TRANSPORT FOR LONDON

London Atmospheric Emissions Inventory (LAEI) 2016 - Methodology

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MAYOR OF LONDON

TRANSPORT FOR LONDON
EVERY JOURNEY MATTERS

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LIST OF ABBREVIATIONS

Abbreviation	Definition
ACMS	Aerosol Chemical Speciation Monitor
AMS	Aerosol Mass Spectrometer
APU	Auxiliary Power Unit
BaP	Benzo[a]pyrene
BEIS	Department for Business, Energy and Industrial Strategy
C_4H_6	1,3-Butadiene
C_6H_6	Benzene
CAA	Civil Aviation Authority
CCZ	Congestion Charge Zone
C_d	Cadmium (Heavy Metal)
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COA	Cooking Organic Aerosols
EMEP/EEA	European Monitoring and Evaluation Program / European Environment Agency
HAEI	Heathrow Atmospheric Emissions Inventory
HCl	Hydrogen Chloride
HDV	Heavy Duty Vehicle (HGV / Bus / Coach)
H_g	Mercury (Heavy Metal)
HGV	Heavy Goods Vehicle
ICAO	International Civil Aviation Organization
LAEI	London Atmospheric Emissions Inventory
LAPPC	Local Authority Pollution Prevention and Control
LDD	London Development Database
LDV	Light Duty Vehicle (LGV / Car)
LGV	Light Goods Vehicle
LPG	Liquefied Petroleum Gas
LTO	Landing and Take-Off
N_2O	Nitrous Oxide
NAEI	National Atmospheric Emissions Inventory
NH_3	Ammonia
NMVOC	Non Methane Volatile Organic Compounds
NO_2	Nitrogen Dioxide

Abbreviation	Definition
NO_x	Nitrogen Oxides
NRMM	Non Road Mobile Machinery
ORR	Office of Rail Road
P_b	Lead (Heavy Metal)
PCB	PolyChlorinatedBiphenyl
PM	Particulate Matter
PM_{10}	Particulate Matter with an aerodynamic diameter < 10 µm
$PM_{2.5}$	Particulate Matter with an aerodynamic diameter < 2.5 µm
PMF	Positive Matrix Factorisation
REM	Rail Emissions Model
SO_2	Sulphur Dioxide
STW	Sewage Treatment Works
TLRN	Transport for London Road Network (London's "Red Routes")
WTS	Waste Transfer Station

1 Overview

1.1.1 The London Atmospheric Emissions Inventory - LAEI - is a database of geographically referenced datasets of pollutant emissions and sources in Greater London[1]. This update of the LAEI includes emissions for a new base year 2016, as well as back projection to previous base years 2010 and 2013. This document sets out the methodology for calculating the emissions in the inventory. The emission sources in the inventory are outlined in Table 1.

1.1.2 Emissions were calculated by source type, represented by points, polygons, lines and areas, depending on the nature and size of each source. They were then projected on a 1km^2 resolution grid, further split by the boundary of each London borough, to allow accurate aggregations of emissions by borough.

1.1.3 The LAEI 2016 includes emissions from the following 4 key pollutants:

- Nitrogen oxides (NO_x);
- Particulate matter with an aerodynamic diameter < 10 μm (PM_{10});
- Particulate matter with an aerodynamic diameter < 2.5 μm ($PM_{2.5}$); and
- Carbon dioxide (CO_2).

1.1.4 Additionally, the LAEI includes emissions from 14 subsidiary pollutants:

- Sulphur Dioxide (SO_2);
- Non Methane Volatile Organic Compounds (NMVOC);
- 1,3-butadiene (C_4H_6) (subset of NMVOC);
- Benzene (C_6H_6) (subset of NMVOC);
- Methane (CH_4);
- Ammonia (NH_3);
- Carbon Monoxide (CO);
- Nitrous Oxide (N_2O);
- Heavy Metals Cadmium (Cd), Mercury (Hg) and Lead (Pb);
- Benzo[a]pyrene (BaP);
- PolyChlorinated Biphenyl (PCB); and
- Hydrogen Chloride (HCl).

1.1.5 Finally, as part of the LAEI, emissions from key pollutants for the base year 2016 have been used to model ground level concentrations of NO_x, NO_2, PM_{10} and $PM_{2.5}$ at 20m resolution across London, with resulting concentration maps and associated data available on the LAEI website.

1.1.6 This document details the method used to estimate the emissions, focusing on the changes in data source and/or methodology improvements since last update. Where input sources or methodology have not changed, this document only provides a brief overview and refers to the previous methodology document published as part of the LAEI 2013 for further information.

[1] The inventory actually covers a wider zone, up to the M25 motorway

Table 1: Emissions Sources in the LAEI

Industrial and Commercial	Industrial Processes	Large Processes (Part A1)
		Small Processes (Part A2/B)
		NRRM Exhaust on Industrial Sites
	Heat and Power Generation	Gas Combustion
		Solid and Liquid Fuel Combustion
	Waste	Landfill Sites
		Sewage Treatment Works
		Waste Transfer Stations
		Small Scale Waste Burning
	Construction	NRMM Exhaust on Construction Sites
		Construction / Demolition Dust
	Commercial Catering (Cooking)	
	Natural Gas Supply Leakage	
Domestic	Heat and Power Generation	Gas Combustion
		Solid and Liquid Fuel Combustion
	House and Garden Machinery (NRMM)	
	Domestic Wood Burning (Biomass)	
Transport	River	Commercial Shipping
		Passenger Shipping
	Road	Cars, LGVs, Taxis, Motorcycles, HGVs, Buses, Coaches
	Rail	Freight
		Passenger
	Aviation	
Miscellaneous	Agriculture	Combustion
		Livestock
		Other Agriculture
	Accidental Fires and Bonfires	
	Forests - Biosynthesis	

2 Industrial and Commercial Sources

Emissions from the industrial and commercial sector include the following subsectors:

- Emissions from regulated industrial processes (Part A1/A2 and B);
- Emissions from the combustion of fuel used to generate heat and/or power for the industrial/commercial sector;
- Emissions from waste;
- Emissions from construction / demolition; and
- Emissions due to gas leakage.

2.1 Industrial Processes

Introduction

2.1.1 Emissions from the Industrial Processes subsector include the following sources:

- Large Processes (Part A1) regulated by the Environment Agency;
- Small Processes (Part A2 and B) regulated by Local Authorities as part of the LA-PPC regime; and
- Non Road Mobile Machinery (NRMM) exhaust emissions on industrial sites.

Large Processes (Part A1)

Pollutants

2.1.2 Emissions from Part A1 sources have been estimated for the pollutants shown in Table 2.

Table 2: Pollutants Reported for Industrial Part A1 Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Part A1	12	•	•	•	•	SO_2, NMVOC, NH_3, C_6H_6, CO, CH_4, N_2O, HCl

Emissions

2.1.3 Emissions data have been gathered from the Environment Agency's Pollution Inventory[2] 2016 dataset. Gaps were completed with the NAEI dataset for large point sources[3] for 2015 (as the 2016 dataset was not available at the time the inventory was compiled), which includes a mix of measured and modelled emissions for all Part A sources across the UK.

2.1.4 As for the previous LAEI, Part A1 processes for wastewater plants have been reported separately within the Sewage Treatment Plants (STW) category, whilst the Part A1 stationary source from Heathrow airport (boiler) has been removed, as

[2] https://data.gov.uk/dataset/cfd94301-a2f2-48a2-9915-e477ca6d8b7e/pollution-inventory
[3] http://naei.beis.gov.uk/data/map-large-source

already accounted for within emissions from the Aviation Sector, as part of the detailed airport emissions inventory.

Historical Emissions

2.1.5 Emissions for 2010 and 2013 have not been revised and remain as reported in the LAEI 2013.

Small Processes (Part A2 and B)

Pollutants

2.1.6 Emissions from Part A2/B sources have been estimated for the pollutants shown in Table 3.

Table 3: Pollutants Reported for Industrial Part A2/B Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Part A2/B	9	●	●	●	●	SO_2, NMVOC, C_6H_6, CO, P_b

Emissions and Spatial Distribution

2.1.7 London Boroughs were asked to update the list of Part A2/Bs last reported for the LAEI 2013. The update included closed and new processes since the previous inventory. Updated lists were provided for 20 of the 33 London boroughs, and included more than 2,000 active Part A2/B sources across London in 2016.

2.1.8 2016 emissions for processes still in activity were kept as reported in the LAEI 2013.

2.1.9 For new processes, emissions were derived from similar processes already in activity in the previous inventory.

Historical Emissions

2.1.10 Emissions for 2010 and 2013 have not been revised and remain as reported in the LAEI 2013.

Non-Road Mobile Machinery on Industrial Sites

2.1.11 Non-Road Mobile Machinery (NRMM) emissions from industry and construction are estimated separately in the LAEI. This section only refers to NRMM from industrial sources. The methodology to estimate construction related NRMM emissions is provided in section 2.4.2.

Pollutants

2.1.12 Exhaust emissions from Non-Road Mobile Machinery (NRRM) industrial sources have been estimated for the pollutants shown in Table 4.

Table 4: Pollutants Reported for NRMM Exhaust Sources from Industrial Sites

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
NRMM Exhaust (Industrial Sites)	16	●	●	●	●	SO_2, NMVOC, C_4H_6, NH_3, C_6H_6, CO, CH_4, N_2O, C_d, H_g, P_b, BaP

Emissions and Spatial Distribution

2.1.13 As for the LAEI 2013, NRMM exhaust emissions from industrial sites for 2016 were determined based on a top down approach, using total NRMM emissions reported in the NAEI for the UK, combined with data from the latest NAEI CO_2 emissions map[4].

2.1.14 NAEI CO_2 emissions reported for the "*Combustion in Industry*" sector, provided at a 1km^2 resolution across the UK, have been used as a proxy indicator of industrial activity across the UK. This is deemed representative of the spatial distribution of NRMM exhaust emissions on industrial sites.

2.1.15 This enabled to estimate the fraction of the UK industrial NRMM emissions within the LAEI area (3.7% assumed in 2016), as well as the distribution of these emissions on the LAEI grid.

Historical Emissions

2.1.16 Emissions for 2010 and 2013 were also revised, in accordance with updated NAEI data (both NRMM emissions and spatial distribution of CO_2 emissions), using the same methodology.

2.2 Heat and Power Generation

Introduction

2.2.1 Emissions from the Heat and Power Generation for the Industrial and Commercial subsector include the following sources:

- Gas combustion sources; and
- Solid and liquid fuel combustion sources.

Gas Combustion

Pollutants

2.2.2 Emissions from gas combustion sources within the industrial and commercial heat and power generation subsector have been estimated for the pollutants shown in Table 5.

[4] Available at http://naei.beis.gov.uk/data/map-uk-das. As the 2016 maps were not published at the time the inventory was compiled, calculations were based on the 2015 map.

Table 5: Pollutants Reported for Gas Combustion Sources from the Industrial/Commercial Heat and Power Generation Subsector

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Gas Combustion (Industrial/Commercial Heat and Power)	9	•	•	•	•	NMVOC, C_6H_6, CO, CH_4, N_2O

2.2.3 Emissions estimates have been based on the same methodology followed in previous LAEI updates, using updated data and applying the following activity-based equation, for each pollutant:

Emissions (tonnes/year) = Gas Consumption (GW.h/year) × Emission Factor (t poll/GW.h)

Activity Data and Spatial Distribution

2.2.4 Updated activity data (the gas consumption, expressed as energy consumed, in gigawatt-hour/year) has been collated from the Department for Business, Energy and Industrial Strategy (BEIS) website, providing non-domestic gas consumption across the UK at MSOA (Middle-layer Super Output Area) level for year 2016. MSOA gas consumption was then projected onto the LAEI grid and used as a proxy for the spatial distribution of emissions.

Emission Factors

2.2.5 Updated emission factors (expressed as the mass of pollutant emitted per amount of energy consumed) were collated from the NAEI for each pollutant. These emission factors are shown in Table A-1, Appendix A.1.

Historical Emissions

2.2.6 Emissions from industrial and commercial gas combustion for previous base years 2010 and 2013 have been recalculated using the revised gas consumption data from BEIS and emission factors for these years.

Solid and Liquid Fuel Combustion

Pollutants

2.2.7 Emissions from other (liquid and solid fuel) combustion sources within the industrial and commercial heat and power generation subsector have been estimated for the pollutants shown in Table 6.

Table 6: Pollutants Reported for Liquid/Solid Fuel Combustion Sources from the Industrial/Commercial Heat and Power Generation Subsector

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Other Fuels Combustion (Industrial/Commercial Heat and Power)	16	•	•	•	•	SO_2, NMVOC, NH_3, C_6H_6, CO, CH_4, N_2O, C_d, H_g, P_b, BaP, PCB

2.2.8 Emissions estimates have been based on the same methodology followed in the LAEI 2013 update, using updated data and applying the following activity-based equation, for each fuel and each pollutant:

> Emissions (tonnes/year) = Fuel Consumption (t fuel consumed/year) × Emission Factor (t poll/t fuel consumed)

Activity Data and Spatial Distribution

2.2.9 Updated activity data (the mass of fuel consumed, in tonnes /year) has been collated from the BEIS website, providing industrial coal, fuel oil and solid smokeless fuel consumption across the UK at local authority level for year 2016. Fuel consumption was then projected onto the LAEI grid and used as a proxy for the spatial distribution of emissions.

Emission Factors

2.2.10 Updated emission factors (expressed as the mass of pollutant emitted per mass of fuel consumed) were collated from the NAEI for each pollutant. These emission factors are shown in Table A-2, Appendix A.1.

Historical Emissions

2.2.11 Emissions from industrial and commercial solid and liquid fuel combustion for previous base years 2010 and 2013 have been recalculated using the revised oil, coal and solid smokeless fuel consumption data published by BEIS and revised emission factors from the NAEI for these years.

2.3 Waste

Introduction

2.3.1 This source sector includes:

- Emissions from waste handling at landfill sites;
- Emissions from waste water handling at Sewage Treatment Works (STW);
- Emissions from Waste Transfer Stations (WTS); and
- Emissions generated by small scale waste burning activities.

Landfill Sites

Pollutants

2.3.2 Emissions from landfill sources have been estimated for the pollutants shown in Table 7.

Table 7: Pollutants Reported for Landfill Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Landfill	8	-	•	•	-	NMVOC, C_4H_6, NH_3, C_6H_6, CH_4, PCB

Emissions

2.3.3 Emission calculations for landfill sites followed the same methodology used for the LAEI 2013,

2.3.4 The update involved scaling down the latest landfill emissions reported in the NAEI for England to the LAEI grid.

Spatial Distribution

2.3.5 Spatial projection was determined using the latest GIS layers of landfill sites in England (represented as polygons) collated from the Environment Agency (both active sites from the "*Permitted Waste Sites - Authorised Landfill Site Boundaries*" dataset, and closed sites from the "*Historical Landfill Sites*" dataset). These two datasets were intersected with the LAEI grid to determine the landfill area in m^2 within each LAEI grid cell.

2.3.6 This area was then divided by the total landfill area across England, and the resulting ratio was applied to the England landfill emissions from the NAEI, to estimate emissions across the LAEI.

Historical Emissions

2.3.7 Revised NAEI emissions for 2010 and 2013 were used to update previous base years using the same methodology as described above.

Sewage Treatment Works (STW)

Pollutants

2.3.8 Emissions from wastewater handling sources have been estimated for the pollutants shown in Table 8.

Table 8: Pollutants Reported for Wastewater Handling Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Wastewater Handling (STW)	4	•	-	-	-	NH_3, CH_4, N_2O

Emissions

2.3.9 Emissions calculations for sewage treatment works (STW) sites followed the same methodology used for the LAEI 2013.

2.3.10 Total 2016 emissions for NH_3, CH_4 and N_2O within the LAEI boundary were estimated by scaling down NAEI UK emissions, using the ratio of London to UK population as a proxy.

2.3.11 NO_x emissions were kept as in the previous LAEI, as UK wastewater handling emissions for that pollutant are not reported in the NAEI, and no new information was available to update data provided in the LAEI 2013.

Spatial Distribution

2.3.12 These emissions were allocated to each of the sewage treatment works operating within the LAEI boundary (Beckton, Beddington, Crossness, Deephams, Hogsmill, Longreach, Maple Lodge, Mogden and Riverside STWs), using the latest Thames Water Population Equivalent (PE) estimates for each site (ratio of PE for each site to total PE for all sites).

2.3.13 Emissions for each STW were then spatially distributed on the LAEI grid, based on the proportion of site area within each grid cell.

Historical Emissions

2.3.14 Emissions for 2010 and 2013 were also revised, in accordance with updated NAEI emissions and London to UK population ratios for these years.

Waste Transfer Stations (WTS)

Pollutants

2.3.15 Emissions from waste transfer station sources have been estimated for the pollutants shown in Table 9.

Table 9: Pollutants Reported for WTS Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Waste Transfer Station	2	-	•	•	-	-

2.3.16 Emissions estimates have been based on the same methodology followed in previous LAEI updates, using updated data and applying the following activity-based equation, for each pollutant:

Emissions (tonnes/year) = Material Received (tonnes/year) × Emission Factor (tonnes pollutant / tonnes of material handled)

Activity Data

2.3.17 Tonnage of material received by waste site operator across the LAEI area was obtained from the latest version (2016) of the Waste Data Interrogator database, maintained and updated by the Environment Agency (EA). This is the first time this database has been used for the LAEI, as, although it was identified in the previous LAEI as the best source to determine activity data, it was not available at the time the LAEI 2013 was compiled.

Emission Factors

2.3.18 PM factors based on the 2016 EMEP/EEA emission factors for the storage, handling and transport of mineral products (section 2.A.5.c Storage, handling and transport of mineral products) have been used. As for the LAEI 2013, a further 5% factor (i.e. a 95% reduction) was applied to these emission factors to account for the fact that these factors were derived for mineral products and are not directly applicable to waste transfer stations due to differing potential for particulate emissions.

Spatial Distribution

2.3.19 The inventory includes all Waste Transfer Stations in the LAEI area, which have been identified by projecting the GIS polygon layer of waste sites from the Waste Data Interrogator database on the LAEI grid. This is an improvement to the methodology followed for the LAEI 201, which could not rely on this database. For each identified waste site, the fraction of its total area within each LAEI grid was used to determine the spatial distribution of emissions.

Historical Emissions

2.3.20 Emissions for 2010 and 2013 have not been revised, and are the same as those reported in the LAEI 2013

Small Scale Waste Burning

2.3.21 The small scale waste burning category covers the following:

- Emissions from residential bonfires;
- Emissions from indoor burning of waste on open fires; and
- Emissions from industrial bonfires.

Pollutants

2.3.22 Emissions from small scale waste burning sources have been estimated for the pollutants shown in Table 10.

Table 10: Pollutants Reported for Small Scale Waste Burning Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Small Scale Waste Burning	7	•	•	•	-	NMVOC, CO, BaP, PCB

Emissions

2.3.23 Emissions estimates have been based on the same methodology followed in the LAEI 2013, scaling down UK emissions from the NAEI based on estimated fraction of the national emissions for London specific for each source based on various proxies.

2.3.24 Updated data used for the LAEI 2016 include new UK emissions published in the NAEI 2016. The proportion of total small scale waste burning emissions allocated to each sub-sector (domestic bonfires, domestic open fireplaces and industrial bonfires) was kept the same as in the LAEI 2013.

2.3.25 The estimated fraction of UK emissions from industrial bonfires allocated to the LAEI area in 2016 was also updated using the 2016 London to UK ratio of employment statistics in the construction sector as a proxy, as these emissions are assumed to be proportional to construction activity.

2.3.26 For residential bonfires and open fireplaces, the fractions of UK emissions allocated to the LAEI area are the same as those reported in the LAEI 2013. These are:

- Residential bonfires: 8.12% of the UK NAEI emissions, based on the proportion of suburban land cover in the LAEI area using the Centre for Ecology and Hydrology (CEH) land cover map;
- Open fireplaces: 0.73% of the UK NAEI emissions, based on the proportion of UK households using solid fuel in the LAEI, derived from national census data on the number of households that use solid fuel for heating.

Spatial Distribution

2.3.27 The same methodology used for in the LAEI 2013 was applied to distribute emissions across the LAEI area, although the following updated databases were used:

- For both residential components (bonfires and open fireplaces) of emissions, the latest CEH land cover map (2015, replacing the 2007 CEH land cover map used in the LAEI 2013);
- For emissions from industrial bonfires, the latest industrial combustion CO_2 emissions map published on the NAEI website (2015 map, replacing the 2012 map used in the LAEI 2013).

Historical Emissions

2.3.28 Emissions for years 2010 and 2013 have been updated based on revised UK emissions available in the NAEI 2016 for these years.

2.4 Construction

Introduction

2.4.1 Emissions from the Construction sector include the following subsectors:

- Non-Road Mobile Machinery (NRMM) Exhaust sources from construction sites; and
- Construction Dust.

Non-Road Mobile Machinery on Construction Sites

2.4.2 NRMM emissions from industry and construction are estimated separately in the LAEI. This section only refers to NRMM from construction sources. The methodology to estimate NRMM emissions from industrial sites is provided in section 2.1.11.

Pollutants

2.4.3 Exhaust emissions from NRRM construction sources have been estimated for the pollutants shown in Table 11.

Table 11: Pollutants Reported for NRMM Exhaust Sources from Construction Sites

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
NRMM Exhaust (Construction Sites)	16	•	•	•	•	SO_2, NMVOC, C_4H_6, NH_3, C_6H_6, CO, CH_4, N_2O, C_d, H_g, P_b, BaP

Emissions and Spatial Distribution

2.4.4 As for the LAEI 2013, NRMM exhaust emissions from construction sites for 2016 were determined combining a top down approach using total NRMM emissions reported in the NAEI for the UK, with a bottom up estimate of emission spatial distribution using active construction sites reported in the London Development Database (LDD)[5].

2.4.5 Employment data in the construction industry across the UK has been used as a proxy indicator of construction activity. Based on the data for 2016, 14.1% of construction-related NRMM emissions reported in the NAEI have been allocated to the LAEI.

Historical Emissions

2.4.6 Emissions for 2010 and 2013 were also revised, in accordance with updated NAEI data using the same methodology. Based on construction employment data, 11.8% and 14.4% of the NAEI emissions were allocate to the LAEI for 2010 and 2013 respectively.

Construction / Demolition Dust

Pollutants

2.4.7 Emissions from construction and demolition dust sources have been estimated for the pollutants shown in Table 12.

Table 12: Pollutants Reported for Construction / Demolition Dust Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Construction / Demolition Dust	2	-	•	•	-	-

Emissions and Spatial Distribution

2.4.8 Estimates of construction dust emissions follow the same methodology used to determine NRMM exhaust emissions from construction sites, using a combination of updated UK construction dust emissions estimates from the NAEI, scaled down to London, combined with construction site information from the LDD.

[5] London Development Database available online at https://www.london.gov.uk/what-we-do/planning/london-plan/london-development-database

2.4.9 The main difference with the NRMM calculation comes from the further disaggregation of UK emissions in the NAEI, which are provided separately for the following subcategories:

- Construction of houses;
- Construction of apartment buildings;
- Non-residential construction; and
- Road construction

Thus, to allocate NAEI emissions from each sub-category to the LAEI, separate proxies have been used. For the construction of houses and apartments, the latest statistical dataset on new built dwellings[6] across the UK and London were used. For non-residential construction, employment statistics on construction across the UK was used (the same as for the NRMM calculation). For road construction, road lengths in Great Britain statistics[7], related to the number of km of roads built, were collated.

The resulting scaling factors applied to NAEI construction dust emissions to estimate total emissions across London are provided in Table A-3, Appendix A.1.

Historical Emissions

2.4.10 Emissions for 2010 and 2013 were also revised, in accordance with updated NAEI data using the same methodology.

2.5 Commercial Catering (Cooking)

2.5.1 An entirely new commercial catering (cooking) PM emissions inventory has been developed as part of this LAEI 2016 update.

Pollutants

2.5.2 Emissions from kitchen flue due to cooking in commercial catering premises have been estimated for the pollutants shown in Table 13.

Table 13: Pollutants Reported for Commercial Catering Kitchen Flues

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Commercial Catering (Cooking)	2	-	•	•	-	-

[6] Live tables on house building: new build dwellings – Available online at https://www.gov.uk/government/statistical-data-sets/live-tables-on-house-building

[7] Road Lengths in Great Britain: 2017 – Available online at https://www.gov.uk/government/statistics/road-lengths-in-great-britain-2017

Source Measurement Methods

2.5.3 Measurements of Cooking Organic Aerosols (COA) in London were available at two air quality monitoring locations: Marylebone Road (kerbside site) and North Kensington (background site).

2.5.4 During the ClearFlo project (from January 2012 to February 2013) three sets of instrumentation were deployed at both sites and COA estimated (Bohnenstengel el al., 2015). The deployed instrumentation consisted on quadruple Aerosol Mass Spectrometer (AMF) (Jayne et al., 2000); compact time-of-flight AMS (DeCarlo et al., 2006); and high-resolution compact time-of-flight AMS, which measured organic aerosols in PM_1 at a high-time resolution. The fraction of COA was then estimated applying Positive Matrix Factorization (PMF) to the organic fraction (Young et al., 2015). Annual mean concentrations for the ClearFlo campaign (2012) were reported in Ots et al. (2016). Hourly mean concentrations at North Kensington were made available for 2012; but only the annual mean at Marylebone Road.

2.5.5 Aerosol Chemical Speciation Monitor (ACSM) (Ng et al., 2011) was later used to measure organic aerosols and PMF applied to estimate COA concentrations at posterior periods. Measurements comprised hourly concentrations and were available for 2013 at North Kensington; and a month (October – November 2014) at Marylebone Road.

2.5.6 These measurements of COA using the AMS and ACSM should be considered in the context of other methods in the assessment of aerosol from this source. Alternative approaches include Chemical Mass Balance, which applies detailed knowledge of the source characteristics to measured data to assess the concentration. This is the alternative to the data driven approach of PMF and both have their merits and limitations. Given the uncertainty in this relatively new area of source quantification it is prudent to consider these independent assessments as being within the range of possible values. The only comparative assessment using these two techniques was from North Kensington in 2012 where the Chemical Mass Balance approach resulted in a mean of 0.42μg/m^3 while the PMF resulted in a mean of 0.80μg/m^3. Assuming that this relationship holds true across different sites for different periods, the PMF results are presented as a range based on this comparison dataset.

Source Measurement Results

<u>Annual Mean Concentrations</u>

2.5.7 COA mean concentrations were larger at Marylebone Road (2.20μg/m^3) compared to North Kensington (0.80μg/m^3) in 2012 from AMS/AMS-PMF. Concentrations in 2013 at North Kensington decreased compared to previous year (0.48μg/m^3). Measurements for a month (October – November) in 2014 at Marylebone Road were 2.64μg/m^3. The range of COA concentrations assuming constant Chemical Mass Balance to AMS/ACSM-PMF ratio are summarised in Table 14.

2.5.8

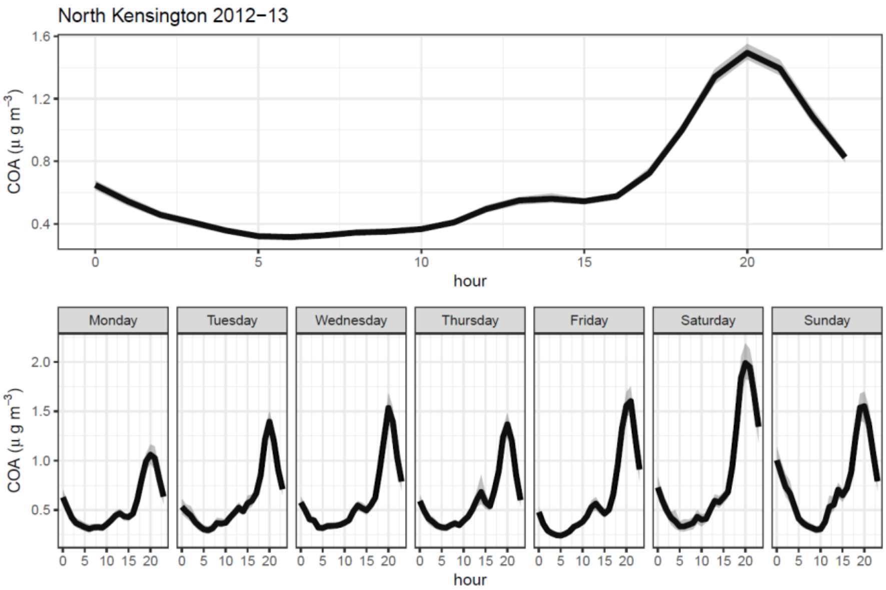
Table 14: Monitored COA Mean Concentrations in London

Year	Concentration (μg/m^3)	
	Marylebone Road	North Kensington
2012	1.16 - 2.20	0.42 - 0.80
2013	-	0.25 - 0.48
2014 (Oct – Nov)	1.39 - 2.64	-

Temporal Patterns of COA

2.5.9 The diurnal pattern of COA measurements at North Kensington for 2012-2013 shows two peak concentration times: one around 1 pm, with concentrations of 0.55μg/m^3; and a larger one between 7 pm - 9 pm, with concentrations attaining ~1.50μg/m^3 on average. Over the timescale of a week, the evening peaks were clearer on Saturdays, reaching hourly concentrations of 2.00μg/m^3. The lowest evening peak was observed on Mondays with an average concentration of 1.06μg/m^3 (see Figure 1).

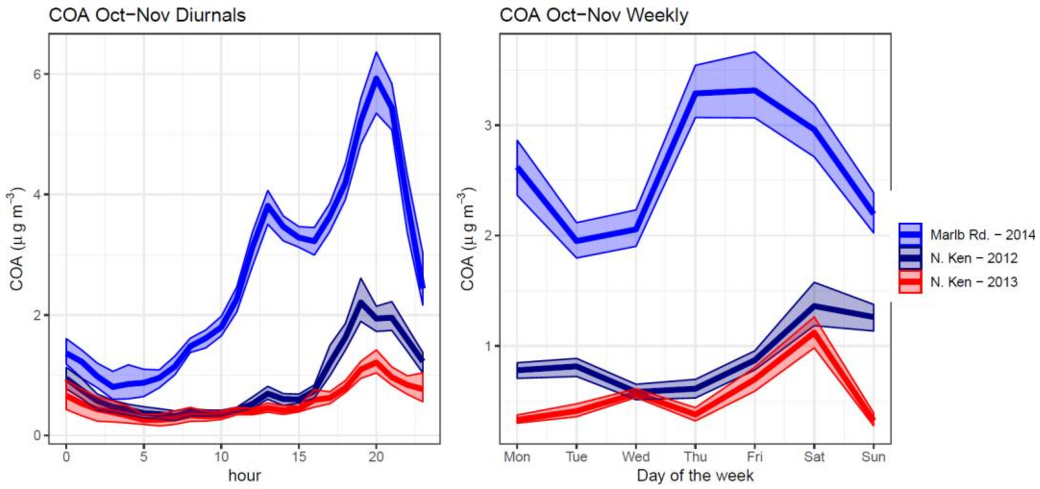
Figure 1: Variation of COA Hourly Mean Concentrations at North Kensington



2.5.10 Comparing the diurnal pattern of COA concentrations in October-November at Marylebone Road and at North Kensington (see Figure 2), the kerbside location showed consistent higher concentrations during all hours of the day. The peak at lunch time at Marylebone Road was almost 4 times higher than that observed at North Kensington. That might reflect a more central location near business with higher activity during daytime. The evening peak at Marylebone Road was also higher, approximately 3 times that at North Kensington. However, this latter showed a broader base indicating that the timing of cooking emissions span longer hours close to residential areas.

2.5.11 The weekly pattern shows that daily mean concentrations at Marylebone Road were higher on Thursday and Friday; and decreased on the weekend. The lowest concentrations were observed in the middle of the week (Tuesdays and Wednesdays). The higher COA concentrations at North Kensington took place over the weekends. The pattern of COA concentrations at Marylebone Road might be representative of higher presence of restaurants in the area with higher intensity at the end of the working week.

Figure 2: Daily and Weekly Patterns of COA Concentrations at Marylebone Road and North Kensington

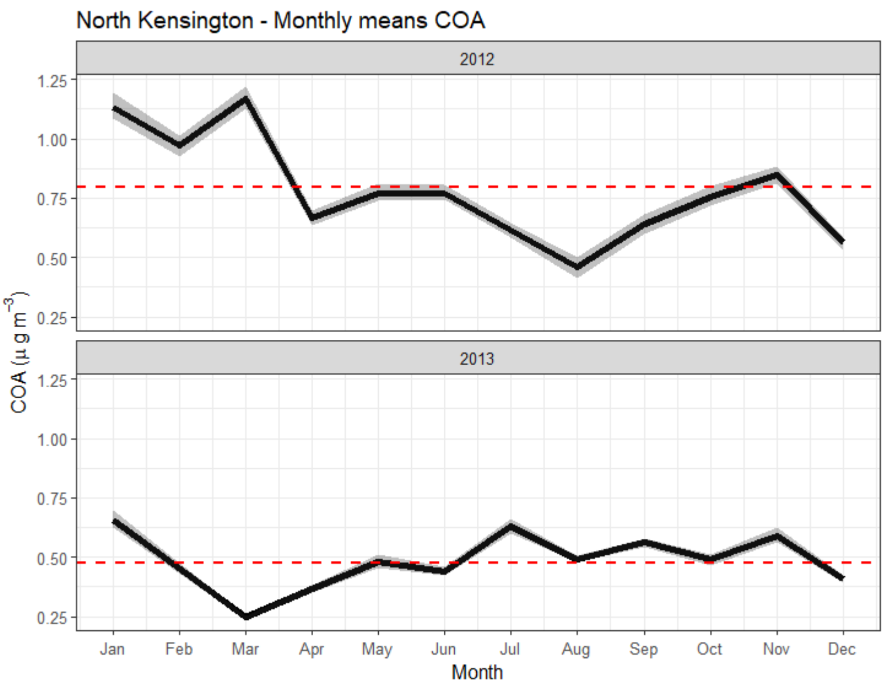


Shade area indicate 95% confidence intervals

Estimating Trends of COA Emissions

2.5.12 The 2014 annual mean COA concentration at Marylebone Road was estimated in order to evaluate possible trends in COA concentrations in London. The North Kensington dataset (AMS/ACMS-PMF) revealed that concentrations in October – November were slightly higher than the annual mean concentration, about 1.1 and 1.2 times higher in 2012 and 2013, respectively (see Figure 3). Using this scaling factor, the annual mean concentration at Marylebone Road was estimated to be 2.27µg/m^3 - 2.42µg/m^3. This annual concentration was similar to the one measured in 2012 (2.20µg/m^3) by the AMS/ACMS-PMF method (see Table 14).

Figure 3: COA Monthly Mean Concentrations at North Kensington



Red line = annual mean concentration – Gray area = 95% confidence interval

Conclusions

2.5.13 PM concentrations from cooking emissions (i.e. COA) in London have only been measured at two locations, North Kensington and Marylebone Road air quality monitoring stations.

2.5.14 COA annual mean concentrations at Marylebone Road were quite similar in 2012 (2.2µg/m^3) and in 2014 (2.3µg/m^3 - 2.4µg/m^3). Concentrations at the North Kensington monitoring station showed a slight decrease from 2012 (0.8µg/m^3) to 2013 (0.5µg/m^3). However, this difference may be a reflection of the change in instrumentation and the uncertainty of the method to quantify COA concentrations.

2.5.15 The Marylebone Road site measured consistently higher concentrations than North Kensington site, with peak concentrations 3 to 4 times higher that peak concentrations at North Kensington. Different weekly patterns were observed at the two locations, reflecting leisure or domestic emissions of cooking aerosols.

2.5.16 These results should be considered in the context of other methods in the assessment of aerosol from this source. In this context, a range of COA annual mean concentrations has been produced for Marylebone Road in 2012 (1.2µg/m^3 - 2.2µg/m^3) and 2014 (1.2µg/m^3 - 2.4µg/m^3) and in North Kensington in 2012 (0.4µg/m^3 - 0.8µg/m^3) and 2013 (0.3µg/m^3 - 0.5µg/m^3).

2.5.17 Measurements thus suggest that PM cooking concentrations could range between 1.2µg/m^3 and 2.4µg/m^3 at Marylebone Road and between 0.3µg/m^3 and 0.8µg/m^3 at North Kensington and since this is close to central London, where many of the commercial sources exist, the average concentration across London would be less than this.

Emissions and Spatial Distribution

2.5.18 2011 OS Mastermap commercial premises data were filtered to include premises registered as preparing food in a kitchen and further refined by removing bakeries and sandwich bars to keep mostly restaurants and takeaways (see Figure 4).

2.5.19 The 2016 food industry sector employment in London (pubs, restaurants and takeaways) was then used as a proxy to better represent the spatial distribution of restaurants and takeaways cooking emissions by local authority.

2.5.20 To reflect the measurements, total commercial catering (cooking) emissions sources were estimated to produce 548 tonnes of PM and were spatially distributed onto the LAEI grid exact cut using restaurants and takeaway commercial premises data described above (see Figure 5).

2.5.21 PM_{10} / $PM_{2.5}$ annual average concentration contribution from commercial catering was estimated to be 1.45µg/m^3 at Marylebone Road, 0.66µg/m^3 at North Kensington and 0.28µg/m^3 as an average over the whole LAEI area.

Figure 4: Distribution of Employment in the Food Sector Industry by Local Authority and Commercial Premises Registered as Preparing Food in a Kitchen

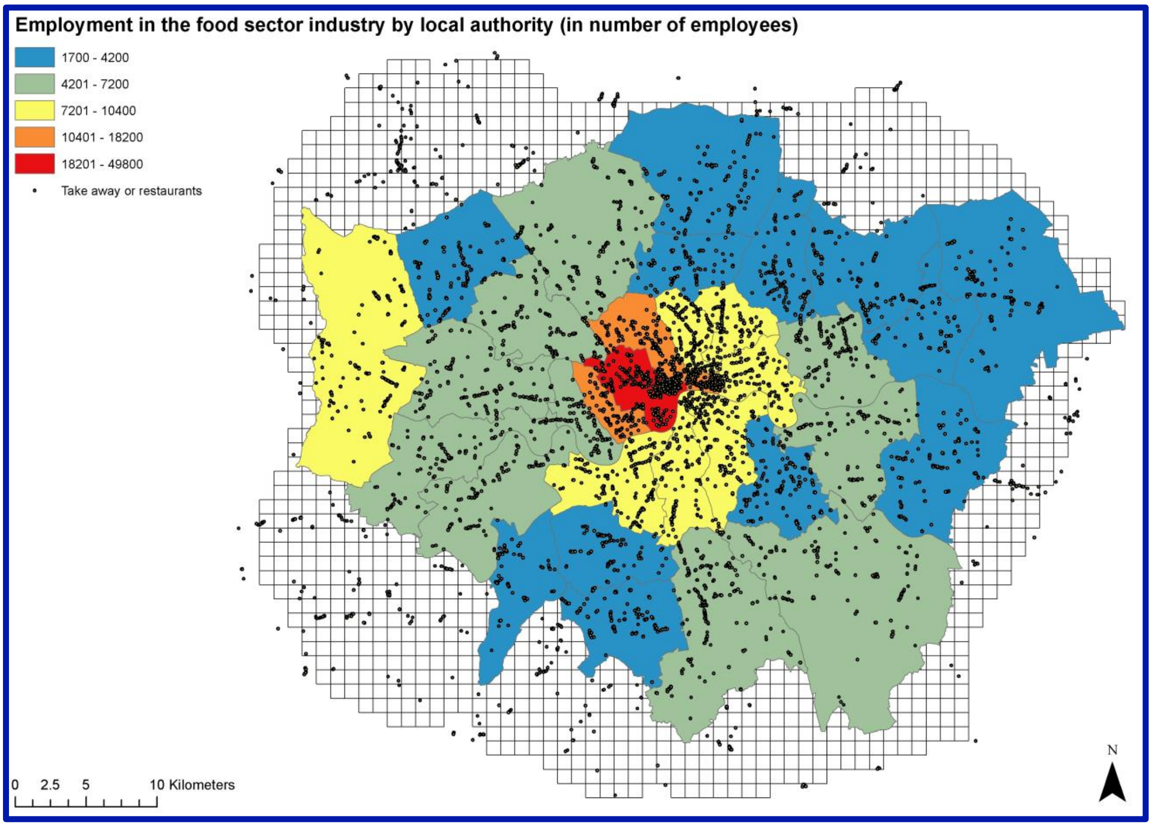
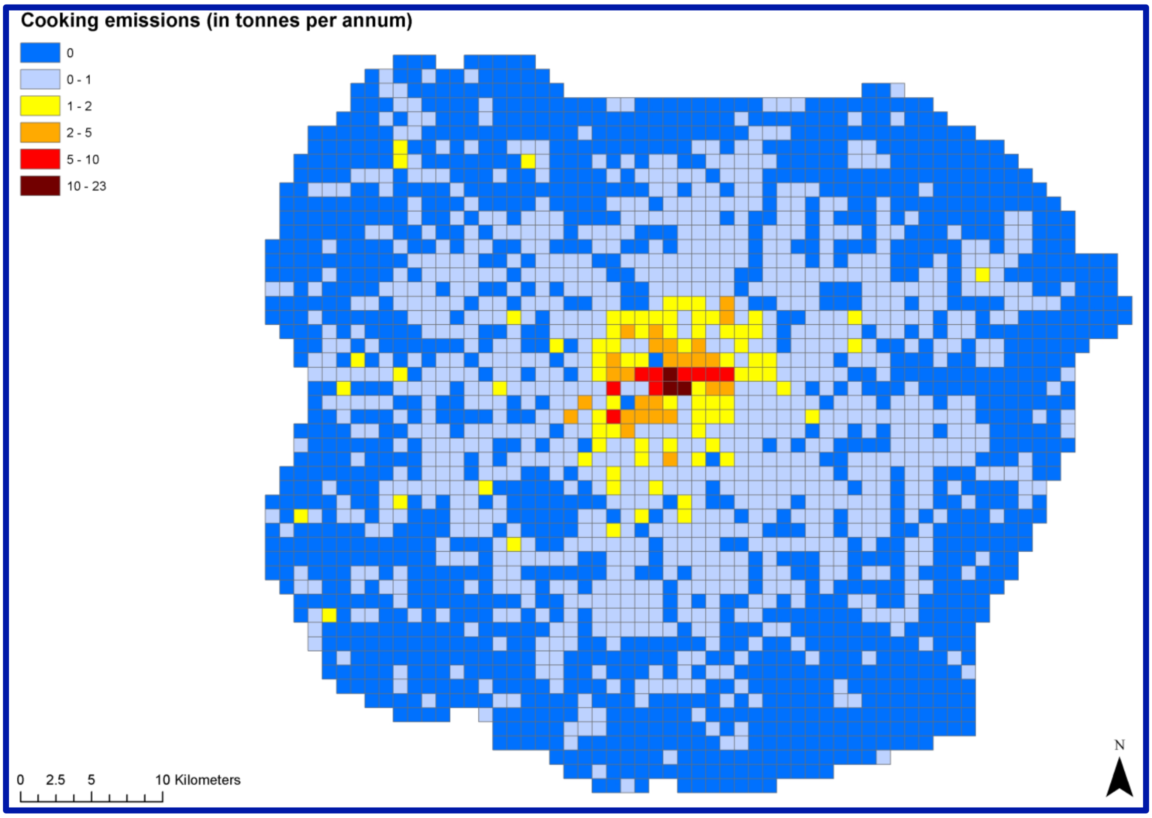


Figure 5: Distribution of Commercial Catering (Cooking) Emissions



2.6 Natural Gas Supply - Gas Leakage

Pollutants

2.6.1 Emissions from gas leakage on the natural gas supply network have been estimated for the pollutants shown in Table 15.

Table 15: Pollutants Reported for Gas Leakage from Natural Gas Supply Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Natural Gas Leakage (Supply Network)	4	-	-	-	●	NMVOC, C_6H_6, CH_4

2.6.2 Emissions estimates have been based on the same methodology followed in the LAEI 2013, using updated data and applying the following activity-based equation, for each pollutant:

Emissions (tonnes/year) = Gas Leakage (t/year) × Emission Factor (t poll/t of natural gas leaked)

Activity Data

2.6.3 Gas leakage estimates in GW.h for 2016 (see Table A-4, Appendix A.1) were estimated based on data from the two London gas network operators: Cadent for the North of London and SGN for the South of London. In order to combine activity data with emission factors, the data was converted into tonnes of natural gas leaked using a conversion factor (GW.h leaked to tonne of natural gas leaked) of 67.2, derived from literature review.

Emission Factors

2.6.4 Emission factors for 2016 were obtained from the NAEI. These are shown in Table A-5, Appendix A.1.

Spatial Distribution

2.6.5 As for the LAEI 2013, the latest map (2015) of CO_2 emissions from industrial gas consumption across the UK, available on the NAEI website at a $1km^2$ resolution, was used as a proxy for the leakage distribution across London.

Historical Emissions

2.6.6 Emissions for 2010 and 2013 have not been revised and remain as reported in the LAEI 2013.

3 Domestic Sources

Emissions from the Domestic Sector include the following subsectors:

- Emissions from the combustion of fuel used to generate heat and/or power for the domestic sector;
- Emissions from household and garden machinery (NRMM); and
- Emissions from biomass (wood) burning.

3.1 Heat and Power Generation

Introduction

3.1.1 Emissions from the Heat and Power Generation for the Domestic subsector include the following sources:

- Gas combustion sources; and
- Solid and liquid fuel combustion sources.

Gas Combustion

Pollutants

3.1.2 Emissions from gas combustion sources within the domestic heat and power generation subsector have been estimated for the pollutants shown in Table 16.

Table 16: Pollutants Reported for Gas Combustion Sources from the Domestic Heat and Power Generation Subsector

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Gas Combustion (Domestic Heat and Power)	9	•	•	•	•	NMVOC, C_6H_6, CO, CH_4, N_2O

3.1.3 Emissions estimates have been based on the same methodology followed in previous LAEI updates, using updated data and applying the following activity-based equation, for each pollutant:

Emissions (tonnes/year) = Gas Consumption (GW.h/year) × Emission Factor (t poll/GW.h)

Activity Data

3.1.4 Updated activity data (the gas consumption, expressed as energy consumed, in gigawatt-hour/year) has been collated from the Department for Business, Energy and Industrial Strategy (BEIS) website, providing domestic gas consumption across the UK at LSOA (Lower-layer Super Output Area) level for year 2016.

Emission Factors

3.1.5 For all pollutants except NO_x, updated emission factors (expressed as the mass of pollutant emitted per amount of energy consumed) were collated from the NAEI. These emission factors are shown in Table A-6, Appendix A.2.

3.1.6 For NO_x, updated emission factors based on the age distribution of boilers in London have been used. The 2010 and 2013 emission factors reported in the LAEI 2013 have also been revised to remove a double count in the age profile calculations, which had the effect of making the average age older than it should have been. As a result, revised NO_x emissions from domestic gas combustion for these years are significantly lower than reported in the previous inventory (around -30% for 2013, and -20% for 2010 emissions). NO_x emission factors are shown in Table A-7, Appendix A.2.

Spatial Distribution

3.1.7 As for the LAEI 2013, further geographical disaggregation of gas consumption - and hence emissions - was made using 2011 Census data related to the number of households using gas for central heating in each census output area. This data, combined with the LSOA gas consumption data, was used to estimate average household gas consumption and then calculate total emissions within each of the LAEI grid area.

Historical Emissions

3.1.8 Emissions from domestic gas combustion for previous base years 2010 and 2013 have been recalculated using the revised gas consumption data from BEIS and emission factors for these years.

Solid and Liquid Fuel Combustion

Pollutants

3.1.9 Emissions from other (liquid and solid fuel) combustion sources within the domestic heat and power generation subsector have been estimated for the pollutants shown in Table 17.

Table 17: Pollutants Reported for Liquid/Solid Fuel Combustion Sources from the Domestic Heat and Power Generation Subsector

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Other Fuels Combustion (Domestic Heat and Power)	16	•	•	•	•	SO_2, NMVOC, NH_3, C_6H_6, CO, CH_4, N_2O, C_d, H_g, P_b, BaP, PCB

3.1.10 Emissions estimates have been based on the same methodology followed in the LAEI 2013 update, using updated data and applying the following activity-based equation, for each fuel and each pollutant:

Emissions (tonnes/year) = Fuel Consumption (t fuel consumed/year) × Emission Factor (t poll/t fuel consumed)

Activity Data

3.1.11 Updated activity data (the mass of fuel consumed, in tonnes /year) has been collated from the BEIS website, providing domestic coal, oil and solid smokeless fuel consumption across the UK at local authority level for year 2016. Fuel consumption was then projected onto the LAEI grid and used as a proxy for the spatial distribution of emissions.

Emission Factors

3.1.12 Updated emission factors (expressed as the mass of pollutant emitted per mass of fuel consumed) were collated from the NAEI for each pollutant. These emission factors are shown in Table A-8, Appendix A.2,

Spatial Distribution

3.1.13 As for the LAEI 2013, further geographical disaggregation of the solid and liquid fuel consumption - and hence emissions - was made using 2011 Census data related to the number of households using fuel other than gas for central heating in each census output area. This data, combined with the fuel consumption data at local authority level, was used to estimate average household consumption of solid and liquid fuel and then calculate total emissions within each of the LAEI grid area.

Historical Emissions

3.1.14 Emissions from domestic solid and liquid fuel combustion for previous base years 2010 and 2013 have been recalculated using the revised consumption data from BEIS and emission factors for these years.

3.2 House and Garden Non-Road Mobile Machinery

Pollutants

3.2.1 Emissions from household and garden NRMM sources have been estimated for the pollutants shown in Table 18.

Table 18: Pollutants Reported for Household and Garden NRMM Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Household and Garden NRMM	15	•	•	•	-	SO_2, NMVOC, C_4H_6, NH_3, C_6H_6, CO, CH_4, N_2O, C_d, H_g, P_b, BaP

3.2.2 Emissions estimates have been based on the same methodology followed in the LAEI 2013, using emissions from the use of machinery in the domestic sector as reported in the NAEI scaled down to London, combined with suburban land cover data as a proxy for spatial distribution.

Emissions

3.2.3 Updated data used for the LAEI 2016 include new UK emissions published in the NAEI 2016. The estimated fraction of UK emissions allocated to the LAEI area was derived from the CEH land cover map 2015 and remain the same as in the LAEI 2013 (8.12%).

Spatial Distribution

Emissions were further distributed on the LAEI grid using the suburban land cover spatial distribution from the CEH 2015 map.

Historical Emissions

3.2.4 Emissions for years 2010 and 2013 have been updated based on revised UK emissions available in the NAEI 2016 for these years.

3.3 Domestic Wood Burning (Biomass)

3.3.1 An entirely new domestic wood burning (biomass) PM emissions inventory has been developed as part of this LAEI 2016 update.

Background

3.3.2 Wood burning is a non-negligible source of fine particles, contributing to the deterioration of air quality in both rural and urban areas. It is believed that domestic wood burning in the UK has been systematically underestimated by a factor of three in the national emissions inventory (Waters, 2016). Earlier work in London suggested that wood burning took place in the capital and that represented ~10% of the winter PM_{10} concentration in inner London in 2010 (Fuller et al., 2014). As part of the LAEI 2016, the contribution of wood burning within London as well as its spatial distribution has been estimated.

Pollutants

3.3.3 Emissions from domestic wood burning sources have been estimated for the pollutants shown in Table 19.

Table 19: Pollutants Reported for Domestic Wood Burning Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Domestic Wood Burning (Biomass)	2	-	•	•	-	-

Source Measurement Methods

Annual Means Concentration Trends

3.3.4 Concentrations of PM from wood burning (C_{wood}) can be quantified using the so-called aethalometer method (Sandradewi et al., 2008a). It is based on the distinct light absorption behaviour of wood burning and traffic fossil fuel combustion aerosols, with biomass aerosols absorbing more at shorter wavelengths (Irchstetter et al., 2004; Zotter et al., 2008 and Sandradewi et al., 2008b). Details about the methodology can be found elsewhere (Fuller et al., 2014 and Font and Fuller, 2017) Aethalometers are operated with $PM_{2.5}$ cyclones and therefore the C_{wood} here is in this size range.

3.3.5 The methodology was applied to the hourly data collected by the Magee AE-22 aethalometers belonging to the Defra's black carbon network for those urban background sites in London for the period 2010 - 2016. This comprises Woolwich (only available for 2010) and North Kensington. The concentrations of C_{wood} at rural sites were also quantified. In south east England there are three rural sites: Harwell and Chilbolton (located south-west to London); and Detling (located east to London). The most frequent wind directions in England are from the southwest and under these conditions Harwell and Chilbolton were upwind of London making them more favourable to represent a regional background for London. Additionally, Detling was affected by some local events characterised by the burning of agricultural waste by nearby farms. The Harwell monitoring site monitored black carbon concentrations until 2015; the site was then moved to the Chilbolton observatory in 2016.

3.3.6 During winter 2010, measurements of levoglucosan (an organic compound used as a chemical tracer for biomass burning, directly proportional to the concentration of wood burning PM) were made at five locations along a 35 km east-west transect across London, from Ealing to Bexley. Daily samples were collected onto quartz fibre filters (47 mm, QM-A, Whatman) using Partisol samplers. Filters were then analysed for levoglucosan as described in Fuller et al (2014).

Source Measurement Results

Uncertainty

3.3.7 No standard method or calibration standards exist for the quantification of wood burning using the aethalometer wood burning model. A lower bound for the uncertainty can be estimated using three of the data sources used to create the model. All uncertainties are estimated at 2 standard deviations (~95% confidence interval). The annual mean uncertainty for black carbon measurements using the aethalometer is estimated at 9.9% (Butterfield, 2016). The uncertainty of the aethalometer model to determine the ratio of elemental carbon into wood burning and diesel finding was found to be 9.3% when compared to carbon 14 analysis (Zotter et al., 2008). The final step in the aethalometer method is the calibration against measurements of organic carbon from the Organic Carbon / Elemental Carbon methods. Comparison of laboratories across Europe suggested maximum uncertainties of around 25% for most organic carbon measurements (Lack and Cappa, 2010). All these uncertainties combined indicated that the total uncertainty in the determination of PM from wood burning using the aethalometer method is at least 28.5% for long term averages, such as those in this analysis.

Annual Means

3.3.8 The annual mean concentrations of C_{wood} for the two urban and two rural sites are summarized in Table 20 for the LAEI base years. A minimum threshold of 75% data capture was applied to calculate annual means.

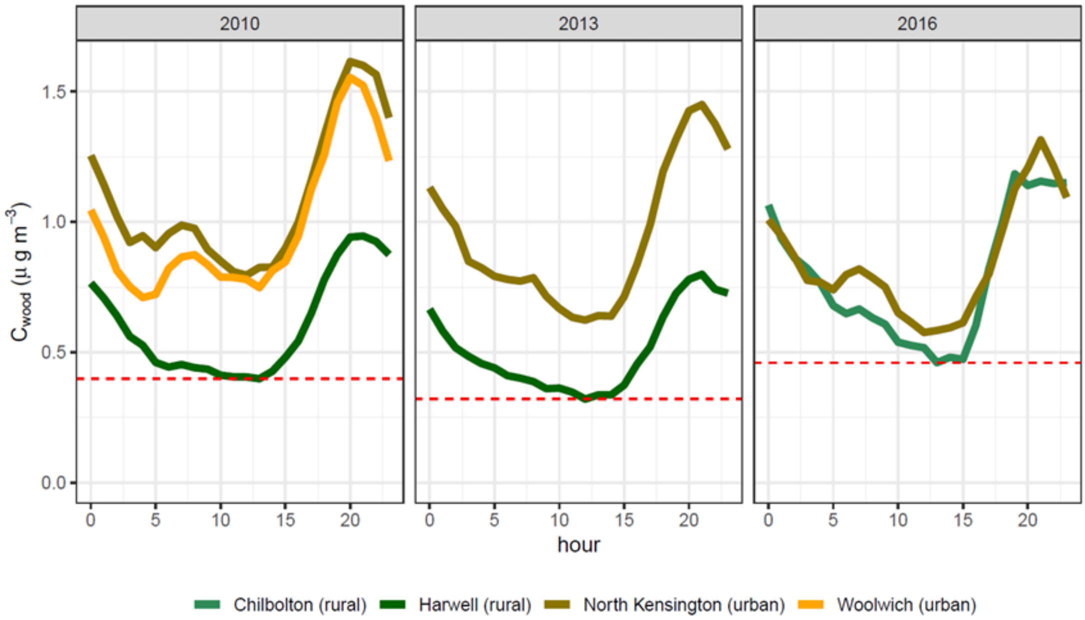
Table 20: Wood Burning PM_{10} Concentrations (C_{wood})

PM_{10} Annual Mean (µg/m³)	2010	2013	2016
Woolwich (Urban)	0.98	-	-
North Kensington (Urban)	1.09	0.94	0.85
Harwell (Rural)	0.60	0.51	-
Chilbolton (Rural)	-	-	0.79

3.3.9 The annual mean concentrations in 2010 for the two London sites were similar: 0.98µg/m³ and 1.09µg/m³ in Woolwich and North Kensington, respectively. C_{wood} at North Kensington decreased in time, from 1.09µg/m³ in 2010 to 0.85µg/m³ in 2016. The concentration at Harwell rural site also exhibited a decrease: from 0.60µg/m³ in 2010 to 0.51µg/m³ in 2013. The annual C_{wood} concentration at Chilbolton rural site was 0.79µg/m³ in 2016.

3.3.10 The diurnal pattern of C_{wood} hourly mean concentrations at the London sites indicates that the greatest concentrations were in the evenings (8 pm - 9 pm) with concentrations between 1.16µg/m³ and 1.56µg/m³ (in 2010); 1.45µg/m³ (2013) and 1.31µg/m³ (2016). That is in accordance with the expected timing of emissions. Evening concentrations tailed off during the night hours. The lowest concentrations in the day were attained between 12 pm and 3 pm: 0.75µg/m³ - 0.80µg/m³ (in 2010); 0.62µg/m³ (2013); and 0.58µg/m³ (2016). The diurnal profile of C_{wood} hourly mean concentrations in the rural site also showed that the greatest concentrations occurred in the evening (0.62µg/m³ and 0.95µg/m³). The lowest concentrations were observed in the afternoon.

Figure 6: Diurnal Patterns of PM Hourly Mean Concentrations from Wood Burning (C_{wood}) at London Monitoring Sites



Red dotted lines = minimum concentration measured at the rural location, representative of the regional concentration

3.3.11 The urban contribution to PM from wood burning was quantified using the Lenschow approach (Lenschow, 2001). The approach is based on the assumption that the concentration measured at an urban location comes from the contribution of 2 separate components - the local urban contribution, and a uniform regional background, as follows:

$$C_{total.urban} = C_{background} + C_{local.urban}$$

3.3.12 However, the diurnal profile at Harwell and Chilbolton indicated that rural concentrations were also affected by local sources. This is clearly seen in the high concentrations that were measured in the evening in accordance with the expected emission patterns. Using the annual mean concentration at the rural site might therefore overestimate the rural background concentration and consequently underestimate the urban contribution. The rural background concentration ($C_{background}$) was therefore taken as the minimum concentration measured during the afternoon (see dotted red line in Figure 6). Local emissions were expected to be minimal at this time, and due to the higher wind speeds and a well-formed boundary layer in the afternoon concentrations were expected to be representative of a wider area (i.e. "regional concentration") rather than a local derived concentration which was dominant during night-time hours.

3.3.13 Using this method, the estimated rural background concentration for London and the surrounding region in the LAEI base years is shown in Table 21.

Table 21: Estimated Regional PM_{10} Background Concentration ($C_{background}$)

PM_{10} Annual Mean ($\mu g/m^3$)	2010	2013	2016
$C_{background}$	0.40	0.32	0.46

3.3.14 The rural background concentration appeared to decrease from 2010 to 2013 by 0.08$\mu g/m^3$; however, it increased by 0.14$\mu g/m^3$ between 2013 and 2016. It is difficult to determine if such increase in 2016 was due to a change in the background concentrations, or a change of the sampling location from Harwell to Chilbolton. The difference between years was within the estimated uncertainty of the method (minimum of 28.5%). The sparsity of rural measurement locations and the uncertainty in the method does not allow concluding whether $C_{background}$ has really changed over time.

3.3.15 Having assumed a $C_{background}$ of 0.39$\mu g/m^3$ (average of 2010, 2013 and 2016 concentrations) for each LAEI base year, the contribution of London sources of wood burning to overall concentrations measured within the city ($C_{local\ urban}$) are shown in Table 22.

Table 22: Estimated Local Urban Contribution to PM_{10} in London North Kensington

PM_{10} Annual Mean ($\mu g/m^3$)	2010	2013	2016
$C_{local\ urban}$	0.70	0.54	0.45

3.3.16 Mean concentrations of levoglucosan along the 2010 transect are shown in Table 23. The data show that concentrations were greatest in suburban London and least in the centre.

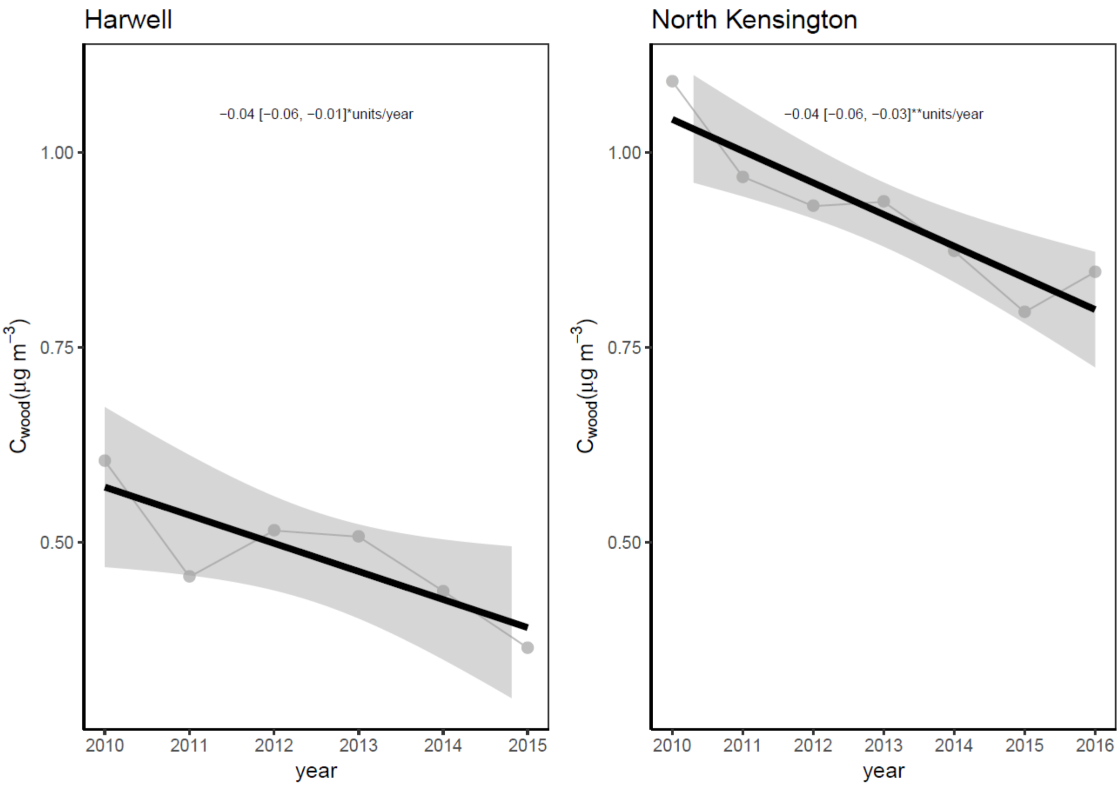
Table 23: Measured Levoglucosan Concentrations

Monitoring Location	Winter 2010 Levoglucosan Concentration ($\mu g/m^3$)
Ealing – Southall	190 ± 21
North Kensington	180 ± 20
Westminster – Horse Ferry Road	162 ± 18
Greenwich – Eltham	180 ± 20
Bexley – Belvedere	190 ± 21

Concentration Trends

3.3.17 As an indicator of the direction of change in PM from wood burning, trends in annual C_{wood} concentrations were calculated by fitting a linear model to annual mean concentrations. Only Harwell (rural) and London North Kensington (urban background) sites were considered due to their time series completeness. Harwell measurements stopped early 2016 and trends were therefore calculated to the end of 2015. Trends in Harwell captured possible changes not only in the rural background concentration but also in local emissions. Fully ratified data for North Kensington was available up to 2016. Both sites showed similar downward trend, with a decrease of 0.04$\mu g/m^3$ per year. Trends were statistically significant ($p<0.01$) (see Figure 7).

Figure 7: Linear Trends in Monitored C_{wood} Annual Mean Concentrations



* Significant at the 0.05 level calculated from annual mean concentrations

** Significant at the 0.01 level calculated from annual mean concentrations

Conclusions

Annual Means

3.3.18 Concentrations of particles from wood burning combustion (C_{wood}) in $PM_{2.5}$ were estimated using the aethalometer model. This has an estimated method uncertainty of at least 28.5%. C_{wood} was estimated at both rural and London urban sites. Both were affected by local emissions and concentrations peaked in the evening hours. A rural background concentration was estimated at that time of the day with the lowest emissions and with the highest boundary layer height, i.e. in the middle of the afternoon. This rural background was estimated from a single location in each year; the monitoring site in Harwell (Oxfordshire) between 2010 and 2015, and then Chilbolton (Hampshire) from 2016. Given the estimated uncertainty in the method used to estimate wood burning PM, and the sparsity of rural measurements, an average rural concentration of 0.39µg/m^3, assessed across the two locations, was used.

3.3.19 The urban contribution of wood burning to $PM_{2.5}$ levels was estimated by removing the background levels. At London North Kensington, the urban increment decreased from 0.70µg/m^3 in 2010 to 0.45µg/m^3 in 2016.

Spatial Distribution

3.3.20 Daily Levoglucosan measurements taken across a transect in London in 2010 confirmed the presence of wood burning in the city and showed a spatial gradient, with higher concentrations in the suburban areas compared to central sites.

Concentration Trends

3.3.21 Trends in C_{wood} concentrations were calculated for the rural and urban sites with the longest time series. Similar downward trends for both sites were observed between 2010 and 2015 (for the rural site) and 2010 and 2016 (for the urban site): -0.04µg/m^3 per year (from annual means).

Spatial Distribution

3.3.22 The spatial distribution of PM wood burning emissions has been determined as follows:

- For the Greater London area (GLA): property data including build period and type were used to represent wood burning spatially across London. These data were filtered to exclude both flats and property built after 1964 (see Figure 8).
- Outside of Greater London (and up to the M25), where the property data were not available, residential wood burning emissions from the NAEI 2015 at 1km^2 resolution were used.

3.3.23 Wood burning emissions were spatially distributed on the LAEI grid exact cut (using both methods as above) using NAEI 2015 residential wood burning emissions estimate (i.e. 2,727 tonnes PM emissions) and Wood burning PM air quality apportionment was predicted at North Kensington.

3.3.24 The model input were then scaled to reflect North Kensington urban increment measurements of 0.70µg/m^3 in 2010, 0.54µg/m^3 in 2013 and 0.45µg/m^3 in 2016 (as above in measurements conclusions section) and total London urban wood burning emissions were estimated to produce 1216, 938 and 781 tonnes of PM in 2010, 2013 and 2016, respectively (see 2016 emissions distribution in Figure 9).

3.3.25 2013 PM_{10} and $PM_{2.5}$ annual average urban wood burning concentration was modelled using 938 tonnes to represent London urban wood burning PM emissions (as above) and Wood burning PM air quality apportionment was predicted to be 0.55μg/m^3 at North Kensington and 0.43μg/m^3 as an average over the whole LAEI area.

3.3.26 London wood burning urban emissions distribution (see Figure 9) generally agree with the spatial representation of daily Levoglucosan measurements taken across a transect in London in 2010 showing a spatial gradient of higher concentrations in the suburban areas compared to central areas.

3.3.27 PM wood burning urban increment annual average concentration in 2013 have been estimated at the sites used to produce levoglucosan transect measurements across London (Table 24). Assuming that the concentration of levoglucosan is directly proportional to the concentration of wood burning PM, Table 24 shows good gradient agreement between Westminster site representing a central location and both suburban sites North Kensington and Greenwich. The comparison with two other suburban sites further away from the central zone, Ealing and Bexley, was under predicted, although these results should be put in the context of:

- High uncertainty in wood burning and levoglucosan measurements;
- The spatial representation method is based on two separate approaches in the greater London and the external area; and
- Emissions and concentration spatial representation resolution is possibly too coarse (1km x 1km grid resolution) to accurately represent the granularity and spatial gradients of the measurement sites.

Table 24: Measured Levoglucosan Concentrations (winter 2010) and 2013 PM Wood Burning Urban Increment Concentration

Measurement sites	Levoglucosan Mean (μg/m^3)	Estimated 2013 PM Annual Mean Concentration (from Wood Burning Increment, in μg/m^3)
Ealing - Southall (EA7)	190 ± 21	0.49
North Kensington KC1)	180 ± 20	0.55
Westminster - Horse Ferry Road (WM0)	162 ±18	0.49
Greenwich - Eltham (GR4)	180 ± 20	0.53
Bexley - Belvedere (BX2)	190 ± 21	0.42

Figure 8: Distribution of Property Built pre 1964 by LSOA

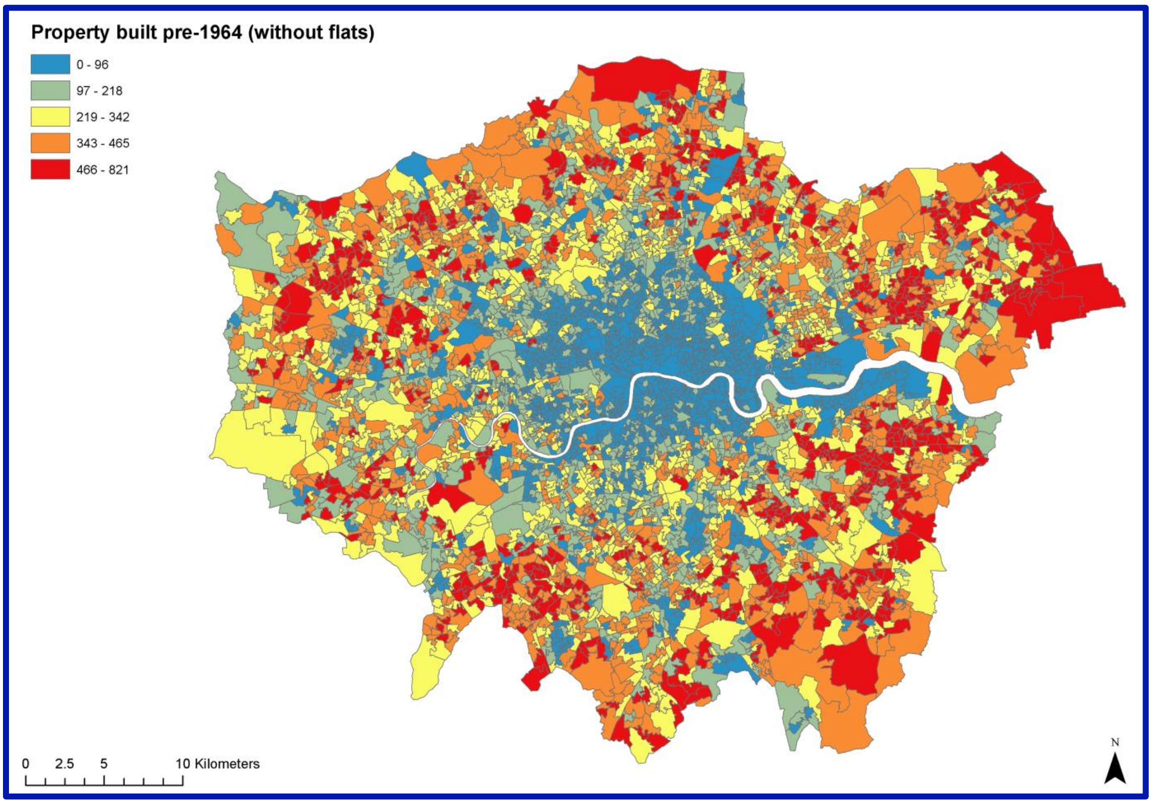
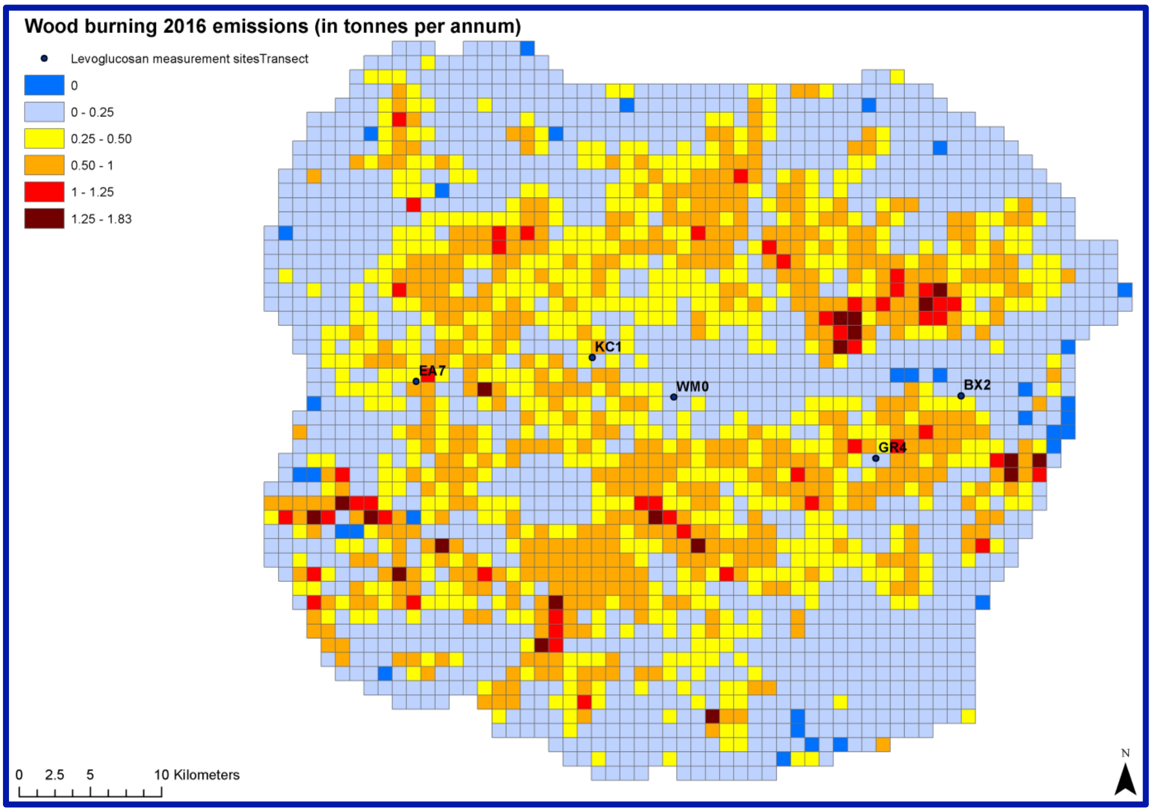


Figure 9: Spatial Distribution of Wood Burning Emissions



4 Transport Sources

Emissions from the transport sector include the following subsectors:

- Emissions from shipping on River Thames;
- Emissions from road transport;
- Emissions from rail; and
- Emissions from aviation.

4.1 River

4.1.1 Emissions from the river transport subsector include the following sources:

- Passenger shipping on the River Thames;
- Commercial shipping on the River Thames; and
- Small vessels on the Thames' tributaries and connected waterways across London, including canals.

Pollutants

4.1.2 Emissions from shipping sources have been estimated for the pollutants shown in Table 25.

Table 25: Pollutants Reported for Shipping Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
River (Shipping)	12	●	●	●	●	SO_2, NMVOC, C_4H_6, NH_3, C_6H_6, CO, CH_4, N_2O

Emissions

4.1.3 Passenger and commercial shipping emissions have been updated, using results from the Port of London Emissions Inventory 2016, commissioned by TfL and the PLA (Port of London Authority), and published in November 2017[8].

4.1.4 The inventory includes better data, and at a higher resolution than the one used in the LAEI 2013. The methodology was also improved compared to the last LAEI update, using more accurate data on ship movements and vessel types, combining the Lloyds List Intelligence and Automatic Identification System databases. This allowed for a better spatial distribution of emissions on the River Thames.

4.1.5 The inventory also included for the first time additional air pollutant sources on the Thames' tributaries and connected waterways across London, including emissions from small vessels on the canals.

Historical Emissions

4.1.6 The Port of London Emissions Inventory includes back calculations of emissions for the previous LAEI base years 2010 and 2013, which have also been incorporated within the LAEI 2016.

4.1.7 Further details on emissions calculations and assumptions are provided in the Port of London Emissions Inventory 2016.

[8] https://www.pla.co.uk/assets/finalplaportwideinventoryoutputsreportv10.2publication.pdf

4.2 Road

Introduction

4.2.1 There have been a number of significant updates to the road transport emissions sources in the LAEI 2016. As far as possible, all information used in the calculation is both London-specific and up to date, with each major development summarised below, and described in detail thereafter. Previous LAEI base years 2010 and 2013 were also updated.

4.2.2 New data sources and/or methodology changes for road transport emissions include:

- A new 2016 estimate of vehicle flows, speeds and cold starts, calculated using growth factors from TfL traffic modelling;
- A comprehensive update to the London vehicle fleet composition model in 2016, including proportions of petrol, diesel and electric vehicles;
- A full update of TfL bus flows and fleet compositions at route level in 2016, using observed data;
- Application of the latest COPERT 5 emissions factors[9] for all vehicle types in 2010, 2013 and 2016, for prediction of NO_x, NO_2 and PM exhaust emissions; and
- An update to the proportions of NO_x emitted as NO_2 in line with the NAEI.

Pollutants

4.2.3 Emissions from road transport sources have been estimated for the pollutants shown in Table 26.

Table 26: Pollutants Reported for Road Transport Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Road Transport	4	●	●	●	●	-

Road Traffic Data

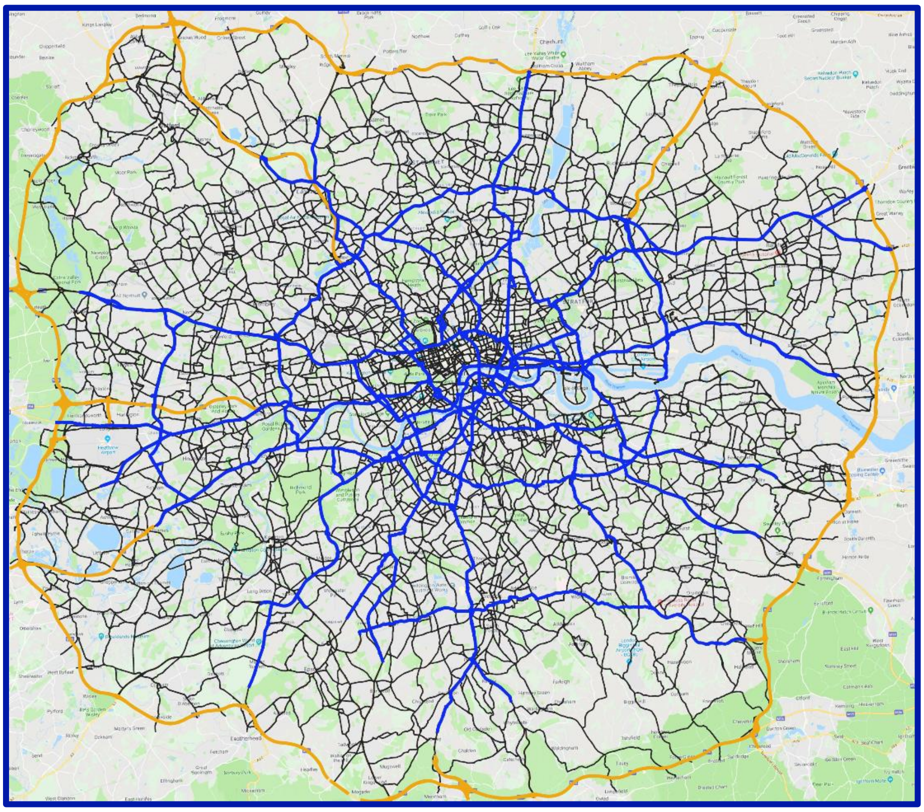
4.2.4 Traffic flows in 2016 were derived using growth factors from 2013 (LAEI 2013) rather than by obtaining new traffic counts.

4.2.5 Growth factors and speed adjustment factors, derived from TfL modelling, were applied to major road flows AM (7-10am), PM (4-7pm) and IP (10am-4pm). Specific growth factors were used for different groups of vehicles: cars, LGVs, HDVs (including HGVs and coaches), and taxis.

4.2.6 The growth factors were further divided into road type (TLRN[10], non-TLRN or motorway segment – see Figure 10), and London borough.

[9] COPERT (COmputer Programme to calculate Emissions from Road Traffic) is the EU standard vehicle emissions calculator published by the European Environment Agency (EEA)
[10] Transport for London Road Network = London's "Red Routes"

Figure 10: Major Roads, TLRN Roads and Motorways within the LAEI



In black = major roads, blue = TLRN, yellow = Motorways

4.2.7 The traffic and speed factors for the overnight period (7pm-7am) were calculated as a simple average of those for the other 12 hours of the day.

4.2.8 Minor road traffic for 2016 was derived using the factors for non-TLRN roads by borough. Since the minor road vehicle km are not held at hourly resolution in the emissions toolkit, weighted average growth factors had to be calculated first from the AM/IP/PM periods. The factors calculated for each borough were then applied to minor road vehicle km in each LAEI polygon. The overall results on vehicle km in the GLA are shown in Table A-9, Appendix A.3.

Vehicle Fleet Compositions and Engine Fuel Type Proportions

4.2.9 A full update of vehicle fleet compositions, and the proportions of petrol / diesel / electric vehicles (see Table A-10, Appendix A.3), was carried out using data from 2016. One set of fleet compositions was used for the Central/CCZ[11], with another used for the rest of London and the external area. As in the LAEI 2013, the latest national motorway fleet compositions have been used for the M25.

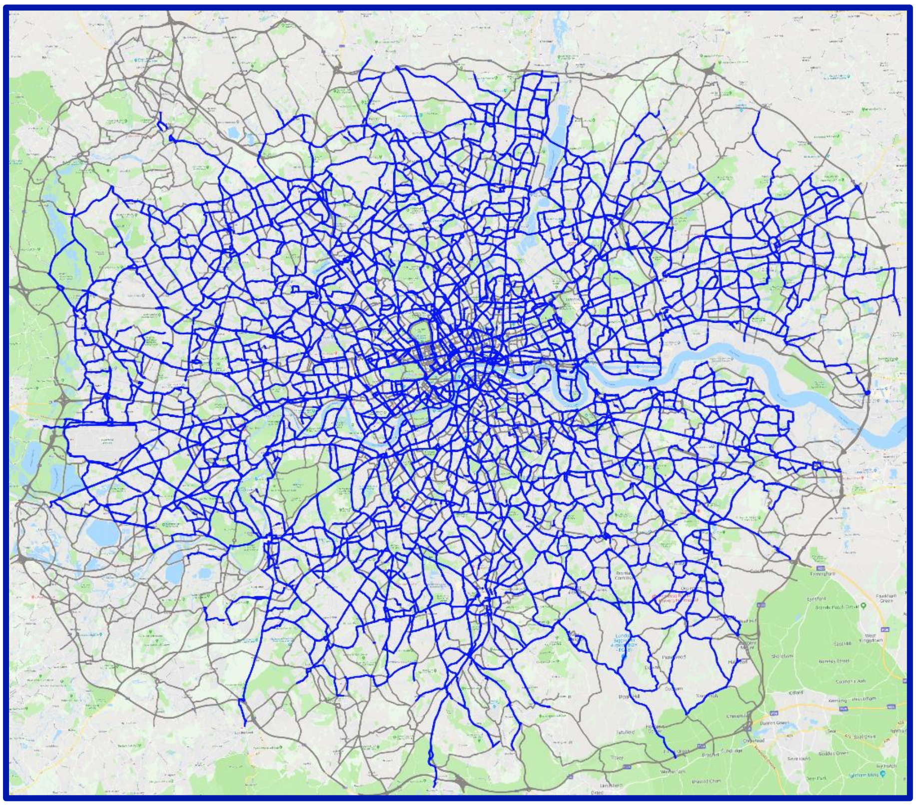
London Buses

4.2.10 The LAEI 2013 included a major revision of the way bus emissions were estimated and included TfL bus traffic, speed and technology composition by individual route derived from iBus[12] data. Building on this dataset, the LAEI 2016 provides a full update of bus flows and fleet compositions using data from 2016. The same network of bus

[11] CCZ = Congestion Charge Zone in Central London
[12] The automatic vehicle location system for London buses

routes was used, with updated fleet compositions and growth factors applied on a route-by-route basis.

Figure 11: TfL Bus and Major Roads Networks



Blue road links = Major Roads with TfL buses. Grey road links = Major Roads without buses

Emissions Factors and f-NO_2

4.2.11 The latest COPERT 5 emissions factors were used, as in the post-LAEI 2013 update. For the LAEI 2016, the proportions of NO_x emitted as NO_2 (also referred to as the primary NO_2 fraction, or f-NO_2) were updated in line with the latest assumptions at the time in the NAEI for all vehicle types and EURO emission standards, except TfL buses (2018 version[13] – see Table A-11, Appendix A.3). As in the LAEI2013, the f-NO_2 from TfL buses was calculated using a different set of ratios derived from TfL emissions tests.

Cold Start Emissions

4.2.12 The number of cold starts in 2016 was calculated in each LAEI polygon using the same factors as applied to minor roads from the 2013 base.

[13] Primary NO_2 emission factors for road transport (2018 version) (http://naei.beis.gov.uk/data/ef-transport/)

4.3 Rail

Introduction

4.3.1 Emissions from the rail transport subsector include exhaust emissions from both freight and passenger train diesel locomotives.

4.3.2 Freight rail activity data was sourced from Network Rail and emission factors from the NAEI. Department for Transport's Rail Emissions Model (REM) provided both activity and emissions data for passenger rail.

4.3.3 Diesel freight rail NO_x emissions are significantly lower for all years in the 2016 LAEI compared to the 2013 LAEI due to a revised emission factor.

Pollutants

4.3.4 Emissions from rail transport sources have been estimated for the pollutants shown in Table 27.

Table 27: Pollutants Reported for Rail Transport Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Rail	7	●	●	●	●	SO_2, NMVOC, CO

Freight Rail

Activity Data

4.3.5 Activity data related to freight rail for 2014 was obtained from Network Rail. The data were provided for the purposes of the LAEI, sourced from a combination of Network Rail's Track Access Billing System and the ACTRAFF (ACtual TRAFFic) system. Information included route descriptions, section names, section lengths, train kilometres (train-km), energy use and type of freight moved. The data allowed the calculation of emissions across London-based routes taking into account density of train movements along the relevant links.

4.3.6 The dataset was adjusted, based on expert judgement, to ensure that relevant freight movements were captured. This resulted in sections being removed from the dataset that had less than 1.5 train-km movements per week and routes with only engineering haulage.

4.3.7 While coal freight traffic is extremely limited in London, the amount of coal freight nationally has significantly reduced across the LAEI timeframe, especially in 2016. However, since Office of Rail Road (ORR) data on train-km excluding coal traffic is not available, ORR national totals of rail freight moved (excluding coal) were used to derive a ratio for 2016 versus 2014. This ratio was then applied to the 2014 train-km data for diesel freight trains for each link. In addition to this general scaling factor, train-km were increased over specific links to reflect London Gateway trains in 2016.

Emissions Factors

4.3.8 Diesel freight rail emission estimates are based on emission factors from the NAEI for 2014 and adjusted for 2016 in line with assumptions used in the NAEI. These emission factors have small variations between years reflecting the introduction of new locomotives. However, the NO_x emission factor for the Class 66 locomotive has been recently revised (decreasing by around 65%) which has a significant impact on freight rail NO_x emissions compared to the LAEI 2013.

Historical Emissions

Emissions for previous base years 2010 and 2013 were revised based on the same methodology as above, using the 2014 freight rail and revised NAEI emission factors for these years.

Train-km were also increased over specific links to reflect Crossrail spoil trains in 2013.

Revised emissions for all pollutants from all diesel freight trains in 2010 are generally lower than in the LAEI 2013 because of the use of lower activity data.

Passenger Rail

Activity Data

4.3.9 Data on passenger movements for 2014, on routes and on journey distance for each timetabled rail journey in the UK were obtained from the REM. Those journeys relevant to the LAEI were extracted. This included: routes starting and ending in London and journeys passing through London. Data were available on train-km which allowed the apportionment of emissions along London specific sections of route.

4.3.10 ORR data on total train-km by operator were used to derive ratios by operator for 2016 versus 2014. This ratio, which reflects changes in services run between the 2 years, was applied to the train-km by operator for diesel trains on each link. In addition, another scaling factor was used to reflect the strengthening of carriage numbers on trains between 2010 and 2016.

Emissions Factors

4.3.11 For diesel passenger rail, the results from the REM model were applied as data on emissions for each route were available. For SO_2 emissions from the NAEI was used to reflect the introduction of a maximum sulphur content (of 10 ppm) for diesel trains from 2012, which is required under the EU Fuel Quality Directive (2009/30/EC).

Historical Emissions

4.3.12 Emissions for previous base years 2010 and 2013 were revised based on the same methodology as above, using the 2014 ORR data and revised NAEI emission factors for these years.

4.4 Aviation

4.4.1 Emissions from the aviation subsector include the following sources:

- Heathrow Airport;
- City Airport; and
- All other smaller airports within the LAEI boundary.

4.4.2 For each airport, emissions from aircraft, airside vehicles, landside vehicles and stationary sources have been included where relevant.

<u>Pollutants</u>

4.4.3 Emissions from aviation sources have been estimated for the pollutants shown in Table 28.

Table 28: Pollutants Reported for Aviation Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Aviation	10	•	•	•	•	SO_2, NMVOC, C_4H_6, C_6H_6, CO, CH_4

Introduction

4.4.4 There have been a number of significant updates to the aviation emissions in the LAEI 2016, including changes in data sources and methodology, such as:

- A new estimate of Heathrow aircraft activity data for the year 2016, compiled using UK Civil Aviation Authority (CAA) aircraft movement data;
- New 2016 aircraft emissions calculated using the latest International Civil Aviation Organization (ICAO) emissions factors;
- An update of the 2016 aircraft times-in-mode for APU (Auxiliary Power Unit), taxi-in, taxi-out and hold based upon the Heathrow Atmospheric Emission Inventory (HAEI) 2016;
- A new estimate of total hydrocarbon emissions (used for the calculation of a number of pollutants such as CH_4 and NMVOC) from refuelling sources in 2016 was made by scaling the CO_2 aircraft emissions changes between 2013 and 2016;
- Airside and Landside vehicle emissions in 2016 were calculated by interpolating emissions between 2013 and 2020 reported in the LAEI 2013;
- For 2010 and 2013, the spatial representation of Heathrow Terminals T1, T3 and T4 was updated, whilst Terminal T5 was included and Terminal T2 removed (closed). In 2016 Terminal T2 was put back into the emissions model, whilst Terminals T3, T4 and T5 were kept the same, and Terminal T1 was removed (closed);
- For London City airport, the 2016 aircraft activity data was compiled using information from the 2016 London City Airport Annual Performance Report, and new 2016 emissions produced using the latest ICAO emissions factors, and consistent with those used at Heathrow airport.

Heathrow Airport

4.4.5 Aviation emissions in the LAEI 2016 are based upon the methodology described in HAEI reports and include the following sources:

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

Aircraft Emissions

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

- The aircraft LTO modes considered in the inventory include:
- Taxi-out (commences at stand and ends when the aircraft joins the departure queue)
- Hold at runway head
- Take-off roll (from start of roll to wheels off)
- Initial climb, from wheels off to throttle back - normally 305m (1000ft) or 457m (1500ft)
- Climb-out (from throttle back to 1000m altitude)
- Approach (from 1000 m altitude to runway threshold)
- Landing roll (from runway threshold to runway exit)
- Taxi-in (commences when the aircraft leaves the runway and ends when the aircraft reaches the stand)

Activity Data

4.4.7 Heathrow activity data for the base year 2016 were compiled using aircraft movements from 1st January to 31st December 2016, made available by the UK Civil Aviation Authority (CCA). The aircraft activity data included each aircraft movement by time and date, disaggregated by plane and engine type, number of engines, call sign, tail number, origin of the flight destination, operation type (arrival or departure) and runway used. The aircraft movement database is very large (>1 million records) and shows overall aircraft movements of 450,735 in 2010; 468,647 in 2013 (source LAEI 2013) and 474,858 in 2016 (i.e. an increase of 4% between 2010 and 2013 and 1.3% between 2013 and 2016). The total number of passengers (source: HAEI 2013 and 2016 reports) was 65.75 million in 2010, 72.33 million in 2013 and 75.67 million in 2016 (i.e.an overall increase of 15.1 % between 2010 and 2016). The number of aircraft movements show a small increase between 2013 and 2016 and the 2016 total is broadly back to what it was in 2008 (472,083), only slightly higher by 0.6% (when comparing 2016 versus 2008), reflecting the fact that the airport is operating close to maximum capacity while the increase of passenger numbers can be explained by an increase of the average number of passengers per aircraft movement.

Emission Factors

4.4.8 To calculate aircraft emissions, the ICAO emissions factors databank (issue 25A released in May 2018) was linked to the CAA aircraft movement database by engine type. The ICAO database provides jet engines certification test results of emission factors (referred to as 'emission index' in the ICAO database), smoke number and fuel factors for every aircraft engine type. Adjustments were made to account for speed effects on stationary engine tests and engine deterioration using forward speed effect factors and degradation factors in line with the Project for Sustainable Development of Heathrow (PSDH) recommendations. The pollutants in the ICAO database include: NO_x, CO and total hydrocarbons (the latter being used for estimating CH_4, NMVOC, C_6H_6 and C_4H_6 emissions) by thrust setting (7%, 30%, 85% and 100%), and these have been used to represent idle, approach, climb-out and take-off operations. The ICAO database provides other information used in the aircraft emission calculations e.g. engine category split between TurboFan and Mixed TurboFan, bypass ratios (both used in the PM calculations) and the engine maximum rated thrust (in kilo Newtons) used to estimate aircraft start-up emissions.

Thrust Settings by Mode

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

Times-in-Mode

4.4.10 Aircraft times-in-mode have been derived from Noise and Track-Keeping radar data and the National Air Traffic Services ground radar data provided by aircraft type, group, wake vortex category or runway type, and for the various LTO and APU running times. Spool up time was taken into account at the start of the take-off roll, as recommended by PSDH, to include a period during which fuel flow rates and thrust levels are significantly less than the take-off values. As part of the LAEI 2016, taxi-in, taxi-out and hold durations were updated using Electronic Flight Progress Strip data reported in the HAEI 2016. Approach, initial climb and climb-out used the same updated Noise and Track-Keeping dataset than in the LAEI 2013. APU running times has increased in 2016 (source HAEI 2016) compared with 2013 due to an increased use of pre-conditioned air.

Additional Aircraft Emissions

- APU (Auxiliary Power Unit): as APU emissions factors are not included in the ICAO test results, emission rates were taken from the HAEI reports and processed by aircraft type. Total APU emissions were calculated as the product of the aircraft activity, APU running time, the fuel consumption and the emission factor for each APU, characterised into three operating modes: no load; Environmental Control System for air conditioning plus electrical power; and main engine start for main engine start plus electrical power.
- Engine Testing: engine testing represents a very small contribution and its 2013 total emissions were kept constant in 2016.
- Refuelling: NMVOC and CH_4 emissions from refuelling source in 2016 have been scaled to the CO_2 aircraft emissions change between 2013 and 2016.

- Start-up: during the starting sequence, due to very low engine temperatures and pressures, very few NO_x emissions are produced compared to the LTO cycle and so only NMVOC and CH_4 emissions have been considered. The International Coordinating Council of Aerospace Industries Associations have performed a detailed analysis of engine starting data and recommends a simple first order linear relationship between total hydrocarbons and the take-off engine thrust rating taken from the ICAO database. Start-up emissions were calculated by multiplying the number of aircraft departing with the start-up hydrocarbon emissions.

Emissions Calculation

4.4.11 NO_x, CO, NMVOC and CH_4 emissions were calculated directly using ICAO emission factors and fuel factors. The NO_2/NO_x ratio was assumed to be 5%. CO_2 and SO_2 were derived from the fuel use, using assumed amounts of pollutant contained in aviation fuel (see Table A-12, Appendix A.3), alongside a list of fuel types used by aircraft type. The fractions of NMVOC and CH_4 within total hydrocarbon emissions were 90.4% and 9.6% respectively. NMVOC was then used to calculate C_6H_6 and C_4H_6 emissions using factors of 0.0197 and 0.018 respectively (as per the LAEI 2013).

4.4.12 PM_{10} was calculated using the PSDH methodology and the ICAO smoke number, estimated by aircraft and engine type, as described in the LAEI 2013. All of the aircraft exhaust PM mass was assumed to be in the $PM_{2.5}$ fraction and thus $PM_{2.5}$ and PM_{10} exhaust emissions are assumed to be the same for this source. PM_{10} non-exhaust emissions were also included as follows:

- PM_{10} brake wear emissions were estimated for each landing, using the following emission factor:

PM_{10} Brake Wear Emission Factor = 2.53×10^{-7} (kg PM_{10} per kg of Maximum Take-Off Weight)

- PM_{10} tyre wear emissions were calculated as the amount of weight lost per landing using the following emission factor:

PM_{10} Tyre Wear Emission Factor = 2.23×10^{-6} (kg PM_{10} per kg of Maximum Ramp Weight) - 0.0874

4.4.13 $PM_{2.5}$ non-exhaust emissions were apportioned directly from PM_{10} non-exhaust totals using brake wear and tyre wear $PM_{2.5}/PM_{10}$ mass ratios of 0.4 and 0.7 respectively.

Non-Aircraft Emissions Methodology

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

Airside Vehicle Sources

4.4.15 Airside vehicle emissions in 2016 were scaled using the LAEI 2013 estimated emissions in 2013 and 2020. The calculations were based on fuel use data for all road and off-road vehicles and plant associated with aircraft turn-around (e.g. caterers, cleaners, fuel handlers and buses) and runway maintenance. Fuel use and associated emission factors were broken down by fuel type (gasoil, diesel, petrol and LPG) and by airside vehicle categories such as road vehicles (car, LGV, HGV, bus) and off-road vehicles diesel (37-75 kW, 75-13 kW and 130-560 kW), petrol and LPG. Additional airside vehicle operation data such as the fraction of time idling and average speed when moving were also taken into account.

Landside Vehicle Sources

4.4.16 Landside vehicle emissions in 2016 were also scaled using the LAEI 2013 estimated emissions in 2013 and 2020. Landside vehicle emissions from staff car parks, taxi queues, car rental and public car parks were estimated by combining cold start and exhaust emissions derived from vehicle parking transaction data, total distance travelled and emission factors by vehicle category. Emissions from taxis queuing at the terminal forecourts were estimated using the total number of taxis passing through the Taxi Feeder Park combined with the average time spent queuing at each terminal.

Stationary Sources

4.4.17 Heating plant emissions estimated in the LAEI 2013 were kept constant in 2016. Fire-training ground emissions estimated in 2013 were also kept constant in 2016.

Spatial Information

4.4.18 The spatial representation of all the London airports has been based upon the LAEI 2013. Emission estimates were spatially analysed by source type to create geographically accurate emissions source locations for use with dispersion modelling. The source locations include:

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

4.4.19 When judged appropriate, the spatial representation was improved to give a more accurate representation of the various sources. Heathrow airport main updates are described in section below (see previous LAEI methodology reports for further information).

4.4.20 The spatial representation of Heathrow Terminals T1, T3 and T4 in 2010 and 2013 was updated, Terminal T5 was included and Terminal T2 was removed (closed). Heathrow spatial representation in 2016 was updated so that Terminal T2 was reinstated, Terminal T1 was removed (closed) and Terminals T3, T4 and T5 were kept the same as in 2010/2013. Figure 12 Illustrates Heathrow's spatial representation point, line and area sources in 2010/2013 and 2016.

4.4.21 Table A-13, Appendix A.3 shows runway utilisation for 2013 and 2016. In both years, very few easterly operations were taking place from 09L runway aircraft departure and 09R runway aircraft arrival due to the Cranford agreement in place (see runway 09L, 09R, 27L, 27R location in Figure 13).

4.4.22 The Cranford Agreement was established in the 1950s and only applies when Heathrow is on easterly operations, i.e. when planes take-off flying east, and only to those aircraft using the northern runway. Heathrow switches to easterly operations when the wind is blowing from the east – which it does about 30% of the time. The Cranford agreement was assumed to be in place in the 2010, 2013 and 2016 spatial representation.

4.4.23 A new mode, cruising-in/cruising-out was plotted at 1 km^2 grid resolution, to represent the aircraft maintaining altitude just below 1000 m until clear of the London Heathrow inbound flight path (between London Bridge and the LAEI boundary).

Figure 12: Heathrow Airport Spatial Representation in 2010/2013 and 2016

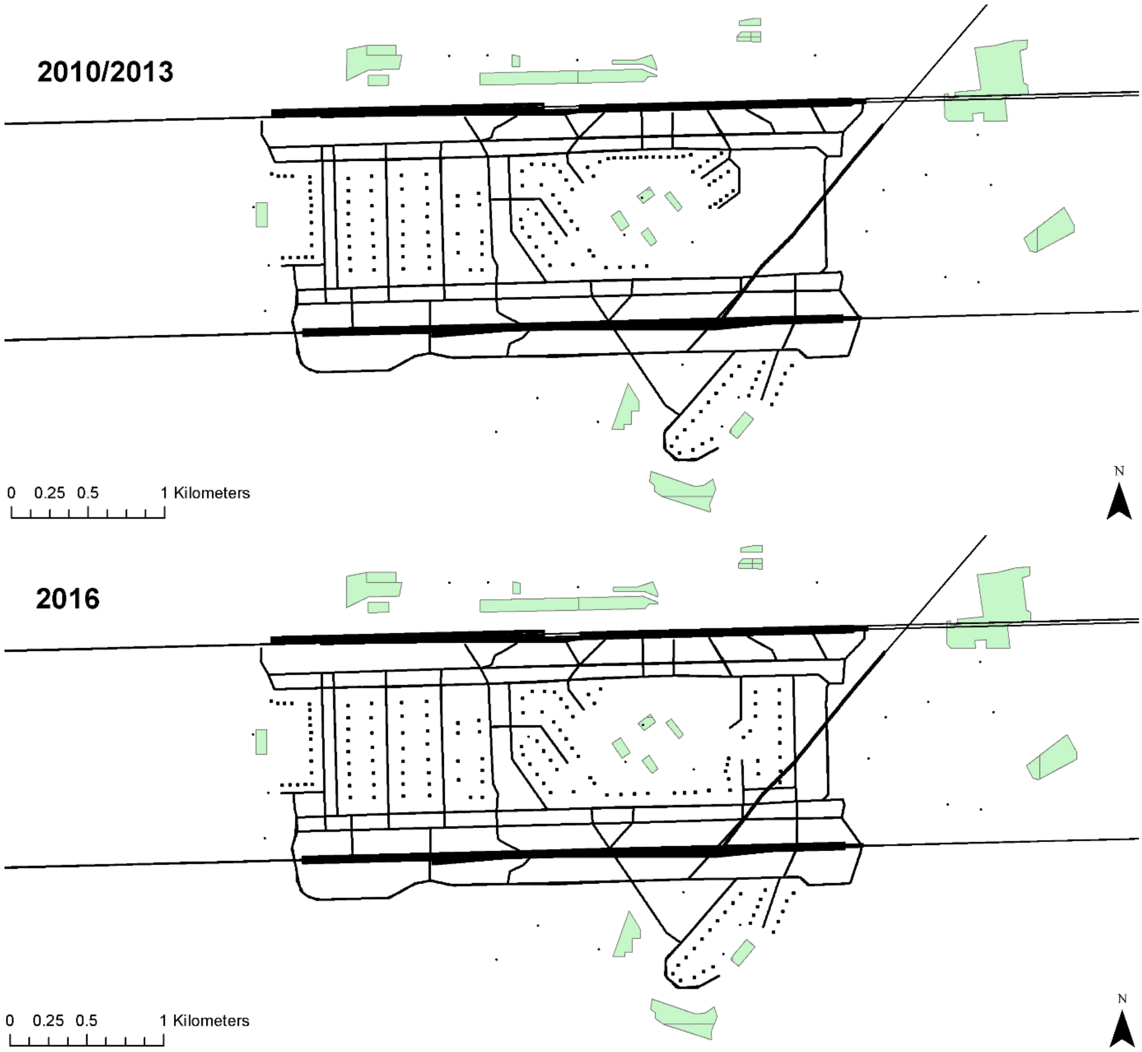
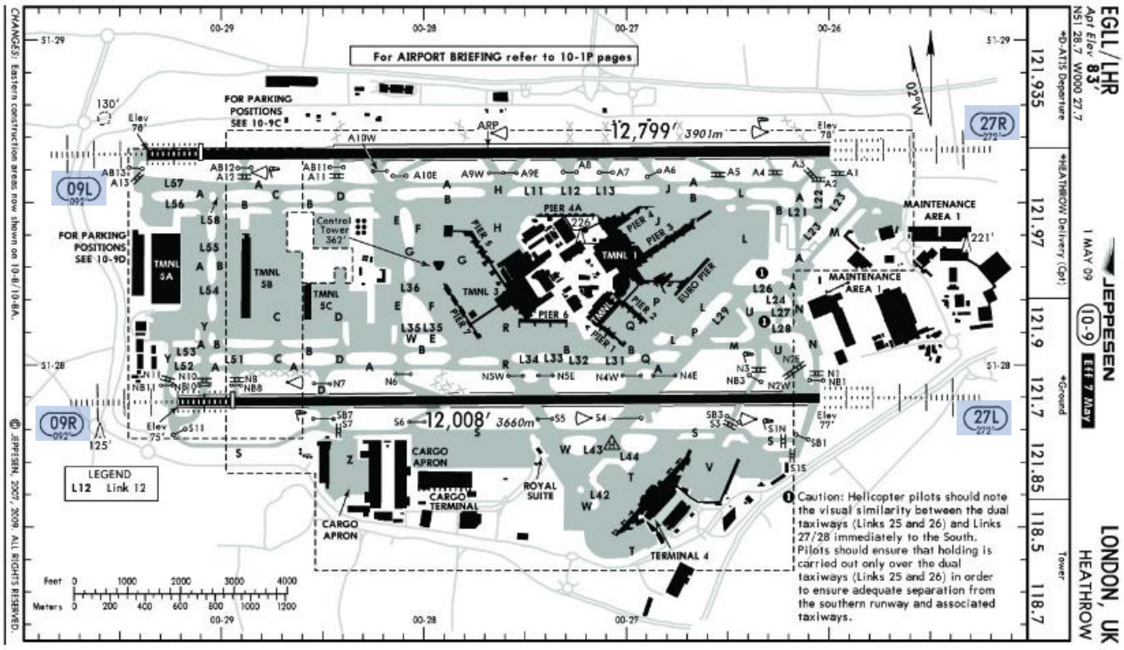


Figure 13: Heathrow Airport Diagram[14]



[14] http://www.nycaviation.com/spotting-guides/lhr/lhr-general-information/

London City Airport

4.4.24 The Heathrow Airport emissions methodology has been adapted to calculate emissions from London City Airport. Some simplifications had to be made however, as most datasets available for London City (e.g. activity and times-in-mode) are less detailed than those available for Heathrow. A brief overview of the assumptions used to produce 2016 emissions at London City airport is provided below (2010 and 2013 assumptions can be found in LAEI 2013 methodology report).

Aircraft Emissions

4.4.25 Aircraft activity data from London City airport have been compiled using information from the 2016 the airport's Annual Performance Report. Aircraft movements in 2016, by aircraft type, are summarised in Table A-14, Appendix A.3.

4.4.26 London City Airport passenger numbers and aircraft movements show a large and steady increase year after year. Aircraft movements increased from 67,871 in 2010, 73,640 in 2013 to 84,955 in 2016 (i.e. an increase of 8.5% between 2010 and 2013 and 15.4% between 2013 and 2016). The total number of passengers was 2.79 million in 2010, 3.40 million in 2013 and 4.54 million in 2016 (i.e. an overall increase of 63% between 2010 and 2016).

4.4.27 The ICAO emission and fuel factor database has been linked to aircraft movements from the Annual Performance Report using the most common engine for each aircraft type and based upon knowledge gained at Heathrow. The aircraft movements were split equally between arrival and departure.

4.4.28 Assumptions for aircraft times-in-mode (see Table A-15, Appendix A.3) were extracted from the 2007 Planning Application report provided by London City.

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

Non-Aircraft Emissions

4.4.30 All other city airport sources are considered to be small, and due to a lack of more specific information, the emissions in 2013 was taken from the LAEI 2013 and growth to 2016 using the total aircraft movement changes between 2013 and 2016.

Spatial Information

4.4.31 At London city, the climb-out length was reduced (to reach London Bridge at 1000 m altitude) to represent the steep glide slope and the stringent rules imposed to limit the noise impact from aircraft operations due to the airport's proximity to Central London. Emissions at London City were assumed to be spatially represented using 60 % of all arrivals approaching from the east side of the airport and 60 % of all departures taking off toward the west (both taking advantage of westerly wind)

Other Smaller Airports

4.4.32 Due to a lack of new and reliable activity datasets for Stapleford, Denham, Elstree, Northolt, Biggin Hill, Battersea Heliport and Lippits Hill Heliport, and the relatively small contribution to total emissions from these sources, estimates of emissions for 2010 and 2013 were taken directly from the LAEI 2013, and 2016 emissions were assumed to be the same as in 2013.

5 Miscellaneous

Emissions from smaller sectors not part of the main sectors (industrial and commercial / domestic / transport) are grouped under the Miscellaneous category. These include the following:

- Emissions from agriculture;
- Emissions from accidental fires and bonfires; and
- Emissions from biosynthesis in forests.

5.1 Agriculture

5.1.1 Emissions from the Agriculture subsector include the following sources:

- Fuel combustion sources for building heating and the use of off-road vehicle and machinery;
- Livestock sources including animal husbandry and manure management; and
- Fertilisers and soils sources.

<u>Pollutants</u>

5.1.2 Emissions from agriculture sources have been estimated for the pollutants shown in Table 29.

Table 29: Pollutants Reported for Agriculture Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Agriculture	15	●	●	●	-	SO_2, NMVOC, C_4H_6, NH_3, C_6H_6, CO, CH_4, N_2O, C_d, H_g, P_b, BaP

<u>Emissions</u>

5.1.3 Emissions estimates have been based on the same methodology followed in the LAEI 2013, scaling down UK emissions from the NAEI based on the estimated fraction of the national emissions that should be allocated to the LAEI area for each source, using various land cover data and, for livestock, animal census data, as a proxy.

5.1.4 Updated data used for the LAEI 2016 include new UK emissions published in the NAEI 2016. As before, gas emissions have been excluded because these are covered in the industrial/commercial gas consumption estimates, whilst emissions from burning straw have also been excluded because these are considered not relevant in London.

5.1.5 For combustion and other agriculture sources, the estimated fraction of UK emissions allocated to the LAEI area, derived from the CEH land cover map 2015, remain the same as those used in the LAEI 2013 for each sub-sector (see Table A-16, Appendix A.4).

5.1.6 For livestock, the fraction of UK emissions allocated to the LAEI area were derived from the latest Defra agricultural census data, provided at Local Authority level (see Table A-17, Appendix A.4).

Spatial Distribution

5.1.7 Emissions were further distributed on the LAEI grid using the spatial distribution of the relevant CEH land use category, as illustrated in the above-mentioned Table A-18, Table A-19 and Table A-20, Appendix A.4.

Historical Emissions

5.1.8 Emissions for years 2010 and 2013 have been updated based on revised UK emissions available in the NAEI 2016 for these years. For livestock emissions, revised animal census data for 2010 and 2013 were also used to review the fraction of UK emissions allocated to the LAEI area.

5.2 Accidental Fires and Bonfires

Pollutants

5.2.1 Emissions from accidental fires and bonfire sources have been estimated for the pollutants shown in Table 30. Note that non methane volatile organic compounds (NVMOC) emissions were missing in previous LAEI updates, so these have been added to the list of reported pollutants this time.

Table 30: Pollutants Reported for Accidental Fires and Bonfire Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Accidental Fires / Bonfires	7	•	•	•	-	CO, CH_4, BaP, PCB, NMVOC

5.2.2 Emissions estimates have been based on the same methodology followed in the LAEI update, using a combination of updated data on accidental fires, estimates of mass burnt, and emission factors from the NAEI.

Activity Data

5.2.3 Data on accidental fires were collated from the London Fire Brigade Incidents Records[15] database update for 2016. Depending on the type of accidental fire, average mass burnt (for buildings or vehicles) or area burnt (for vegetation and forests) has been estimated.

5.2.4 The allocation of each fire incident to a specific NAEI emission sector, and the assumptions on estimates of mass / area burnt, based on the average size of fire (determined using the number of pumps attending the incident as a proxy) are the same as those used for the LAEI 2013, and are summarised in Table A-18, Table A-19 and Table A-20 respectively.

Emission Factors

5.2.5 Emission factors for various types of accidental fires are provided either as mass of pollutant per mass burnt (for vehicles, dwellings and other buildings) or mass of

[15] Available online at https://data.london.gov.uk/dataset/london-fire-brigade-incident-records/

pollutant per area burnt (for forest and vegetation). Emission factors used in the NAEI 2016 have not been revised and remain the same as those used in the previous inventory. These are provided in Table A-21, Appendix A.4.

Historical Emissions

5.2.6 Emissions for base years 2010 and 2013 have not been revised and remain as those reported in the LAEI 2013.

5.3 Forests - Biosynthesis

Pollutants

5.3.1 Emissions from forests (biosynthesis) sources have been estimated for the pollutants shown in Table 31.

Table 31: Pollutants Reported for the Forest (Biosynthesis) Sources

Source	N.o. Pollutants Reported	Key Pollutants				Other Pollutants
		NO_x	PM_{10}	$PM_{2.5}$	CO_2	
Forests (Biosynthesis)	1	-	-	-	-	NMVOC

Emissions

5.3.2 Emissions from forestry were calculated using the same methodology followed in the LAEI 2013, scaling down UK emissions from the latest NAEI based on the fraction of UK woodland within the LAEI area.

Spatial Distribution

5.3.3 Emissions were distributed on the LAEI grid using the spatial distribution of woodlands (both broadleaf and coniferous) from the 2015 CEH land cover map as a proxy.

Historical Emissions

5.3.4 Emissions for years 2010 and 2013 have been updated in line with the revised NAEI emissions for these years.

Appendix A Data Tables

A.1 Industrial and Commercial Sector

Table A-1: NAEI Emission Factors for Industrial and Commercial Gas Combustion Sector

Pollutant	Emission Factor (kg pollutant/GW.h) *
NO_x	239.7
PM_{10}	2.527
$PM_{2.5}$	2.527
CO_2 **	184,200
NMVOC	8.0
C_6H_6	0.728
CO	94.0
CH_4	16.2
N_2O	0.324

* Same data for all years (2010, 2013, 2016)

** Converted from Carbon emission factor

Table A-2: NAEI Emission Factors for Industrial and Commercial Other Fuels Combustion Sector

Pollutant	Emission Factor (tonne pollutant / tonne fuel consumed)					
	2010		2013		2016	
	Fuel Oil	Coal	Fuel Oil	Coal	Fuel Oil	Coal
NO_x	1.246E-02	4.197E-03	1.245E-02	4.329E-03	1.246E-02	4.335E-03
PM_{10}	8.551E-04	2.838E-03	8.547E-04	2.928E-03	8.552E-04	2.932E-03
$PM_{2.5}$	7.330E-04	2.620E-03	7.326E-04	2.702E-03	7.330E-04	2.707E-03
CO_2	3.223E+00	2.305E+00	3.223E+00	2.378E+00	3.223E+00	2.381E+00
SO_2	1.532E-02	1.743E-02	1.568E-02	1.532E-02	1.392E-02	1.348E-02
NMVOC	1.376E-04	5.000E-05	1.376E-04	5.000E-05	1.376E-04	5.000E-05
C_6H_6	-	1.890E-06	-	1.890E-06	-	1.890E-06
CO	3.787E-03	2.258E-02	3.785E-03	2.330E-02	3.787E-03	2.333E-02
CH_4	4.072E-04	2.426E-04	4.070E-04	2.502E-04	4.072E-04	2.506E-04
N_2O	2.443E-05	6.064E-05	2.442E-05	6.256E-05	2.443E-05	6.265E-05
C_d	2.952E-07	3.000E-08	2.952E-07	3.000E-08	2.952E-07	3.000E-08
H_g	1.469E-08	4.500E-07	1.469E-08	4.500E-07	1.469E-08	4.500E-07
P_b	5.218E-07	4.760E-06	5.218E-07	4.760E-06	5.218E-07	4.760E-06
BaP	7.751E-11	2.250E-09	7.751E-11	2.250E-09	7.751E-11	2.250E-09
PCB	-	1.000E-09	-	1.000E-09	-	1.000E-09

Table A-3: Scaling Factors for Allocation of NAEI Construction Dust Emissions to LAEI

Construction Category	Percentage of NAEI Emissions Allocated to LAEI
Houses	11%
Apartment Buildings	11%
Non-Residential	14.1%
Roads	3%

Table A-4: Estimated Natural gas leakage in London (GW.h)

Year	North London (Cadent)	South London (SGN)	Total	Source
2010	263	171	435	LAEI 2013
2013	220	154	374	LAEI 2013
2016	175	110	285	Latest data from operators

Table A-5: Emission Factors for Gas Leakage, NAEI 2016 (t of pollutant / t of gas leaked)

Pollutant	2010	2013	2016
CO_2 *	0.029	0.035	0.035
CH_4	0.801	0.799	0.814
C_6H_6	0.002	0.002	0.001
NMVOC	0.143	0.137	0.132

* Converted from Carbon emission factor

A.2 Domestic Sector

Table A-6: NAEI Emission Factors for Domestic Gas Combustion Sector

Pollutant	Emission Factor (kg pollutant/GW.h) *
PM_{10}	3.888
$PM_{2.5}$	3.888
CO_2 **	674,700
NMVOC	8.003
C_6H_6	0.720
CO	84.2
CH_4	16.2
N_2O	0.324

* Same data for all years (2010, 2013, 2016)

** Converted from Carbon emission factor

Table A-7: NO_x Emission Factors by Borough for Domestic Gas Combustion Sector

Area/Borough	2010	2013	2016
Barking and Dagenham	102.36	81.29	65.44
Bexley	99.85	78.70	62.23
Bromley	98.39	82.43	68.41
Camden	87.95	68.17	58.69
Croydon	105.98	86.13	70.19
Greenwich	95.35	74.46	61.66
Hackney	100.91	83.10	65.45
Hammersmith and Fulham	83.00	63.79	54.01
Havering	107.62	89.39	70.06
Hounslow	93.50	75.30	56.30
Islington	100.65	81.22	65.44
Kensington and Chelsea	92.83	72.28	59.82
Kingston	102.75	85.81	70.58
Lambeth	102.10	82.71	67.50
Merton	104.02	81.01	65.21
Newham	94.68	75.50	61.05
Redbridge	94.72	77.68	64.05
Richmond	107.02	86.47	70.61
Southwark	100.00	79.78	64.59
Sutton	103.09	84.07	68.34
Tower Hamlets	87.43	68.55	56.79
Waltham Forest	95.90	74.68	58.35
Wandsworth	97.47	76.63	62.69
Inner London	100.65	81.22	65.44
Outer London	94.20	75.25	62.25
Average	98.24	78.98	64.25

Table A-8: NAEI Emission Factors for Domestic Other Fuels Combustion Sector

Pollutant	Emission Factor (tonne pollutant / tonne fuel consumed)								
	2010			2013			2016		
	Oil	Coal	SSF	Oil	Coal	SSF	Oil	Coal	SSF
NO_x	2.24E-03	3.55E-03	4.16E-03	2.24E-03	3.56E-03	4.16E-03	2.24E-03	3.52E-03	4.15E-03
PM_{10}	8.34E-05	9.27E-03	1.78E-03	8.34E-05	9.29E-03	1.78E-03	8.33E-05	9.18E-03	1.78E-03
$PM_{2.5}$	8.34E-05	9.13E-03	1.76E-03	8.34E-05	9.15E-03	1.75E-03	8.33E-05	9.04E-03	1.75E-03
CO_2	3.15E+00	2.63E+00	2.90E+00	3.15E+00	2.64E+00	2.90E+00	3.15E+00	2.61E+00	2.90E+00
SO_2	2.86E-04	2.32E-02	1.60E-02	4.68E-04	2.09E-02	1.60E-02	5.06E-04	1.79E-02	1.60E-02
NMVOC	5.08E-05	1.40E-02	4.90E-03	5.08E-05	1.40E-02	4.90E-03	5.08E-05	1.40E-02	4.90E-03
NH_3	-	2.40E-05	-	-	2.41E-05	-	-	2.38E-05	-
C_6H_6	2.54E-06	6.18E-04	2.17E-04	2.54E-06	6.18E-04	2.17E-04	2.54E-06	6.18E-04	2.17E-04
CO	2.50E-03	1.40E-01	1.51E-01	2.50E-03	1.40E-01	1.51E-01	2.50E-03	1.39E-01	1.51E-01
CH_4	4.39E-04	8.58E-03	9.33E-03	4.39E-04	8.60E-03	9.31E-03	4.39E-04	8.50E-03	9.29E-03
N_2O	2.63E-05	1.23E-04	1.34E-04	2.63E-05	1.23E-04	1.33E-04	2.63E-05	1.22E-04	1.33E-04
C_d	1.00E-08	3.00E-08	3.11E-08	1.00E-08	3.00E-08	2.64E-08	1.00E-08	3.00E-08	2.56E-08
H_g	1.00E-10	1.10E-07	2.40E-07	1.00E-10	1.10E-07	2.04E-07	1.00E-10	1.10E-07	2.17E-07
P_b	9.00E-08	2.85E-06	2.89E-06	9.00E-08	-	2.46E-06	9.00E-08	2.85E-06	2.37E-06
BaP	3.51E-09	1.55E-06	3.30E-07	3.51E-09	1.55E-06	3.30E-07	3.51E-09	1.55E-06	3.30E-07
PCB	-	3.60E-09	3.60E-09	-	3.60E-09	3.60E-09	-	3.60E-09	3.60E-09

A.3 Transport Sector

Table A-9: Billion vehicle km Travelled in the Greater London Area

Year	Motorcycle	Taxi	Car	Bus and Coach	LGV	Rigid HGV	Artic HGV
2010	0.63	1.07	22.86	0.72	3.22	0.92	0.28
2013	0.61	1.01	22.13	0.72	3.18	0.89	0.28
2016	0.61	1.04	22.55	0.73	3.39	0.91	0.28

Table A-10: LDV Split by Fuel Type in 2016

Location	Petrol Car	Diesel Car	Electric Car	Petrol LGV	Diesel LGV	Electric LGV
CCZ	53.8%	45.7%	0.5%	1.2%	98.2%	0.5%
M25	40.0%	60.0%	0.0%	3.3%	96.7%	0.0%
Inner / Outer London / External Area	59.4%	40.5%	0.2%	1.3%	98.6%	0.2%

Table A-11: Assumed f-NO_2 Values by Vehicle Type and EURO Emissions Standard

Vehicle Types	Engine EURO Standard Classification	f-NO_2
Petrol Cars and LGVs	Pre-Euro 1	0.04
	Euro 1	0.04
	Euro 2	0.04
	Euro 3	0.03
	Euro 4	0.03
	Euro 5	0.03
	Euro 6	0.03
Diesel Cars and LGVs	Pre-Euro 1	0.15
	Euro 1	0.13
	Euro 2	0.13
	Euro 3	0.27
	Euro 3 with DPF	0.51
	Euro 4	0.46
	Euro 4 with DPF	0.42
	Euro 5	0.33
	Euro 6	0.3

Vehicle Types	Engine EURO Standard Classification	f-NO_2
HGVs and Coaches	Pre-Euro I	0.11
	Euro I	0.11
	Euro II	0.11
	Euro III	0.14
	Euro IV	0.1
	Euro V	0.08
	Euro VI	0.05
Motorcycles	All	0.04

Table A-12: Aviation: CO_2 and SO_2 Emission Factors

Fuel Type	Emission Factor (kg/tonne)	
	CO_2	SO_2
Aviation Turbine Fuel	3,150	0.87
Aviation Spirit	3,172	0.87

Table A-13: Distribution of Aircraft Movements on Runways at Heathrow Airport

Runway	Distribution of Aircraft Movements	
	2013	2016
09L	16.0%	13.8%
09R	17.5%	15.8%
27L	32.8%	35.3%
27R	33.7%	35.1%

Table A-14: London City Airport 2016 Aircraft Movements and Fraction by Aircraft Type

Aircraft Type	2016 Movements	
	Aircraft Movements	% of Total Movements
Airbus A318	956	1.1%
ATR-42 + ATR-72	3,206	3.8%
Bae 146-100 146-200 146-300	540	0.6%
Cessna Citation CJ2-C25A CJ3-C25B CJ1-C525 CJ4-C25C Mustang-C510 C560 Excel-C56X	1,788	2.1%

Aircraft Type	2016 Movements	
	Aircraft Movements	% of Total Movements
Sovereign-C680		
Dornier 328 D328	2,026	2.4%
Dash 8 Q400	12,860	15.1%
Embraer ERJ-170 E170	10,821	12.7%
Embraer ERJ-190 E190	26,429	31.1%
Fokker 50 F50	1,076	1.3%
Dassault Falcon 2000-F2TH F900 10-FA10 50-FA50 FA7X	682	0.8%
Hawker 800 H25B	788	0.9%
Dornier 328 Jet D328J	532	0.6%
Avro RJ-100 RJIH	3,760	4.4%
Avro RJ-85 RJ85	14,860	17.5%
Saab 2000 SB20	3,996	4.7%
Others	635	0.7%
Totals	84,955	100%

Table A-15: Aircraft Times-in-Mode for the LTO Cycle Stages

Mode	Time (s)
Taxi-out/Taxi-in/Hold	150
Take-off	18.5
Initial Climb	52
Climb-out	68
Cruising out/Cruising in	113
Approach	200
Landing	41
APU Narrow Bodied	1,974

A.4 Miscellaneous Sector

Table A-16: Agriculture Sector - Fraction of UK Emissions Applied to LAEI (Combustion and Other Agriculture)

Emission source	Sub Source	% of UK emission assigned to LAEI	CEH Land Use Category used for Spatial Distribution
Combustion	Combustion	0.65%	Arable and improved grassland
Other Agriculture	Agricultural soils	0.41%	Arable and improved grassland
	Synthetic N-fertilizers	0.41%	Arable land
	Fertiliser use	0.65%	Arable and improved grassland
	N-excretion on pasture range and paddock unspecified	0.89%	Improved grassland

Table A-17: Agriculture Sector – Fraction of UK Emissions Applied to LAEI (Livestock)

Emission source	2010	2013	2016	CEH Land Use Category used for Spatial Distribution
Dairy and Non-dairy cattle	0.12%	0.12%	0.10%	Improved grassland land cover
Sheep	0.07%	0.07%	0.07%	Improved grassland land cover
Horses	0.89%	0.89%	0.89%	Improved grassland
Swine	0.14%	0.12%	0.14%	Arable and improved grassland
Poultry	0.08%	0.06%	0.12%	Arable and improved grassland
Manure management *	0.12%	0.12%	0.10%	Improved grassland land cover

* Same distribution as cattle, as waste mainly associated with cattle

Table A-18: Accidental Fires – Fire Property and NAEI Emission Sector Allocation

LBF Incident Report Database - Property Types	NAEI Sector	Units for Activity
Road vehicle	Accidental fires – vehicles	mass burnt
Dwellings and other residential	Accidental fires – dwellings	mass burnt
Non-residential and outdoor structure and outdoor refuse related types	Accidental fires - other buildings	mass burnt
Outdoor (Straw/stubble burning)	Accidental fires – straw	mass burnt
Part of outdoor category (not including refuse burning)	Accidental fires – vegetation	area burnt
Part of outdoor category (Woodland/forest - broadleaf/hardwood Woodland/forest - conifers/softwood)	Accidental fires – forests	area burnt

Table A-19: Accidental Fires – Mass Burnt Assumptions

Size of Fire	N.o. Pumps Attending	Assumed Average Mass Burnt (kg)
Very small	0	62.5
Small	1	250
Medium	2 - 3	500
Big	4 - 8	750
Very big	> 8	1500

Table A-20: Accidental Fires – Area Burnt Assumptions

Size of Fire	N.o. Pumps Attending	Assumed Average Area Burnt (ha)
Very small	0	0.0025
Small	1	0.005
Small-medium	2 - 3	0.01
Medium	4 - 5	0.02
Medium-big	6 - 7	0.2
Big	8 - 9	0.5
Very big	9	1

Table A-21: Accidental Fires – Emission Factors

Accidental Fires Type	Units	CO	CH_4	NO_x	NMVOC	PM_{10}	$PM_{2.5}$	PCB	BaP
Dwellings	g/kg mass burnt	42	6.5	3	15	8	7.4	0.00051	0.0012
Vehicles	g/kg mass burnt	63	5	2	8.5	50	46.5	0.0255	0.0012
Other buildings	g/kg mass burnt	42	6.5	3	15	8	7.4	0.00051	0.0012
Refuse	g/kg mass burnt	52.4	-	1.5	13.8	12.8	11.9	0.00056	0.0001
Straw	g/kg mass burnt	58	2.7	2.3	9	11	9	-	-
Forests	kg/ha burnt	5400	357	190	500	324	265	-	-
Vegetation	kg/ha burnt	1436	94	51	132	21.6	17.6	-	-

London Atmospheric Emissions Inventory (LAEI) 2016 - Methodology

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