlying LEGGI 2008 emission datasets.

The LEGGI 2008 was created using Access 2002 and do not need to be converted for use with Office Access 2007. You can open the LEGGI 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 LEGGI 2008 (old versions of Access) 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.

The GLA provides the LEGGI 2008 to London boroughs and other users free of charge. Requests for the LEGGI 2008 must be made to the Greater London Authority:

Public Liaison Unit
Greater London Authority
City Hall
The Queen's Walk
London SE1 2AA
United Kingdom

Fax: 020 7983 4057
Email: mayor@london.gov.uk

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2. Energy Use and Greenhouse Gas Emission Estimation Methodologies

2.1. Energy Consumption and Greenhouse Gas Emissions from Road Transport

This section deals with fuel/energy consumption and greenhouse gas emissions from petrol and diesel (DERV) consumption by various road vehicles (i.e., cars, taxis, motorcycles, buses and coaches, light goods vehicles, rigid heavy goods vehicles and articulated heavy goods vehicles) in Greater London. The methodology outlined below has been mainly extracted from the "London Atmospheric Emissions Inventory (LAEI) 2008 Road Traffic Inventory Methodology Report, January 2010", prepared for the GLA and Transport for London (TfL) by Environmental Research Group (ERG), King's College London.

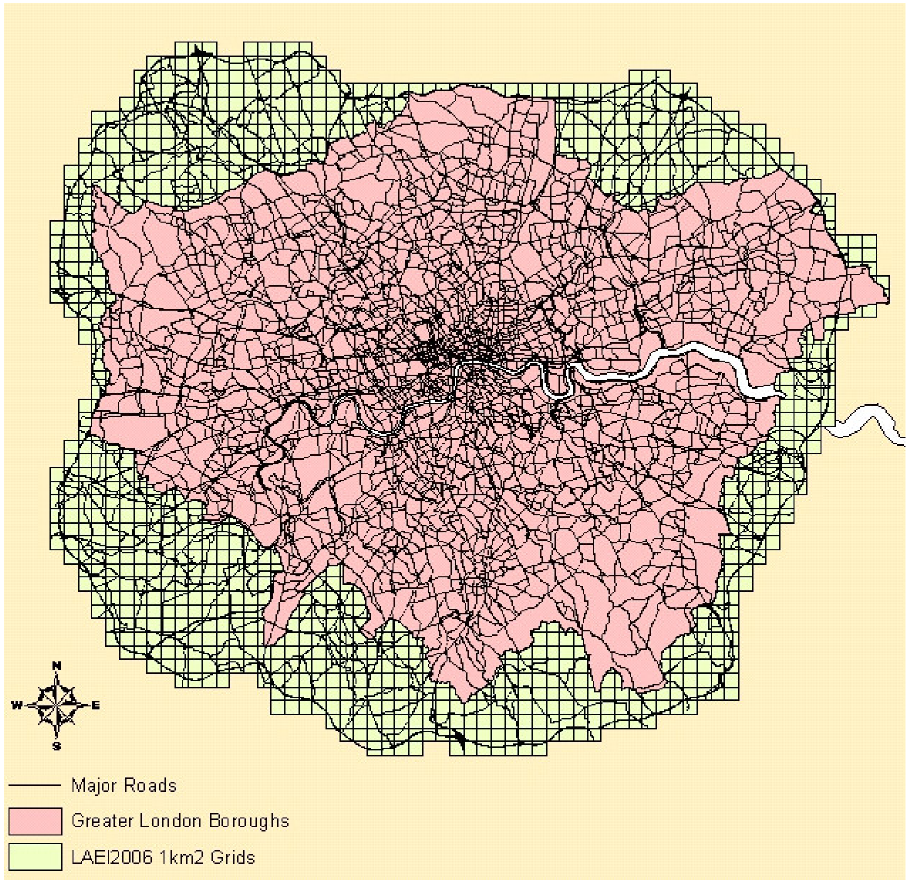
Summary

Fuel/energy consumption and greenhouse gas emissions were estimated from the detailed Greater London Authority's (GLA) LAEI 2008 Road Transport datasets that were prepared by ERG, who used monitored and modelled traffic counts of 11 classes of road vehicle from the Department for Transport (DfT), TfL and MVA traffic counts. The ERG methodology took into consideration Greater London-specific vehicle fleet ages and mixes for central, inner and outer London, average and traffic-peak speeds, hourly and daily flow profiles for thousands of road links and the impacts of the implementation of the Mayor's environmental and transport strategies (e.g., the London Congestion Charging Scheme (CCS) , Mayor's Taxi Strategy, Mayor's Bus Strategy, etc).

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.

Figure 5: Extent of the LAEI 2008 illustrated by the 1km² grid cells



Major road vehicle flows

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[21]). The reasons for developing the new methods include:

- 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

[21] 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

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. These results a summary of bias and the RMS error are presented (Table 2). 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 2 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%.

Table 2: Comparison of predicted, measured and predicted-measured hourly total traffic flows.

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

Vehicle kilometre (VKM) changes in Greater London between 2006 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.

The vehicle kms travelled on minor roads have been re-calculated (Table 3), based on the latest estimates provided by TfL[22] 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[23]

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. The minor road vehicle km for the LAEI 2008 has increased by around 20% compared to that of the LAEI 2006 (yr 2006) due mainly to the total vehicle kms driven in the Greater London area having increased from 31.15 bvkm in the LAEI2006 to 31.78 bvkm in the LAEI2008.

Table 3: 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

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[22] Charles Buckingham personal communication.

[23] 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.

AADT comparison

The vehicle kms travelled, by vehicle type, between 2003 and 2008 has been calculated and is displayed in Table 4. Note that Table 4 is concerned with the LAEI area and not the GLA area, which corresponds to the LEGGI area, discussed previously.

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.

Table 4: Vehicle km (billion) for each vehicle type for the LAEI area.

LEGGI 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

Including taxis within London traffic data

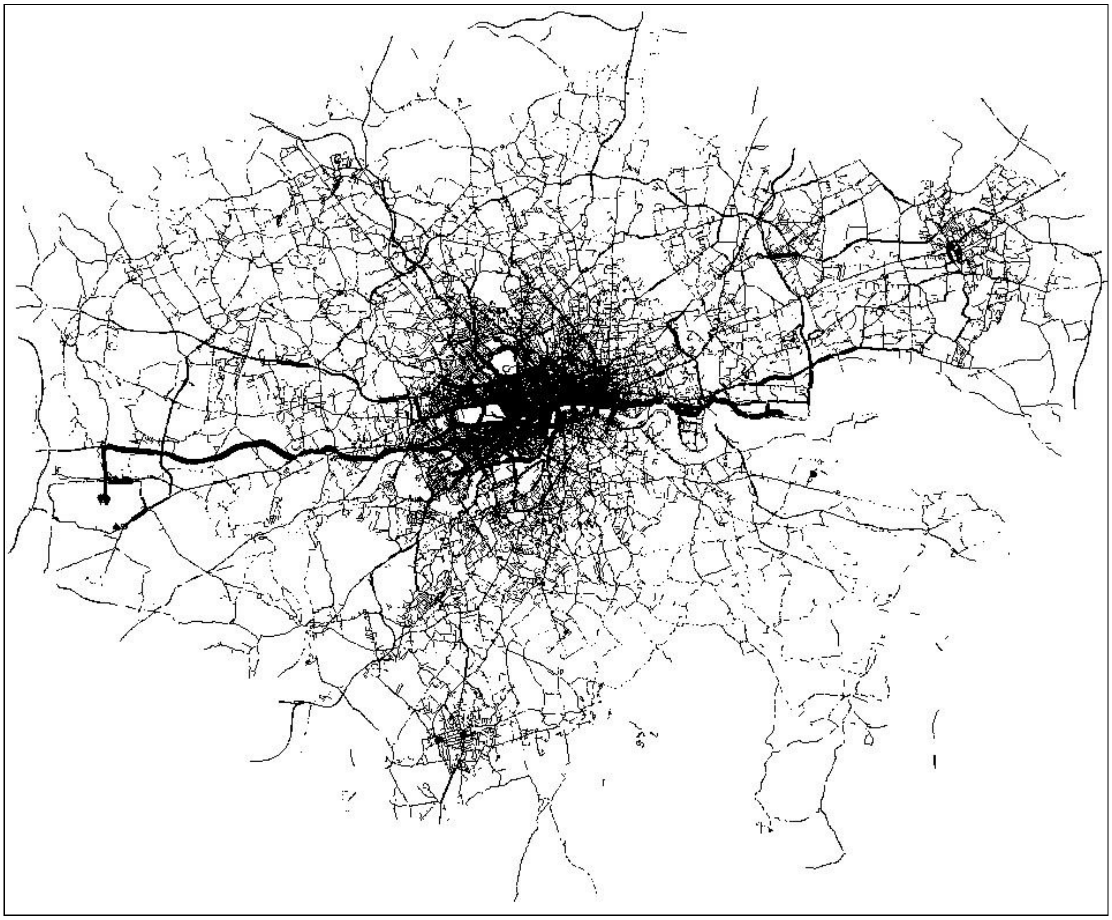
Traffic count data for taxis are very limited; they are generally counted as cars. Some TfL manual classified data have separate counts for cars and taxis. These data have been used to calculate a revised set of proportions of taxis by area of London (Table 5). The zones within which these proportions 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 6).

Table 5: 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 6: Estimation of taxi operation in London using GPS tracking (LAEI 2001)



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 7). 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}.

Speed has changed little between 2006 and 2008. There is however a pronounced region of discrepancy in speeds on the DfT referenced links and further analysis of these speeds 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 7: The CSS speed network used in compiling central and inner London speeds

Vehicle Stock Data

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[24]. 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. Unlike cars, LGVs catalyst failure rates remain at about 11% after 2009 until 2015.

Taxi stock has been updated based on information from the Public Carriage Office (PCO) for 2003, 2004, 2006, 2008, 2011 and 2015[25] (Table 6). Stock up to and including 2008 data are based on the actual fleet, whereas the 2011 and 2015 information is based on forecast data. All of the taxi stock reflects GLA's strategy to improve the emissions performance of the taxi fleet.

[24] Personal communication with Tim Murrells at AEAT; NAEI Department for Transport (DfT) forecast dated April 2008.
[25] Personal communication with Finn Coyle at TfL.

Table 6: Taxi Stock data (%) for the years 2004, 2006, 2008, 2011 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

The LT bus stock has also been revised according to the latest information (Table 7). In common with Taxi's, bus stock up to 2008 is based on the actual fleet, whereas the 2011 and 2015 information is based on forecast data.

Table 7: TfL Bus Stock data (%) for the years 2004, 2006, 2008, 2011 and 2015

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

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[26]. 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 8:

- Total PM_{10} emissions are 12 % lower

[26] See http://www.naei.org.uk/emissions/index.php for details.

- 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 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 8: 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%

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 coldstart NMVOC emissions and is similar to CO.

Evaporative emissions

Evaporative emissions of NMVOCs for petrol vehicles arise from a number of different sources. The methodology that was 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.

Assumptions for the 2011 and 2015 emissions inventories

For traffic data, post 2008, forecast traffic changes were provided by TfL and were consistent with the TfL Business Plan. Between 2006 to 2015 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 9). 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 10).

Table 9: Growth factors, expressed as a % change between 2008 and the forecast year, by period and location

Peak Periods	Location	2011	2015
AM	central	0.95	2.22
AM	inner	0.95	2.22
AM	outer	0.98	2.28
AM	external	0.97	2.26
INTER	central	1.17	2.74
INTER	inner	1.16	2.70
INTER	outer	1.15	2.67
INTER	external	1.15	2.68
PM	central	1.28	2.99
PM	inner	1.09	2.55
PM	outer	1.08	2.53
PM	external	1.09	2.55
Overnight	central	1.15	2.68
Overnight	inner	1.09	2.54

Overnight	outer	1.08	2.52
Overnight	external	1.09	2.53

Table 10: 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

The effect of the LEZ was also applied to vehicle stock projections for all years, using part 5 of the LEZ impacts analysis work[27]. The LEZ affects the composition of HGVs, coaches, heavier diesel LGVs and minibuses and the assumptions for these vehicle types are given in Table 11 to Table 14.

Table 11: 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	32.3	30.2	15.1
Euro 5	3.0	40.8	50.5
Euro 6	0	0	34.5

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

Table 12: 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	26.0	22.4	13.8
Euro 5	2.9	38.9	53.8
Euro 6	0	0	32.4

Table 13: LEZ Coach stock composition (%)

Euro Class	Coaches		
	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 3	48.9	35.8	0
Euro 3 (PM) + Euro2 (NO_X)	5.9	2.2	0
Euro 4	25.4	23.0	21.7
Euro 5	2.7	32.2	52.8
Euro 6	0	0	25.5

Table 14: LEZ diesel LGVs and minibus stock composition (%)

Euro Class	Diesel LGVs and Minibuses	
	2011	2015
Pre Euro	0.0	0
Euro 1	0.1	0.0
Euro 2	0.6	0.1
Euro 3	30.3	7.1
Euro 4	62.3	40.7
Euro 5	6.7	52.2
Euro 6	0	0

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 15.

Table 15: 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

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 16 to both traffic flow and speed for the appropriate hours charging hours[28].

Table 16: Western Extension traffic change during charging hours (07.00am to 6.00 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

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 17. 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.

Table 17: Particle trap assumptions for pollutant emissions

NO_X	PM_{10}[29]	CO	HC[30]	SO_2	CO_2
0.95	0.05	0.1	0.1	1.008	1.008

[28] TfL personal communication

[29] Also applied to PaH and $PM_{2.5}$

[30] Also applied to CH_4, Benzene and 1-3 Butadiene

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2.2. Energy consumption and greenhouse gas 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 comprehensively estimate emissions from rail traffic in the LEGGI 2008.

Projection Years: 2011 and 2015
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.

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 Greater London, 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 combustion. Therefore, the extensive use of electrically powered trains in London makes it difficult to attribute emissions directly to the place of energy consumption, further complicating the allocation of emissions to the railway source in the LEGGI 2008. In order to attribute emissions directly to the place of energy consumption by trains, 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 to the trains in Greater London 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 Greater London. Unfortunately, the exact type and amount of fuel used by these power stations for the generation of the electric power is not known.

Prior to the LEGGI 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[31]) 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 Jorgensen & Sorenson (1997) for CO_2, CO, HC and SO_2 and for NOx and PM from National Transport Model (DfT). The emission factors for electric trains, based on the averaged energy-specific emission factors of the electricity generation mix for the UK, were obtained from DUKES (2008).

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

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

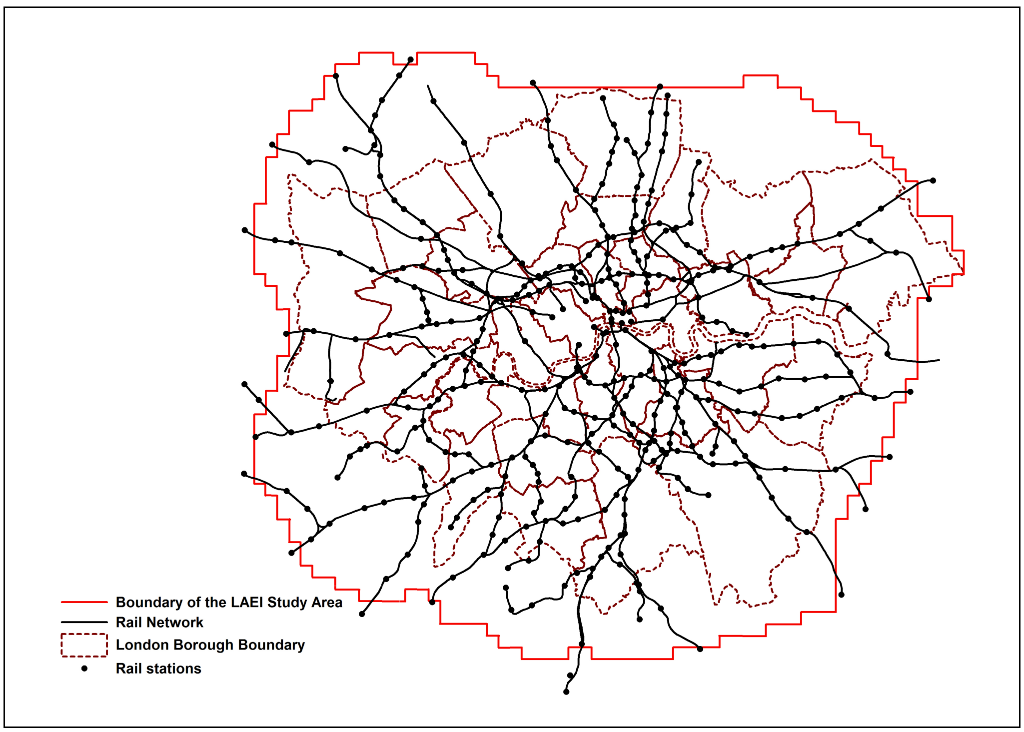
EC = Energy consumption, kWh

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

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

For the purpose of spatially analysing and allocating rail traffic CO_2 emissions 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 (see Figure 8) in the Greater London area was developed, with each railway link represented as a linear feature and allocated a unique identification number, and both spatial and non-spatial attributes attached.

Figure 8: Spatial distribution of the rail network in the LEGGI area



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 (see Table 18) was agreed. Detailed train classes, formation and traction details are provided in Table 22 and Table 23.

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.

Table 18: 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 19 was extracted from the ACTRAFF database for the calendar year 2008 across the LEGGI area on a link-by-link (a section of track) basis.

Table 19: 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)

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 was 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 20 shows the information extracted by TRATIM.

Table 20: Energy consumption information from the TRATIM database

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)	

Emission factors

Table 21 below presents the energy-specific emission factors for diesel engines per unit of power produced and were extracted from Jorgensen & Sorenson (1997). In the case of electric trains, emissions are not produced locally, but at remote power plants both within and outside Greater London, 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 Greater London 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 14 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.

Table 21: Energy–specific emission factors for diesel and electric trains, 2008

Fuel type	CO_2
Diesel (g/kWh)	640
Electricity (g/GJ)[32]	152,5132
Electricity (g/kWh)	455

[32] Averages for the production of electricity in the UK given in DUKES (2008).

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 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, grammes to tonne

The following steps were employed in estimating GHG 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 CO_2 by train category *t* on link ***l***, using energy-specific emission factors (expressed in g/kWh).

$$EM_{CO_2,t,l} = PEC_{t,l} * EF_{CO_2} * 10^{-6}$$

Where;

$EM_{CO_2,t,l}$ = Emission rate (tonne/annum) of CO_2 by train category *t* on link *l*
$PEC_{t,l}$ = Primary energy consumption (kWh) by train category *t* on link *l*
EF_{CO_2} = Energy-specific emission factor (g/kWh) for CO_2
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.

Emissions Projections

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[33] (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

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

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.

To aid future decision-making, the energy-specific emission factors 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.

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 22: 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
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

Train Class / Powered Vehicle	Category
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: Class 221 - 5 car formation (Dx) Class 332 - 5 car formation (Ey) Class 376, 442 & 444 - 5 car formation (Ey)	

Table 23: 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	Formation	Mass Tonne
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	Formation	Mass Tonne
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

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2.3. Energy consumption and greenhouse gas emissions from shipping

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 LEGGI 2006, which included information on marine vessel characteristics and activities within the LEGGI 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.
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 LEGGI 2006 (using 2010 projection).

2008 emission estimation methodology: Same as the LEGGI 2006 methodology

Below is a synopsis of the methodological approach used in the LEGGI 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 1km² grid cells. Apportionment of the combined "at sea" and "in port" emissions to the generic 1km² grid cells of the LEGGI area were they intersected using the "proportion summed" algorithm in GIS.

9. Presentation of the emission results at the 1km² resolution.

For the purpose of estimating emissions from marine vessels in this study, only the 33 ports and terminals (see Table 24) on the Thames and within the LEGGI 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 24: Ports and terminal within the LEGGI area

Ports	Approximate distance (km) from the LEGGI boundary[34]
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

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

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

Vessel characteristics and movement

The primary source of information in terms of vessel characteristics and movements was a comprehensive database[35] 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, floating storage, molasses tanker, naval auxiliary, product tanker, non specific tanker, wine tank, water tanker*

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

[35] 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.

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

Table 25: 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 LEGGI area for the year 2004.

Table 26: 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 carbon dioxide (CO_2) form the Entec Report (Entec UK Ltd, 2000).

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

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

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

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

Equation 2

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

Where:

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

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

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

Table 27: 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 28: 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 27) 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 28 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 LEGGI 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 GHG emissions from ships in the LEGGI.

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 29) 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 29: Average vessel power (kW) by vessel type

Type of Vessel	Average Vessel Power ,kW[36]
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 load factors and the average vessel power (average power of the main engine) by vessel type

[36] 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.

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 30: Rated average vessel power (kW)

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

Average Energy Consumption

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

Average energy consumption (kWh) "at sea"

Equation 5

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

Where:

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

Average energy consumption (kWh) "in port"

Equation 6

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

Where:

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

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

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

Emission factors

The installed engine type on board a vessel and the fuel used largely dictates the ship's emissions. Since the emission factors for individual engines on vessels in this study were not known, a decision was taken to use the emission factors from the Entec UK Ltd 2000 Report. While the Entec UK Ltd 2000 study was geared towards estimating emissions for the European Union, it provides an insightful analysis of the worldwide commercial marine vessel fleet, even including a statistical analysis of variance in emission factors. The Entec UK Ltd 2000 study estimated emission factors for CO_2 for "at sea" and "in port" activities as shown in Table 31 and Table 32[37]. The emission factors for main engines "at sea" and "in port" were assumed to be operating at 80% and 20% maximum continuous rating respectively

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

Table 31: Emission factors for "at sea" operation regarding vessel type, 2004

Type of Ship	CO_2
Bulk Carrier	624
Tanker	645
Pallet Carrier	631
General Cargo	644
Specialised Cargo	822
Liquified Gas Carrier	822
Dredge/Tug	705
Ro-Ro Cargo	659

Source: Entec UK Ltd, 2000

Table 32: Emission factors for "in port" operation regarding vessel type, 2004

Type of Ship	CO_2

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

Bulk Carrier	706
Tanker	710
Pallet Carrier	710
General Cargo	716
Specialised Cargo	884
Liquified Gas Carrier	884
Dredge/Tug	729
Ro-Ro Cargo	723

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 33: Estimated uncertainties at the 95% confidence interval

Pollutant	At sea	In port
CO_2	±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 33, 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, compared to starts with relatively warm engines. Secondly, because engine loads can change rapidly during "in port" operations, the variability in emissions are increased.

Estimating emissions

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

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

"At sea" emission calculation

Equation 7

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

Where:

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

VC_{port} =Number of vessel calls at port

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

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

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

"In port" emission calculation

Equation 8

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

Where:

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

VC_{port} =Number of vessel calls at port

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

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

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

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

2011 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[38] and restriction of fuel type use. Consequently, a high degree of uncertainty will be introduced in any future projections (specifically, 2011 projections) of atmospheric emissions from marine vessels operating in the Port of London.

Although a steady course of investment and expansion is set to create a number of high-profile new facilities[39], which will confirm London's status as the major gateway to UK market, most of these expansions lie outside the LEGGI area. Quantitative estimates of

[38] 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.

[39] 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 LEGGI area.

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 LEGGI area) for future years was estimated from the "Port of London Handbook 2006" and "PLA Annual Review 2004", which was assumed at 1% growth per annum in number of vessel calls for the period 2003 – 2010. To project 2011 and 2015 emissions, the estimated emission factors for future scenarios (i.e., 2008) for "at sea" and "in port" activities (shown in Table 34 and Table 35) were derived from the Entec UK Ltd Report. Entec's estimated emission factors for 2008 years have been used to project 2011 and 2015 emissions in this study.

Table 34: Emission factors for "at sea" operation regarding vessel type, 2011and 2015

Type of Ship	CO_2
Bulk Carrier	688
Tanker	706
Pallet Carrier	691
General Cargo	698
Specialised Cargo	881
Liquified Gas Carrier	881
Dredge/Tug	707
Ro-Ro Cargo	7.3

Table 35: Emission factors for "in port" operation regarding vessel type, 2010 and 2015

Type of Ship	CO_2
Bulk Carrier	688
Tanker	706
Pallet Carrier	691
General Cargo	698
Specialised Cargo	881
Liquified Gas Carrier	881
Dredge/Tug	747
Ro-Ro Cargo	703

Source: Entec UK Ltd, 2000

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2.4. Energy Consumption and GHG Emissions from Domestic Aviation

2.4.1. London Heathrow

This section deals with energy/fuel use and greenhouse gas emissions from civil aviation (i.e., domestic and international flights/aircrafts in the landing and take-off (LTO) flight phases up to 1,000m) and management of airports (including airside support vehicles, stationary heating and power, etc) at London Heathrow Airport[40]. Energy consumption and greenhouse gas emissions from road traffic around the Heathrow Airport were excluded to avoid double counting as these were already estimated under the Road Transport sector.

Summary

Base Year: 2008
Because of lack of recent, representative and reliable activity datasets for the 2008 base year, emission estimates for CO_2 from the 2002 Heathrow Emissions Inventory (HEI), which were provided by AEA were used. These 2002 base year emission estimates were spatially analysed and integrated into the LEGGI 2008 to represent the 2008 base year. Emissions from Heathrow's road traffic were excluded from the HEI dataset used to compile the LEGGI 2008 in order to avoid double counting as these were already estimated under the Road Transport sector of the LEGGI 2008.

Projection Years: 2011 and 2015
AEA provided projected (2010) emission estimates for CO_2 from the 2010 Heathrow Emissions Inventory, which were then spatially analysed and integrated into the LEGGI 2008. Again, emissions from Heathrow's road traffic were also excluded from the HEI dataset used in compiling the LEGGI 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 GHG 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).

AEA provided the entire fuel consumption and CO_2 emission estimates (CH_4 and N_2O were not estimated) 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.

This 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

[40] A flight is domestic if the initial point on the service is a domestic and the final point is a domestic airport. A
flight is international if either the initial point or the final point on the service is an international airport.

oxides), 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 included 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 the immediate road network around the
- airport;
- Car parks and taxi queues;
- Airport heating plant; and
- Fire-training ground.

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.

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. These data were used for the future years 2011 and 2015. 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[41]. 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.

[41] 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[42]), 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

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

from airport-related road traffic on the designated road network.

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.

2.4.2. Smaller airport in Greater London

Summary

Base Year: 2008
Because of lack of recent activity datasets for the 2008 base year, estimate of airside emissions for the 2008 base year (from the LEGGI 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 (GLA) 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 LEGGI 2006 (same as the 2010 projection).

2008 emission estimation methodology: (Same as the LEGGI 2006 methodology)

This section describes the LEGGI 2006 methodology, data used and results obtained from the calculation of airside emissions from minor Greater London airports and airfields, undertaken by AEA 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:

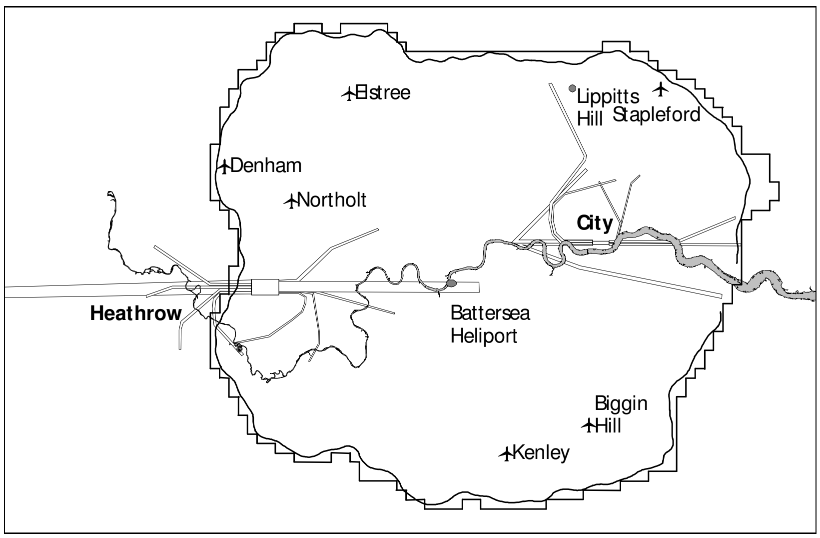
- London City
- Stapleford
- Elstree
- Northolt
- Battersea
- Kenley
- Biggin Hill
- Lippits Hill Heliport
- Denham
- Metro London Heliport

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 9. Location of airports in 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.

Emission sources included

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).

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.

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 1000m);
(6) approach (from 1000m 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 36: Emission factors for aviation fuels (kg/t)

Fuel	CO_2 (kt / tonne)	SO_2 (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

PM_{10} From Aircraft Brake And Tyre Wear

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 1105547kg 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 5th 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 total 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:

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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.

2.5. Energy Consumption and GHG Emissions from Electricity Consumption

This section deals with electricity use and greenhouse gas emissions calculated from actual and estimated meter reading at domestic, industrial and commercial premises, including electricity consumption by over ground electric trains/locomotives and the London Underground trains.

Summary

Electricity consumption and CO_2 emissions for 2008 were estimated from Department for Energy and Climate Change (DECC) 2008 Middle Layer Super Output Area (MLSOA) level Electricity and Gas Consumption datasets and Department for Environment, Food and Rural Affairs (DEFRA) 2008 National Statistics[43] on CO_2 Emissions at Local Authority and Regional Levels datasets[44].

Department for Energy and Climate Change (DECC) electricity consumption data were collected by obtaining the full co-operation of the electricity industry: annualised consumption data were generated by the data aggregators, agents of the electricity suppliers, who collate and aggregate electricity consumption levels for each customer meter or MPAN (meter point administration number). In addition to this, information is obtained from the Gemserv meter postcode address file, which provides the geographical location of each MPAN, including the full address and postcode. For the 2008 dataset, Gemserv data were from a quarterly produced extract file produced by the electricity distribution companies' meter point administration system (MPAS)[45]. The geographical and electricity consumption data are then merged together to enable consumption data to be mapped to postcodes and aggregated to MLSOA (as well as local authority areas and government office regions) levels. The electricity consumption data are generated for both non-half hourly (NHH) meters (domestic and small/medium commercial-industrial customers) and for half hourly (HH) meters (larger commercial-industrial customers).

For the NHH data, annualised estimates are based on either an annualised advance (AA) or estimated annual consumption (EAC). The AA is an estimate of annualised consumption based on consumption recorded between two meter readings. In comparison an EAC is used where two meter readings are not available and an estimate of annualised consumption is produced by the energy company using historical information and the profile information relating to the meter. These data provide a good approximation of annualised consumption, but do not cover exactly the calendar year. For the half hourly meter consumption estimates, data aggregators are asked to produce a simple report for each MPAN for the relevant calendar year.

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[43] In March 2008 gas consumption dataset gained National Statistics status. This status applies to all data from 2005 onwards. Please note that the 2004 data are still classed as experimental.

[44] The main data sources are the UK National Atmospheric Emissions Inventory, maintained by AEA on behalf of DEFRA and the Devolved Administrations, and DECC's National Statistics of energy consumption for local authority areas. The work to produce the estimates was carried out by AEA.

[45] In 2006 the MPAS data moved onto an on-line system named the Electricity Central Online Enquiry Service (ECOES), which provides similar, but more up-to-date information to the Gemserv file.

DECC uses the aforementioned data to produce a domestic/non-domestic split, with aggregate and average consumption figures provided for all local authorities and regions. The domestic consumption is based on NHH meters with profiles 1 and 2 (these are the standard Domestic and Economy 7 type tariffs respectively). Non-domestic (i.e. industrial and commercial) consumption is based on NHH meters with profiles 3 to 8 and all HH meters. In addition some of the larger domestic consumers of electricity are reallocated to the industrial-commercial sector if annual consumption is greater than 100,000 kWh.

The 2007 electricity consumption and numbers of customers by region and local authority workbooks were obtained from the DECC's website[46]. DECC collects and compiles estimates of electricity consumption at regional (NUTS1) and local authority levels (NUTS4).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 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 08/487c" at http://www.berr.gov.uk/files/file42994.pdf.

The project team obtained workbooks of electricity consumption from the DECC's website. Within each workbook are worksheets giving details of electricity and gas consumption down to MLSOA level for each LA in that region. The 2008 datasheets showed electricity and gas consumption data (given in kWh for the entire year) for England regarding total consumption, number of meters and average consumption levels for domestic and non-domestic users. Also included are figures for industrial half hourly meter electricity consumption (relating to larger business consumers) within the LA; this data cannot be disaggregated to MLSOA as doing so would break the National Statistics Code of Practice guidelines on data disclosure. Due to data disclosure issues, 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 2007 regional and local electricity consumption statistics obtained from DECC's Energy Statistics were spatially analysed and apportioned to 1-km^2 grid cells by the project team to enable sub-borough areas to be monitored and targeted. In order to produce local electricity consumption statistics for 2008 at the 1-km^2 spatial resolution, the electricity consumption statistics for each MLSOA was first analysed, reformated 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 1,604 1-km^2 grid cells). Where a MLSOA covered more than one 1-km^2 grid cell area, the electricity 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 electricity data when deriving statistics. Furthermore, due to data disclosure issues, electricity 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.

[46] http://www.berr.gov.uk/energy/statistics/regional/regional-local-gas/page36200.html

CO_2 emission estimates

CO_2 emissions estimates from electricity consumption in the LEGGI 2008 were obtained from DEFRA's 'Detailed Sector Split' Local and Regional CO_2 Emissions Estimates for 2007 spreadsheet, which was produced by AEA for DEFRA in December 2008. The spreadsheet was used with reference to the report 'Local and Regional CO_2 Emissions Estimates for 2008'[47]. The nationally consistent carbon dioxide emission estimates for "Domestic" and "Industrial & Commercial" sectors at local authority (London boroughs) and regional level (Greater London) that are contained within the spreadsheet were produced following the publication of local gas, electricity and road transport fuel consumption estimates by DECC. The 'Detailed Sector Split' worksheet shows the elements of data (such as the domestic gas and electricity estimates and the estimates for road transport) included within the CO_2 estimates are of reasonable certainty, as they are based on local readings and sales data.

The 2007 regional and local CO_2 emissions from electricity consumption statistics were spatially analysed and apportioned to 1-km^2 grid cells to enable sub-borough areas such as electoral wards to be monitored and targeted. In order to produce CO_2 emissions at the 1-km2 spatial resolution, the CO_2 emissions statistics for each London borough was first disaggregated (using the area of domestic and non-domestic buildings categories obtained from Department for Communities and Local Government (DCLG)'s Generalised Land Use Database Statistics for England 2005[48] as a weighting factor) to Census ward areas and then aggregated to the 1-km^2 grid cells using GIS functionality (i.e., spatial analysis by overlaying the Census wards' electricity consumption data with the 1,604 1-km^2 grid cells of the LEGGI area).

Emission estimates of methane and nitrous oxide in the LEGGI 2008 were calculated from the energy data, using emissions factors derived from the "2009 Guidance to DEFRA/DECC's GHG Conversion Factors for Company Reporting"[49] provided by AEA for DECC and DEFRA.

Projection Years: 2011 and 2015

Projections of GHG emissions for electricity were based on an analysis of historical trends in energy consumption. Electricity consumption trends have been used to estimate the projections of Methane and N_2O.

[47] http://www.defra.gov.uk/environment/statistics/globatmos/galocalghg.htm
[48] The Generalised Land Use Database Statistics for England 2005 categorises land parcels into nine key themes: domestic buildings, gardens, non-domestic buildings, road, rail, path, greenspace, water and others and provides statistics for each local authority and also for each Census ward (as defined for 2005). The statistics are produced for DCLG (formerly, ODPM) on behalf of the Office for National Statistics' Neighbourhood Statistics service. http://www.communities.gov.uk/publications/planningandbuilding/generalisedlanduse

[49] (http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm).

Electricity

The % per annum growth/decay rates in electricity consumption (2005-2008) from the domestic and industrial-commercial sectors in the Greater London area were calculated as follows (see **Error! Reference source not found.** and **Error! Reference source not found.**):

For Domestic electricity projections to 2011 = -1.14%
For Industrial-Commercial electricity projections to 2011 = 1.03%

For Domestic electricity projections to 2015 = -1.11%
For Industrial-Commercial electricity projections to 2015 = 1.05%

Table 37: Trends in Domestic electricity consumption (GWh) in Greater London and projection factors

Years	Electricity Sales (GWh)		
2005	13,885		
2006	13,701		
2007	13,774		
2008	13,410		
2011	**12,951**	% decrease between 2007-2011	-5.97%
2012			
2013			
2014			
2015	**12,364**	% decrease between 2007-2015	-10.24%

Table 38: Trends in Industrial and Commercial electricity consumption (GWh) in Greater London and projection factors

Years	Electricity Sales (GWh)		
2005	27,550		
2006	29,143		
2007	28,423		
2008	28,404		
2011	**29,284**	% increase between 2007-2011	3.03%
2012			
2013			
2014			
2015	**30,501**	% increase between 2007-2015	7.31%

As a result of these growth rates the following conversion factors were calculated. These conversion factors were applied to the values for 2008 (base year) to calculate the projections in energy consumption for 2011 and 2015.

Conversion factor for Domestic electricity projections to 2011 = 0.9403
Conversion factor for Industrial-Commercial electricity projections to 2011 = 1.0303

Conversion factor for Domestic electricity projections to 2015 = 0.8976
Conversion factor for Industrial-Commercial electricity projections to 2015 = 1.0731

2.6. Energy Consumption and GHG Emissions from Gas Consumption

This section deals with energy use and greenhouse gas emissions from natural gas supplied to homes, where it is used for cooking in natural gas-powered ranges and ovens, natural gas heated clothes dryers, water and central heating, and domestic boilers. It also includes energy
use and greenhouse gas emissions from industrial (excluding gas-fired electricity generation/power stations), commercial (e.g., hotel and catering, warehouses, retail, sport and
leisure, etc) and public services (e.g., education, Government, health, etc) gas use.

Summary

Gas consumption and CO_2 emissions for 2008 were estimated from Department for Energy and Climate Change (DECC) 2007 Middle Layer Super Output Area (MLSOA) level Electricity and Gas Consumption datasets and Department for Environment, Food and Rural Affairs (DEFRA) 2007 National Statistics on CO_2 Emissions at Local Authority and Regional Levels datasets.

After some key structural changes in the British gas distribution network in 2005, the National Grid were no longer able to provide gas sales data at the postcode sector level because they sold off some of the local distribution zones (LDZs) and were no longer responsible for the whole of the gas distribution network in Great Britain. However, through an agreement with Xoserve[50], DECC now obtains annualised gas consumption estimates (similar to those already collected from the electricity industry) from Xoserve. Xoserve is the company now responsible for the collation and aggregation of gas consumption, subject to permissions being provided by the owners of the LDZ network. Xoserve provides annualised estimates of gas consumption for all the MPRNs (meter point reference numbers or gas meters) based on an Annualised Quantity (an estimate of annualised gas consumption using consumption recorded between two meter readings at least six months apart. The estimate is then adjusted to reflect a 17-year weather correction factor). The AQ for each MPRN represents consumption relating to the financial year 1 April to 31 March, rather than for a calendar year.

The data quality of the gas data from Xoserve is high; however, the problem previously noted for the National Grid dataset with regards to the allocation of gas meters to either the domestic or commercial sector is still relevant to the Xoserve dataset, as no reliable criteria exists on the dataset to identify the sector to which the meter belongs. However the reliability of the 2007 gas datasets are significantly higher than the previous National Grid datasets due to the improved geographical mapping of gas consumption from individual MPRNs using the National Statistics Post Code Directory.

The 2007 gas consumption and numbers of customers by region and local authority workbooks were obtained from the DECC's website[51]. DECC collects and compiles

[50] In addition to the gas consumption estimates (from meters connected to the main distribution network)
obtained from Xoserve, BERR also obtains similar information from the independent gas transporters that are responsible for transporting gas to mainly new housing estates or connected system exit points (CSEPs).

[51] http://www.berr.gov.uk/energy/statistics/regional/regional-local-gas/page36200.html

estimates of gas consumption at regional (NUTS1) and local authority levels NUTS4).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 gas consumption data (given in kWh for the entire year) for the Greater London area regarding total consumption, number of meters points 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 08/487c" at http://www.berr.gov.uk/files/file42994.pdf.

DECC's sub local authority gas consumption estimates at Middle Layer Super Output Area (MLSOA) level in England for 2007 was used for the 2008 energy estimates in the LEGGI 2008. However, 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.

For the analysis, the project team spatially analysed and aggregated the gas consumption data from MLSOA level to the 1-km^2 grid cells. However where a MLSOA covered more than one 1-km^2 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, DECC combined MLSOA data, and each MLSOA was given an equal share of the gas data when deriving statistics.

CO_2 emission estimates

CO_2 emissions estimates from gas consumption in the LEGGI 2008 were obtained from DEFRA's 'Detailed Sector Split' Local and Regional CO_2 Emissions Estimates for 2007 spreadsheet, which was produced by AEA for DEFRA in December 2008. The spreadsheet was used with reference to the report 'Local and Regional CO_2 Emissions Estimates for 2008'[52] . The nationally consistent carbon dioxide emission estimates for "Domestic" and "Industrial & Commercial" sectors at local authority (London boroughs) and regional level (Greater London) that are contained within the spreadsheet were produced following the publication of local gas, electricity and road transport fuel consumption estimates by DECC. The 'Detailed Sector Split' worksheet shows the elements of data (such as the domestic gas and electricity estimates and the estimates for road transport) included within the CO_2 estimates are of reasonable certainty, as they are based on local readings and sales data.

The 2007 regional and local CO_2 emissions from gas consumption statistics were spatially analysed and apportioned to 1-km^2 grid cells to enable sub-borough areas such as electoral wards to be monitored and targeted. In order to produce CO_2 emissions at the 1-km^2 spatial resolution, the CO_2 emissions statistics for each London borough was first disaggregated (using the area of domestic and non-domestic buildings categories obtained from Department for Communities and Local Government (DCLG)'s Generalised Land Use Database Statistics for England 2005[53] as a weighting factor) to Census ward areas and

[52] http://www.defra.gov.uk/environment/statistics/globatmos/galocalghg.htm
[53] The Generalised Land Use Database Statistics for England 2005 categorises land parcels into nine key themes: domestic buildings, gardens, non-domestic buildings, road, rail, path, greenspace, water and others and provides statistics for each local authority and also for each Census ward (as defined for 2005). The statistics are produced for DCLG (formerly,

then aggregated to the 1-km² grid cells using GIS functionality (i.e., spatial analysis by overlaying the Census wards' electricity consumption data with the 1,604 1-km² grid cells of the LEGGI area).

Emission estimates of methane and nitrous oxide in the LEGGI 2008 were calculated from the energy data, using emissions factors derived from the "2009 Guidance to DEFRA/DECC's GHG Conversion Factors for Company Reporting"[54] provided by AEA for DECC and DEFRA.

Projection Years: 2011 and 2015

Projections of atmospheric emissions from gas consumption were based on an analysis of historical trends in energy consumption. Electricity consumption trends have been used to estimate the projections of Methane and N_2O.

Gas

The % per annum growth/decay rates in gas consumption (2005-2008) from the domestic and industrial-commercial sectors in the Greater London area were calculated as follows (see **Error! Reference source not found.** and **Error! Reference source not found.**):

For Domestic gas projections to 2011 = -2.60%
For Industrial-Commercial gas projections to 2011 = -3.60%

For Domestic gas projections to 2015 = -2.47%
For Industrial-Commercial gas projections to 2015 = -3.35%

Table 39: Trends in Domestic gas consumption (GWh) in Greater London and projection factors

Years	Gas Sales (GWh)		
2005	52,635		
2006	50,943		
2007	49,921		
2008	48,528		
2011	**44,741**	% decrease between 2007-2011	-10.38%
2012			
2013			
2014			
2015	**40,148**	% decrease between 2007-2015	-19.58%

ODPM) on behalf of the Office for National Statistics' Neighbourhood Statistics service. http://www.communities.gov.uk/publications/planningandbuilding/generalisedlanduse

[54] (http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm).

Table 40: Trends in Industrial and Commercial gas consumption (GWh) in Greater London and projection factors

Years	Gas Sales (GWh)		
2005	27,215		
2006	26,008		
2007	24,429		
2008	24,272		
2011	**21,647**	% decrease between 2007-2011	-19.58%
2012			
2013			
2014			
2015	**18,584**	% decrease between 2007-2015	-23.93%

As a result of these growth rates the following conversion factors were calculated. These conversion factors were applied to the values for 2008 (base year) to calculate the projections in gas consumption for 2011 and 2015.

Conversion factor for Domestic gas projections to 2011 = 0.8962
Conversion factor for Industrial-Commercial gas projections to 2011 = 0.8861

Conversion factor for Domestic gas projections to 2015 = 0.8042
Conversion factor for Industrial-Commercial gas projections to 2015 = 0.7607

2.7. Energy Use and GHG Emissions from Coal, Oil and Wastes & Renewables

The fuels covered in this section are solid and liquid fuels: coal, oil and wastes & renewables.

Domestic Coal: Energy use and greenhouse gas emissions from smokeless solid fuels (SSF) - coke and anthracite - burnt exclusively within Smoke Control Areas and used for room heaters, cookers, boilers, open fires and stoves.

Industrial and Commercial Coal: Energy use and greenhouse gas emissions from industrial
(e.g., iron and steel production, excluding coal-fired electricity generation at power stations)
and commercial/ public (e.g., as feedstock for boilers providing heating and hot water in public buildings such as hospitals and schools) coal consumption.

Domestic Oil: Energy use and greenhouse gas emissions from domestic oil (e.g., heating oil,
gas oils, kerosene, etc) used for oil- fired central heating in residential homes.

Industrial and Commercial Oil: Energy use and greenhouse gas emissions from oil (e.g., heavy, medium and light fuel oil) used in general industrial and commercial applications, including boiler firing for hot water and steam raising, furnaces and large air heater and dryers but excluding petrol and gas oil/diesel (DERV) used by road and rail transport as well as oil used for electricity generation at power stations.

Wastes & Renewables: Energy use and greenhouse gas emissions from wastes (excepting greenhouse gases from waste incinerated and/or used to generate energy) and renewables (including, landfill gas, sewage gas, wood, municipal solid waste, scrap tyres, waste oils, clinical waste, waste solvents, etc,). CO_2 emissions from biomass are excluded but non-carbon dioxide greenhouse gases (methane and nitrous oxide) are included.

Summary

Energy consumption from coal, oil and wastes & renewables were estimated from DECC's UK Local and Regional estimates of non-gas, non-electricity and non-transport energy consumption for 2007. The local and regional estimates for coal, oil and wastes & renewables are produced by DECC's contractor AEA and are calculated from a number of different information sources. DECC advises users to recognise that the information contained in the datasets are based on modelled rather than real data, and as such are subject to potential modelling error. These datasets are available at DECC's Energy Statistics website[55].

Greenhouse gas emissions were estimated from DEFRA's National Statistics on CO_2 Emissions at Local Authority and Regional Levels datasets 2007.

Up-to-date 2008 sewage datasets were obtained from WRc and were used to comprehensively estimate emissions from sewage in the LEGGI 2008.

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

The main source of information used to calculate coal, oil and wastes & renewables energy use is the National Atmospheric Emissions Inventory (NAEI) database. The breakdowns provided by DECC only provide aggregated consumption figures for the different energy sources at London borough and Greater London levels. This is because in the domestic sector average consumption figures for coal, manufactured solid fuels and oil consumption could be misleading given that few domestic properties use either solid fuel or oil fired central heating systems in their homes. Aggregated consumption from the local and regional dataset differs from the UK energy statistics produced in the DUKES, because the statistics for DUKES are based on information from UK energy suppliers, whilst AEA have used a variety of data sources to produce their estimates. Due to the limitations of the source data (particularly of energy consumption for smaller industrial and commercial sites and the domestic sector), many of the local authority estimates are based on heavily modelled data, which use less well-linked spatial information, incorporating a significant number of assumptions.

Full information on the 2007 datasets and methodology report are accessible from the web links below:

http://www.berr.gov.uk/whatwedo/energy/statistics/publications/dukes/page45537.html

UK sub-national estimates of non-gas, non electricity and non road transport energy consumption on 2005, 2006 and 2007 from
http://www.decc.gov.uk/en/content/cms/statistics/regional/other/other.aspx

The regional and local oil, coal and wastes & renewable fuel consumption (expressed in thousand tonnes of oil equivalent, ktoe) statistics for 2007 were further disaggregated to 1-km^2 grid cells to enable sub-borough areas such as electoral wards to be monitored and targeted. The spatial analysis methodology is the same as those used for analysing electricity and gas consumption data. That is, to produce local oil, coal and renewables & wastes fuel consumption statistics for 2007 at the 1-km^2 spatial resolution, the oil, coal and renewables & wastes fuel consumption statistics for each London borough was first disaggregated (using the area of domestic and non-domestic buildings categories from the DCLG's Generalised Land Use Database Statistics for England 2005 as a weighting factor) to the Census ward areas and then aggregated to the 1-km^2 grid cells using GIS algorithms by overlaying the Census wards' oil, coal and renewables & wastes fuel consumption data (map) with the 1,604 km^2 grid cells.

CO_2 emission estimates

CO_2 emissions estimates from oil, coal and wastes & renewable fuel consumption in the LEGGI 2008 were obtained from DEFRA's 'Detailed Sector Split' Local and Regional CO_2 Emissions Estimates for 2007 spreadsheet, which was produced by AEA for DEFRA in November 2009. The spreadsheet was used with reference to the report 'Local and Regional CO_2 Emissions Estimates for 2008'[56] . The nationally consistent carbon dioxide emission estimates for "Domestic" and "Industrial & Commercial" sectors at local authority (London boroughs) and regional level (Greater London) that are contained within the spreadsheet were produced following the publication of local oil, coal and wastes & renewable fuel consumption estimates by DECC. The 'Detailed Sector Split' worksheet shows the elements

[56] http://www.defra.gov.uk/environment/statistics/globatmos/galocalghg.htm

of data included within the CO_2 estimates are of reasonable certainty, as they are based on local readings and sales data.

The 2008 regional and local CO_2 emissions from oil, coal and wastes & renewable fuel consumption statistics were spatially analysed and apportioned to 1-km^2 grid cells to enable sub-borough areas such as electoral wards to be monitored and targeted. In order to produce CO_2 emissions at the 1-km^2 spatial resolution, the CO_2 emissions statistics for each London borough was first disaggregated (using the area of domestic and non-domestic buildings categories obtained from Department for Communities and Local Government (DCLG)'s Generalised Land Use Database Statistics for England 2005 as a weighting factor) to Census ward areas and then aggregated to the 1-km^2 grid cells using GIS functionality (i.e., spatial analysis by overlaying the Census wards' oil, coal and wastes & renewable fuel consumption data with the 1,604 1-km^2 grid cells of the LEGGI area).

Methane and N2O emissions estimates from oil, coal and wastes & renewable fuel consumption in the LEGGI 2008 were calculated by multiplying the energy consumption by the Fuel Conversion Factors (Table 41). These conversion factors were published by Defra under the "2009 Guidelines to Defra/DECC's GHG Conversion Factors for Company Reporting" in September 2009.

Table 41: Fuel Conversion Factors

Fuel Type	CH_4 (kg CO_2eq per kWh)	N_2O (kg CO_2eq per kWh)
Coal - Domestic	0.03892	0.00447
Coal - Industrial and Commercial	0.00002	0.00494
Oil – Domestic[57]	0.00026	0.02412
Oil - Industrial and Commercial[58]	0.00020	0.00092
Gas – Domestic, Industrial and Commercial[59]	0.00028	0.00011
Waste - Industrial and Commercial		

Projection Years: 2011 and 2015

Projections of atmospheric emissions from oil, coal and wastes & renewable fuel consumption were based on an analysis of historical trends in energy consumption. Because of the lack of data on Methane and N_2O emissions, electricity consumption trends have been used to estimate the projections on these gases.

Coal

The % per annum growth/decay rates in coal consumption (2005-2007) from the domestic and industrial-commercial sectors in the Greater London area were calculated as follows (see Table 42and Table 43):

For Domestic coal projections to 2011 = -0.40%
For Industrial-Commercial coal projections to 2011 = 1.60%

For Domestic coal projections to 2015 = -0.40%
For Industrial-Commercial coal projections to 2015 = 1.65%

[57] In Annex 1 Fuel Conversion Factors (Table 1b) as Gas Oil
[58] In Annex 1 Fuel Conversion Factors (Table 1b) as Fuel Oil.
[59] In Annex 1 Fuel Conversion Factors (Table 1b) as Natural Gas.

Table 42: Trends in Domestic coal consumption (ktoe) in Greater London and projection factors

Years	Coal Consumption (ktoe)		
2005	2.06		
2006	2.90		
2007	3.00		
2011	**2.96**	% decrease between 2007-2011	-51.20%
2012			
2013			
2014			
2015	**2.92**	% decrease between 2007-2015	-2.77%

Table 43: Trends in Industrial and Commercial coal consumption (ktoe) in Greater London and projection factors

Years	Coal Consumption (ktoe)		
2005	1.23		
2006	2.00		
2007	1.40		
2011	**1.47**	% increase between 2007-2011	4.79%
2012			
2013			
2014			
2015	**1.56**	% increase between 2007-2015	11.54%

As a result of these growth rates the following conversion factors were calculated. These conversion factors were applied to the values for 2007 (base year) to calculate the projections in coal consumption for 2011 and 2015.

Conversion factor for Domestic coal projections to 2011 = 0.9880
Conversion factor for Industrial-Commercial coal projections to 2011 = 1.0479

Conversion factor for Domestic coal projections to 2015 = 0.9723
Conversion factor for Industrial-Commercial coal projections to 2015 = 1.1154

Oil

The % per annum growth/decay rates in oil consumption (2005-2007) from the domestic and industrial-commercial sectors in the Greater London area were calculated as follows (see Table 44 and Table 45):

For Domestic oil projections to 2011 = -0.40%
For Industrial-Commercial oil projections to 2011 = 1.60%

For Domestic oil projections to 2015 = -0.40%
For Industrial-Commercial oil projections to 2015 = 1.65%

Table 44: Trends in Domestic oil consumption (ktoe) in Greater London and projection factors

Years	Oil Consumption (ktoe)		
2005	23.36		
2006	24.69		
2007	25.06		
2011	**24.76**	% decrease between 2007-2011	-1.20%
2012			
2013			
2014			
2015	**34.36**	% decrease between 2007-2015	-2.77%

Table 45: Trends in Industrial and Commercial oil consumption (ktoe) in Greater London and projection factors

Years	Oil Consumption (ktoe)		
2005	239.10		
2006	275.90		
2007	279.40		
2011	**292.79**	% increase between 2007-2011	4.79%
2012			
2013			
2014			
2015	**311.63**	% increase between 2007-2015	11.54%

As a result of these growth rates the following conversion factors were calculated. These conversion factors were applied to the values for 2007 (base year) to calculate the projections in oil consumption for 2011 and 2015.

Conversion factor for Domestic oil projections to 2011 = 0.9880
Conversion factor for Industrial-Commercial oil projections to 2011 = 1.0479

Conversion factor for Domestic oil projections to 2015 = 0.9723
Conversion factor for Industrial-Commercial oil projections to 2015 = 1.1154

Waste and renewables

The % per annum growth/decay rates in waste and renewables consumption (2005-2008) from the industrial-commercial sector in the Greater London area were calculated as follows (see Table 46):

For Industrial-Commercial waste and renewables projections to 2011 = 1.79%

For Industrial-Commercial waste and renewables projections to 2015 = 1.85%

Table 46: Trends in Industrial and Commercial waste and renewables consumption (ktoe) in Greater London and projection factors

Years	Waste and Renewables (ktoe)		
2005	10.07		
2006	10.13		
2007	10.43		
2011	**10.99**	% increase between 2007-2011	5.36%
2012			
2013			
2014			
2015	**11.78**	% increase between 2007-2015	12.96%

As a result of these growth rates the following conversion factors were calculated. These conversion factors were applied to the values for 2007 (base year) to calculate the projections in waste and renewables consumption for 2011 and 2015.

Conversion factor for Industrial-Commercial electricity projections to 2011 = 1.0536

Conversion factor for Industrial-Commercial electricity projections to 2015 = 1.1296

CONVERSION FACTORS AND GLOBAL WARMING POTENTIALS

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} m^3

The following prefixes are used for multiples of joules, watts and watt hours:

kilo (k) = 1,000 or 10^3
mega (M) = 1,000,000 or 10^6
giga (G) = 1,000,000,000 or 10^9
tera (T) = 1,000,000,000,000 or 10^{12}
peta (P) = 1,000,000,000,000,000 or 10^{15}