Heathrow Airport 2013 Air Quality Assessment

Report for Heathrow Airport

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Executive summary

This report presents an assessment of air quality in the neighbourhood of Heathrow Airport in the year 2013. It considers the impacts of the operation of the airport (including road traffic to and from the airport), as well as non-airport sources of air pollution, in order to estimate both the overall picture of air quality and the airport's contribution to it.

Broadly speaking, near Heathrow there are three main categories of air pollution:

- Road traffic, some of which will be travelling to or from the airport;
- Heathrow Airport itself, especially aircraft engines and the ground support vehicles and equipment that service the aircraft;
- Other sources both local and more distant, such as domestic and commercial heating, industrial processes, and other vehicles and equipment powered by combustion engines.

The study was designed with these purposes in mind. The work falls into three main parts:

- First, an emissions inventory is calculated to estimate how much of each pollutant is emitted from the different sources.
- Second, dispersion modelling calculates how the emissions are carried through the air, due to meteorological conditions such as wind speed and direction, and the resulting concentrations of pollution in the air.
- These modelled concentrations are then compared with monitoring data as a check on the accuracy of the model.

The final total concentrations are also compared with the air quality limit values to see if there is a risk of them being exceeded.

Since the methodology is largely the same as that used for the 2008/9 work, which was extensively documented[1,2], only those aspects which are materially different are described in this report. Primarily the methodology follows the recommendations of the Project for the Sustainable Development of Heathrow (PSDH)[3], a project sponsored by the Department for Transport to formulate the best practical methodology. The methodology is also consistent with the International Civil Aviation Organization's Airport Air Quality Manual[4], meeting the requirements of the 'Advanced' approach with elements of the 'Sophisticated' approach where data is available. For dispersion modelling ADMS-Airport was used as per the PSDH recommendations.

Using up to date activity data and emission factors, emissions and air quality impacts were calculated for:

- Aircraft – The main methodology change related to the use of electronic flight progress strips (EFPS) for calculating taxiing times. The EFPS is expected to result in more accurate taxiing times.
- Ground Support Equipment – More detailed fuel use data was available for some vehicles (per vehicle) in 2013, resulting in more accurate allocation of fuel use to particular vehicle types.
- Car Parks – No methodological changes.
- Stationary Sources – No methodological changes.

1 Underwood B Y, Walker C T and Peirce M J (2010) Heathrow Airport Emission Inventory 2008/9. AEAT/ENV/R/2906.
2 Underwood B Y, Walker C T and Peirce M J (2010) Air Quality Modelling for Heathrow Airport 2008/9: methodology. AEAT/ENV/R/2915.
3 Department for Transport (2006) Project for the Sustainable Development of Heathrow. Report of the Airport Air Quality Technical Panels.
4 International Civil Aviation Organization (2011) Airport Air Quality Manual. Doc 9889, ISBN 978-92-9231-862-8.

- Road – Updated traffic model (2009 base – consistent with Airport Commission submission).
- Background emissions updated.

Note that new road traffic emission factors were released in June 2014, and therefore this study includes two sets of results:

- Old EFs – refers to results utilising the previously released emission factors (current at the start of this study).
- New EFs – refers to results utilising the current set of emission factors for roads (released summer 2014).

Pollutants included:

- NOx – oxides of nitrogen
- NO_2 – nitrogen dioxide – total concentrations only
- PM_{10} – particle matter – coarse (includes dust, brake and tyre wear)
- $PM_{2.5}$ – particle matter – fine (includes dust, brake and tyre wear)
- CO_2 – Carbon dioxide (other sources added for 2013) – emissions only

Runway utilisation:

The split between easterly and westerly operations varies from year to year depending on weather conditions. Westerly operations were conducted 66.5% of the time in 2013, a decrease from 71.7% in 2008/9.

NOx Emissions

Table E1 shows the calculated annual NO_x emissions for 2013 and 2008/9 for each major source category. Emissions from all airport source have declined over the period 2008/9 to 2013.

Table E1: NO_x emission rate (tonne/year) by source category

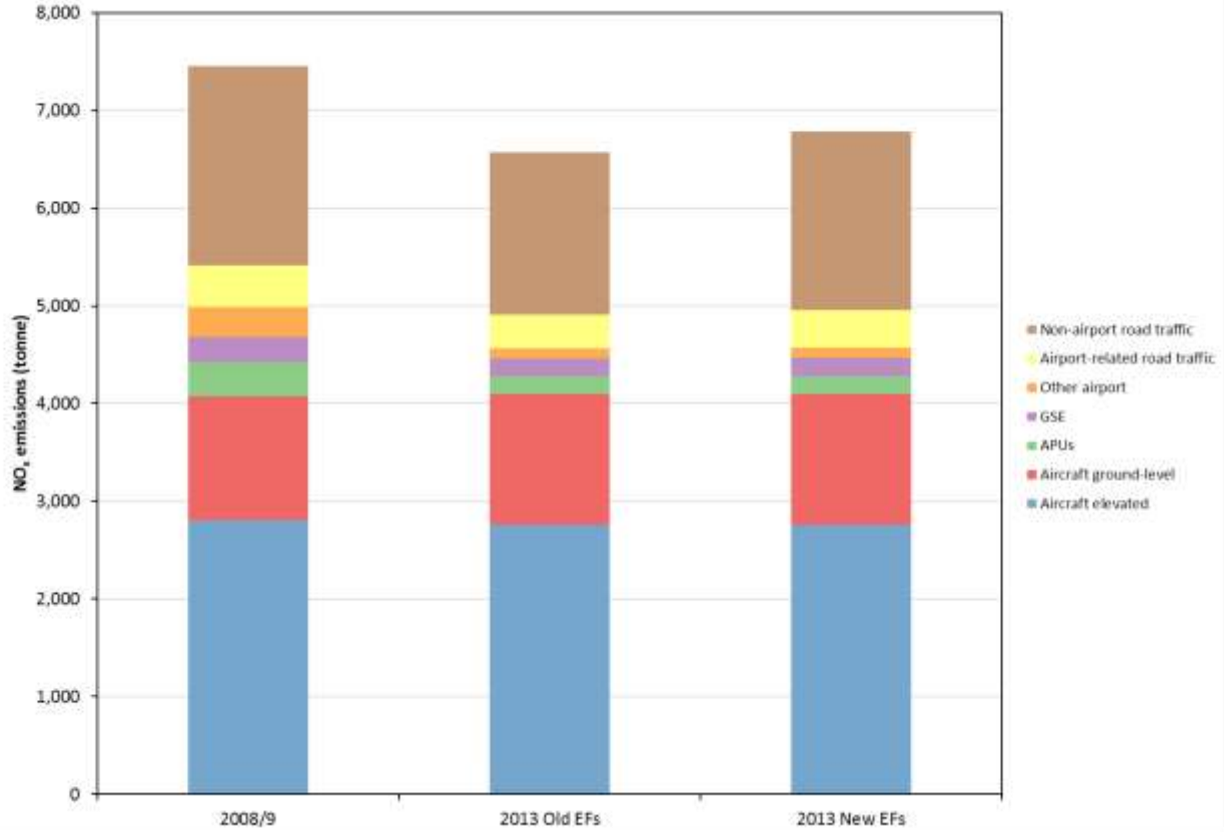
Source category		NO_x emission rate (tonne/year)			Difference (%)[a]	
		2013 Old EFs	2013 New EFs	2008/9[g]	Old EFs	New EFs
Airport	Aircraft – elevated[b]	2761.41	2761.41	2830.92	-2	-2
	Aircraft – ground[c]	1524.36	1524.36	1633.60	-7	-7
	GSE	177.40	186.79	260.50	-32	-28
	Road traffic[d]	350.55	386.82	429.22	-18	-10
	Heating plant	85.78	85.78	283.60	-70	-70
	Other[e]	12.10	12.03	18.41	-34	-35
Non-airport	Road traffic[f]	1661.51	1829.76	2034.37	-18	-10

[a] Difference (%) = 100 * (2013 value – 2008/9 value) / 2008/9 value
[b] From wheels off to 1000 m above ground (departure) and from 1000 m to touchdown (arrival)
[c] Emissions from aircraft on the ground, including main engines, APU and engine testing emissions
[d] Total for airport-related trips within the 11 km × 11 km rectangular major road network area
[e] Includes additional car parking emissions and fire training ground emissions
[f] Total for non-airport trips within the 11 km × 11 km rectangular major road network area
[g] The airport-related/non-airport split is not available for road network emissions for 2008/9, so for the purposes of this table, they have been split in the same proportion as 2013

Aircraft make a dominant contribution to the airport NO_x emissions. It should be borne in mind that this is for aircraft emissions in the LTO cycle (so cruise emissions are excluded because they have no impact on local air quality), and road network emissions are presented only on major roads within the 11 km × 11 km area around the airport. Choosing a larger road network area would change the balance of calculated emissions.

The fall in emissions from heating plant is largely a result of the decommissioning of the Combined Heat and Power plant operated on behalf of Heathrow Airport by Thames Valley Power, which occurred in 2011.

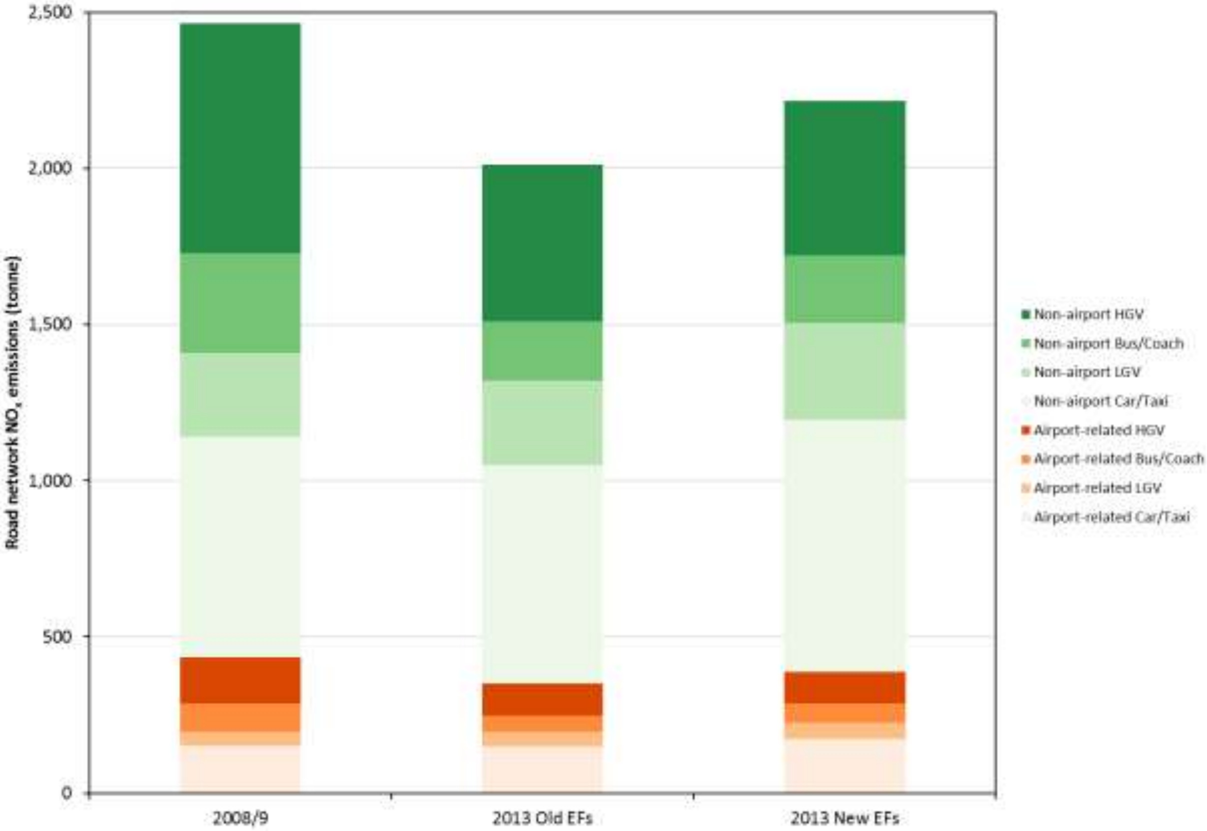
Figure E1: NO_x emissions by source category



Emissions of aircraft and roads are the dominant sources.

Although the traffic, both airport-related and non-airport, is dominated by cars (Figure 7), the higher emission factors for HDVs mean that the latter contribute appreciably to NO_x emissions.

Figure E2: Breakdown of road network NO_x emissions by vehicle type



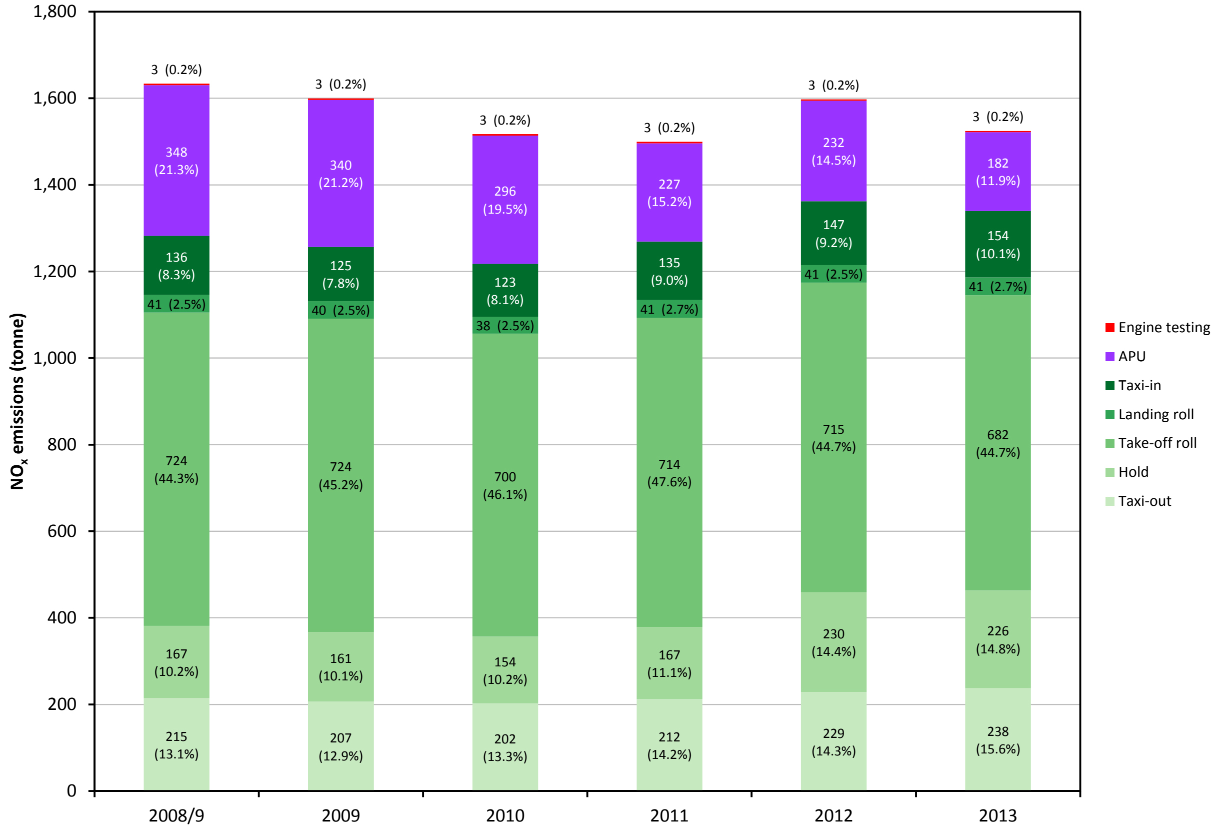
Take-off roll contributes a relatively large fraction of ground-level emissions, but the hot exhaust gases from engines at high thrust lead to plume rise (i.e. hot air rises), which tends to lower the ground-level concentration per unit emission. The dispersion modelling process takes this into account when determining ground-level concentrations.

The methodology for calculating taxiing and hold times changed in the 2012 inventory as taxi times were taken from EFPS data. This results in a step change (increase) in calculated emissions, especially for hold. Emissions from taxi-in, taxi-out and hold are 19.1% higher in 2013 than 2008/9. The EFPS data appears to be more accurate than the radar-based data used in the 2008/9 assessment, and has higher coverage and better availability.

APU emissions (purple) are another major contributor, but the calculations are sensitive to the assumptions about APU running times. APU times have fallen steadily over the last few years, and this is reflected in the emissions, with a 47.7% fall in emissions between 2008/9 and 2013.

Emissions from engine ground runs (engine testing) are included in the inventory for completeness, but they are very small.

Figure E3: Breakdown of ground-level aircraft NO_x emissions by mode



PM Emissions

Table E2 and Table E3 show the calculated annual PM_{10} and $PM_{2.5}$ (collectively referred to as PM) emissions respectively, for 2013 for each major source category. It is worth noting that for aircraft exhaust emissions the $PM_{2.5}$ mass has been assumed equal to the PM_{10} mass, but this is not the case for brake and tyre wear emissions.

Focusing on airport-related sources, emissions from airport-related traffic on the road network are roughly equal to aircraft emissions, in contrast to NO_x where aircraft emissions were dominant. However it should be repeated that choosing a different road network area would change the balance of calculated emissions.

Table E2: PM_{10} emission rate (tonne/year) by source category

Source category		PM_{10} emission rate (tonne/year)			Difference (%)[a]	
		2013 Old EFs	2013 New EFs	2008/9[g]	Old EFs	New EFs
Airport	Aircraft – elevated[b]	15.5	15.5	15.0	3	3
	Aircraft – ground[c]	35.5	35.5	36.6	-3	-3
	GSE	9.9	10.9	21.4	-54	-49
	Road traffic[d]	38.4	44.6	41.4	-7	8
	Heating plant	6.9	6.9	26.1	-74	-74
	Other[e]	1.2	1.4	1.6	-25	-13
Non-airport	Road traffic[f]	183.3	211.9	197.9	-7	7

[a] Difference (%) = 100 * (2013 value – 2008/9 value) / 2008/9 value
[b] From wheels off to 1000 m above ground (departure) and from 1000 m to touchdown (arrival)
[c] Emissions from aircraft on the ground, including main engines, APUs, engine testing, brake wear and tyre wear
[d] Total for airport-related trips within the 11 km x 11 km rectangular major road network area
[e] Includes additional car parking emissions and fire training ground emissions
[f] Total for non-airport trips within the 11 km x 11 km rectangular major road network area
[g] The airport-related/non-airport split is not available for road network emissions for 2008/9, so for the purposes of this table, they have been split in the same proportion as 2013

Table E3: $PM_{2.5}$ emission rate (tonne/year) by source category

Source category		$PM_{2.5}$ emission rate (tonne/year)			Difference (%)[a]	
		2013 Old EFs	2013 New EFs	2008/9[g]	Old EFs	New EFs
Airport	Aircraft – elevated[b]	15.5	15.5	15.0	3	3
	Aircraft – ground[c]	28.1	28.1	29.3	-4	-4
	GSE	7.5	7.9	18.8	-60	-58
	Road traffic[d]	22.6	26.3	27.0	-16	-2
	Heating plant	6.9	6.9	26.1	-74	-74
	Other[e]	0.8	1.0	1.1	-28	-13
Non-airport	Road traffic[f]	108.5	125.2	129.1	-16	-3

[a] Difference (%) = 100 * (2013 value – 2008/9 value) / 2008/9 value
[b] From wheels off to 1000 m above ground (departure) and from 1000 m to touchdown (arrival)
[c] Emissions from aircraft on the ground, including main engines, APUs, engine testing, brake wear and tyre wear
[d] Total for airport-related trips within the 11 km x 11 km rectangular major road network area
[e] Includes additional car parking emissions and fire training ground emissions
[f] Total for non-airport trips within the 11 km x 11 km rectangular major road network area
[g] The airport-related/non-airport split is not available for road network emissions for 2008/9, so for the purposes of this table, they have been split in the same proportion as 2013

CO_2 Emissions

Aircraft make a dominant contribution to the airport CO_2 emissions, similar to NOx. Road emissions are also a key source.

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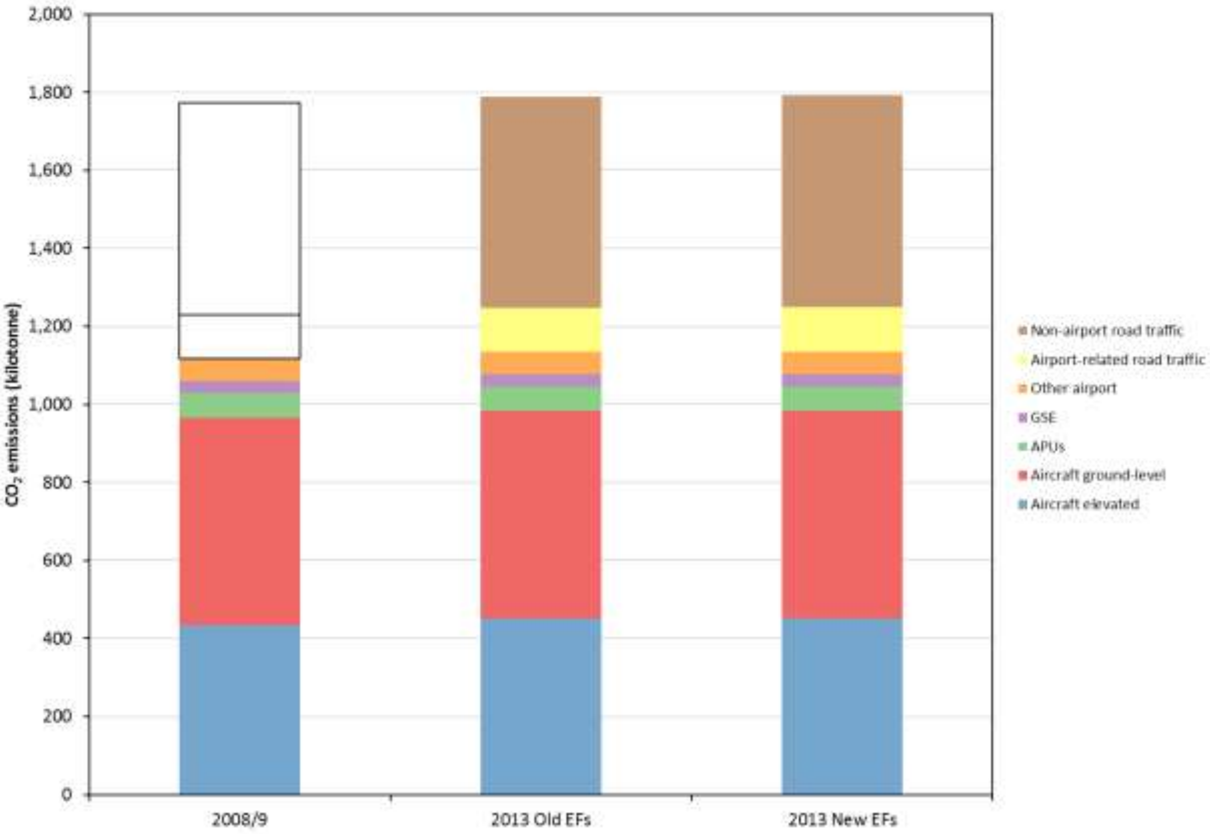
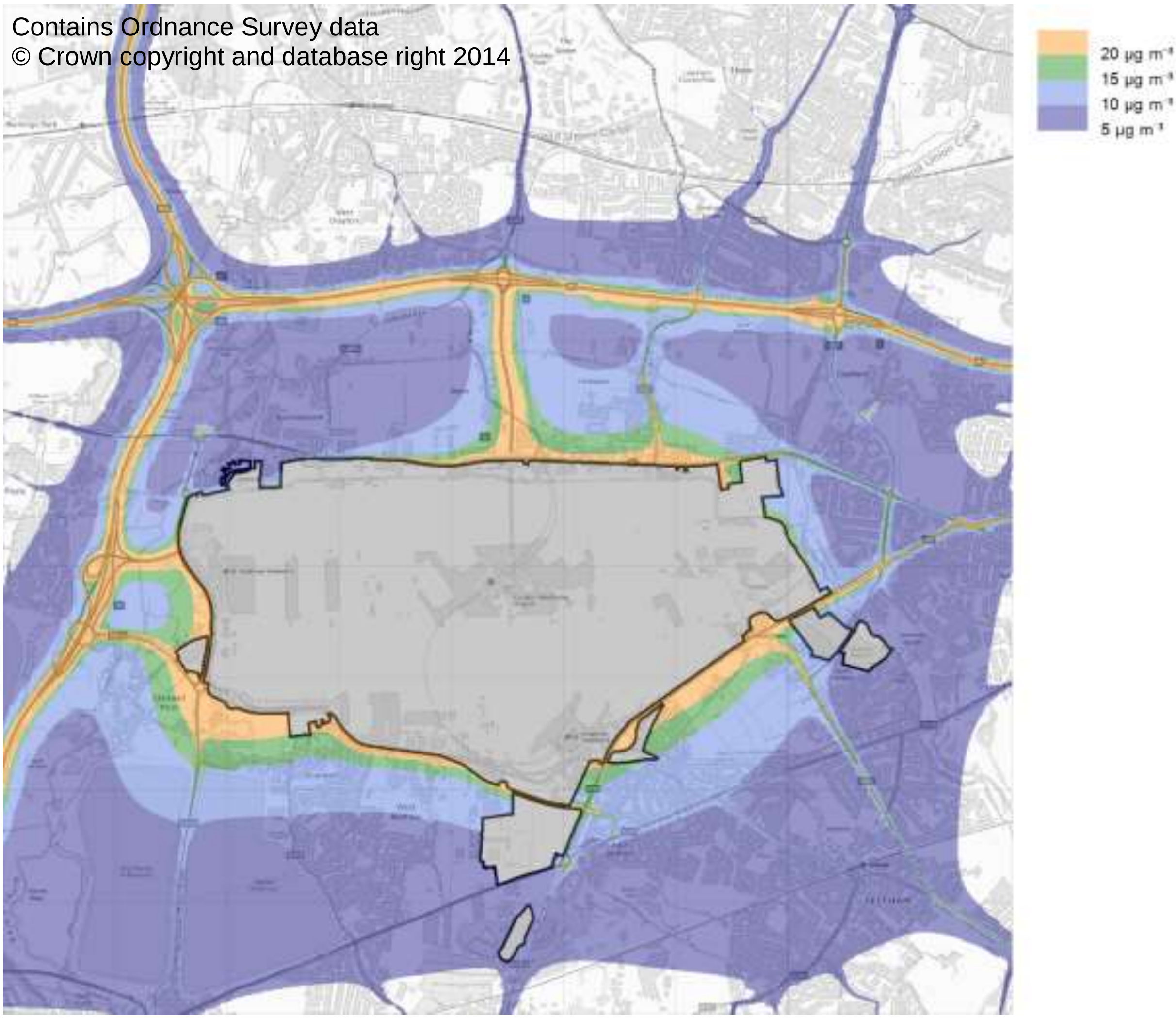
Figure E4: CO_2 emissions by source category



Concentrations

Generally concentrations of airport sources decrease with distance from the airport for both NOx and PM. There are no exceedances of any of the PM related air quality standards, in fact concentrations are way below the PM standards. NO_2 is only exceeded close to major roads. The NO_2 exceedances are dominated by road traffic as can be seen in the NO_2 plot (which has monitoring concentrations superimposed), of which a small proportion is related to the airport in most locations.

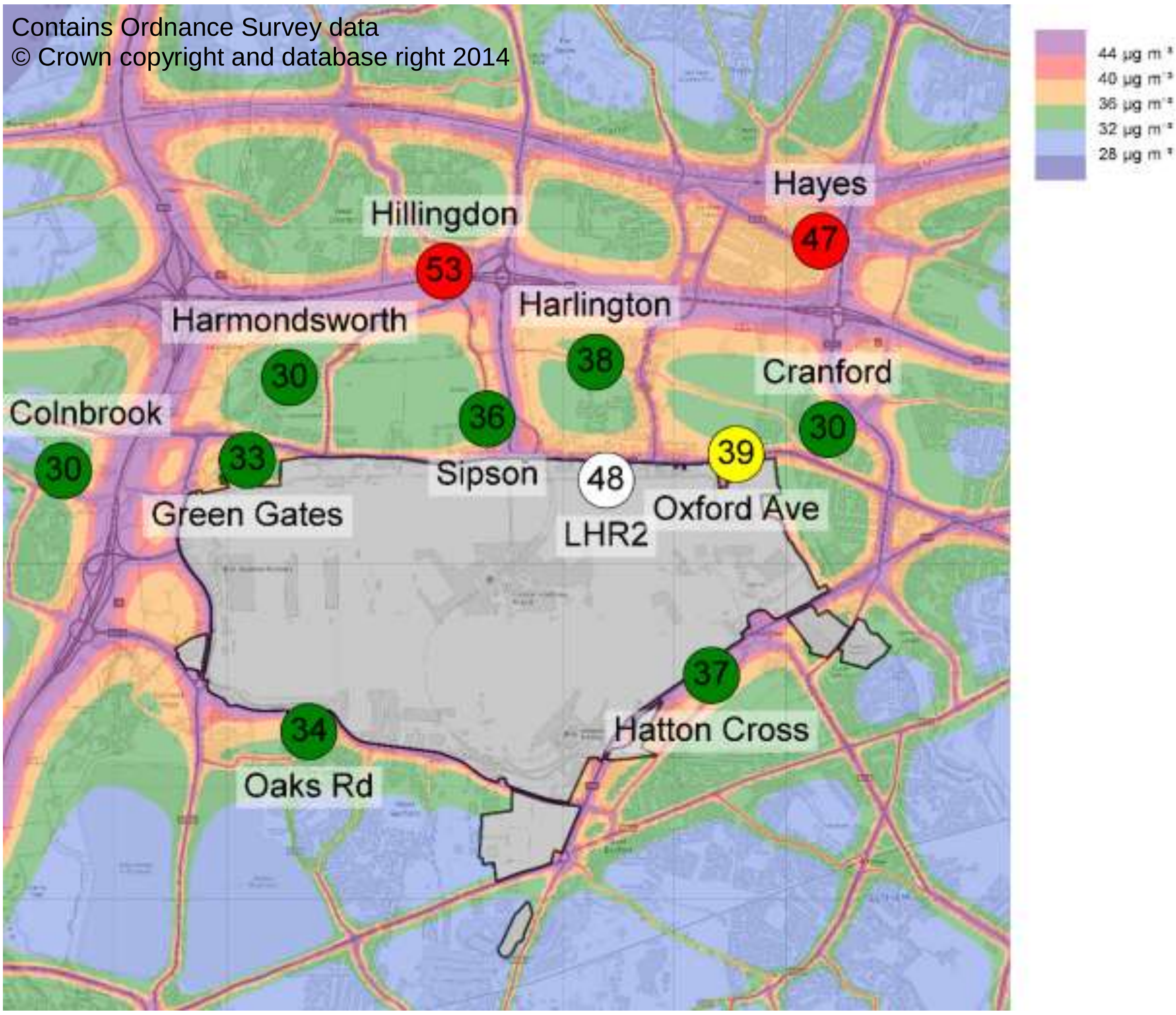
Figure E5: Airport-related contribution[a] to annual mean NO_x concentrations in 2013 New EFs Adjusted



[a] Includes aircraft, APUs, GSE, airport-related traffic on the road network, car parking and stationary sources

Figure E6: Modelled and measured annual mean NO_2 concentrations in 2013

New EFs Adjusted

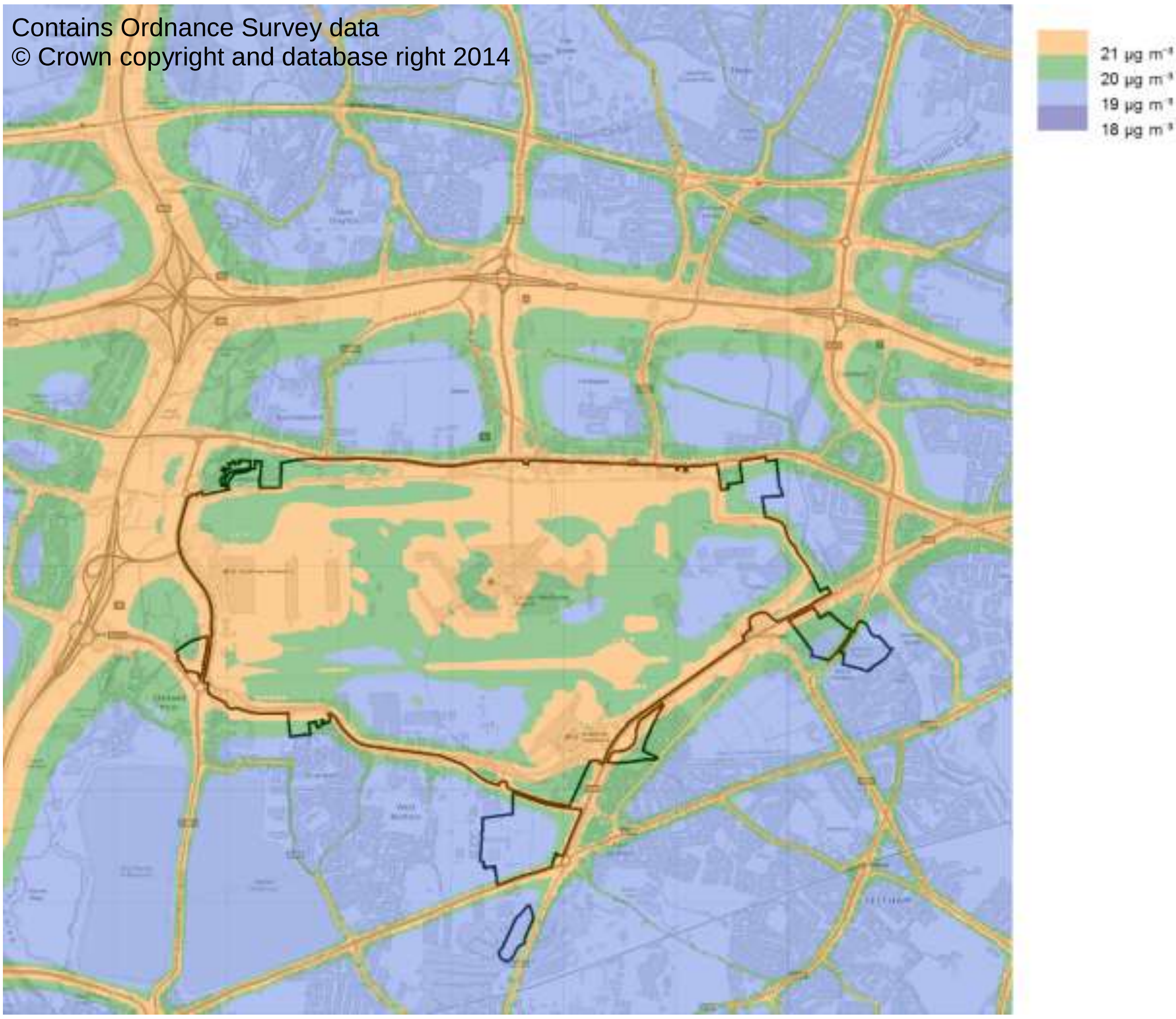


The annual mean EU limit value for NO_2 is 40 µg m^{-3}.
Contours show modelled concentrations. Spot values at monitoring locations are measured NO_2 concentrations in µg m^{-3}.

- ● Exceeds EU limit value (40 µg m^{-3} or more).
- ● Close to EU limit value (38 µg m^{-3} to 40 µg m^{-3}).
- ● Meets EU limit value (below 38 µg m^{-3}).
- ○ EU limit value does not apply.

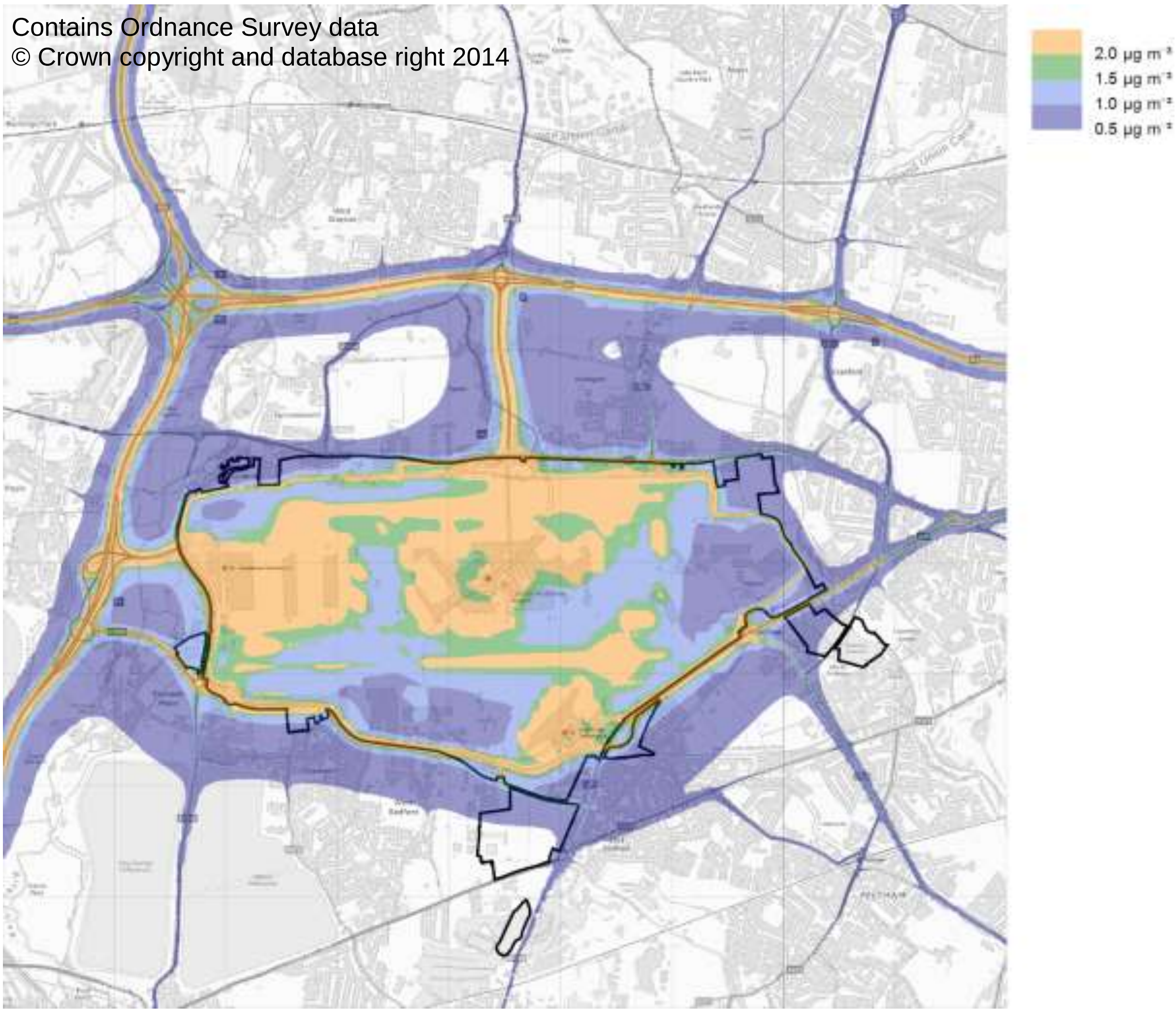
Figure E7: Total annual mean PM_{10} concentration in 2013

New EFs



The annual mean EU limit value for PM_{10} is 40 µg m^{-3}.
The 50 µg m^{-3} daily mean EU limit value for PM_{10} is roughly equivalent to an annual mean of 31.5 µg m^{-3}.

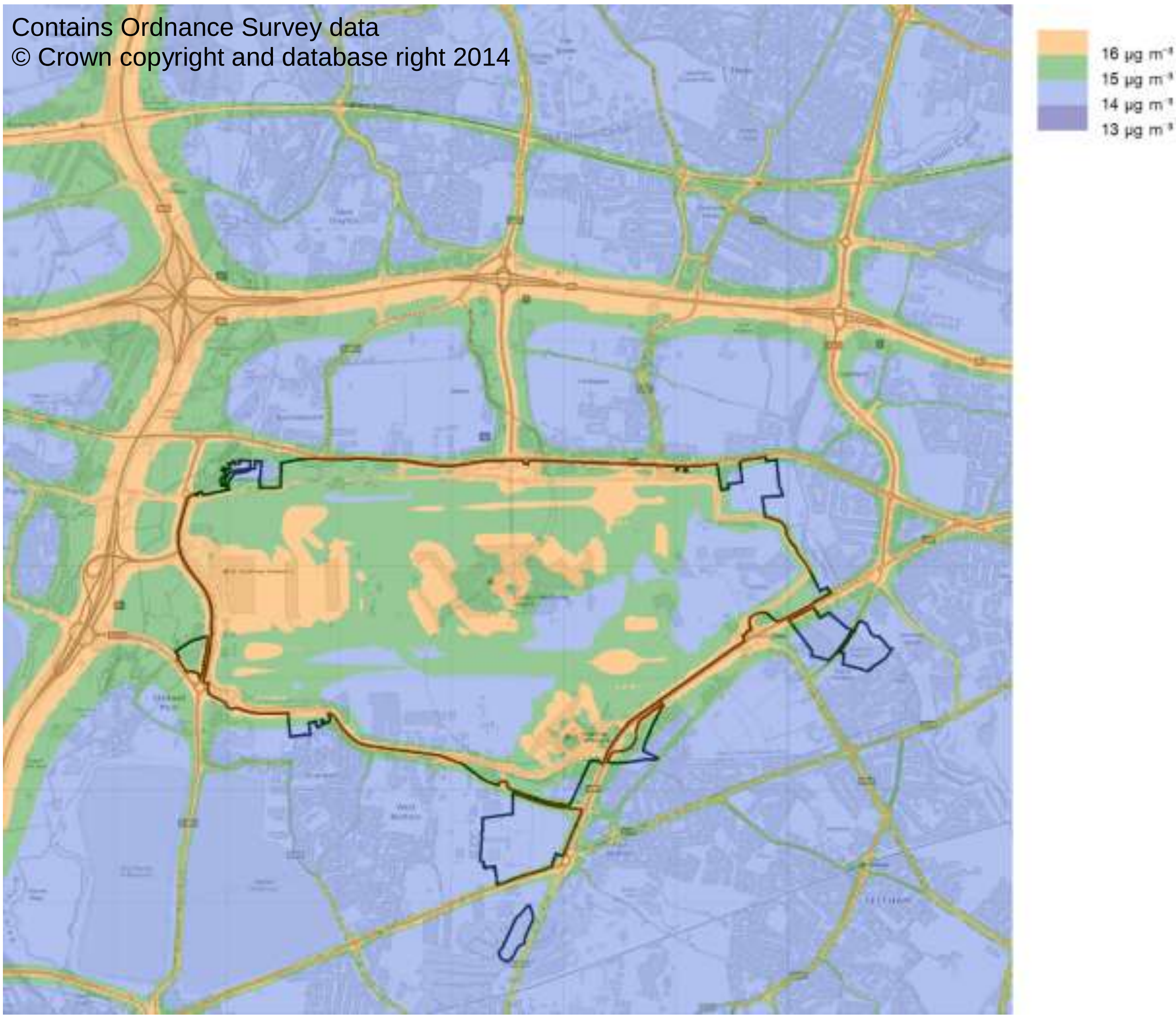
Figure E8: Airport-related contribution[a] to annual mean PM_{10} concentration in 2013 New EFs



[a] Includes aircraft, APUs, GSE, airport-related traffic on the road network, car parking and stationary sources

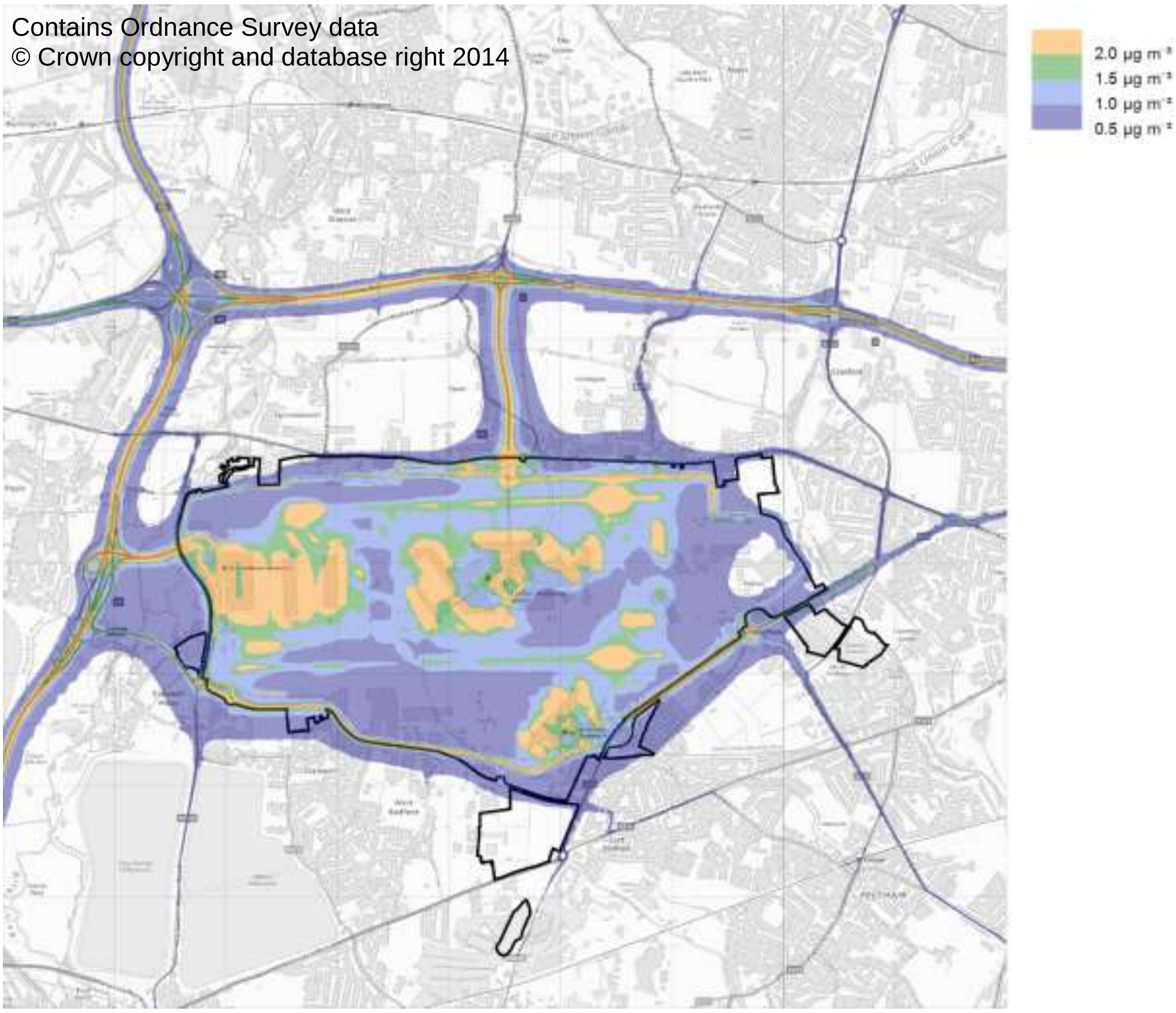
Figure E9: Total annual mean $PM_{2.5}$ concentration in 2013

New EFs



The annual mean EU limit value for $PM_{2.5}$ is 25 µg m^{-3}.

Figure E10: Airport-related contribution[a] to annual mean $PM_{2.5}$ concentration in 2013 New EFs



[a] Includes aircraft, APUs, GSE, airport-related traffic on the road network, car parking and stationary sources

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Glossary

APU - Auxiliary Power Units

AQMA - Air Quality Management Area

AQS - Air Quality Strategy

ATM – Air Traffic Movements

BA – British Airways

BOOS - Heathrow's Business Objective Search System

CAEP- Committee on Aviation Environmental Protection

CO_2 – Carbon dioxide

EF – Emission factor

EFPS - Electronic Flight Progress Strip

GSE - Ground Support Equipment

HAL – Heathrow Airport Limited

HDV – Heavy Duty Vehicle

HGV – Heavy Good Vehicle

ICAO – International Civil Aviation Organization

LDV – Light Duty Vehicle

LGV – Light Goods Vehicle

LTO – Landing Take-Off cycle

Met – Meteorological data

Mppa – million passengers per annum

MTOW – Maximum TakeOff Weight

NAEI – National Atmospheric Emissions Inventory

NO_2 – Nitrogen dioxide

NOx – Oxides of nitrogen

NTK - Noise and Track-Keeping

PAX - Passengers

PCA - Pre-Conditioned Air

PM – Particulate Matter

PM_{10} – Particle matter – coarse

$PM_{2.5}$ – Particle matter – fine

PSDH - Project for the Sustainable Development of Heathrow

1 Introduction

1.1 Context

This report presents an assessment of air quality in the neighbourhood of Heathrow Airport in the year 2013. It considers the impacts of the operation of the airport (including road traffic to and from the airport), as well as non-airport sources of air pollution, in order to estimate both the overall picture of air quality and the airport's contribution to it.

This study is one of a series of assessments that have been carried out for Heathrow Airport. A major study for 2008/9 included an emission inventory[5], dispersion modelling study[6], and model evaluation against monitoring data[7]. For the years 2009–2013, annual smaller studies calculated emissions from aircraft[8,9,10,11,12], but did not calculate concentrations. The present work updates the major 2008/9 study to 2013 with a full emission inventory (adding to the smaller 2013 study already issued[13], dispersion modelling and model evaluation. This report discusses the emissions inventory and dispersion modelling, a further report discusses how the modelling performs in detail compared to air pollution monitored data[14].

1.2 Air quality

Legal limits on the concentrations of key pollutants have been introduced by the EU, and several of these limits have proved to be challenging to meet in urban areas across the UK and Europe. In the airport context, the air quality limit that appears most challenging in the UK (and Europe) is the 40 µg m^{-3} limit for annual-mean nitrogen dioxide (NO_2) concentrations. Air Quality Management Areas are declared for an areas exceeding one of the air quality legal limits. The whole of the London Borough of Hillingdon south of the Chiltern-Marylebone railway line, in which Heathrow Airport sits, has been declared an Air Quality Management Area (AQMA)[15], though it should be emphasised that the airport is only one contributor to air quality problems within any AQMA. The impacts of airports on local air quality are a major constraint on airport growth in many parts of the world, and are a key issue in the Airports Commission's deliberations into provision of additional runway capacity in the UK.

Most NO_2 in the air arises as a side-effect of combustion, the high temperatures oxidising a small fraction of the nitrogen in the air. Broadly speaking, near Heathrow there are three main categories of source:

- Road traffic, some of which will be travelling to or from the airport;
- Heathrow Airport itself, especially aircraft engines and the ground support vehicles and equipment that service the aircraft;
- Other sources both local and more distant, such as domestic and commercial heating, industrial processes, and other vehicles and equipment powered by combustion engines.

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5 Underwood B Y, Walker C T and Peirce M J (2010) Heathrow Airport Emission Inventory 2008/9. AEAT/ENV/R/2906.
6 Underwood B Y, Walker C T and Peirce M J (2010) Air Quality Modelling for Heathrow Airport 2008/9: methodology. AEAT/ENV/R/2915.
7 Underwood B Y, Walker C T and Peirce M J (2010) Heathrow Airport Air Quality Modelling for 2008/9: Results and Model Evaluation. AEAT/ENV/R/2948.
8 Underwood B Y (2010) Heathrow 2008/9 Air Quality. ED45973/N/002.
9 Peirce M J and Walker C T (2011) Heathrow Airport 2010 Emission Inventory. AEAT/ENV/R/3200.
10 Peirce M J and Walker C T (2012) Heathrow Airport 2011 Emission Inventory. AEAT/ENV/R/3313.
11 Cookson J and Peirce M J (2013) Heathrow Airport 2012 Emission Inventory. AEAT/ENV/R/3371.
12 Peace H and Peirce M J (2014) Heathrow Airport 2013 Emission Inventory. AEAT/ENV/R/3411.
13 Peace H and Peirce M J (2014) Heathrow Airport 2013 Emission Inventory. AEAT/ENV/R/3411.
14 Ricardo-AEA (2014) Heathrow Airport 2013 Air Quality Assessment: Model Evaluation, Draft Report November 2014.
15 London Borough of Hillingdon (2014) Designation of Air Quality Management Areas (AQMAs). http://www.hillingdon-air.info/daqma.php. Retrieved 7 August 2014.

In addition, although airports are not considered to be a major source of particulate matter (PM_{10}) emissions, achieving the current objectives of the national Air Quality Strategy (AQS)[16] for this pollutant presents challenges for many areas of the UK. Furthermore, in view of the EU cap[17] on $PM_{2.5}$ concentrations, the list of key pollutants for an airport emissions inventory needs to include both PM_{10} and $PM_{2.5}$.

1.3 The role of modelling

While it is possible to measure concentrations of pollutants of concern, and several monitoring stations are operating in the area around Heathrow, these are expensive to run and it is impractical to have enough to provide a full picture of local air quality. It is therefore necessary to turn to modelling to fill out the picture. A modelling study has several benefits:

- It can fill in the spatial gaps between monitors, allowing air quality to be assessed at all locations of interest. For example, the area impacted by air quality limit exceedances can be calculated and the number of households covered by the area as well.
- It makes it possible to see which sources are responsible for how much pollution ("source apportionment"). For example, if you have an exceedance of a limit value, how much is due to the airport, how much due non-airport road traffic and how much due remote sources?
- It provides a basis for forecasting how air quality will behave in the future. Even in the case of 'business as usual', there will be changes in the number and types of aircraft using the airport, for example. In addition, where there are proposals for changes to airport infrastructure, such as a new runway, modelling is necessary to understand the effects of such developments.
- Bringing the last two points together, modelling can inform action planning, i.e. implementing measures aimed at improving air quality and eliminating exceedances, by helping to understand whether proposed measures are likely to be effective and cost-effective.

1.4 About this assessment

The study reported here was designed with these purposes in mind. The work falls into three main parts:

- First, an emissions inventory is calculated to estimate how much of the pollutants is emitted from the different sources.
- Second, dispersion modelling calculates how the emissions are carried through the air, due to meteorological conditions such as wind speed and direction, and the resulting concentrations of pollution in the air.
- These modelled concentrations are compared with monitoring data as a check on the accuracy of the model.

The final total concentrations are also compared with the air quality limit values to see if there is a risk of them being exceeded.

This report presents the methodology and results of the emissions inventory and dispersion modelling (including an analysis of the airport's activity). It also includes a brief comparison with monitoring data. A more detailed model evaluation, and conclusions about the suitability of the model, are discussed in a separate report[18].

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16 Defra (2007) The Air Quality Strategy for England, Scotland, Wales and Northern Ireland, July 2007.
17 Directive 2008/50/EC of The European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe.
18 Ricardo-AEA (2014) Heathrow Airport 2013 Air Quality Assessment: Model Evaluation, Draft Report November 2014.

2 Methodology

The methodology for the present work closely resembles that of the 2008/9 work[19,20,21], but as new data has become available and operational changes have occurred, an update was desirable. The 2008/9 methodology followed the recommendations of the Project for the Sustainable Development of Heathrow (PSDH)[22], a project sponsored by the Department for Transport to formulate the best practical methodology for airport air quality assessments.

The methodology is also consistent with the International Civil Aviation Organization's Airport Air Quality Manual[23], meeting the requirements of the 'Advanced' approach with elements of the 'Sophisticated' approach where data is available.

Since the methodology is largely the same as that used for the 2008/9 work, only those aspects which are materially different are described in this report.

2.1 Aircraft

Aircraft movement data is based on an extract from Heathrow's Business Objective Search System (BOSS) database, providing all the movements in the calendar year 2013. Both Air Transport Movements (ATMs) (landings or take-offs of aircraft engaged on the transport of passengers, cargo or mail on commercial terms, including scheduled movements operated empty) and non-ATMs (which include empty positioning movements and non-commercial flights) are included; out of 471,938 movements, 2386 (0.5%) were non-ATMs. The BOSS data included aircraft registration number, flight date and time, runway, stand, and whether the flight was arrival or departure.

Each aircraft's engine was determined by looking up the registration number (from BOSS) in a recent version of the JP Airline Fleets database[24]. These were then mapped to an entry in the ICAO (International Civil Aviation Organization) Aircraft Engine Emissions Databank[25] using the same procedure as the 2008/9 work.

Factors for adjusting emissions according to ambient temperature, pressure and humidity, and for adjusting for the forward speed effect on take-off, were derived using a method based on that devised by QinetiQ for PSDH, but updated and extended to all current engines[26].

Engine testing (ground run) emissions were calculated in the same way as in the 2008/9 work, using new data which was provided in essentially the same format as that used for 2008/9.

2.1.1 Aircraft times in mode

Take-off roll and landing roll

No new data has been obtained for estimating take-off roll or landing roll durations, so these are taken from 2008/9 data. There is no particular reason to expect there to be any systematic change in these durations.

19 Underwood B Y, Walker C T and Peirce M J (2010) Heathrow Airport Emission Inventory 2008/9. AEAT/ENV/R/2906.
20 Underwood B Y, Walker C T and Peirce M J (2010) Air Quality Modelling for Heathrow Airport 2008/9: methodology. AEAT/ENV/R/2915.
21 Underwood B Y, Walker C T and Peirce M J (2010) Heathrow Airport Air Quality Modelling for 2008/9: Results and Model Evaluation. AEAT/ENV/R/2948.
22 Department for Transport (2006) Project for the Sustainable Development of Heathrow. Report of the Airport Air Quality Technical Panels.
23 International Civil Aviation Organization (2011) Airport Air Quality Manual. Doc 9889, ISBN 978-92-9231-862-8.
24 Flightglobal (2013) JP Airline Fleets International 2013/14, 47th edition. ISBN 978-1-898779-49-0.
25 International Civil Aviation Organization (2014) ICAO Aircraft Engine Emissions Databank, issue 20. http://easa.europa.eu/document-library/icao-aircraft-engine-emissions-databank. Retrieved 25 February 2014.
26 Horton G (2013) A methodology for including the effects of ambient conditions and forward speed in aircraft emissions inventories. Ricardo-AEA/R/ED57235.

Taxi-in, taxi-out and hold

For taxi-in, taxi-out and hold, durations were derived from an analysis of Electronic Flight Progress Strip (EFPS) data for the 2013 calendar year. For arrivals, this data provides:

- Actual time of arrival (i.e. touchdown on the runway)
- Time on stand (e.g. at gate).

For departures, the EFPS data provides:

- Start of pushback time
- Start of taxi time
- Arrival at hold point time
- Start of line-up time
- Actual time of departure (i.e. start of take-off roll).

These times are given with one-second precision from the database. The accuracy is likely to be much less than one second, but it is expected that on average errors - won't have a significant impact.

The taxi-in duration was calculated as:

Time on stand − Actual time of arrival − Landing roll duration.

The taxi-out duration was calculated as:

Arrival at hold point time − Start of pushback time.

The hold duration was calculated as:

Actual time of departure (start of take-off roll) − Arrival at hold point time.

The time that aircraft spend lining up and any further delay prior to start of roll has been included within hold.

Data is provided on a movement-by-movement basis, and also includes the aircraft registration number, which makes it possible to match EFPS records with BOSS records. It was possible to match 97% of departures and 97% of arrivals in BOSS with EFPS records. For these matched movements, the duration for that movement was used. Lookup tables of the durations averaged over each runway/apron combination were also prepared, and these tables of averages were used for the remaining 3% of movements. Table 1 shows times averaged over runway and terminal: it is therefore shorter than the full lookup table used in the assessment which is broken down by runway and apron.

Table 1: Taxi-in, taxi-out and hold durations by runway and terminal

Runway	Terminal	Taxi-in (s)	Taxi-out (s)	Hold (s)
09L	T1	256	734	722
09R	T1	517	717	605
27L	T1	484	544	569
27R	T1	272	455	532
09L	T2	327	907	819
09R	T2	471	853	642
27L	T2	576	573	593
27R	T2	402	526	555
09L	T3	389	840	817
09R	T3	383	608	668
27L	T3	328	634	609
27R	T3	329	702	587
09L	T4	732	874	1109
09R	T4	291	619	666
27L	T4	398	519	558
27R	T4	719	512	801
09L	T5	493	628	765
09R	T5	639	508	689
27L	T5	423	751	584
27R	T5	428	786	560
09L	Cargo	669	854	830
09L	Cargo	669	854	830
09R	Cargo	307	572	531
27L	Cargo	223	743	484
27R	Cargo	667	785	807

In the 2012 inventory update[27], emissions were calculated using both the original 2008/9 taxi and hold durations and using EFPS data. The comparison showed that the EFPS data gave higher times in mode, by roughly 10% for taxi-in and taxi-out. It was also concluded that the EFPS data appears to be more accurate than the radar-based data used in the 2008/9 assessment, and has higher coverage and better availability. These are the reasons that EFPS-derived times were chosen for the present assessment.

Approach, initial climb and climb-out

Approach, initial climb and climb-out durations were derived from data sampled from the Noise and Track-Keeping (NTK) database. The data was in essentially the same format as received for the 2008/9 work, but with a much larger sample size: it contained 15,522 arrivals and 14,685 departures, covering two two-week periods in June and November. In addition, for arrivals individual squawks were available, not just summary data as in 2008/9, allowing a slightly more robust analysis (although in practice there is little variation in approach paths below 1000 m). Many different aircraft types were included. The data was analysed in the same way as in the 2008/9 work[28]. The resulting times in mode are given in Tables 2 and 3. They are broadly similar to those used in the 2008/9 work, confirming the expectation that there is no reason to expect systematic differences. There seems to be less variation in climb durations between aircraft types in the 2013 data, which may be because the larger dataset provides better averages.

27 Cookson J and Peirce M J (2013) Heathrow Airport 2012 Emission Inventory. AEAT/ENV/R/3371.
28 Underwood B Y, Walker C T and Peirce M J (2010) Heathrow Airport Emission Inventory 2008/9. AEAT/ENV/R/2906.

Table 2: Initial climb and climb-out durations[a]

Aircraft Type	Initial climb duration (s)				Climb-out duration (s)			
	To 1000 ft		To 1500 ft		From 1000 ft		From 1500 ft	
	2013	2008/9	2013	2008/9	2013	2008/9	2013	2008/9
A300	-	26.0	-	-	-	60.9	-	-
A318	36.6	-	52.9	-	81.3	-	65.0	-
A319	30.2	25.7	45.5	37.7	72.2	63.7	56.9	51.8
A320	31.6	24.1	47.6	36.6	79.2	65.1	63.3	52.6
A321	33.6	24.9	48.7	35.9	79.0	62.1	63.9	51.2
A330	37.4	31.5	52.3	-	92.2	78.8	77.3	-
A342	42.7	-	62.7	-	102.8	-	82.8	-
A343	43.1	52.6	63.6	-	115.7	107.8	95.3	-
A345	36.2	-	57.1	-	83.2	-	62.3	-
A346	38.2	50.7	55.7	-	109.9	101.6	92.3	-
A380	37.9	52.8	60.6	-	93.6	98.4	70.9	-
B737	29.4	26.1	44.4	38.3	65.2	59.6	50.2	47.5
B747	35.1	44.3	54.6	-	75.6	76.6	56.0	-
B757	26.8	23.8	39.9	35.2	64.9	62.5	51.8	51.1
B767	30.0	31.0	44.4	-	69.4	70.9	55.0	-
B777	33.8	34.4	48.4	-	84.4	76.5	69.8	-
B777-ER	30.5	35.6	43.2	-	71.5	67.7	58.8	-
B777-LR	25.2	-	36.9	-	54.9	-	43.2	-
B777 Freight	26.4	-	37.8	-	50.2	-	38.8	-
B787	30.3	-	43.7	-	70.7	-	57.4	-
ER145	28.4	23.6	41.9	33.1	78.1	51.8	64.6	42.3
MD80	31.3	-	46.9	32.8	68.6	-	53.0	48.9
MD90	31.3	-	46.9	33.5	68.6	-	53.0	34.7

[a] Times for cutback at 1000 ft and 1500 ft are given for aircraft types where either is used depending on operator.

Table 3: Approach durations by aircraft size (wake vortex category)

Category	2013 (s)	2008/9 (s)
Heavy	233	225
Medium	239	231
Small	237[a]	233
Light	237[a]	243

[a] Analysis provided 246 s for Small and 278 s for Light; however, the sample sizes were just 56 and 3 movements respectively so the combined value was used.

Auxiliary Power Units (APUs)

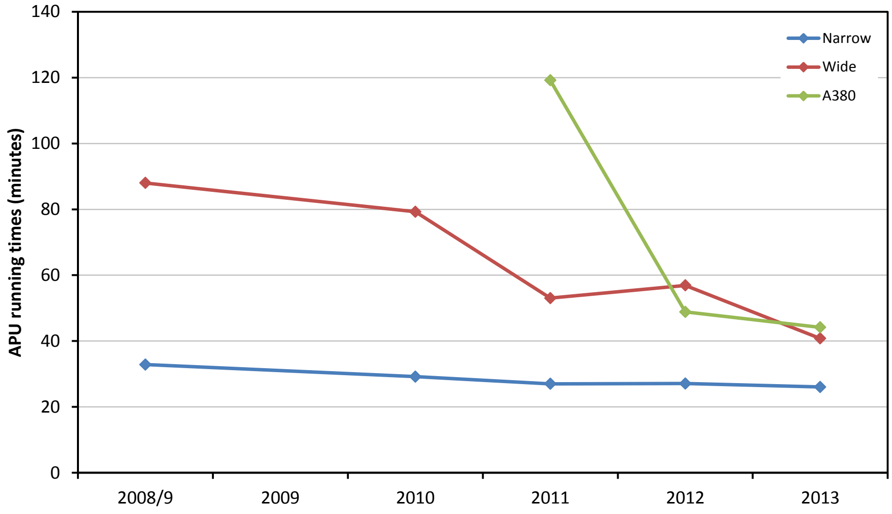
Surveys of APU running times have been conducted annually since 2008 to assess compliance with the airport's regulations on APU usage. The survey results have been analysed for each of the annual inventory updates[29,30,31,32,33,34], and although there remains considerable uncertainty about the resulting times, there is a clear trend of falling usage durations, as shown in Figure 1. This is likely to be a response to pressure from airport management on aircraft operators to reduce running times, as part of its Air Quality Action Plan. Therefore, times derived from the 2013 study have been used in the present assessment. Results for other years presented below also use the APU times from the corresponding year's survey.

One of the measures to facilitate the reduction in APU running times is the provision of pre-conditioned air (PCA) at new and refurbished stands, namely those on Terminal 5,

29 Underwood B Y, Walker C T and Peirce M J (2010) Heathrow Airport Emission Inventory 2008/9. AEAT/ENV/R/2906.
30 Underwood B Y (2010) Heathrow 2008/9 Air Quality. ED45973/N/002.
31 Peirce M J and Walker C T (2011) Heathrow Airport 2010 Emission Inventory. AEAT/ENV/R/3200.
32 Peirce M J and Walker C T (2012) Heathrow Airport 2011 Emission Inventory. AEAT/ENV/R/3313.
33 Cookson J and Peirce M J (2013) Heathrow Airport 2012 Emission Inventory. AEAT/ENV/R/3371.
34 Peace H and Peirce M J (2014) Heathrow Airport 2013 Emission Inventory. AEAT/ENV/R/3411.

reconfigured stands on Terminal 2 and a small number of stands on Terminal 3. However, the available data does not show any clear difference between running times at terminals with and without PCA; this may be because the survey data is too sparse.

Figure 1: APU running times



2.1.2 Spatial representation of aircraft emissions

No new information was available on the runway exit taxiways or hold points/runway access taxiways used by aircraft in 2013. These have not been included in the EFPS data. Therefore, movements were assigned these probabilistically using data from 2008/9 ground radar.

Taxiways, stand locations and hold areas have been updated to reflect the airfield layout in 2013.

Climb angles were derived from the new NTK data as described in the previous section. Analysis of NTK arrivals data confirmed that approach angles are very close to 3°, so all aircraft were assumed to approach at an angle of 3°.

2.2 Ground Support Equipment (GSE)

The emissions from ground support equipment are estimated from the quantities of fuel dispensed airside. It is recognised that if any fuel is sourced landside and brought in airside it will be missed in the inventory. Likewise any fuel sourced airside and used landside will be double counted. However, this represents a very small fraction of the total airside fuel.

Schematically, the emissions (g) are calculated as the product of fuel consumed (kg) and emission factor (g/kg fuel).

Vehicles are categorised depending on their emission factors (expressed in terms of g pollutant per kg fuel consumed). A distinction is drawn between road vehicles (manufactured to operate on public roads) and off-road vehicles. They are subject to different emission regulations, so are associated with different sets of emissions factors for their typical duty cycles. Road vehicle emission factors, which vary with fuel type, speed and vehicle type (e.g. car, van, HGV), were taken from the NAEI[35] in June 2014, examples of speed related emission curves are included in Appendix A. These new emission factors included updated NO_x and PM speed-related emission functions (COPERT 4v10) and vehicle fleet composition projections, consistent with the current (2013/14) NAEI emission projections for road transport and the Emission Factor Toolkit EFTv6.0. However, road traffic emissions had already been calculated using the previous set of emission factors (based on COPERT 4v8.1

35 Defra (2014) http://naei.defra.gov.uk/data/ef-transport accessed July 2014

and TRL emission factors)[36] . Therefore two set of road emissions and related modelling are presented in this report.

For off-road vehicles, vehicles are characterised from an emissions perspective in terms of the power rating of their engines, and appropriate emission factors are compiled by the European Environment Agency[37].

Data on airside duty cycles[38] were made available for this study. However, for off-road vehicles the emission factors are not provided in sufficient detail to make use of the duty cycle data.

A log of transactions at the airport filling stations during 2013 provided data on airside fuel use by operator and vehicle. These data have been used along with the new emission factors and revised airside fleet data, including new data from British Airways, to estimate emissions from GSE.

Table 4 shows estimated fuel use by GSE type, along with, for comparison, estimates from the 2008/9 inventory. It should be noted that the alignment of fuel data by operator and vehicle and vehicles in the Heathrow airside database was poor. This is partly due to the fact that much of the fuel supplied to GSE is distributed via bowsers, but it is also down to the quality of the airside database. Consequently, where there was no alignment, a similar approach to that taken in the 2008/9 inventory was used to apportion fuel to individual plant. However, this step was taken after the fuel had been apportioned amongst airside operators.

Table 4: Fuel use by GSE type: 2013 compared with 2008/9

GSE type	Fuel (1000 l)		Change %[a]
	2013	2008/9	
Road vehicles	**9070**	**8735**	**3.8**
Cars	2347	1651	42.2
LGVs	2396	2999	-20.1
Rigid HGVs	3377	2856	18.2
Artic HGVs	567	706	-19.7
Buses	349	424	-17.7
Coaches	33	98	-66.3
Off-road vehicles	**2319**	**3844**	**-39.7**
Diesel 37-75 kW	664	1342	-50.5
Diesel 75-130 kW	618	311	98.5
Diesel 130-560 kW	1035	2172	-52.3
Petrol	2	17	-86.1
LPG	0	3	-100.0
Total	**11389**[b]	**12579**[c]	**-9.5**

[a]Change % = 100 * (2011 value - 2008/9 value) / (2008/9 value).
[b]The 2013 fuel data contained an additional 1669 thousand litres not included in the total used landside by Menzies Buses.
[c]The 2008/9 fuel data contained an additional 1500 thousand litres not included in the total used landside by Menzies Buses.

36 Defra (2010) http://naei.defra.gov.uk/data/ef-transport accessed April 2014

37 EEA (2009) EMEP/EEA Air Pollutant Emission Inventory Guidebook 2009. Technical Report 9/2009.
38 Millbrook (2005) Heathrow vehicle airside duty cycle.

The spatial representation of GSE emissions was derived from aircraft activity, as described in the 2008/9 report[39]. Stand locations were updated in order to reflect the airfield layout in 2013.

2.3 Landside road network

For the Heathrow resilience project (Cranford), AECOM supplied modelled road traffic flow data for 2009, 2014 and 2020. The data included estimated traffic flows and congested speeds for AM and PM peak hour and an inter peak hour broken down by vehicle type (Car, Taxi, LGV, rigid HGV, artic HGV, bus coach and motorcycle) separately for airport and non-airport traffic for each section of road (i.e. a road link) on an approximate 9km by 9km area surrounding the airport. The data for 2009 and 2014 were interpolated to derive 2013 road traffic data.

Hourly profiles of traffic by vehicle type and road class were provided with the road traffic data.

Schematically, the emissions (g/hour) on a given link for vehicles in a given category are calculated as the product of traffic volume (vehicles/hour), link length (km) and emission factor (g/km).

The emission factors for a given pollutant vary with speed and vehicle category, and therefore the above calculation was undertaken for each specific vehicle type using the relevant speed-related emission factor, examples of speed related emission curves are included in Appendix A.

Road vehicle emission factors, which vary with fuel type, speed and vehicle type (e.g. car, van, HGV), and vehicle fleet composition projections were taken from the NAEI[40] in June 2014, examples of speed related emission curves are included in Appendix A. These new emission factors included updated NO_x and PM speed-related emission functions (COPERT 4v10) and vehicle fleet composition projections, consistent with the current (2013/14) NAEI emission projections for road transport and the Emission Factor Toolkit EFTv6.0. However, road traffic emissions had already been calculated using the previous set of emission factors (based on COPERT 4v8.1 and TRL emission factors)[41] . Therefore two set of road emissions and related modelling are presented in this report.

Separate emission factors are available for a finer categorisation of vehicles than available in the traffic model output (for example, making the distinction between petrol and diesel cars). National and London traffic-composition[42] data from the NAEI are used to apportion the modelled traffic volumes amongst the pertinent sub-categories (e.g. by engine size and age). This approach makes the tacit assumption that the composition of traffic on the roads around Heathrow Airport at the sub-category level is not materially different from the national or London average (e.g. the age distribution and engine size of vehicles).

A proportion of vehicles on the network will be near the start of a journey, so will not have reached the optimum operating range for engine (and catalyst if fitted). This leads to additional emissions, which are often expressed as a cold start ‘penalty’ per trip. Such emissions are widely distributed over the network, and the NAEI makes estimates for the national network. However, the airport is a spatial focus for cold-start emissions arising from vehicles leaving the airport after having parked there, and this contribution is estimated as part of the airport inventory. This is further discussed in Section 2.4. The remaining cold start emissions associated with other vehicles on the network are taken from the NAEI, accepting that this may involve a certain amount of double counting.

39 Underwood B Y, Walker C T and Peirce M J (2010) Heathrow Airport Emission Inventory 2008/9. AEAT/ENV/R/2906.
40 Defra (2014) http://naei.defra.gov.uk/data/ef-transport accessed July 2014
41 Defra (2010) http://naei.defra.gov.uk/data/ef-transport accessed April 2014

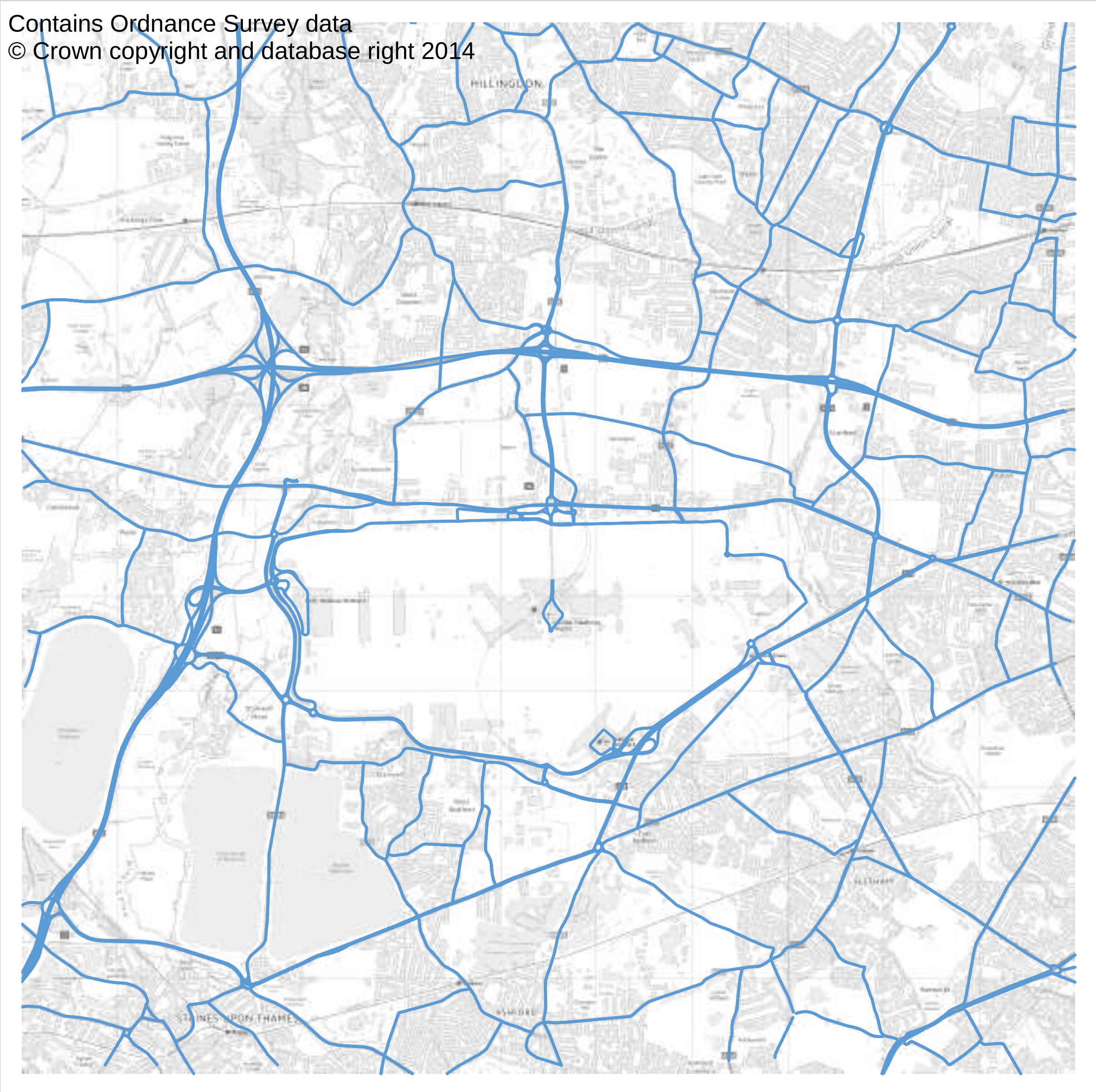
42 Traffic composition information is given in terms of vehicle-km rather than vehicle number, recognising that different categories of vehicle travel different average distances per year.

For particulate matter, four non-exhaust sources of emissions are also included: brake wear, tyre wear, road abrasion and the re-suspension of road dusts. The emission factors for brake and tyre wear were derived using the methodology adopted by the NAEI, as described in the Air Quality Expert Group report on particles[43]. These emissions factors are speed-dependent and vary with vehicle type, examples of speed related emission curves are included in Appendix A. For road abrasion, constant emission factors of 0.0075 g/km for light duty vehicles and 0.038g/km for heavy duty vehicles, taken from the NAEI, have been included. For re-suspended road dust, a constant emission factor of 0.04 g/km has been included, although there is some uncertainty over whether this may partly double count contributions included elsewhere in the methodology. As the exhaust contribution to particle emissions is subject to increasingly more stringent regulation, the non-exhaust contributions have become a major component of the calculated mass of particulate matter emitted by road vehicles.

The landside road network was redigitised using Ordnance Survey Landline data, which contains vector representations of road centrelines (carriageway centrelines in the case of motorways and dual carriageways). This work required a large degree of manual matching AECOM road link identifiers with actual road centre lines. This is expected to improve the spatial accuracy of modelled roads to within 1 m. The road network used in the modelling is shown in Figure 2.

43 AQEG (2005) Particulate Matter in the United Kingdom. Defra 2005.

Figure 2: Road network for which emissions are calculated for the 2013 inventory



2.4 Other airport sources

2.4.1 Heating plant

Monthly fuel use data were supplied by Heathrow Airport as per Table 5 and emissions calculated using emission factors updated with those in the NAEI[44] using the same methodology as 2008/9. Spatially the emissions were allocated to the location of the emission stack/flue.

Table 5: Fuel use by plant: 2013 compared with 2008/9

Plant	Annual fuel energy input (106 MJ)	2013 MJoules x10^6	2008/9 MJoules x10^6
Gas (HAL)	CHP	-	1335.37
	448	273.05	373.16

44 Emission factors detailed by source and fuel, http://naei.defra.gov.uk/data/ef-all, accessed April 2014.

	T2	143.63	-
	T4	102.73	64.56
	T5	68.00	18.97
	Compass Centre	23.50	-
	T4 Early Baggage Store	1.63	-
Gas (BA)	BA Cargo	35.81	253.44
	BA Maint 1	199.04	535.27
	BA Maint 2	93.61	103.52
	Compass Centre	-	14.77
	T4 Early Baggage Store	-	1.03
	Museum	0.64	0.40
	Northside House	17.15	10.78
	BMI Hanger	14.43	-
Gasoil	CHP	0.12	0.19
	British Midland	7.01	11.02
	Viscount	3.35	5.27
	450 Old Fire Station	3.89	6.11
	895	0.51	0.81
	679	4.13	6.49
	1092	3.28	5.16
	1157 ASU	0.34	0.54
	Control tower	0.54	0.85
	Metro	1.03	1.62
Biomass	Biomass plant	6355 Tonnes	-
Total		**983.02 + 6355 Tonnes of biomass**	**2749.32**

2.4.2 Car parks, car rentals, taxis and cold starts

The methodology for car parks, car rentals, taxis and cold starts remains the same as 2008/9. However transaction data was updated with that provided by HAL for 2013. Emission factors were also updated for running emissions (e.g. car travel within car park) as discussed in Section 2.3. Cold start emission factors for were taken from the NAEI[45] in June 2014. Running emissions were allocation to the location of the car parks, car rental areas and taxi ranks respectively. Cold start emissions were predominantly allocated to the road network surrounding the airports up to the motorway as per the 2008/9 study.

2.4.3 Fire training ground

Emissions from the fire training ground were calculated using estimates of fuel used in 2013, namely 29.3 m^3 of propane. Emission factors were the same as in 2008/9.

45 Defra (2014) http://naei.defra.gov.uk/data/ef-transport accessed July 2014

2.4.4 Construction

Emissions from activity associated with construction work at Terminal 2 have only been included insofar as they relate to Airport Energy fuel dispensed airside. Emissions relating to fuel sourced off-airport and other emissions such as fugitive dust have not been considered.

2.5 Background and rural sources

The concentrations from 'background' sources, also referred to as NAEI/LAEI sources, are calculated using the same methodology as in the 2008/9 work[46] (the 'revised approach'). Emissions for the region outside the M25 are taken from the 2012 NAEI and extrapolated to 2013 using national emission estimates[47]. Emissions for the region within the M25 are taken from the 2010 LAEI[48], and interpolated between 2012 and 2015 data.

The contribution from all sources not modelled explicitly (the 'rural' term) is, as in the 2008/9 work, taken from measurements at rural monitoring sites. The sites used were Harwell in westerly wind directions and Rochester Stoke in easterly wind directions. As was the case during 2008/9, there were major outages of the NO/NO_2 monitors at both sites during 2013, so these were filled in using scaled data from Lullington Heath, using the same procedure as in the 2008/9 work. Data capture for PM_{10} and $PM_{2.5}$ at Harwell were also very low (52% and 55% respectively), but no alternative rural PM monitors were identified so no adjustment was made.

2.6 Dispersion modelling

Dispersion modelling was carried out using ADMS-Airport version 3.2.4. For the New EFs (new road emission factors) related dispersion modelling a scaling factor of 1.4 was used, the derivation of this factor is in-line with Defra guidance on modelling and is discussed in more detail in the model evaluation report[49]. Meteorological data was for the Heathrow monitoring station; however cloud cover data for a large part of 2013 was missing, so this was supplemented with cloud cover data from the nearby Northolt meteorological station.

46 Underwood B Y, Walker C T and Peirce M J (2010) Air Quality Modelling for Heathrow Airport 2008/9: methodology. AEAT/ENV/R/2915.
47 National Atmospheric Emissions Inventory (2012) UK Emission Projections of Air Quality Pollutants to 2030. http://uk-air.defra.gov.uk/reports/cat07/1211071420_UEP43_(2009)_Projections_Final.pdf. Retrieved 4 December 2012.
48 Greater London Authority (2013) London Atmospheric Emissions Inventory 2010. http://data.london.gov.uk/datastore/package/london-atmospheric-emissions-inventory-2010. Retrieved 29 August 2013.
49 Ricardo-AEA (2014) Heathrow Airport 2013 Air Quality Assessment: Model Evaluation, Draft Report November 2014.

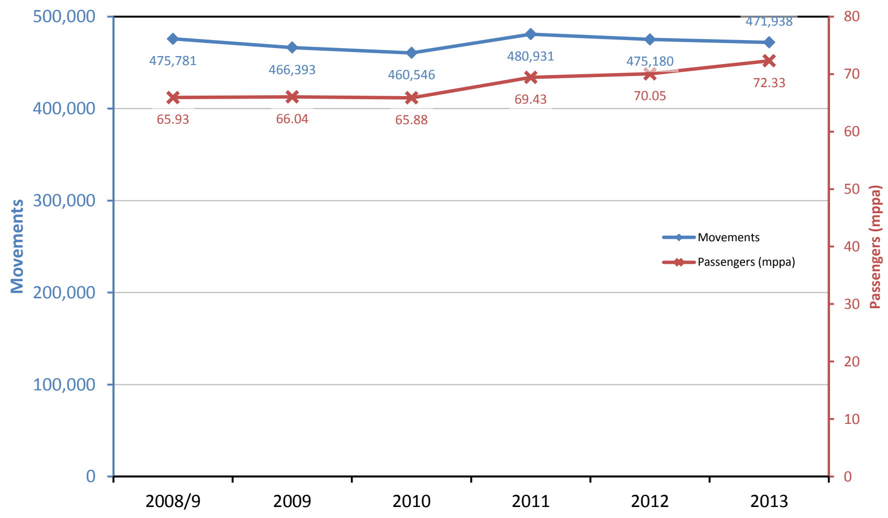
3 Activity on and around the airport

As a first step in understanding the results of the assessment, it is useful to understand how much activity of different types is happening on and around the airport, and how this is changing over time.

3.1 Movements and passenger numbers

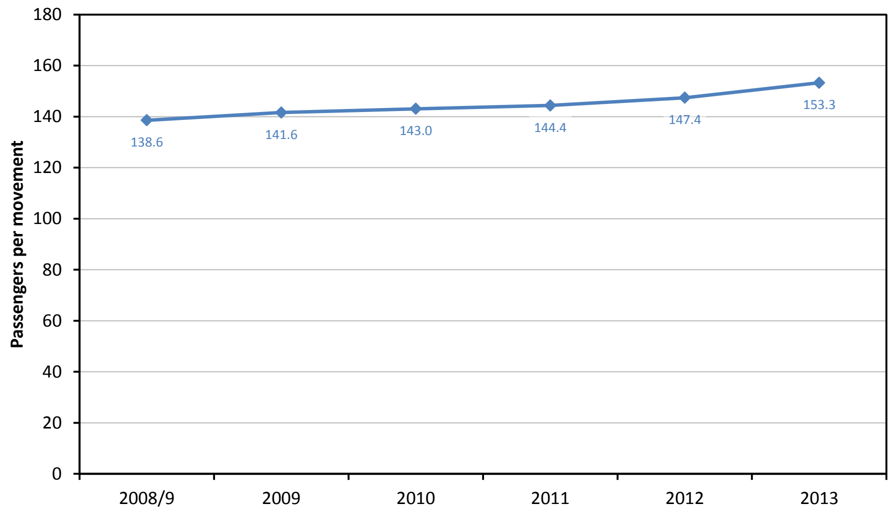
The number of aircraft movements (Figure 3) has remained broadly constant, reflecting the fact that the airport is operating close to maximum capacity, with some variation due to severe weather and the Eyjafjallajökull volcano eruption disrupting operations. The number of passengers has however risen steadily over the last few years, accommodated by a larger number of passengers per movement on average (Figure 4). The number of passengers increased by 9.7% from 2008/9 to 2013, whereas movements were 0.8% lower in 2013 than 2008/9, meaning that there has been an increase in average aircraft capacity and/or load factor.

Figure 3: Aircraft movement[a] and passenger numbers



[a] ATMs and non-ATMs

Figure 4: Average number of passengers per movement[a]

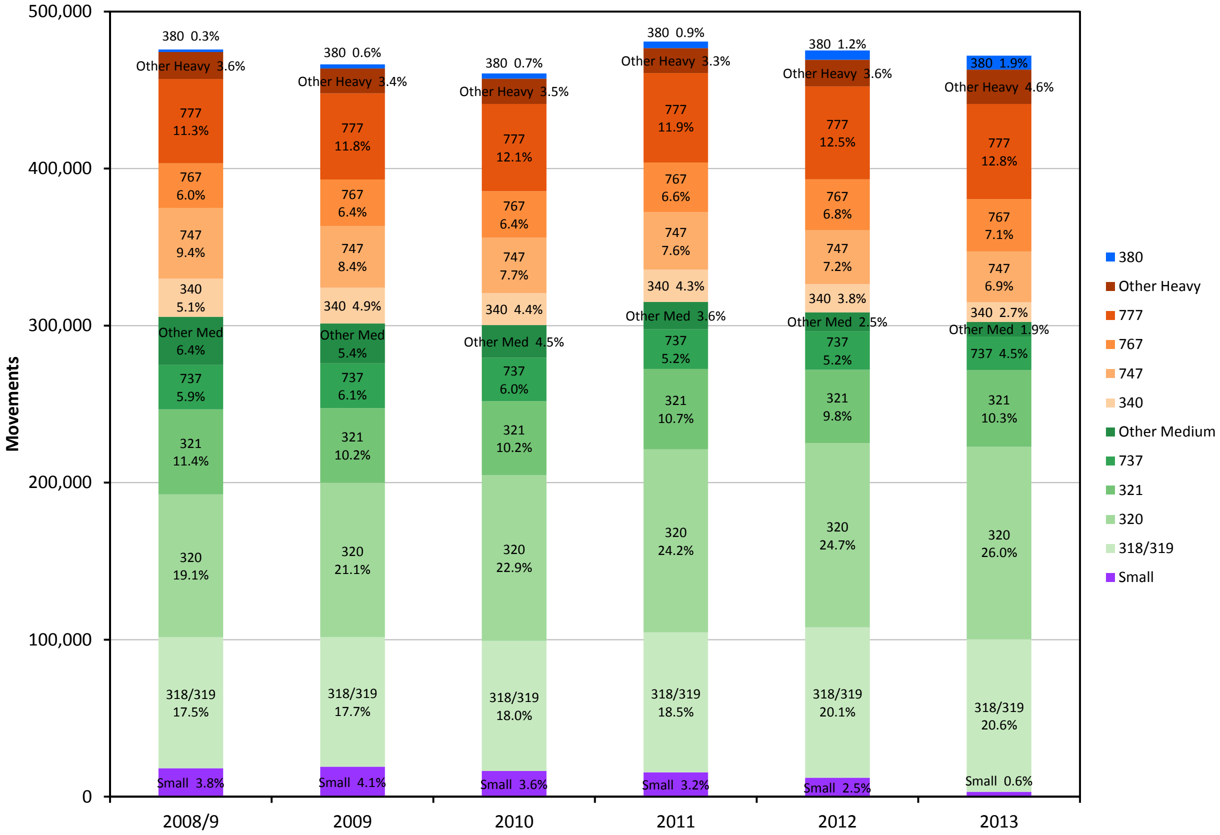


[a] ATMs and non-ATMs

3.2 Aircraft fleet mix

The mix of aircraft types has evolved (Figure 5). Notable changes include the reduction in the number of small and light aircraft using the airport, and the steady growth in the number of Airbus 380 aircraft. There is little change in the balance between medium (green) and heavy (orange) aircraft categories. The Boeing 787 entered the fleet in 2012 but by 2013 still represented less than 0.5% of total movements.

Figure 5: Number of movements[a] by aircraft type



[a] ATMs and non-ATMs

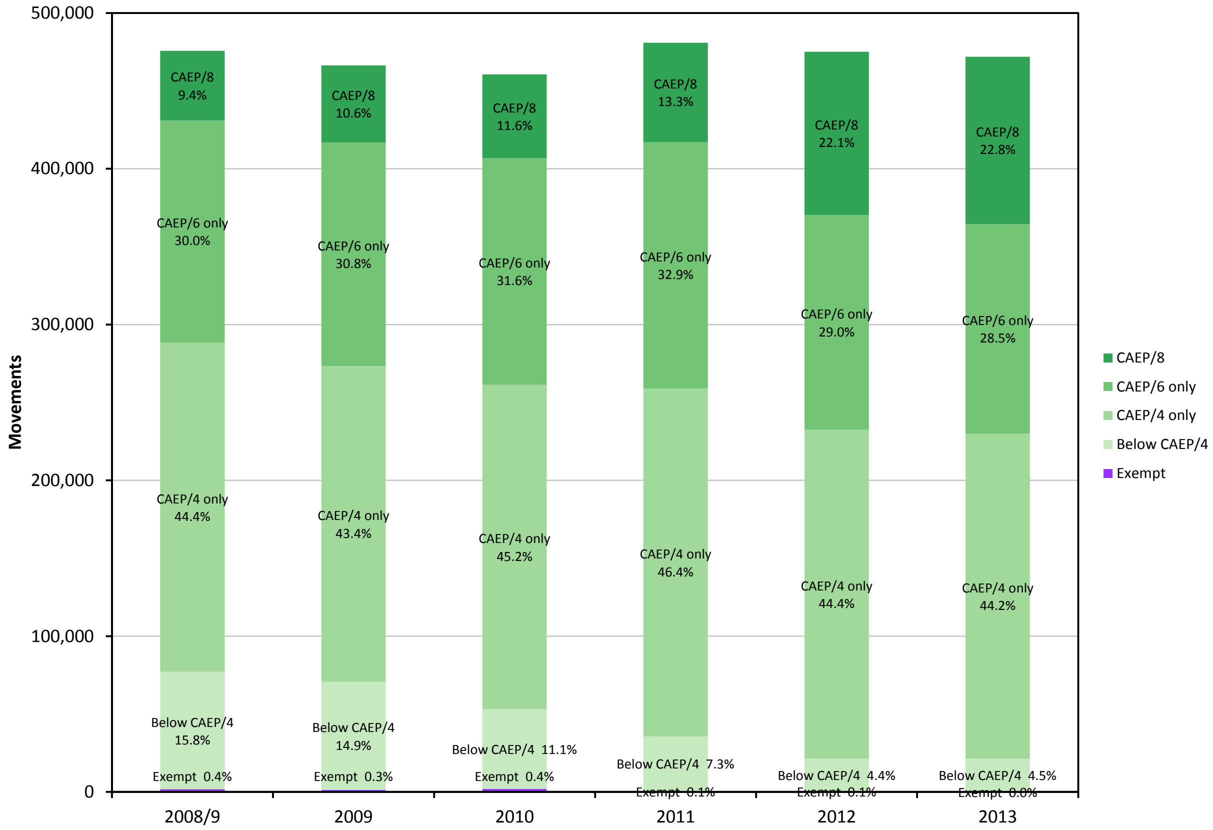
These relatively limited changes in the fleet mean that the number of aircraft seats increased by just 2.5% from 2008/9 to 2013. The large increase in passenger numbers but the small increase in the number of seats is explained by an increase in the average aircraft load factor from about 71% in 2008/9 to about 76% in 2013.

3.3 Aircraft engine mix

Older, more polluting aircraft engines are leaving the fleet to be replaced by newer, cleaner and more efficient ones. The CAEP standards are established for engine NO_x emissions set by the International Civil Aviation Organization (ICAO) as recommended by its Committee on Aviation Environmental Protection (CAEP). Specifically, the number of movements that do not meet the CAEP/4 standard has reduced substantially over the last six years, while the number that meet CAEP/8 has grown (Figure 6). The CAEP/4 standard applies to new aircraft engine models certified on or after 1 January 2004, CAEP/6 to engines certified on or after 1 January 2008, and CAEP/8 to engines certified on or after 1 January 2014. The new CAEP/8 standard reduces the NO_x limits compared to CAEP/6 by about 15 percent[50].

The jump in CAEP/8 fraction between 2011 and 2012 appears to be an artefact of the data and methodology used. From 2012, a new version of JP Airline Fleets[51] was used for engine assignments. The new version gives limited information on engine combustor, and the procedure used for choosing between different entries in the ICAO databank means that most of the CFM56-5B4 engines (commonly fitted to A320 aircraft) are taken to be /2P or /3 variants (which meet CAEP/8) rather than /P (which only meets CAEP/6, not CAEP/8). The previous version of the data, used up to the 2011 inventory, implied a larger number of /P variants.

Figure 6: Total movements[a] by CAEP standard[b]



[a] ATMs and non-ATMs
[b] "CAEP/4 only" means engines that meet the CAEP/4 standard but **not** the CAEP/6 standard. Similarly, "CAEP/6 only" means engines that meet the CAEP/6 standard but **not** the CAEP/8 standard.

3.4 Runway utilisation and easterly/westerly split

Runway utilisation, especially the split between easterly and westerly operations, varies from year to year depending on weather conditions. Table 6 shows the runway utilisation for 2013, compared with 2008/9. Compared with 2008/9, there are more easterlies and fewer westerlies in 2013.

50 Further details on the CAEP standards are available at https://easa.europa.eu/document-library/icao-aircraft-engine-emissions-databank
51 Flightglobal (2013) JP Airline Fleets International 2013/14, 47th edition. ISBN 978-1-898779-49-0.

Table 6: Number of movements[a] by runway

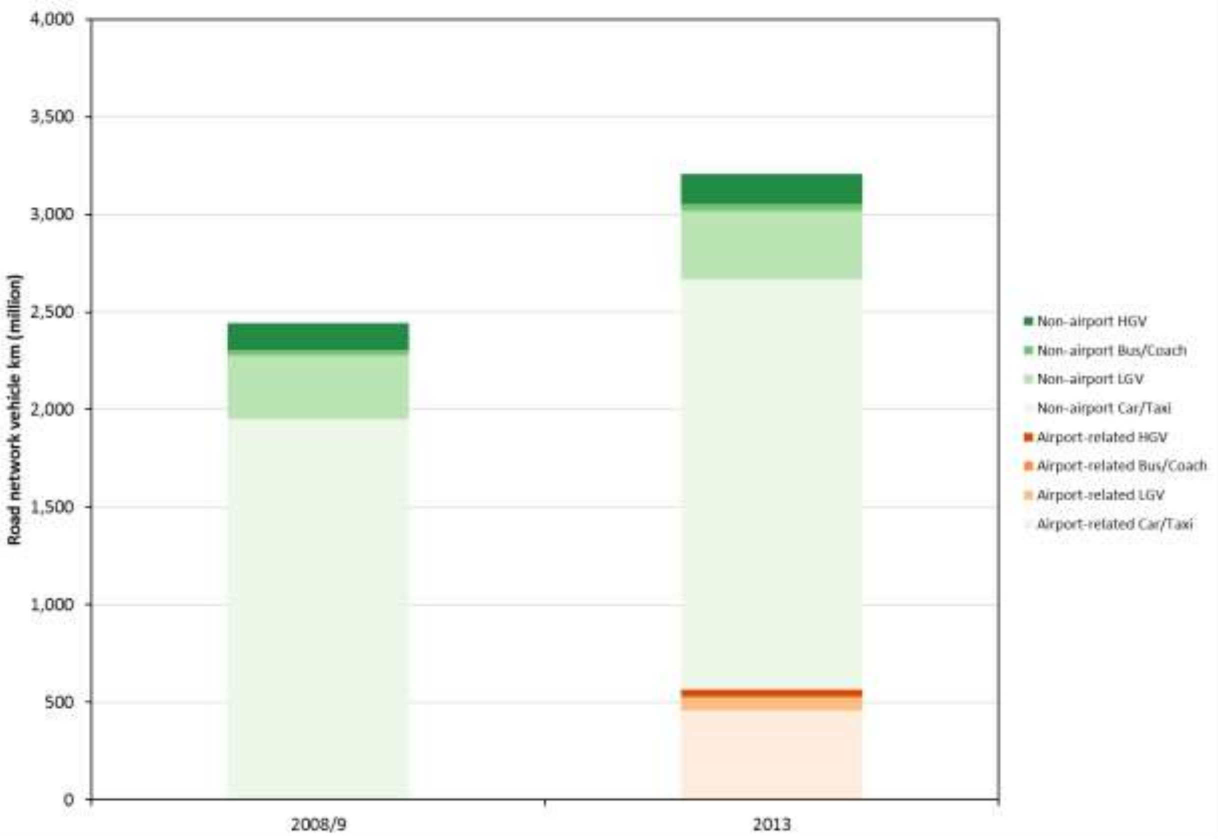
	Movements		Percentage	
Runway	2013	2008/9	2013	2008/9
09L	76,885	66,964	16.3%	14.1%
09R	81,013	67,863	17.2%	14.3%
Total easterly	157,898	134,827	33.5%	28.3%
27L	154,869	171,327	32.8%	36.0%
27R	159,171	169,627	33.7%	35.7%
Total westerly	314,040	340,954	66.5%	71.7%

[a] ATMs and non-ATMs

3.5 Road network

The total number of vehicle-km on the explicitly modelled road network in 2013 has increased since 2008/9, as shown in Figure 7, this may be a function of the updated traffic model that has been used for the 2013 inventory. The split between airport-related and non-airport traffic, and different vehicle types, is shown in Figure 7. For 2008/9, only the split between light and heavy duty vehicles (LDVs and HDVs) is available, so other elements of the breakdown are assumed to be the same as for 2013. Taxis and motorcycles are included with cars, as they each represent a small fraction of the total. They are separated out in a table in Appendix A.

Figure 7: Vehicle km by vehicle type



4 Emissions

4.1 NO_x emissions

4.1.1 Overview

Table 7 shows the calculated annual NO_x emissions for 2013 and 2008/9 for each major source category. Emissions from all airport source have declined over the period 2008/9 to 2013.

Table 7: NO_x emission rate (tonne/year) by source category

Source category		NO_x emission rate (tonne/year)			Difference (%)[a]	
		2013 Old EFs	2013 New EFs	2008/9[g]	Old EFs	New EFs
Airport	Aircraft – elevated[b]	2761.41	2761.41	2830.92	-2	-2
	Aircraft – ground[c]	1524.36	1524.36	1633.60	-7	-7
	GSE	177.40	186.79	260.50	-32	-28
	Road traffic[d]	350.55	386.82	429.22	-18	-10
	Heating plant	85.78	85.78	283.60	-70	-70
	Other[e]	12.10	12.03	18.41	-34	-35
Non-airport	Road traffic[f]	1661.51	1829.76	2034.37	-18	-10

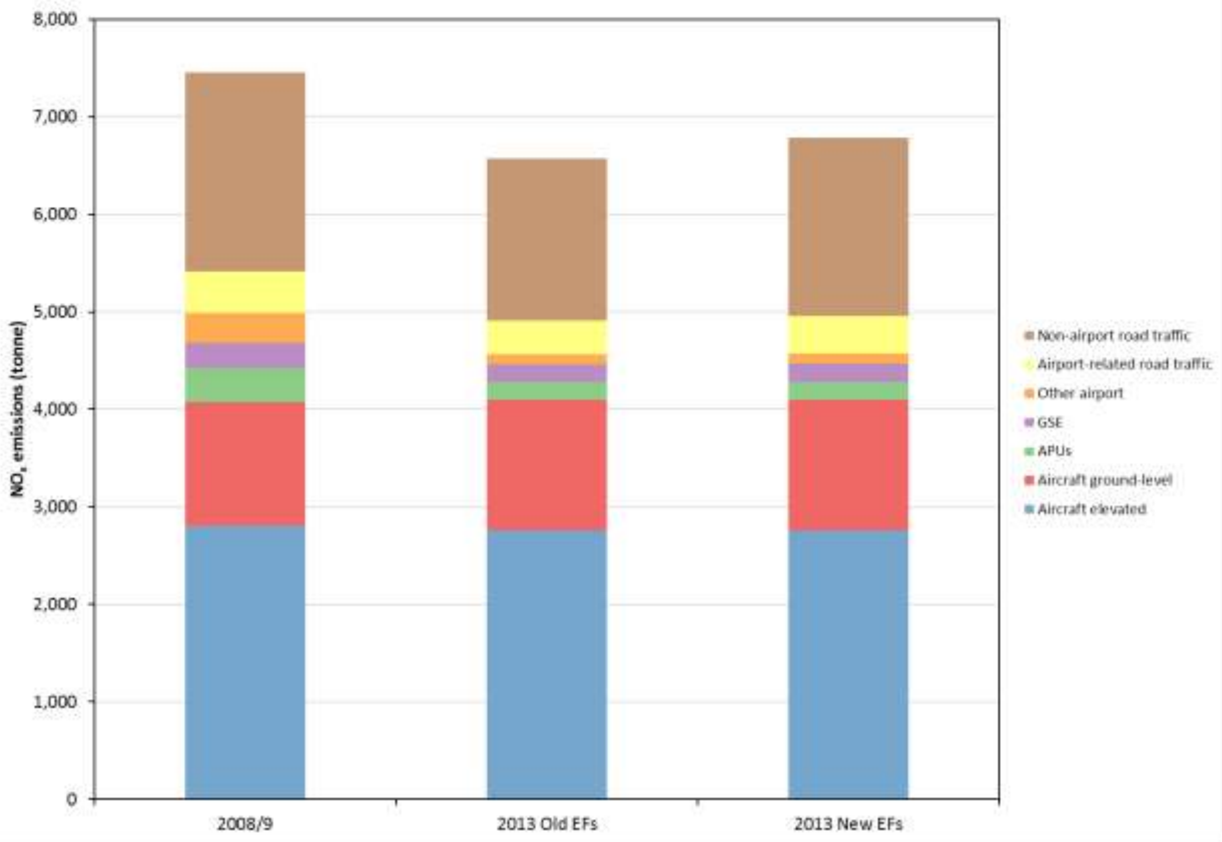
[a] Difference (%) = 100 * (2013 value – 2008/9 value) / 2008/9 value
[b] From wheels off to 1000 m above ground (departure) and from 1000 m to touchdown (arrival)
[c] Emissions from aircraft on the ground, including main engines, APU and engine testing emissions
[d] Total for airport-related trips within the 11 km × 11 km rectangular major road network area
[e] Includes additional car parking emissions and fire training ground emissions
[f] Total for non-airport trips within the 11 km × 11 km rectangular major road network area
[g] The airport-related/non-airport split is not available for road network emissions for 2008/9, so for the purposes of this table, they have been split in the same proportion as 2013

It can be seen in the table above, that aircraft make a dominant contribution to the airport NO_x emissions. It should be borne in mind that this is for aircraft emissions in the LTO cycle (so cruise emissions are excluded because they have no impact on local air quality), and road network emissions are presented only on major roads within the 11 km × 11 km area around the airport. Choosing a larger road network area would change the balance of calculated emissions.

The fall in emissions from heating plant is largely a result of the decommissioning of the Combined Heat and Power plant operated on behalf of Heathrow Airport by Thames Valley Power, which occurred in 2011.

NO_x emissions are shown graphically in Figure 8, which also shows emissions calculated using the Old road traffic related emission factors.

Figure 8: NO_x emissions by source category



4.1.2 Aircraft

The decrease in aircraft emissions from 2008/9 to 2013 is despite an increase in passenger numbers (9.7%, from 65.9 million passengers per annum (mppa) to 72.3 mppa). Table 8 shows the total aircraft LTO NO_x emissions (on the ground and up to 1000 m) normalised by passenger numbers. It shows a reduction of 12.5% in LTO emissions per passenger between the year 2008/9 and 2013.

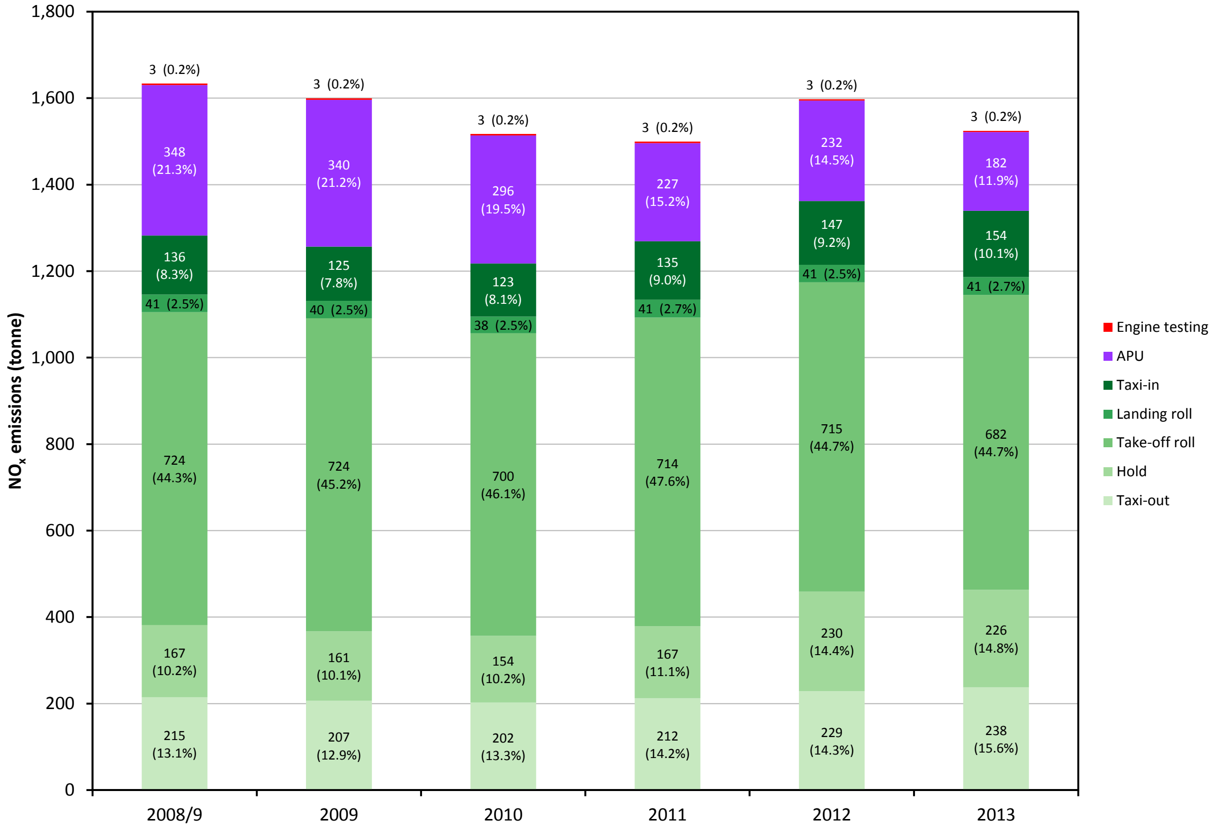
Table 8: NO_x emissions normalised by passenger number

Metric	2013	2008/9	Difference (%)[a]
LTO NO_x emission rate (tonnes/year)	4286	4465	-4.0
Passengers per year (mppa)	72.33	65.93	9.71
Ratio (g/pax)	59.25	67.72	-12.50

[a] Difference (%) = 100 * (2013 value – 2008/9 value) / 2008/9 value

As has been noted, emissions from aircraft on the ground are more important for local air quality than emissions above the ground. Figure 9 gives a breakdown of the pertinent NO_x emissions by 'mode' (phase of the LTO cycle), comparing the relative distribution in 2013 with its equivalent for preceding years.

Figure 9: Breakdown of ground-level aircraft NO_x emissions by mode



Take-off roll contributes a relatively large fraction of ground-level emissions, but the hot exhaust gases from engines at high thrust lead to plume rise (i.e. hot air rises), which tends to lower the ground-level concentration per unit emission. The dispersion modelling process takes this into account when determining ground-level concentrations. Take-off roll emissions are 5.8% lower in 2013 than 2008/9.

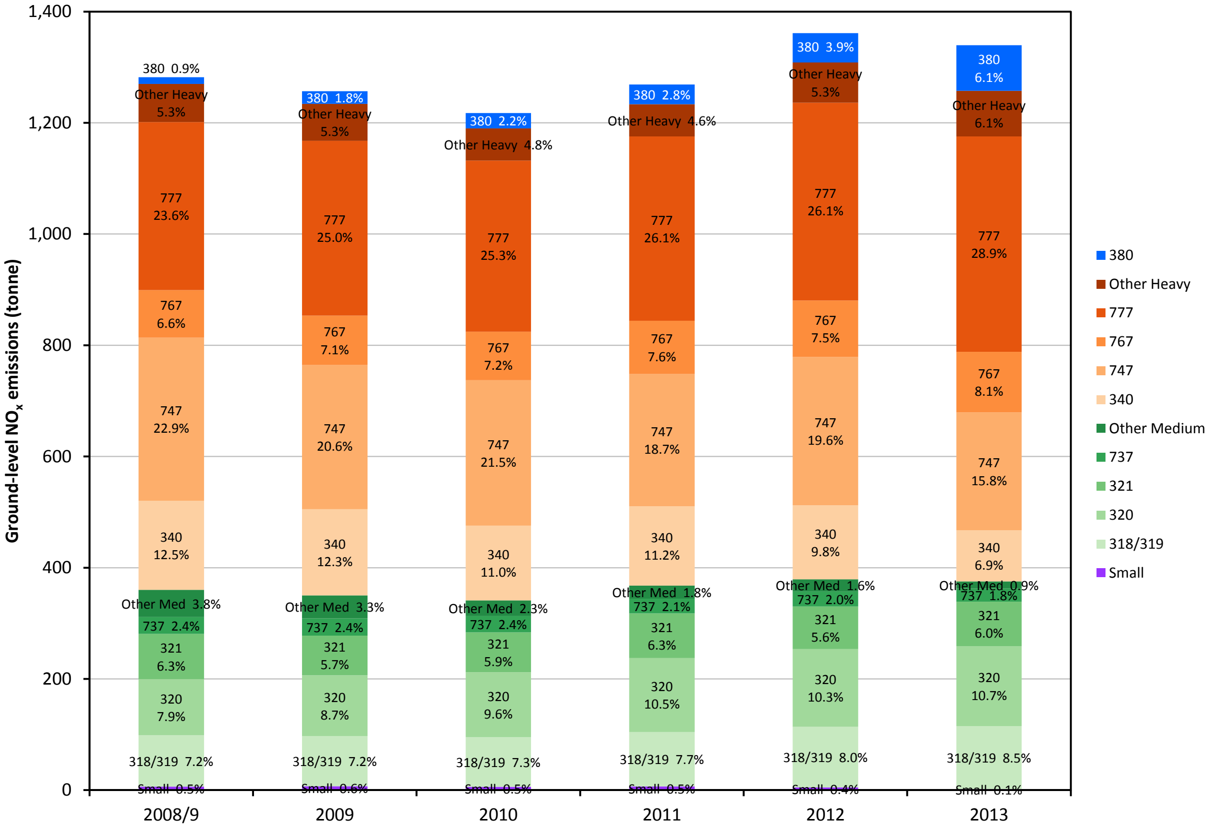
The methodology for calculating taxiing and hold times changed in the 2012 inventory. As detailed in Section 2.1.1, for 2012 and 2013 times were taken from EFPS data. This results in a step change (increase) in calculated emissions, especially for hold. Emissions from taxi-in, taxi-out and hold are 19.1% higher in 2013 than 2008/9.

APU emissions (purple) are another major contributor, but the calculations are sensitive to the assumptions about APU running times. As noted in the methodology section, times have fallen steadily over the last few years, and this is reflected in the emissions, with a 47.7% fall in emissions between 2008/9 and 2013.

Emissions from engine ground runs (engine testing) are included in the inventory for completeness, but they are very small.

It is of interest to see how much the various aircraft types contribute to the overall ground-level aircraft emissions, in light of the distribution of movements amongst aircraft types given in Figure 5. Figure 10 shows the relative contribution by aircraft type to the total ground-level NO_x emissions (excluding APU and engine testing emissions). It is notable that the larger jets (blue and orange: A380, A340, B747, B767, B777 and other heavy types) contribute 72% of the NO_x emissions in 2013, despite accounting for just 36% of the movements. A similar relative contribution can be seen for earlier years. Emissions from the A380 (blue) are growing steadily, as these aircraft become increasingly common. A more detailed table of contributions by aircraft type is given in Appendix A.

Figure 10: Breakdown of ground-level aircraft NO_x emissions[a] by aircraft type



[a] Excludes APU and engine testing emissions

The differences between Figure 5 and Figure 10 point to significant differences in the ground-level NO_x emissions per cycle (arrival plus departure), and some examples are shown in Table 9. It clearly indicates that there are large variations from one aircraft type to another. Of course, one would expect the larger aircraft types to emit more NO_x per cycle, given that they have larger engines to carry a greater number of passengers. However, the differences cannot be explained simply by seat capacity, with a component of the increase for current large aircraft types relating to generally higher engine pressure ratios. It should be noted that there are quite large variations in the NO_x emissions performance of engines that can be fitted to aircraft of similar size, so the specifics of engine fit in a given fleet are important.

Table 9: Ground-level NO_x emissions per cycle (arrival plus departure)

Aircraft type	2013 NO_x (kg/cycle[a])	2008/9 NO_x (kg/cycle[a])
Small	1.1	0.7
318/319	2.3	2.2
320	2.3	2.2
321	3.3	3.0
737	2.2	2.1
Other Medium	2.7	3.2
340	14.6	13.1
747	13.1	13.1
767	6.5	6.0
777	12.8	11.3
Other Heavy	7.5	7.9
380	18.3	16.1

[a] Ground-level aircraft NO_x excluding APU and engine testing emissions

4.1.3 Ground support equipment (GSE)

Table 9 shows how the total NOx emissions from GSE are split between contributions from road vehicles and off-road vehicles. In 2013 for the results with the new road emission factors, 78% of the total NOx from GSE is estimated to be emitted by road vehicles (from 80% of the fuel). The average emission factor (in g NOx per kg fuel burned) associated with the road-vehicle category is estimated to be 18.97 g/kg, compared to 20.65 g/kg for off-road vehicles, for the new road emission factors.

Compared to 2008/9, the total fuel use decreased by 8% in 2013 and the total NOx emissions (using the new road emission factors) have reduced by 28%. The reduction in emissions is almost entirely from off-road equipment, which showed both reduced activity (fuel use) and lower emission factors.

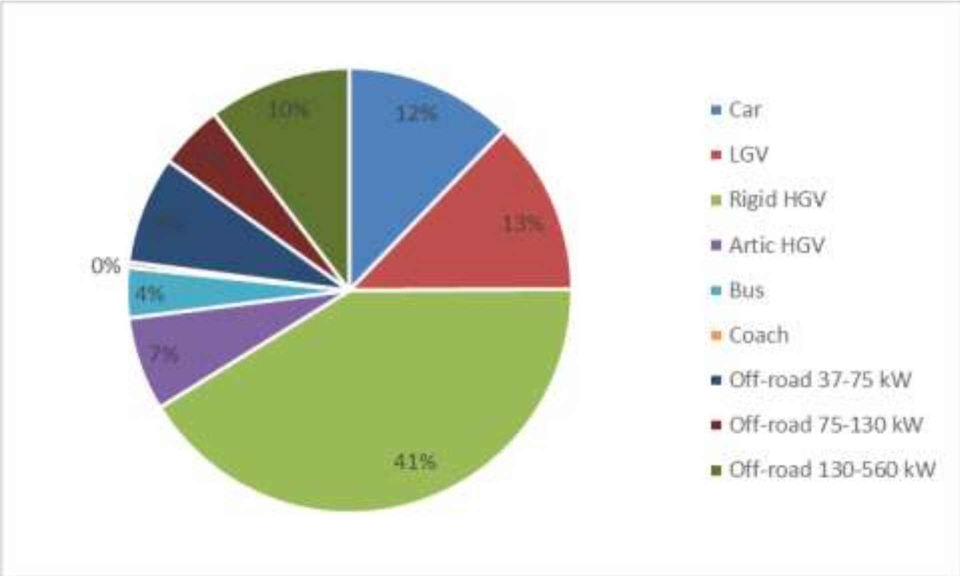
Table 10: Road/off-road split of GSE NO_x emissions; average emission factors

Quantity	Units	2013 Old EFs	2013 New EFs	2008/9
Road vehicles				
NO_x emissions	t/year	136.70	146.08	138.41
Fuel	kt/year	7.70	7.70	7.33
Ratio	g/kg	17.75	18.97	18.88
Off-road vehicles				
NO_x emissions	t/year	40.70	40.70	122.09
Fuel	kt/year	1.97	1.97	3.23
Ratio	g/kg	20.65	20.65	37.79
Total				
NO_x emissions	t/year	177.40	186.79	260.50
Fuel	kt/year	9.67	9.67	10.56
Ratio	g/kg	18.34	19.32	24.67

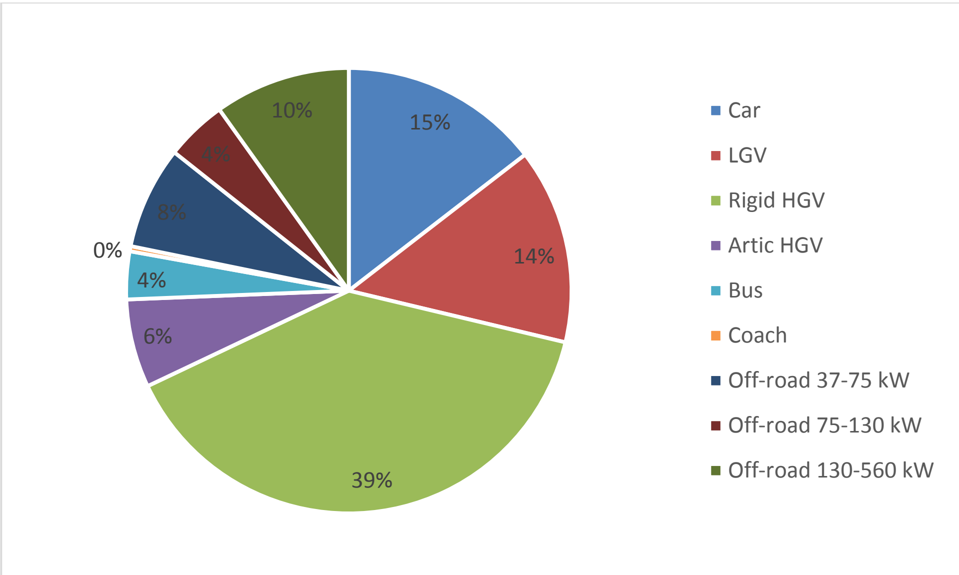
For GSE, the distribution by vehicle type is shown in Figure 11, highlighting the dominance of emissions from HGVs in 2013 and HGVs in 2008/9 (though to a lesser extent.

Figure 11: Breakdown of GSE NO_x emissions by vehicle type

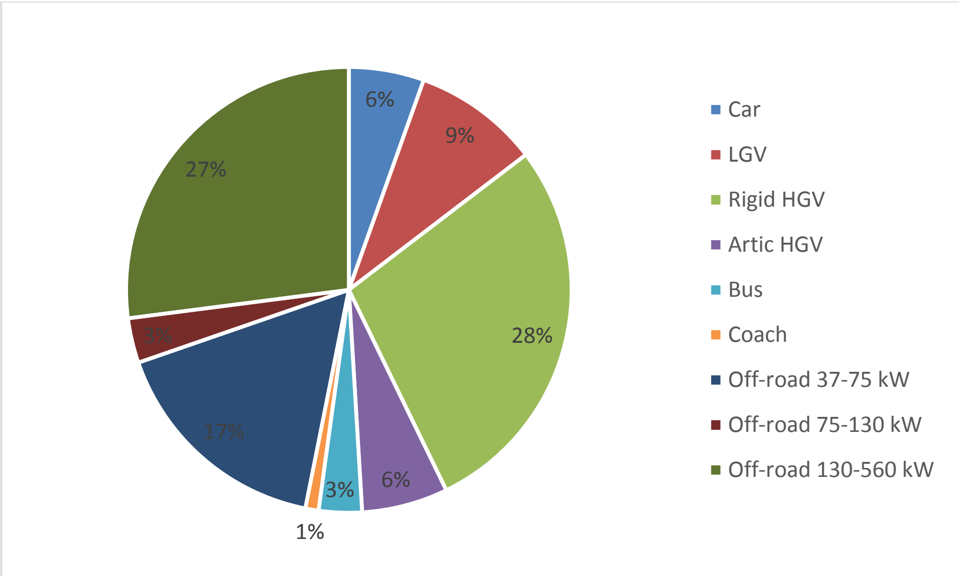
a) 2013 Old EFs



b) 2013 New EFs



c) 2008/9

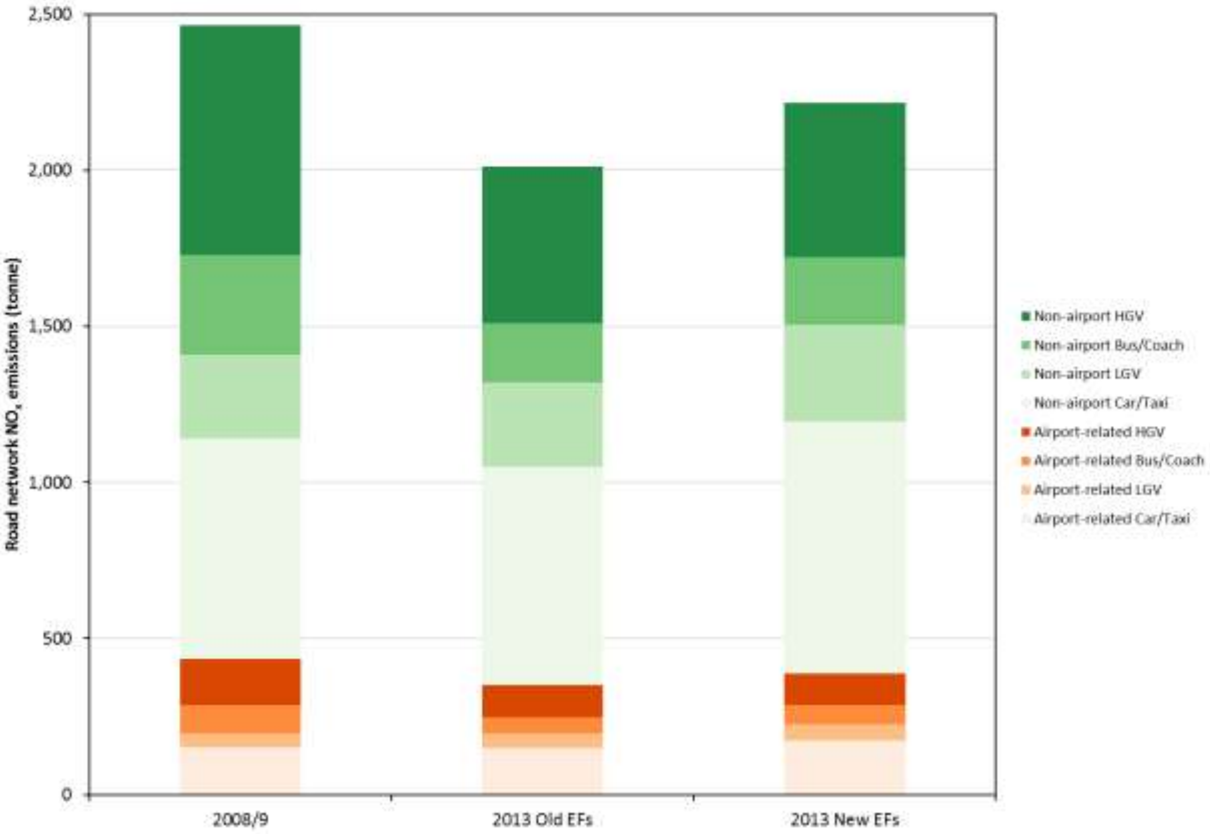


4.1.4 Landside road network

The estimated NO_x emissions from traffic on the landside road network for 2013 are 18% (old road emission factors) and 10% (new road emission factors) lower than the values calculated for the 2008/9 air quality study. This reduction is largely due to a more modern fleet with tighter emissions standards; this is offset somewhat by the use of updated emission factors, which tend to give higher estimated emissions than the factors used in the 2008/9 work. Differences in the process for generating the underlying traffic data may also cause differences in the emissions. Airport-related traffic contributed 17% of the emissions on the modelled network in 2013 (the corresponding figure for 2008/9 is not available); note that if a different network area had been used this fraction would be different.

Emissions by vehicle type are shown in Figure 12, which also compares the New EFs (new road emission factors) with the Old EFs (old road emission factors). For 2008/9, the split between airport-related and non-airport traffic is not available, so for the purposes of Figure 12, the split has been assumed to be the same as in 2013.

Figure 12: Breakdown of road network NO_x emissions by vehicle type



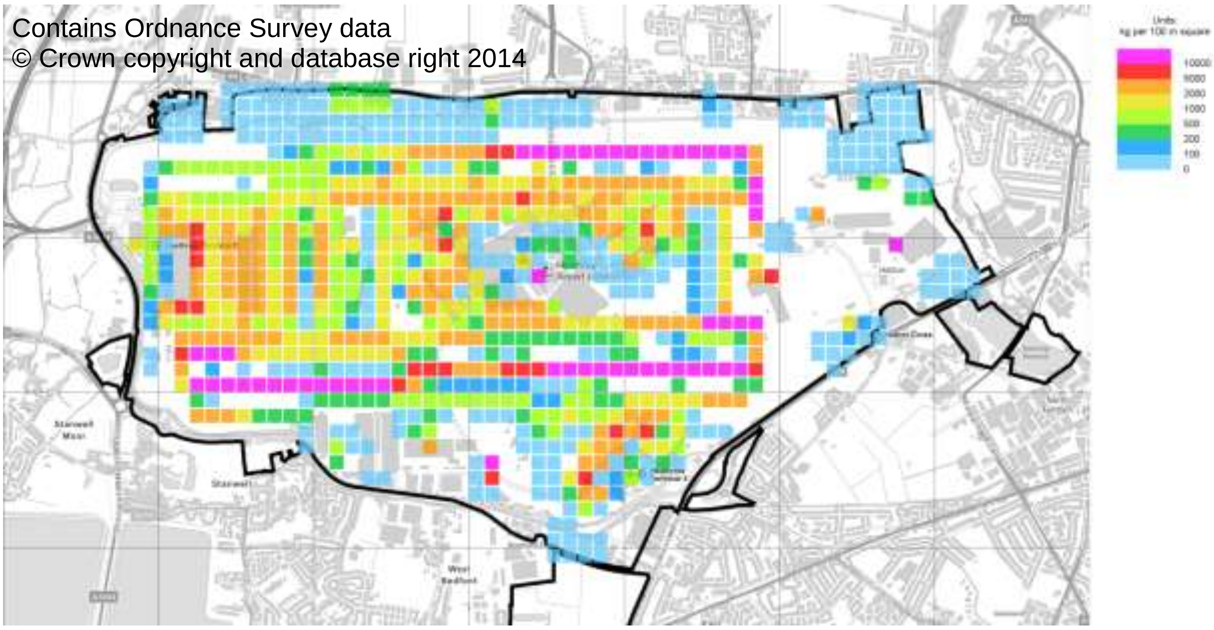
Although the traffic, both airport-related and non-airport, is dominated by cars (Figure 7), the higher emission factors for HDVs mean that the latter contribute appreciably to NO_x emissions.

4.1.5 Spatial density of emissions

Figure 13 shows the spatial density of ground-level on-airport NO_x emissions. The sources included are ground-level aircraft, APUs, engine testing, GSE, heating plant, car parks and the fire training ground; it does not show the network roads. The figure shows the total NO_x emission, from each of these sources, within each 100 m square on the airport.

The runways and hold areas can clearly be seen as areas of high emission density (magenta and red), with the aprons being more extensive areas of relatively high emission (orange and yellow). Taxiways generally have a lower emission density (green). Car parks are extensive areas of low emission density (pale blue), although the Terminal 5 short-term car park shows up as relatively high. Heating plant appear as often isolated sources, sometimes of high emission density (e.g. in the Central Terminal Area and the Maintenance Area).

Figure 13: Spatial density of ground-level on-airport NO_x emissions



4.2 PM_{10} and $PM_{2.5}$ emissions

4.2.1 Overview

Table 11 and Table 12 show the calculated annual PM_{10} and $PM_{2.5}$ (collectively referred to as PM) emissions respectively, for 2013 for each major source category. A more detailed breakdown is given in Appendix A. It is worth noting that for aircraft exhaust emissions the $PM_{2.5}$ mass has been assumed equal to the PM_{10} mass, but this is not the case for brake and tyre wear emissions.

Focusing on airport-related sources, emissions from airport-related on the road network are roughly equal to aircraft emissions, in contrast to NO_x where aircraft emissions were dominant. However it should be repeated that choosing a different road network area would change the balance of calculated emissions.

Table 11: PM_{10} emission rate (tonne/year) by source category

Source category		PM_{10} emission rate (tonne/year)			Difference (%)[a]	
		2013 Old EFs	2013 New EFs	2008/9[g]	Old EFs	New EFs
Airport	Aircraft – elevated[b]	15.5	15.5	15.0	3	3
	Aircraft – ground[c]	35.5	35.5	36.6	-3	-3
	GSE	9.9	10.9	21.4	-54	-49
	Road traffic[d]	38.4	44.6	41.4	-7	8
	Heating plant	6.9	6.9	26.1	-74	-74
	Other[e]	1.2	1.4	1.6	-25	-13
Non-airport	Road traffic[f]	183.3	211.9	197.9	-7	7

[a] Difference (%) = 100 * (2013 value – 2008/9 value) / 2008/9 value
[b] From wheels off to 1000 m above ground (departure) and from 1000 m to touchdown (arrival)
[c] Emissions from aircraft on the ground, including main engines, APUs, engine testing, brake wear and tyre wear
[d] Total for airport-related trips within the 11 km x 11 km rectangular major road network area
[e] Includes additional car parking emissions and fire training ground emissions
[f] Total for non-airport trips within the 11 km x 11 km rectangular major road network area
[g] The airport-related/non-airport split is not available for road network emissions for 2008/9, so for the purposes of this table, they have been split in the same proportion as 2013

Table 12: $PM_{2.5}$ emission rate (tonne/year) by source category

Source category		$PM_{2.5}$ emission rate (tonne/year)			Difference (%)[a]	
		2013 Old EFs	2013 New EFs	2008/9[g]	Old EFs	New EFs
Airport	Aircraft – elevated[b]	15.5	15.5	15.0	3	3
	Aircraft – ground[c]	28.1	28.1	29.3	-4	-4
	GSE	7.5	7.9	18.8	-60	-58
	Road traffic[d]	22.6	26.3	27.0	-16	-2
	Heating plant	6.9	6.9	26.1	-74	-74
	Other[e]	0.8	1.0	1.1	-28	-13
Non-airport	Road traffic[f]	108.5	125.2	129.1	-16	-3

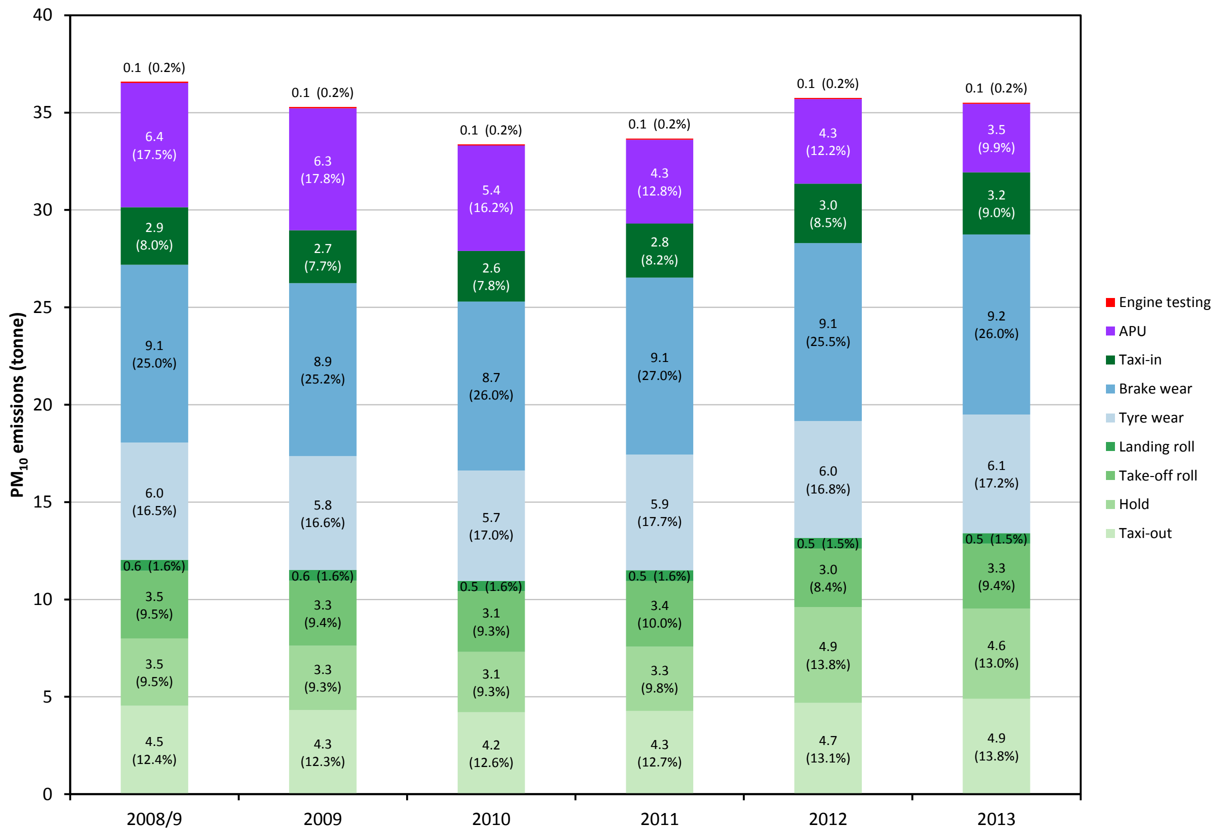
[a] Difference (%) = 100 * (2013 value – 2008/9 value) / 2008/9 value
[b] From wheels off to 1000 m above ground (departure) and from 1000 m to touchdown (arrival)
[c] Emissions from aircraft on the ground, including main engines, APUs, engine testing, brake wear and tyre wear
[d] Total for airport-related trips within the 11 km x 11 km rectangular major road network area
[e] Includes additional car parking emissions and fire training ground emissions
[f] Total for non-airport trips within the 11 km x 11 km rectangular major road network area
[g] The airport-related/non-airport split is not available for road network emissions for 2008/9, so for the purposes of this table, they have been split in the same proportion as 2013

4.2.2 Aircraft

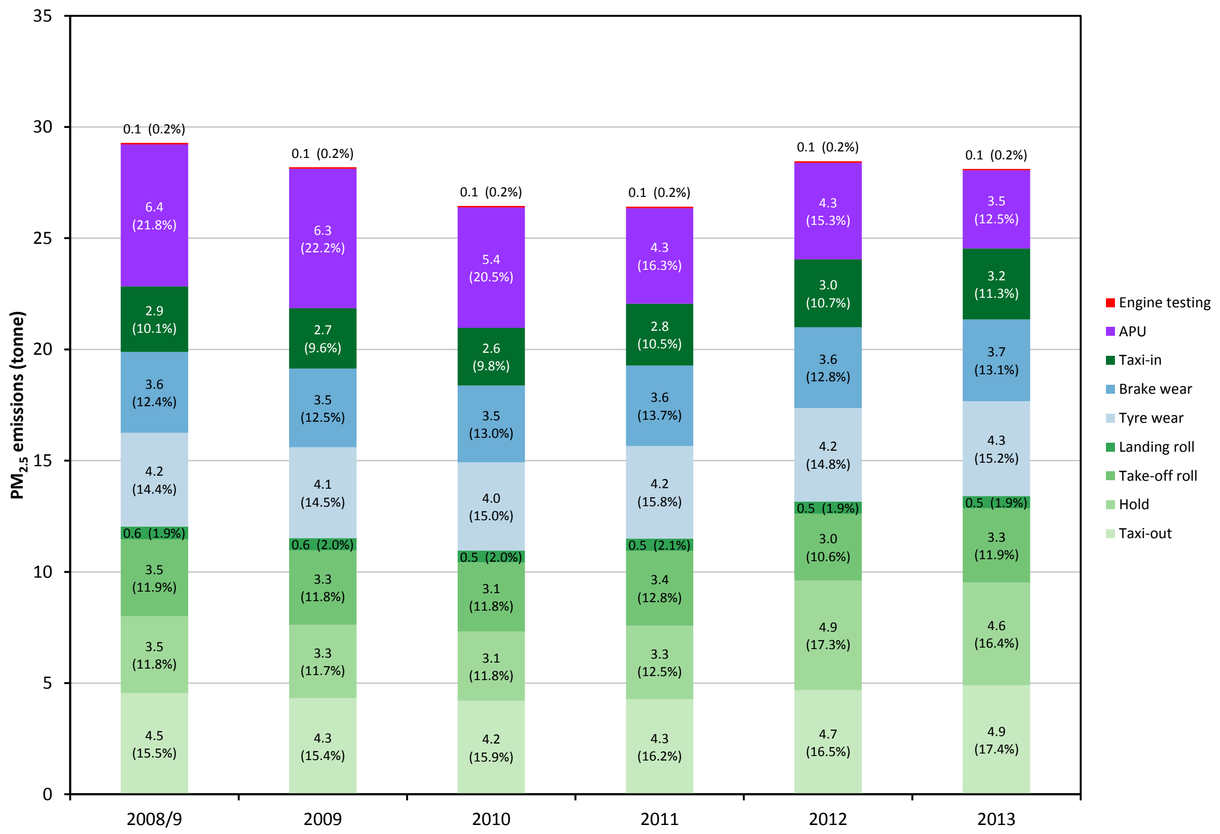
Figure 14 gives a breakdown of the ground-level aircraft PM emissions by 'mode' (component of the LTO cycle), with PM_{10} and $PM_{2.5}$ shown separately. The picture is broadly the same for each year, allowing for different numbers of movements. For exhaust emissions, the $PM_{2.5}$ and PM_{10} masses are taken to be the same. Clearly, according to the current methodology brake and tyre wear (blue) are major contributors, together accounting for 43% of the total for PM_{10} and 28% for $PM_{2.5}$ in 2013, although the pertinent emission factors are subject to significant uncertainties. In contrast to the situation for NO_x, for PM take-off roll is not a dominant contributor to the total ground-level aircraft exhaust emissions. In this case, the emission rate at higher thrust does not compensate for the shorter time-in-mode, so the longer running times for taxiing and hold lead to larger contributions.

Figure 14: Breakdown of ground-level aircraft PM emissions by mode

(a) PM_{10}



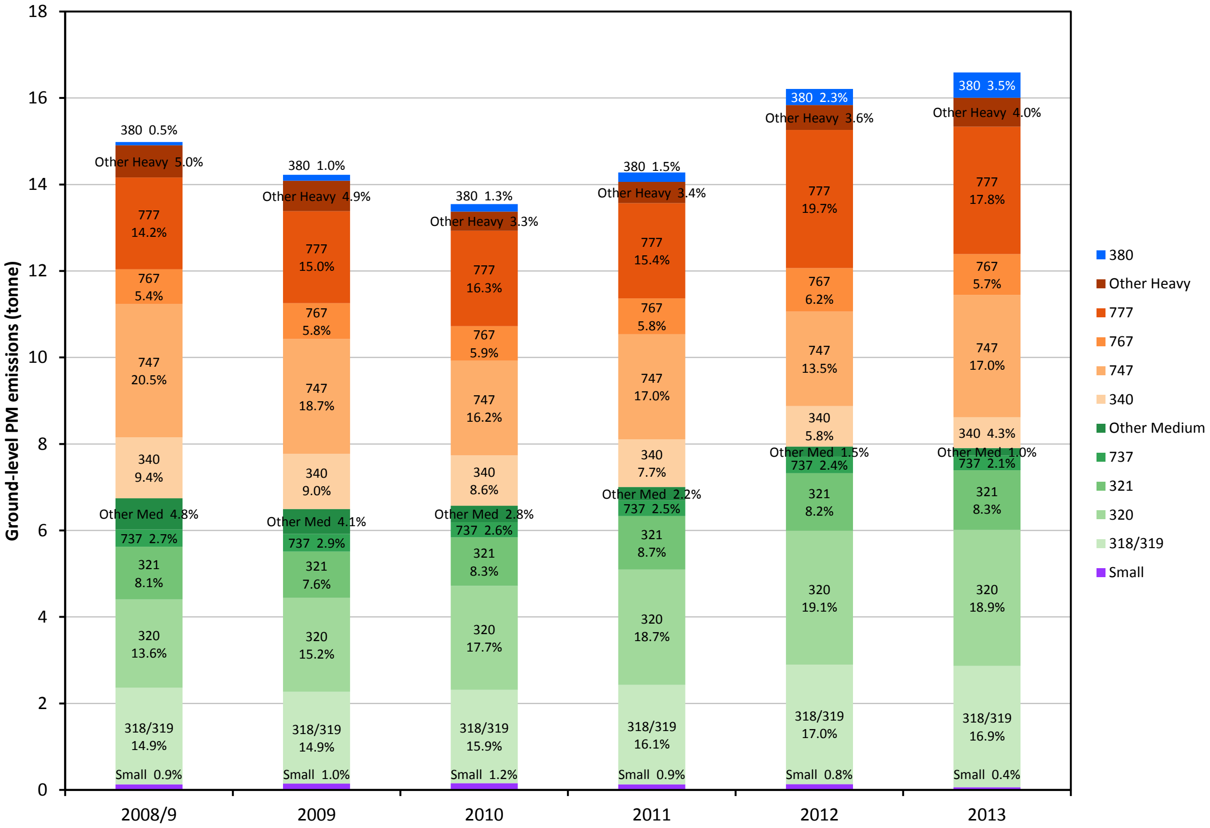
(b) $PM_{2.5}$



Aircraft exhaust emissions still account for a major part of the airport ground level PM emissions, and it is of interest to examine the contribution from various aircraft types. Figure 15 shows the relative contribution from the major aircraft categories, which can be compared to the movement breakdown in Figure 5. A more detailed emissions breakdown is given in Appendix A.

For PM, the A319/320/321 account for a larger fraction of the total than for NO_x, with the pressure-ratio effect observed for NO_x (which led to the larger aircraft types accounting for a disproportionate share of the emissions) not an effect for PM. Larger jets account for around 52% of the exhaust PM emission in 2013 (for 36% of the movements). A similar contribution can be seen for other years.

Figure 15: Breakdown of ground-level aircraft exhaust PM emissions[a] by aircraft type



[a] Excludes APU, engine testing, brake wear and tyre wear

The lower variability in aircraft PM exhaust emissions with aircraft type is displayed more directly in Table 13, which can be compared with Table 9 for NO_x.

Table 13: Ground-level PM exhaust emissions per cycle (arrival plus departure)

Aircraft type	2008/9 PM (kg/cycle[a])	2013 PM (kg/cycle[a])
Small	0.04	0.01
318/319	0.06	0.05
320	0.05	0.04
321	0.06	0.04
737	0.03	0.03
Other Medium	0.04	0.05
340	0.11	0.12
747	0.17	0.14
767	0.06	0.06
777	0.10	0.08
Other Heavy	0.06	0.09
380	0.13	0.10

[a] Ground-level aircraft PM emissions excluding APU, engine testing, brake wear and tyre wear

According to the current methodology, the brake and tyre wear contribution to PM emissions is almost directly proportional to the aircraft size (as represented by its maximum take-off weight (MTOW)).

4.2.3 Ground support equipment (GSE)

For GSE, there is interest in the relative contributions from road vehicles and off-road vehicles, given their different emission factors, as well as in the split between exhaust and fugitive emissions. Table 14 shows the relevant contributions.

Table 14: Relative contributions to GSE PM emissions

		2013 Old EFs		2013 New EFs		2008/9	
		PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Exhaust	Road	23.28%	29.27%	22.12%	29.21%	25.21%	27.25%
	Off-road	33.55%	41.80%	30.49%	39.92%	57.55%	62.79%
Fugitive[a]	Road	37.76%	25.28%	40.99%	27.05%	13.94%	8.03%
	Off-road	5.41%	3.65%	6.40%	3.82%	3.30%	1.93%
Total		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

[a] 'Fugitive' includes brake wear, tyre wear and re-suspended road dust

For GSE the overall contribution from fugitive PM emissions is much smaller than that from exhaust emissions, due to the relatively small contribution from off-road vehicles. For exhaust PM emissions, off-road vehicles account for a larger share than road vehicles, despite accounting for less than a quarter of the fuel use in 2013; this is because of the larger emission factors (in g/kg fuel consumed) on average for off-road vehicles compared to those for road vehicles. For fugitive emissions, the larger contribution derives from road vehicles, principally reflecting the lower (estimated) average distances travelled airside by off-road vehicles.

4.2.4 Landside road network

The estimated PM_{10} emissions from traffic on the landside road network for 2013 are 7% lower (old road emission factors) and 7% higher (new road emission factors) than the values calculated for the 2008/9 air quality study ($PM_{2.5}$: 16% lower and 3% lower respectively). These changes are primarily related to the updated emission factors used, which tend to give higher estimated emissions per vehicle for the same year than the factors used in the 2008/9 work. Differences in the process for generating the underlying traffic data may also cause differences in the emissions.

For both PM_{10} and $PM_{2.5}$, airport-related traffic contributed 17% of the emissions on the modelled network in 2013 (the corresponding figure for 2008/9 is not available). This fraction is only true for the particular 11 km × 11 km road network modelled.

Emissions of PM_{10} and $PM_{2.5}$ by vehicle type are shown in Figures 16 and 17, which also compares the New EFs (new road emission factors) with the Old EFs (old road emission factors). For 2008/9, the split between airport-related and non-airport traffic is not available, so for the purposes of Figures 16 and 17, the split has been assumed to be the same as in 2013.

Figure 16: Breakdown of road network PM_{10} emissions by vehicle type

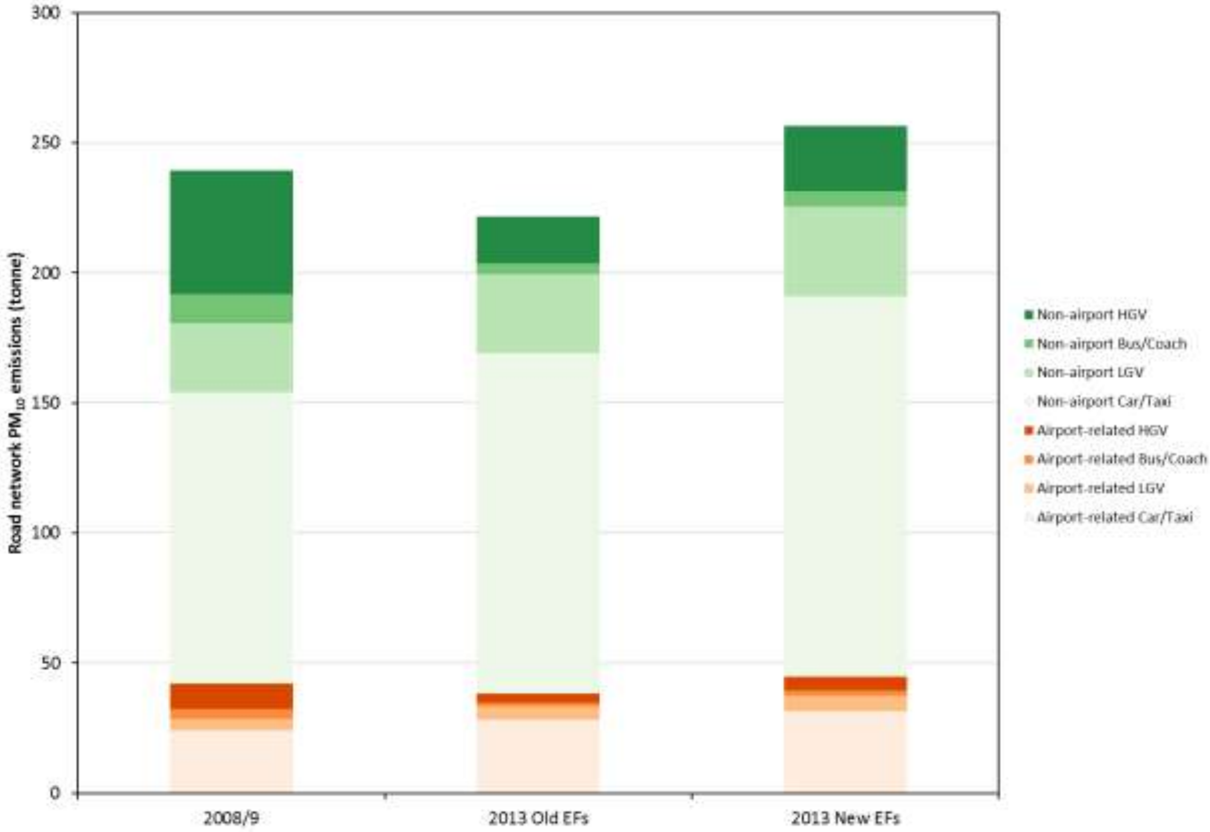
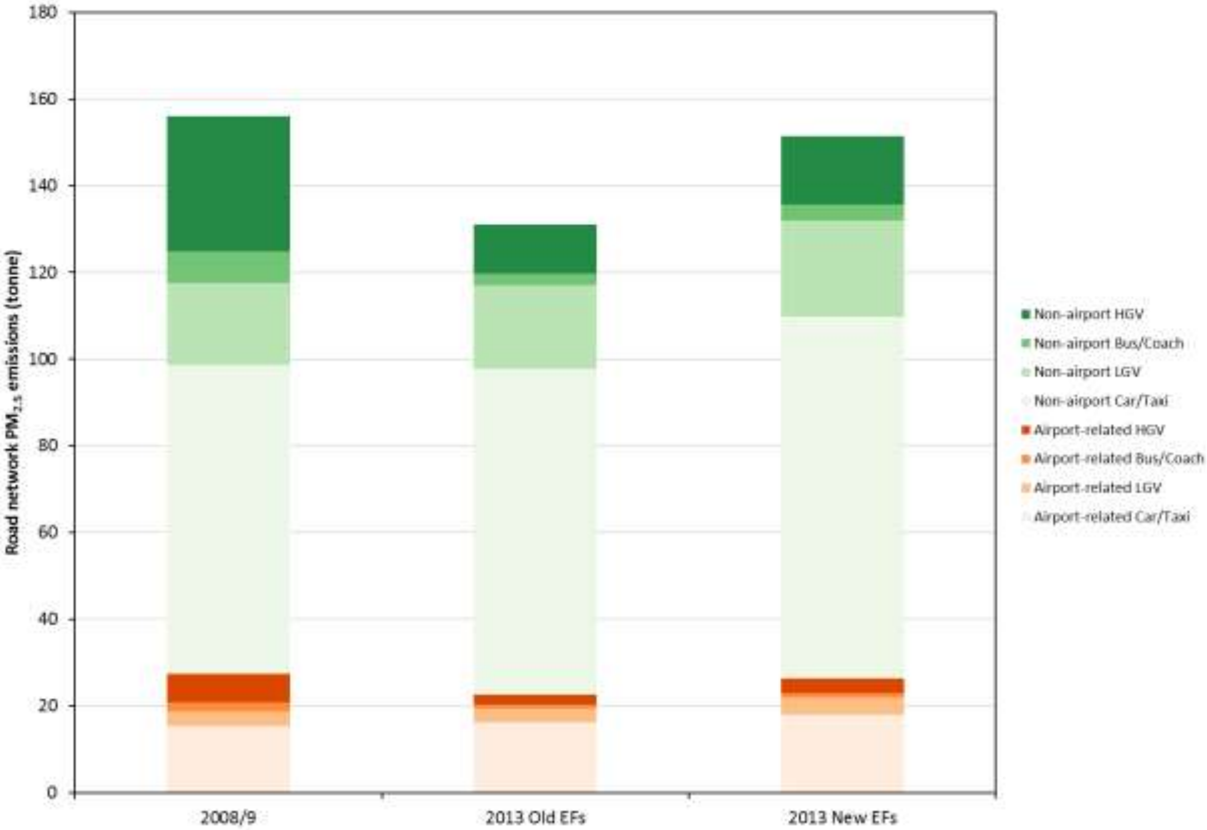


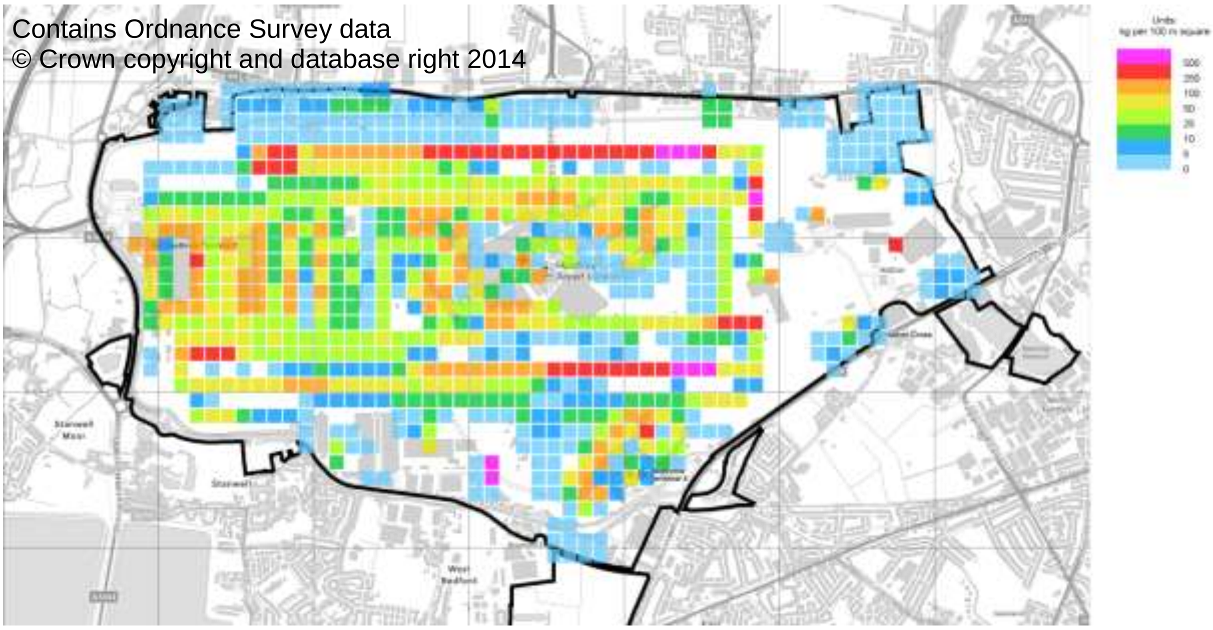
Figure 17: Breakdown of road network $PM_{2.5}$ emissions by vehicle type



4.2.5 Spatial density of emissions

Figure 18 shows the spatial density of ground-level on-airport PM_{10} emissions. The sources included are ground-level aircraft, APUs, engine testing, GSE, heating plant, car parks and the fire training ground; it does not show the network roads. The figure shows the total PM_{10} emission, from each of these sources, within each 100 m square on the airport.

Figure 18: Spatial density of ground-level on-airport PM_{10} emissions



4.3 CO_2 emissions

4.3.1 Overview

Table 15 shows the calculated annual CO_2 emissions for 2013 for each major source category. Data for 2008/9 is available for aircraft and GSE only. All emissions are presented as CO_2.

Table 15: CO_2 emission rate (kilotonne/year) by source category

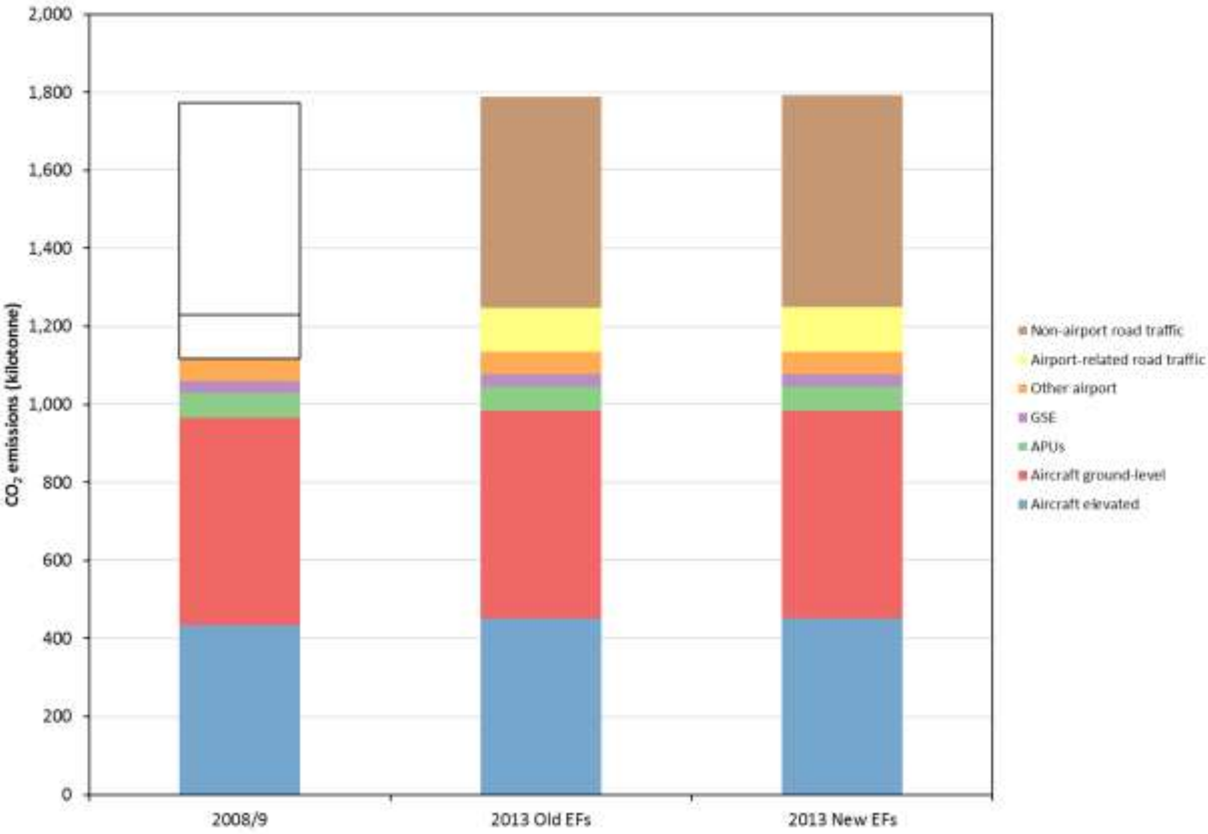
Source category		CO_2 emission rate (kilotonne/year)			Difference (%)[a]	
		2013 Old EFs	2013 New EFs	2008/9	2013 Old EFs	2013 New EFs
Airport	Aircraft – elevated[b]	451	451	434	4	4
	Aircraft – ground[c]	596	596	586	2	2
	GSE	31	31	34	-9	-9
	Road traffic[d]	113	114	N/A	N/A	N/A
	Heating plant	52	52	N/A	N/A	N/A
	Other[e]	4	4	N/A	N/A	N/A
Non-airport	Road traffic[f]	542	544	N/A	N/A	N/A

[a] Difference (%) = 100 * (2013 value – 2008/9 value) / 2008/9 value
[b] From wheels off to 1000 m above ground (departure) and from 1000 m to touchdown (arrival)
[c] Emissions from aircraft on the ground, including main engines, APU and engine testing emissions
[d] Total for airport-related trips within the 11 km × 11 km rectangular major road network area
[e] Includes additional car parking emissions and fire training ground emissions
[f] Total for non-airport trips within the 11 km × 11 km rectangular major road network area

From the table, aircraft make a dominant contribution to the airport CO_2 emissions, but it should be borne in mind that this is for aircraft emissions in the LTO cycle (cruise emissions are not calculated), and road network emissions are presented only on major roads within the within the 11 km × 11 km area around the airport. Choosing a larger road network area, or including cruise, would change the balance of calculated emissions.

CO_2 emissions are shown graphically in Figure 19, which also shows emissions calculated using the New EFs (new road emission factors) and the Old EFs (old road emission factors).

Figure 19: CO_2 emissions by source category



4.3.2 Aircraft

The increase in aircraft CO_2 emissions from 2008/9 to 2013 is a little lower than the increase in passenger numbers (9.7%, from 65.9 mppa to 72.3 mppa). Table 16 shows the total aircraft LTO CO_2 emissions (on the ground and up to 1000 m) normalised by passenger numbers. It shows a reduction of 2.4% in LTO emissions per passenger between 2008/9 and 2013.

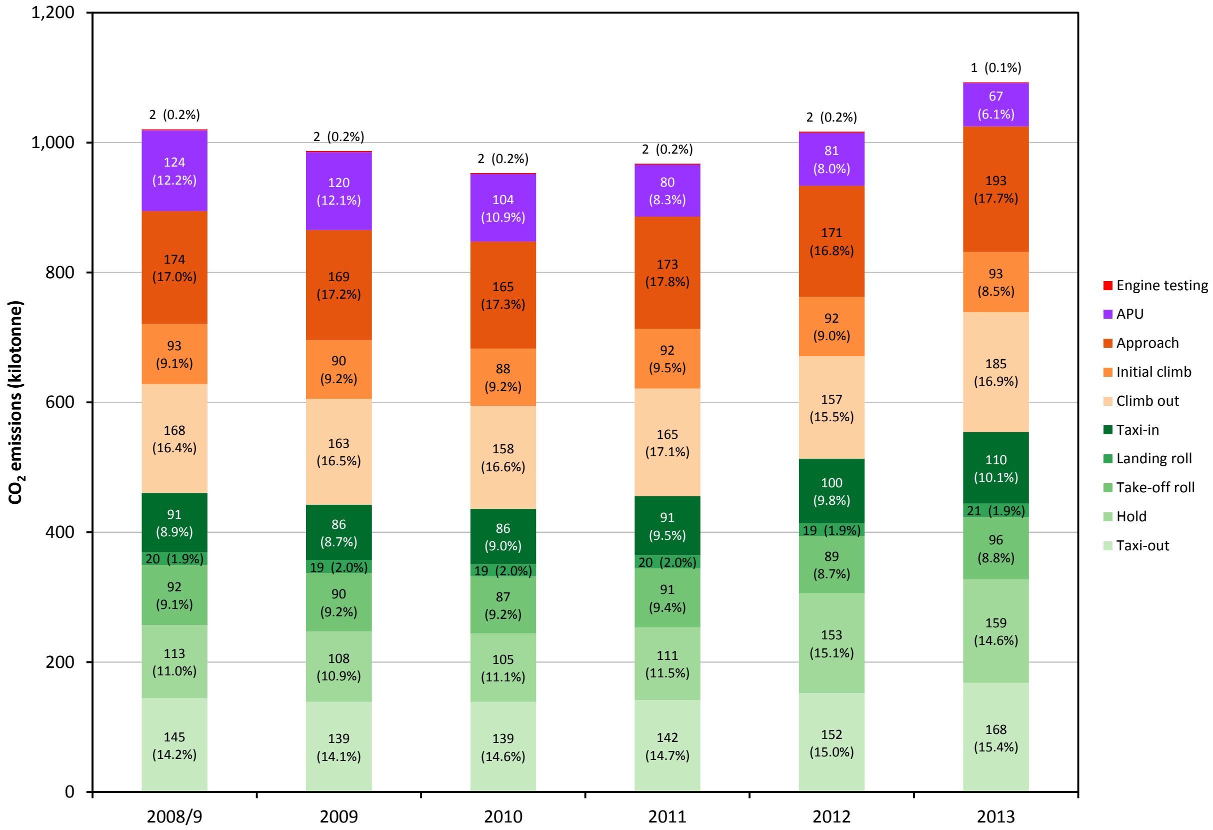
Table 16: CO_2 emissions normalised by passenger number

Metric	2013	2008/9	Difference (%)[a]
LTO CO_2 emission rate (kilotonnes/year)	1093	1020	7.1
Passengers per year (mppa)	72.33	65.93	9.71
Ratio (kg/pax)	15.11	15.48	-2.39

[a] Difference (%) = 100 * (2013 value – 2008/9 value) / 2008/9 value

Figure 20 gives a breakdown of the aircraft CO_2 emissions by 'mode' (phase of the LTO cycle), comparing the relative distribution in 2013 with its equivalent for preceding years.

Figure 20: Breakdown of aircraft CO_2 emissions by mode

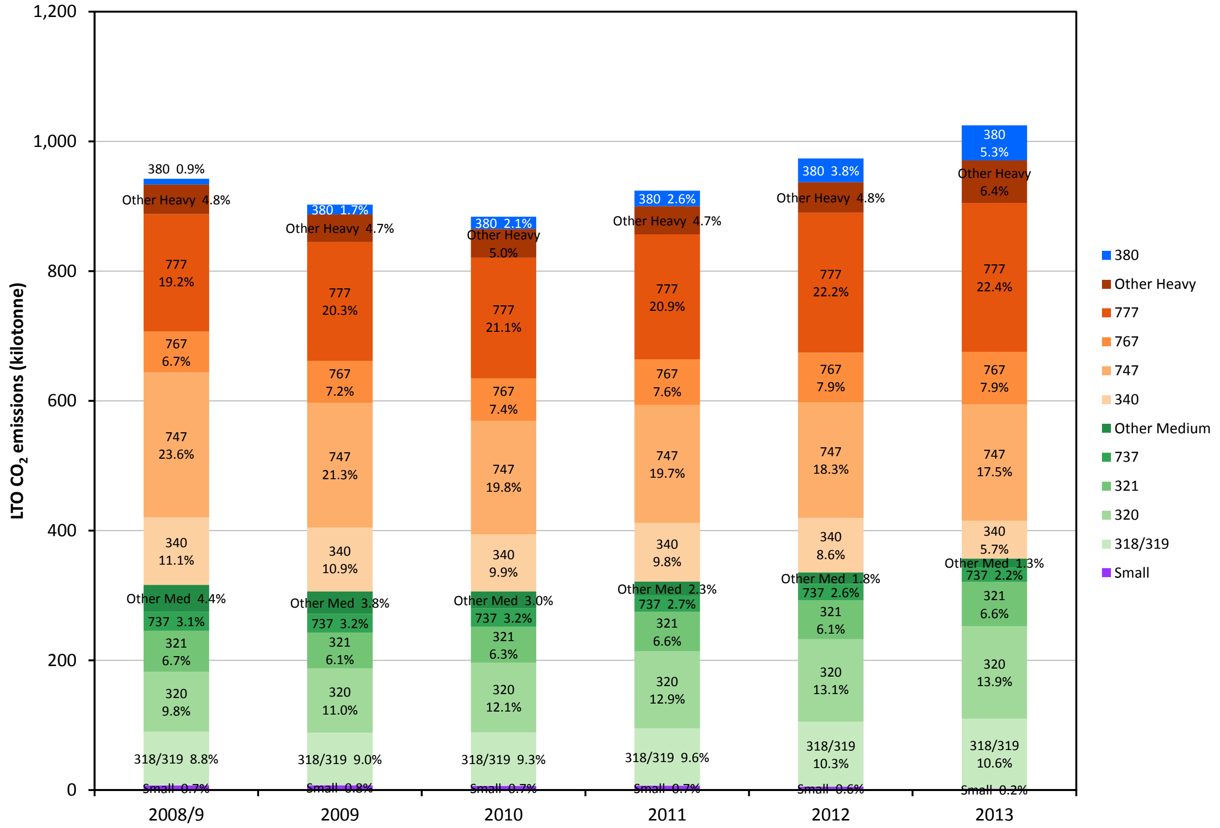


Generally, each mode makes a roughly comparable contribution to CO_2 emissions. There is an increase in 2012/2013 in modelled taxi and hold emissions, resulting from the increased times derived from EFPS data discussed previously.

Emissions from engine ground runs (engine testing) are included in the inventory for completeness, but they have an insignificant contribution.

It is of interest to see how much the various aircraft types contribute to the overall aircraft emissions, in light of the distribution of movements amongst aircraft types given in Figure 5. Figure 21 shows the relative contribution by aircraft type to the total LTO CO_2 emissions (excluding APU and engine testing emissions). Larger jets (blue and orange: A380, A340, B747, B767, B777 and other heavy types) contribute 60% of the CO_2 emissions in 2013, despite accounting for just 36% of the movements. A more detailed table of contributions by aircraft type is given in Appendix A.

Figure 21: Breakdown of aircraft CO_2 emissions[a] by aircraft type



[a] Excludes APU and engine testing emissions

As with the other pollutants, there are significant differences in the CO_2 emissions per cycle (arrival plus departure) by aircraft type, and some examples are shown in Table 9.

Table 17: LTO CO_2 emissions per cycle (arrival plus departure)

Aircraft type	2013 CO_2 (tonne/cycle[a])	2008/9 CO_2 (tonne/cycle[a])
Small	1.4	0.8
318/319	2.2	2.0
320	2.3	2.0
321	2.8	2.3
737	2.1	2.1
Other Medium	2.9	2.7
340	9.3	8.5
747	11.1	9.9
767	4.8	4.5
777	7.6	6.8
Other Heavy	6.0	5.2
380	12.2	11.7

[a] Aircraft LTO CO_2 excluding APU and engine testing emissions

4.3.3 Ground support equipment (GSE)

Table 18 shows how the total CO_2 emissions from GSE are split between contributions from road vehicles and off-road vehicles. As GSE emission are calculated on fuel use and CO_2 is directly related to fuel use only one set of CO_2 emission data are presented for 2013. About 80% of the total CO_2 from GSE is estimated to be emitted by road vehicles in 2013 (from

80% of the fuel). The average emission factor (in kg CO_2 per kg fuel burned) associated with the road-vehicle category is estimated to be 3.18 kg/kg, and is approximately the same as the 3.18 kg/kg for off-road vehicles.

Compared to 2008/9, the total fuel use has decreased by 8% in 2013 while the total CO_2 emissions have reduced by 9%.

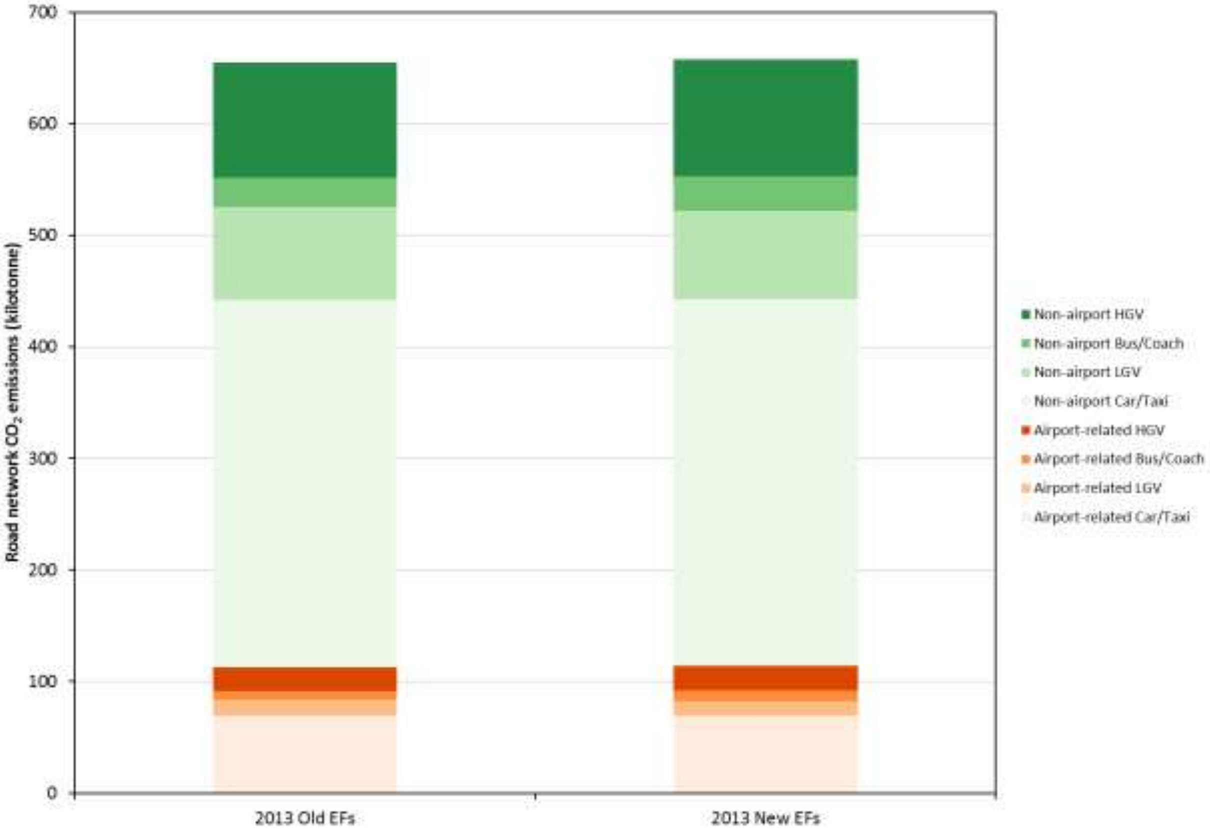
Table 18: Road/off-road split of GSE CO_2 emissions; average emission factors

Quantity	Units	2013	2008/9[a]
Road vehicles			
CO_2 emissions	kt/year	24.46	23.43
Fuel	kt/year	7.70	7.33
Ratio	kg/kg	3.18	3.20
Off-road vehicles			
CO_2 emissions	kt/year	6.26	10.36
Fuel	kt/year	1.97	3.23
Ratio	kg/kg	3.18	3.21
Total			
CO_2 emissions	kt/year	30.72	33.79
Fuel	kt/year	9.67	10.56
Ratio	kg/kg	3.18	3.20

4.3.4 Landside road network

Emissions of CO_2 by vehicle type are shown in Figure 16, which also compares the New EFs (new road emission factors) with the Old EFs (old road emission factors).

Figure 22: Breakdown of road network CO_2 emissions by vehicle type



5 Concentrations

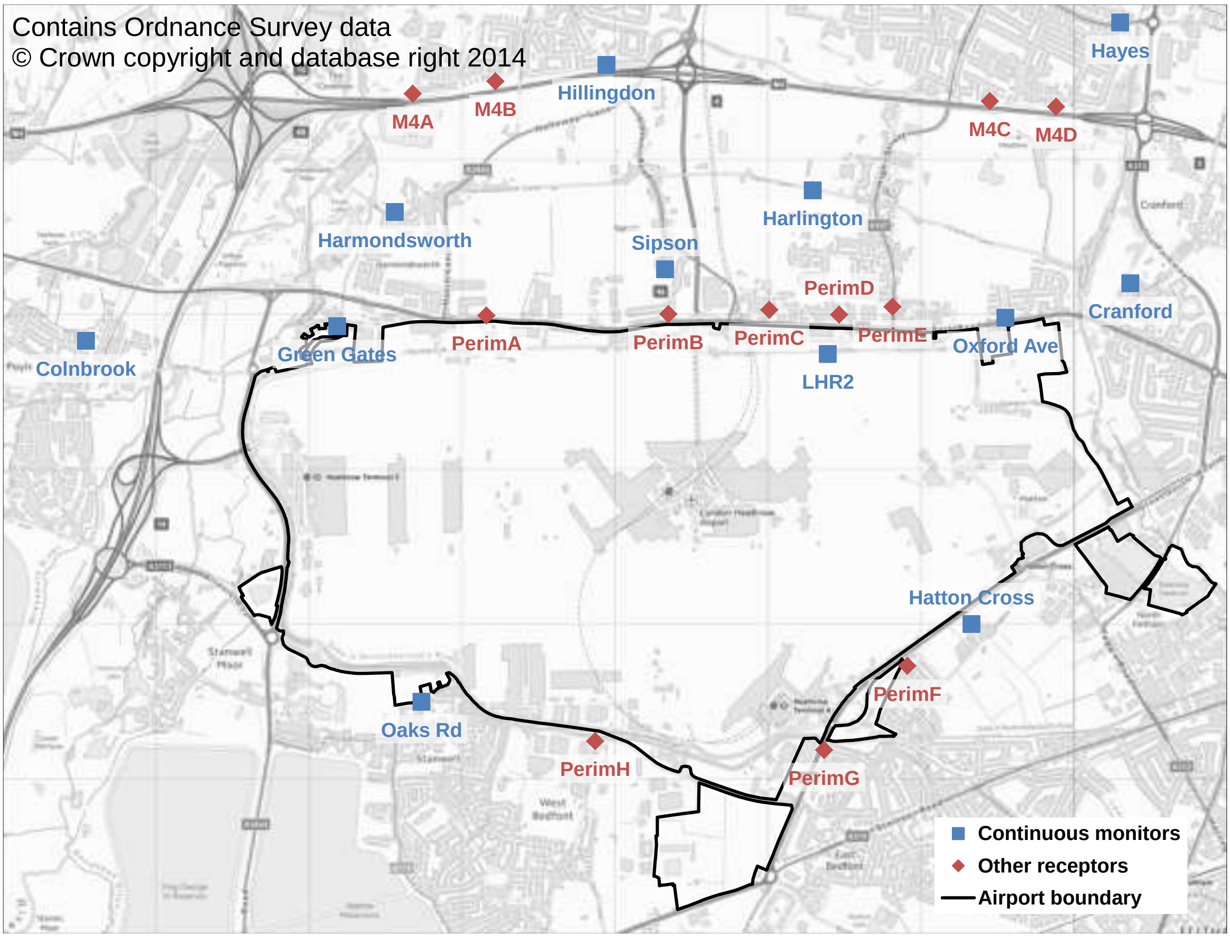
5.1 Selection of receptor locations

Concentrations are presented at a number of selected receptor locations, namely:

- The twelve continuous monitors near Heathrow
- A number of points to represent residential properties around the perimeter of the airport (PerimA to PerimH)
- A number of points to represent residential properties alongside the M4 motorway (M4A to M4D).

These are shown in Figure 23.

Figure 23: Locations of selected receptors



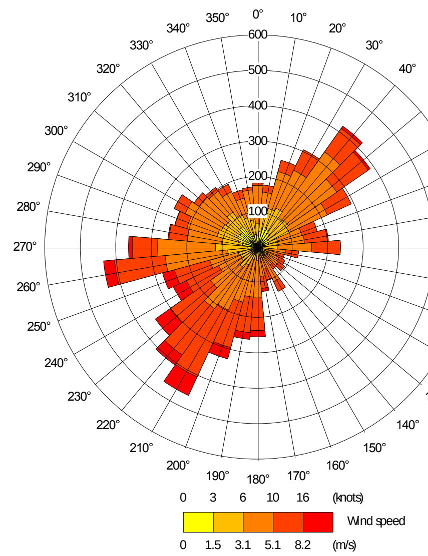
Properties alongside the M4 motorway are at particular risk of air quality exceedances. Concentrations fall off quickly with distance from the motorway, so concentrations are sensitive to the exact location of the receptor. Accordingly, concentrations were calculated for 29 receptor locations along the M4, representing the facades of the buildings closest to the motorway. The four motorway receptor locations reported here (M4A to M4D) represent the highest modelled concentrations along different stretches of the motorway. These four receptor locations are all approximately 30 m from the edge of the nearest carriageway.

5.2 Meteorological conditions

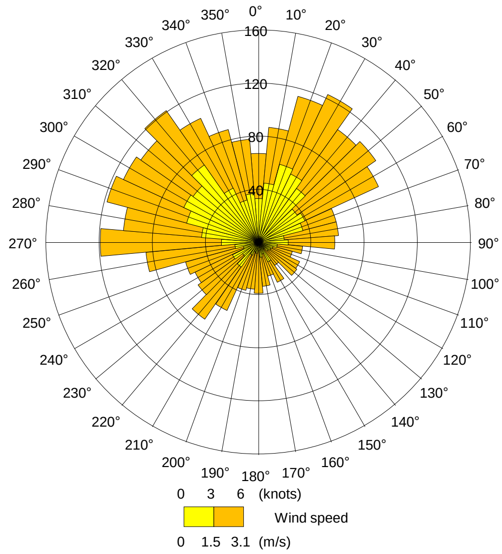
Figure 24 shows the wind rose for 2013 alongside that for 2008/9, which represent the wind speeds and directions The wind roses for the two years are fairly similar in terms of frequency of different wind directions and frequency of low wind speeds. This suggests that any differences between annual mean concentrations in the two years are unlikely to be due to weather conditions to any great extent. However, as noted in Table 6 above, the fraction of easterly operations is somewhat higher in 2013 than in 2008/9, and this will affect the spatial configuration of runway sources with knock-on effects on concentrations.

Figure 24: Wind roses

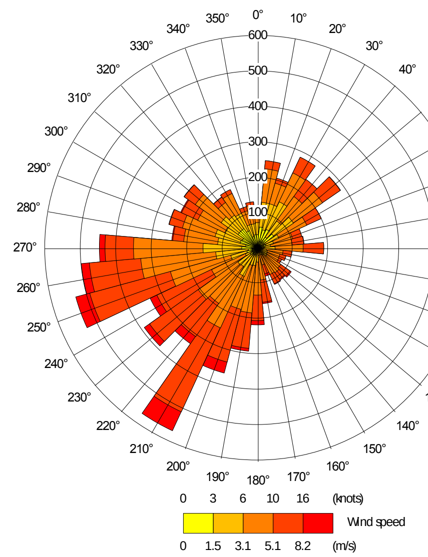
(a) 2013



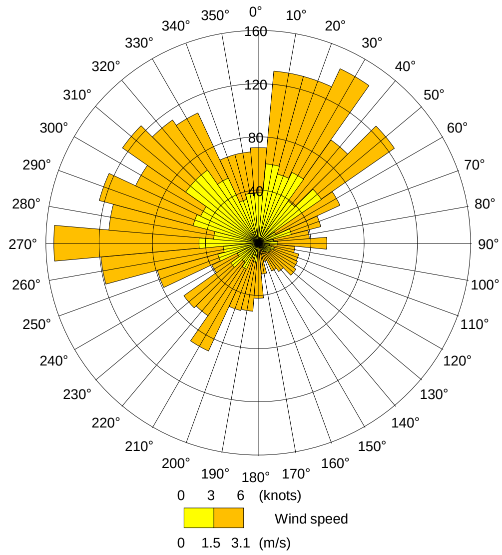
(b) 2013, cropped to low wind speeds only



(c) 2008/9



(d) 2008/9, cropped to low wind speeds only



5.3 NO_x concentrations

Although the focus of interest from a human health standpoint is annual mean NO_2 concentrations, discussion of the relative contribution from various sources is best conducted in terms of annual mean NO_x concentrations. These are related directly to NO_x emission rates, whereas the relationship between NO_2 and NO_x concentrations is non-linear as a result of gas-phase reactions in the atmosphere.

Focusing first on concentrations at the set of key receptor locations shown in Figure 23, Table 19 shows the split of total NO_x concentrations between airport-related and non-airport source categories. (The table also shows annual mean NO_2 concentrations for later discussion in Section 5.4.)

The estimated total NO_x concentrations at receptor locations span a large range, from 47.1 µg m^{-3} (Colnbrook) to 91.2 µg m^{-3} (LHR2) for modelling with the old road emission factors and from 55.7 µg m^{-3} (Colnbrook) to 110.9 µg m^{-3} (LHR2) for modelling with the new road emission factors. A major part of this variation derives from the variation in the airport contribution, which ranges from 3.9 µg m^{-3} at Colnbrook to 44.0 µg m^{-3} at LHR2 for modelling with the old road emission factors and from 4.8 µg m^{-3} (Colnbrook) to 53.6 µg m^{-3} (LHR2) for modelling with the old road emission factors.

Table 19: Airport and non-airport contributions to annual mean NO_x concentrations

a) Old EFs Unadjusted

Receptor	NO_x (µg m^{-3})			NO_2 (µg m^{-3})
	Airport[a]	Non-airport[b]	Total	
LHR2	44.0	47.2	91.2	47.6
Oaks Rd	17.0	37.6	54.7	34.1
Green Gates	6.6	43.1	49.7	32.2
Colnbrook	3.9	43.2	47.1	30.8
Harmondsworth	4.8	42.9	47.7	31.2
Hillingdon	10.9	62.5	73.4	43.5
Sipson	11.9	41.2	53.1	33.6
Harlington	8.5	46.6	55.1	34.6
Oxford Ave	14.2	45.8	60.0	36.8
Hayes	4.5	66.8	71.2	41.3
Cranford	6.9	44.4	51.2	32.8
Hatton Cross	22.1	45.6	67.7	39.8
PerimA	10.4	46.5	56.9	35.4
PerimB	17.9	44.2	62.1	37.6
PerimC	16.5	42.4	58.9	36.0
PerimD	18.1	42.8	60.8	36.7
PerimE	22.2	56.3	78.5	44.1
PerimF	22.1	47.3	69.4	40.6
PerimG	16.8	56.9	73.8	42.6
PerimH	18.2	48.8	67.0	39.5
M4A	10.8	63.1	73.9	43.9
M4B	10.3	61.5	71.8	42.9
M4C	11.7	69.7	81.4	46.5
M4D	11.0	68.7	79.6	45.8

b) New EFs Adjusted

Receptor	NO_x (µg m^{-3})			NO_2 (µg m^{-3})
	Airport[a]	Non-airport[b]	Total	
LHR2	53.6	57.3	110.9	53.2
Oaks Rd	18.5	43.4	61.9	35.7
Green Gates	7.7	51.0	58.8	35.0
Colnbrook	4.8	51.0	55.7	33.5
Harmondsworth	5.9	50.1	56.0	33.7
Hillingdon	15.2	79.2	94.4	50.5
Sipson	14.3	47.5	61.9	36.2
Harlington	9.8	55.2	65.0	37.5
Oxford Ave	15.9	54.8	70.7	39.8
Hayes	5.1	80.9	86.0	45.4
Cranford	7.7	52.2	59.9	35.2
Hatton Cross	24.6	55.2	79.8	43.0
PerimA	11.5	56.2	67.7	38.7
PerimB	21.8	52.6	74.4	41.3
PerimC	18.7	49.7	68.4	38.5
PerimD	19.9	50.2	70.1	39.0
PerimE	25.8	70.7	96.5	49.4
PerimF	25.1	57.7	82.8	44.3
PerimG	18.9	71.9	90.8	47.6
PerimH	21.8	59.8	81.6	43.8
M4A	15.6	80.6	96.2	51.4
M4B	14.7	78.0	92.6	49.9
M4C	15.4	88.7	104.2	53.7
M4D	14.5	87.2	101.8	52.8

[a] Includes aircraft, APUs, GSE, airport-related traffic on the road network, car parking and stationary sources
[b] Includes non-airport traffic on the road network, LAEI/NAEI area sources and rural background

5.3.1 Airport-related NO_x

As in past air quality studies, LHR2 is estimated to have by far the largest airport-related NO_x contribution, as a result of its proximity to the runway (it is the only one of the receptor locations to be on the airfield). PerimE (on Harlington High Street), PerimF (East Bedfont) and Hatton Cross show the next largest estimated airport-related NO_x contribution.

Table 20 shows a breakdown of the airport-related contribution. It is clear that the large airport contribution at LHR2 derives from aircraft main engines and the landside road network (as well as being close to the runway, it is close to a junction on the Northern Perimeter Road). In general, apron sources (APUs and GSE) make a relatively small contribution, because the layout of the airfield places these sources further from receptor locations than the runway sources; an exception is PerimG, which is close to Terminal 4.

Table 20: Breakdown of the airport contribution to annual mean NO_x concentrations by source category

a) Old EFs Unadjusted

Receptor	Annual mean NO_x contribution (µg m^{-3})				
	Aircraft[a]	Apron[b]	Road traffic	Other[c]	Total
LHR2	21.6	3.0	18.6	0.8	44.0
Oaks Rd	9.2	4.1	3.1	0.6	17.0
Green Gates	2.0	1.7	2.4	0.5	6.6
Colnbrook	1.5	0.5	1.7	0.1	3.9
Harmondsworth	1.4	1.0	2.1	0.2	4.8
Hillingdon	1.8	0.8	8.1	0.2	10.9
Sipson	5.0	2.0	4.5	0.5	11.9
Harlington	4.8	1.2	2.3	0.3	8.5
Oxford Ave	9.2	1.0	3.4	0.5	14.2
Hayes	2.5	0.4	1.4	0.2	4.5
Cranford	4.3	0.6	1.6	0.4	6.9
Hatton Cross	13.5	2.3	5.1	1.2	22.1
PerimA	3.0	2.4	2.9	2.1	10.4
PerimB	7.1	2.7	7.2	0.9	17.9
PerimC	9.4	2.4	4.2	0.5	16.5
PerimD	11.9	2.1	3.6	0.6	18.1
PerimE	13.0	1.6	7.0	0.5	22.2
PerimF	11.6	3.5	6.0	0.9	22.1
PerimG	5.8	5.5	4.5	1.1	16.8
PerimH	5.3	4.1	7.6	1.3	18.2
M4A	1.1	0.6	8.9	0.1	10.8
M4B	1.3	0.7	8.2	0.2	10.3
M4C	3.6	0.7	7.2	0.2	11.7
M4D	3.4	0.6	6.8	0.2	11.0

b) New EFs Adjusted

Receptor	Annual mean NO_x contribution (µg m^{-3})				
	Aircraft[a]	Apron[b]	Road traffic	Other[c]	Total
LHR2	21.6	3.1	28.3	0.7	53.6
Oaks Rd	9.2	4.2	4.7	0.4	18.5
Green Gates	2.0	1.7	3.7	0.3	7.7
Colnbrook	1.5	0.5	2.6	0.1	4.8
Harmondsworth	1.4	1.0	3.3	0.1	5.9
Hillingdon	1.8	0.8	12.5	0.1	15.2
Sipson	5.0	2.0	7.0	0.4	14.3
Harlington	4.8	1.3	3.5	0.2	9.8
Oxford Ave	9.2	1.0	5.2	0.5	15.9
Hayes	2.5	0.4	2.1	0.1	5.1
Cranford	4.3	0.7	2.4	0.3	7.7
Hatton Cross	13.5	2.3	7.7	1.1	24.6
PerimA	3.0	2.5	4.4	1.7	11.5
PerimB	7.1	2.7	11.2	0.7	21.8
PerimC	9.4	2.4	6.5	0.4	18.7
PerimD	11.9	2.2	5.4	0.5	19.9
PerimE	13.0	1.7	10.7	0.4	25.8
PerimF	11.6	3.6	9.1	0.8	25.1
PerimG	5.8	5.7	6.7	0.7	18.9
PerimH	5.3	4.2	11.2	1.2	21.8
M4A	1.1	0.7	13.7	0.1	15.6
M4B	1.3	0.7	12.5	0.1	14.7
M4C	3.6	0.7	10.9	0.2	15.4
M4D	3.4	0.6	10.4	0.2	14.5

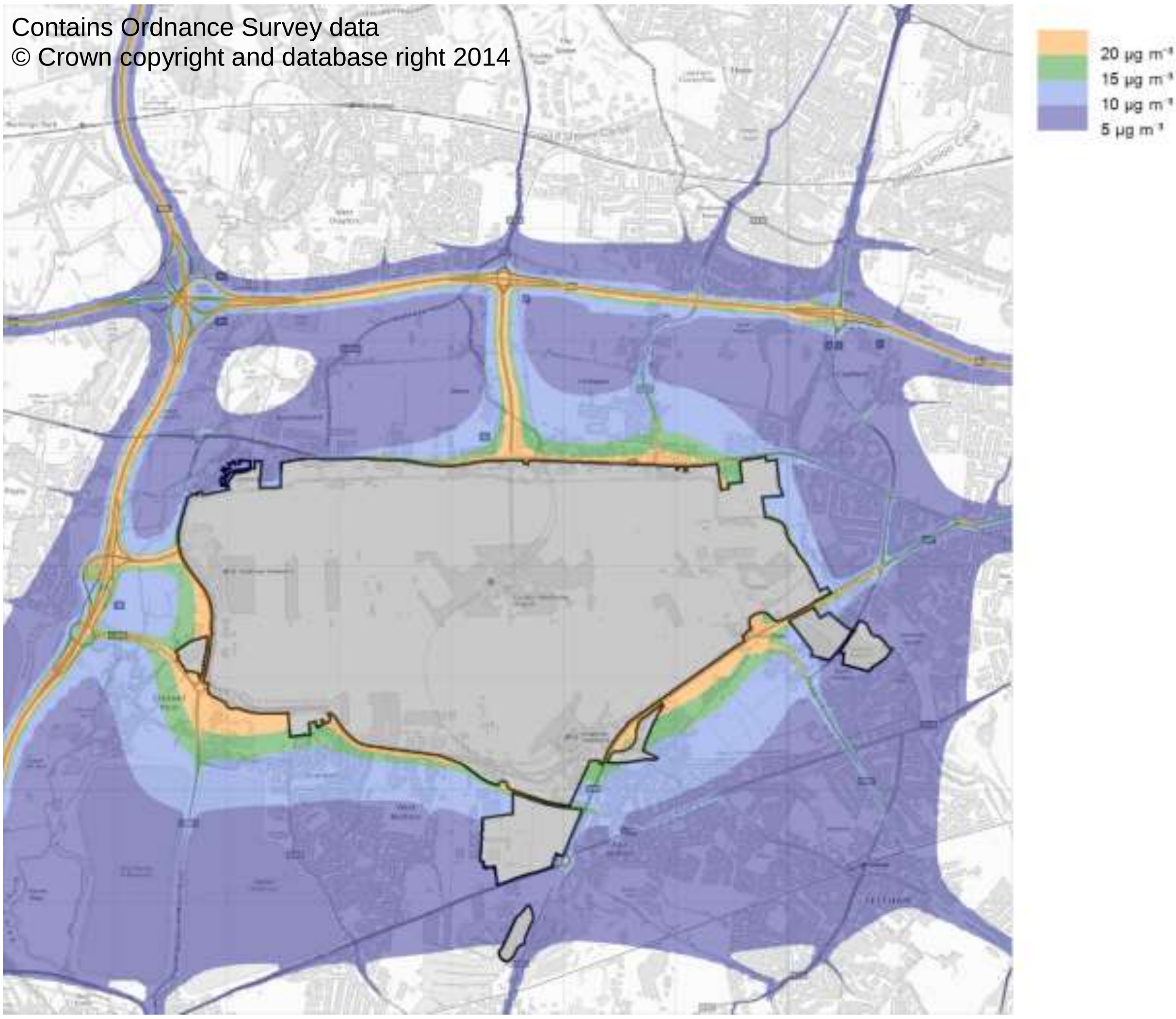
[a] Aircraft main engines, including engine testing
[b] APU and GSE emissions
[c] Car parking and stationary sources

Figure 25 shows contour plots of the airport-related NO_x concentrations around the airport. The NO_x contribution from aircraft and other on-airport sources falls off to less than 5 µg m^{-3} more than about 2 km from the airport boundary, except along motorways and major roads.

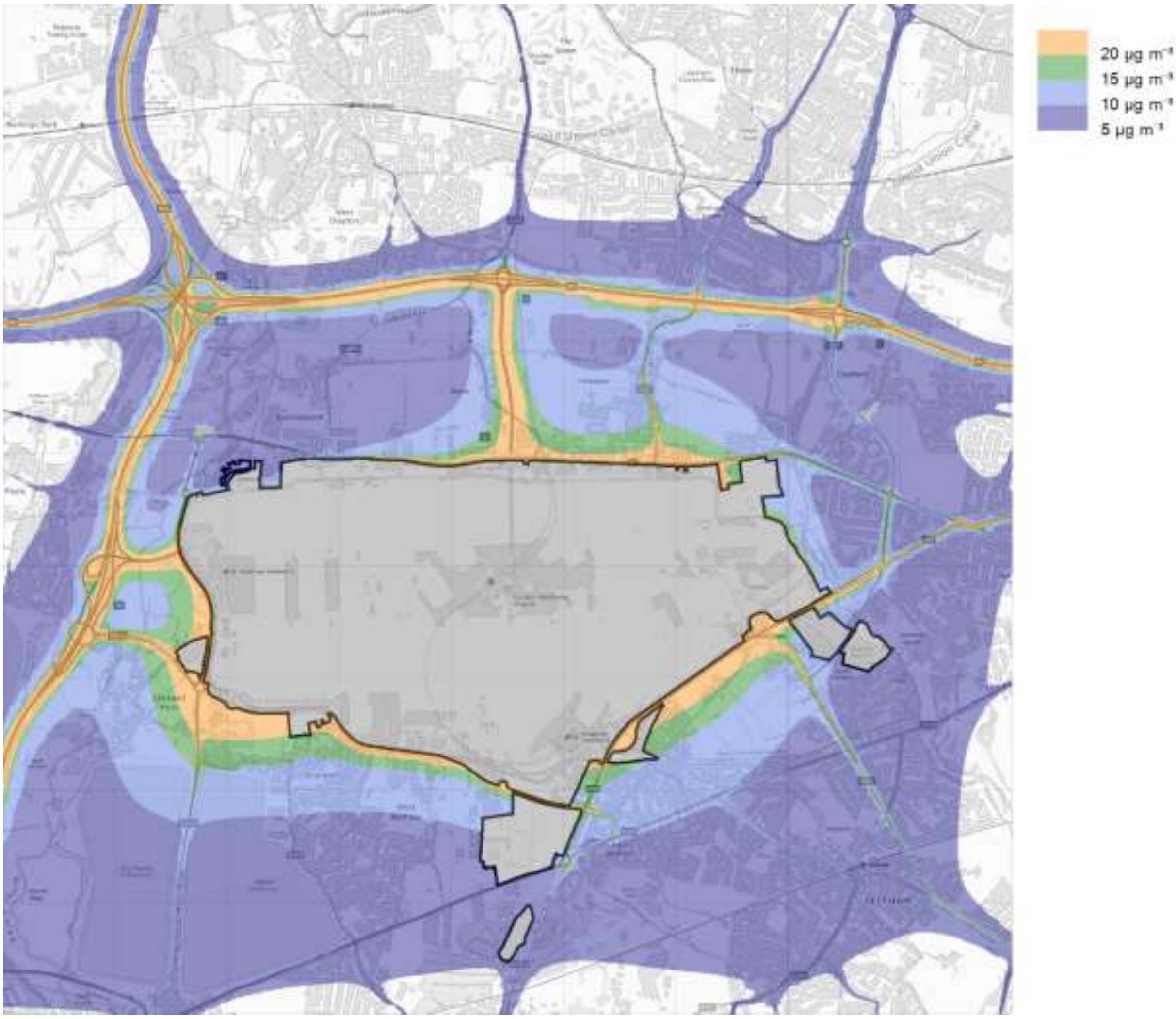
Appendix A gives the corresponding contour plot of total NO_x.

Figure 25: Airport-related contribution[a] to annual mean NO_x concentrations in 2013

a) Old EFs Unadjusted



b) New EFs Adjusted



[a] Includes aircraft, APUs, GSE, airport-related traffic on the road network, car parking and stationary sources

5.3.2 Non-airport NO_x

A breakdown of the non-airport contribution to NO_x concentrations is given in Table 21. The greatest non-airport contributions are at Hayes (a kerbside location near a busy road junction), and the receptor locations close to the M4 motorway, namely Hillingdon, M4A, M4B, M4C and M4D. The variability in the estimated non-airport contribution largely depends on distance from major roads. Other non-airport sources ("background") are much less variable, reflecting the fact that they are more distant and less spatially defined.

Table 21: Breakdown of the non-airport NO_x contribution by source category

a) Old EFs Unadjusted

Receptor	Annual mean NO_x contribution ($\mu g\ m^{-3}$)		
	Road traffic	Background[a]	Total
LHR2	13.7	33.5	47.2
Oaks Rd	5.4	32.2	37.6
Green Gates	9.6	33.5	43.1
Colnbrook	8.9	34.3	43.2
Harmondsworth	8.2	34.7	42.9
Hillingdon	25.8	36.7	62.5
Sipson	6.6	34.6	41.2
Harlington	10.7	35.9	46.6
Oxford Ave	11.8	34.1	45.8
Hayes	22.5	44.3	66.8
Cranford	9.6	34.8	44.4
Hatton Cross	13.0	32.6	45.6
PerimA	12.9	33.6	46.5
PerimB	10.3	33.9	44.2
PerimC	8.3	34.1	42.4
PerimD	8.7	34.1	42.8
PerimE	22.1	34.2	56.3
PerimF	14.6	32.7	47.3
PerimG	24.3	32.6	56.9
PerimH	16.6	32.1	48.8
M4A	27.4	35.7	63.1
M4B	25.4	36.1	61.5
M4C	30.6	39.1	69.7
M4D	30.0	38.6	68.7

b) New EFs Adjusted

Receptor	Annual mean NO_x contribution ($\mu g\ m^{-3}$)		
	Road traffic	Background[a]	Total
LHR2	20.9	36.3	57.3
Oaks Rd	8.2	35.2	43.4
Green Gates	14.7	36.3	51.0
Colnbrook	13.7	37.2	51.0
Harmondsworth	12.6	37.5	50.1
Hillingdon	39.7	39.5	79.2
Sipson	10.2	37.4	47.5
Harlington	16.5	38.7	55.2
Oxford Ave	17.9	37.0	54.8
Hayes	33.6	47.2	80.9
Cranford	14.5	37.8	52.2
Hatton Cross	19.7	35.5	55.2
PerimA	19.8	36.4	56.2
PerimB	15.9	36.7	52.6
PerimC	12.8	36.9	49.7
PerimD	13.2	36.9	50.2
PerimE	33.6	37.1	70.7
PerimF	22.0	35.7	57.7
PerimG	36.2	35.6	71.9
PerimH	24.8	35.1	59.8
M4A	42.1	38.5	80.6
M4B	39.0	38.9	78.0
M4C	46.7	42.1	88.7
M4D	45.6	41.6	87.2

[a] Sources from the LAEI and NAEI not already included in the airport and road network source categories

5.3.3 Comparison with 2008/9

Table 22 compares the NO_x concentrations in 2013 and 2008/9 at the continuous monitors. A more detailed version of the table, giving a breakdown of the different source contributions, is given in Appendix A.

Table 22: Comparison of modelled NO_x concentrations for 2013 and 2008/9

a) Old EFs Unadjusted

Receptor	2013 concentration ($\mu g\ m^{-3}$)		Fractional difference from 2008/9 (%)	
	Total NO_x	Total NO_2	Total NO_x	Total NO_2
LHR2	91.2	47.6	-15.5	-5.6
Oaks Rd	54.7	34.1	-14.1	-6.2
Green Gates	49.7	32.2	-15.7	-7.4
Colnbrook	47.1	30.8	-13.0	-6.0
Harmondsworth	47.7	31.2	-18.5	-9.7
Hillingdon	73.4	43.5	-21.9	-7.6
Sipson	53.1	33.6	-19.3	-9.7
Harlington	55.1	34.6	-17.0	-7.6
Oxford Ave	60.0	36.8	-16.5	-7.1
Hayes	71.2	41.3	-20.1	-8.5
Cranford	51.2	32.8	-18.0	-9.1
Hatton Cross	67.7	39.8	-12.1	-3.7

b) New EFs Adjusted

Receptor	2013 concentration ($\mu g\ m^{-3}$)		Fractional difference from 2008/9 (%)	
	Total NO_x	Total NO_2	Total NO_x	Total NO_2
LHR2	110.9	53.2	2.7	5.5
Oaks Rd	61.9	35.7	-2.8	-1.8
Green Gates	58.8	35.0	-0.3	0.6
Colnbrook	55.7	33.5	3.0	2.1
Harmondsworth	56.0	33.7	-4.2	-2.4
Hillingdon	94.4	50.5	0.4	7.3
Sipson	61.9	36.2	-5.9	-3.0
Harlington	65.0	37.5	-2.2	0.1
Oxford Ave	70.7	39.8	-1.5	0.5
Hayes	86.0	45.4	-3.5	0.8
Cranford	59.9	35.2	-4.2	-2.3
Hatton Cross	79.8	43.0	3.6	4.1

[a] Fractional Difference (%) = 100 * (2013 value – 2008/9 value) / 2008/9 value

The total modelled concentrations are lower in 2013 than in 2008/9 for the old road traffic emission factors related modelling for both NOx and NO_2, with contributions from almost all sources falling. The main exception is the contribution from aircraft main engines (i.e. excluding APUs), which reflects a small rise in emissions but also a higher fraction of easterly operations in 2013, meaning that receptor locations to the west of the airfield (e.g. Green Gates) tend to have an increase from this source relative to 2008/9, while receptor locations to the east (e.g. LHR2) tend to have a decrease.

However, for the new road traffic emission factor related modelling total modelled NOx concentrations are lower in 2013 than in 2008/9 for most sites, the exceptions are mainly related to higher road traffic contributions. Contributions from all sources, other than road traffic and aircraft main engines, are falling. NO_2 concentrations have increased at a number of sites, primarily related to road traffic contributions.

Overall, though, the on-airport contribution is lower in 2013 than in 2008/9, largely due to the steep reductions in emissions from APUs and GSE.

5.4 NO_2 concentrations

Annual mean NO_2 concentrations at the chosen receptor locations are shown in Table 19 in Section 5.3. There are a number of exceedances of the 40 µg m^{-3} limit, especially along the M4 motorway, reaching as high as 53.7 µg m^{-3} (new road emission factor modelling), at the M4C receptor location near the M4, but also at locations close to the airport's eastern side where concentrations are up to 49.4 µg m^{-3} (PerimE).

Table 22 above shows that modelled NO_2 concentrations at the continuous monitors are consistently lower for the old road traffic emissions factor modelling than in 2008/9, reflecting the lower modelled NO_x. The reduction is smaller in percentage terms for NO_2 (around 6%) than for NO_x (around 15%) because of the non-linear relationship between the two (discussed further in Appendix A and model evaluation report[52]). However, this is not the case for NO_2 concentrations at the continuous monitors for the new road traffic emissions factor modelling – there is an increase for some sites with a large road contribution when compared to 2008/9.

Figure 26 displays annual mean concentrations of NO_2 outside the airport. This shows that off-airport annual mean NO_2 concentrations above 40 µg m^{-3} (red and purple) are mainly associated with roads and motorways, and Great Western railway line. Around the perimeter of the airport, concentrations above 40 µg m^{-3} are confined to within about 100 m of the boundary, and concentrations above 36 µg m^{-3} are mostly limited to within about 300 m of the boundary; this includes some residential areas.

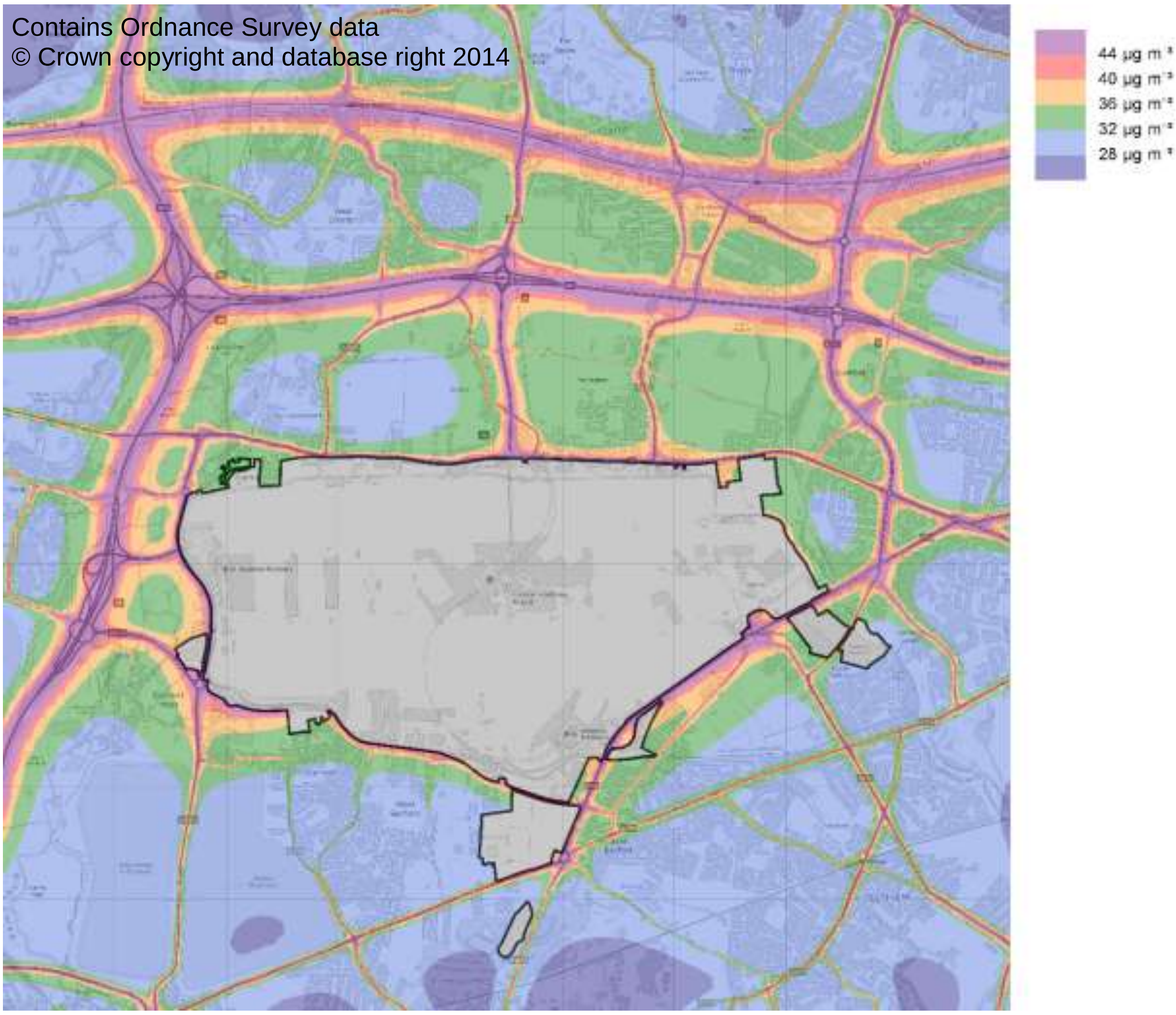
Concentrations above 40 µg m^{-3} are also found along roads throughout the study area. For A-roads and smaller, these are mainly confined to within a few metres of the carriageway. However for the M4 and M25, the 40 µg m^{-3} contour extends up to around 150 m from the motorway.

The Great Western railway line, which passes east–west about 1 km north of the M4 motorway, is also a significant source of emissions, and the 40 µg m^{-3} contour is estimated to extend up to around 150 m from the railway line. The line carries in the region of 120,000 passengers per day (two-way)[53]; for comparison, the M4 carries around 120,000 vehicles per day between junctions 3 and 4[54].

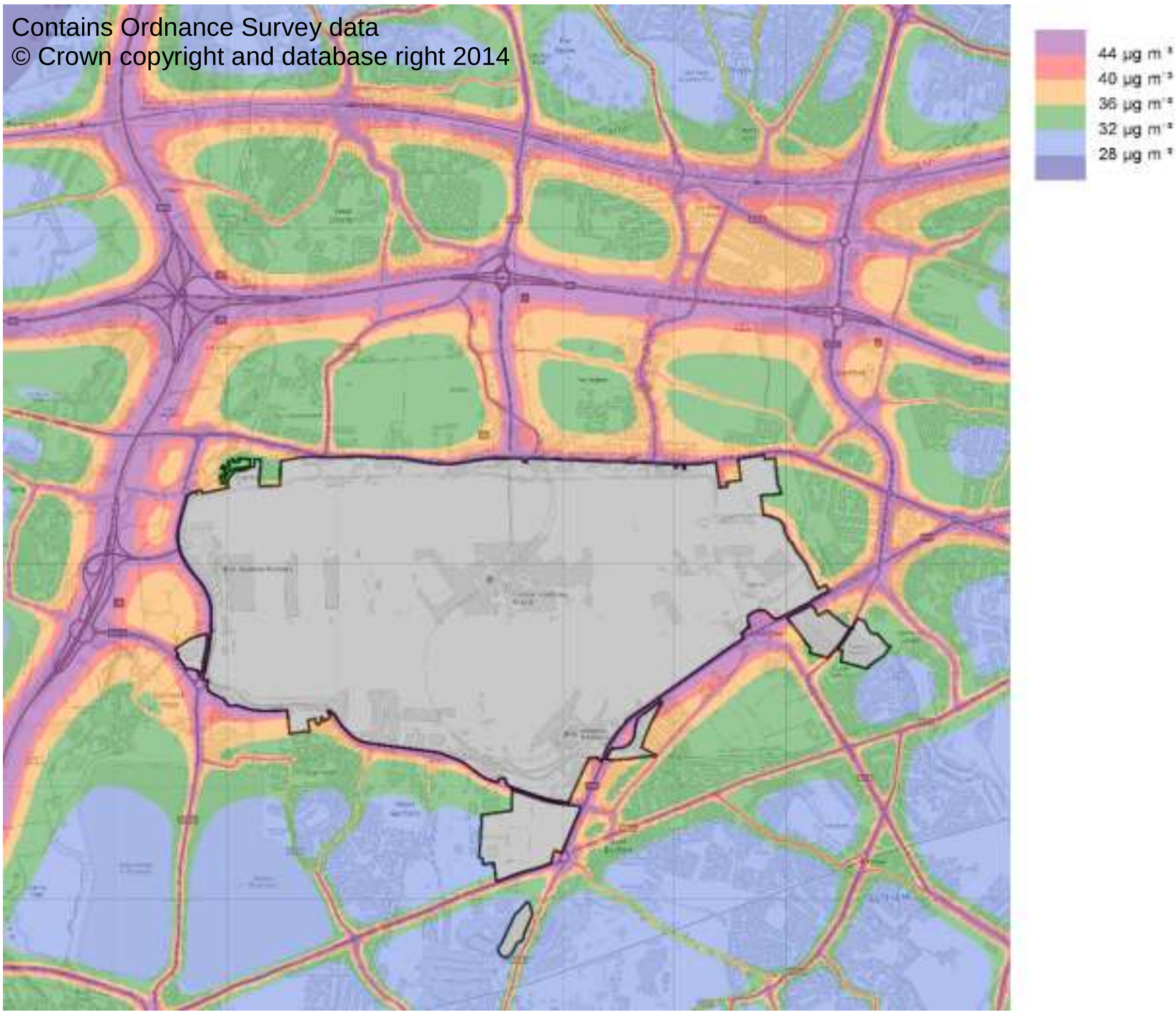
52 Ricardo-AEA (2014) Heathrow Airport 2013 Air Quality Assessment: Model Evaluation, Draft Report November 2014.
53 Department for Transport (2012) Correction to Rail passenger numbers and crowding on weekdays in major cities in England and Wales: 2011. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/16599/rail-passenger-numbers-and-crowding-statistics-note-of-correction.pdf. Retrieved 25 July 2014.
54 Department for Transport (2012) Traffic Counts: Hillingdon. http://www.dft.gov.uk/traffic-counts/cp.php?la=Hillingdon#6013. Retrieved 25 July 2014.

Figure 26: Annual mean NO_2 concentrations in 2013 outside the airport boundary

a) Old EFs Unadjusted



b) New EFs Adjusted



Concentrations within the airport boundary are not shown in the above figure, to emphasise that the spatial representation of the emissions on the airport and the spatial detail in the dispersion modelling has been aimed at the estimation of concentrations in residential areas around the airport. In addition, the AQS objectives apply at locations with relevant public exposure, which would exclude locations within the airport boundary from the annual mean NO_2 objective. Annual mean NO_2 concentrations within the airport boundary are shown in Appendix A, but the caveats on spatial resolution given above should be borne in mind.

5.5 PM concentrations

Table 23 gives the estimated PM concentrations for 2013 at the set of receptor locations introduced in earlier sections, showing the split between airport-related and non-airport contributions.

Table 23: Airport and non-airport contributions to annual mean PM concentrations in 2010

a) Old EFs

Receptor	PM_{10} (µg m^{-3})			$PM_{2.5}$ (µg m^{-3})		
	Airport[a]	Non-airport[b]	Total	Airport[a]	Non-airport[b]	Total
LHR2	3.3	19.7	23.0	2.1	14.5	16.6
Oaks Rd	0.8	19.0	19.7	0.5	14.2	14.7
Green Gates	0.5	19.5	20.0	0.3	14.5	14.9
Colnbrook	0.3	19.6	19.9	0.2	14.6	14.8
Harmondsworth	0.4	19.3	19.7	0.2	14.4	14.6
Hillingdon	1.0	21.3	22.3	0.6	15.6	16.2
Sipson	0.8	19.1	19.9	0.5	14.2	14.7
Harlington	0.5	19.7	20.2	0.3	14.5	14.8
Oxford Ave	0.7	19.9	20.6	0.5	14.6	15.1
Hayes	0.2	20.3	20.6	0.2	14.9	15.1
Cranford	0.3	19.4	19.8	0.2	14.3	14.5
Hatton Cross	1.1	19.8	20.9	0.7	14.6	15.3
PerimA	0.7	19.9	20.5	0.4	14.7	15.1
PerimB	1.2	19.4	20.6	0.8	14.4	15.2
PerimC	0.9	19.3	20.2	0.6	14.3	14.9
PerimD	1.1	19.4	20.4	0.7	14.3	15.0
PerimE	1.2	20.8	22.0	0.8	15.1	15.9
PerimF	1.3	20.0	21.3	0.8	14.7	15.5
PerimG	1.0	21.5	22.5	0.7	15.5	16.2
PerimH	1.2	20.1	21.3	0.8	14.8	15.5
M4A	1.1	21.5	22.5	0.7	15.7	16.4
M4B	1.0	21.3	22.3	0.6	15.6	16.2
M4C	0.9	21.9	22.9	0.6	15.9	16.4
M4D	0.9	21.8	22.6	0.6	15.8	16.3

b) New EFs

Receptor	PM_{10} (µg m^{-3})			$PM_{2.5}$ (µg m^{-3})		
	Airport[a]	Non-airport[b]	Total	Airport[a]	Non-airport[b]	Total
LHR2	3.5	20.0	23.5	2.2	14.7	16.9
Oaks Rd	0.8	19.1	19.9	0.6	14.2	14.8
Green Gates	0.5	19.7	20.2	0.3	14.6	15.0
Colnbrook	0.3	19.8	20.1	0.2	14.7	14.9
Harmondsworth	0.4	19.5	19.8	0.2	14.5	14.7
Hillingdon	1.2	21.8	23.0	0.7	15.9	16.6
Sipson	0.8	19.2	20.0	0.5	14.3	14.8
Harlington	0.5	19.9	20.4	0.3	14.6	15.0
Oxford Ave	0.8	20.1	20.9	0.5	14.7	15.2
Hayes	0.3	20.6	20.8	0.2	15.0	15.2
Cranford	0.4	19.6	19.9	0.2	14.4	14.6
Hatton Cross	1.1	20.0	21.2	0.7	14.7	15.4
PerimA	0.7	20.1	20.8	0.4	14.8	15.3
PerimB	1.3	19.6	20.9	0.8	14.5	15.3
PerimC	1.0	19.4	20.4	0.6	14.4	15.0
PerimD	1.1	19.5	20.6	0.7	14.4	15.1
PerimE	1.3	21.1	22.4	0.9	15.3	16.2
PerimF	1.4	20.3	21.6	0.9	14.8	15.7
PerimG	1.0	21.9	23.0	0.7	15.8	16.5
PerimH	1.3	20.3	21.7	0.8	14.9	15.8
M4A	1.2	22.0	23.3	0.8	16.1	16.8
M4B	1.1	21.8	22.9	0.7	15.9	16.6
M4C	1.1	22.5	23.6	0.7	16.2	16.9
M4D	1.0	22.3	23.4	0.6	16.1	16.7

[a] Includes aircraft, APUs, GSE, airport-related traffic on the road network, car parking and stationary sources
[b] Includes non-airport traffic on the road network, LAEI/NAEI area sources and rural background

The estimated total annual mean PM_{10} concentrations at all the sites are well below the 40 µg m^{-3} limit value. For PM_{10}, however, the limit on the annual number of daily exceedences of a 24-hour mean concentration of 50 µg m^{-3} (no more than 35) is generally more onerous, and it is common practice to take an annual mean value of 31.5 µg m^{-3} to be equivalent to the shorter-period limit. Clearly, estimated annual mean PM_{10} concentrations are also well below this surrogate limit. For $PM_{2.5}$, estimated annual mean concentrations are well below the 25 µg m^{-3} objective and limit value which come into force in 2010 and 2015 respectively. The values are also well below the exposure related 18 µg m^{-3} EU limit value (applicable from 2020).

5.5.1 Airport-related PM

Clearly from Table 23, the estimated contribution from airport-related sources is small, ranging from 0.2 µg m^{-3} (Hayes) to 3.3 µg m^{-3} (LHR2) for PM_{10} and from 0.2 µg m^{-3} (Hayes) to 2.1 µg m^{-3} (LHR2) for $PM_{2.5}$ for the old road traffic emission factor modelling. For the new road traffic emission factor modelling the range is 0.3 µg m^{-3} (Hayes) to 3.5 µg m^{-3} (LHR2) for PM_{10} and from 0.2 µg m^{-3} (Hayes) to 2.2 µg m^{-3} (LHR2) for $PM_{2.5}$. The highest contributions at off-airport receptor locations are 1.3 µg m^{-3} (Old EFs) and 1.4 µg m^{-3} (New EFs) for PM_{10} and 0.8 µg m^{-3} (Old EFs) 0.9 µg m^{-3} (New EFs) or $PM_{2.5}$, in all cases at PerimF; these represent a very small contribution to the total. Both aircraft and the landside road network make appreciable contributions to the airport contribution, depending on the location of the receptor. This is shown in Table 24, which gives a breakdown of the airport-related to PM_{10} by source category. (The relative breakdown for $PM_{2.5}$ is similar.)

Table 24: Breakdown of the airport contribution to annual mean PM_{10} concentrations by source category

a) Old EFs

Receptor	Annual mean PM_{10} contribution (µg m^{-3})				
	Aircraft[a]	Apron[b]	Road traffic	Other[c]	Total
LHR2	1.39	0.12	1.69	0.10	3.29
Oaks Rd	0.22	0.17	0.34	0.06	0.79
Green Gates	0.12	0.07	0.28	0.05	0.53
Colnbrook	0.05	0.02	0.19	0.01	0.28
Harmondsworth	0.05	0.04	0.24	0.02	0.36
Hillingdon	0.05	0.03	0.92	0.02	1.01
Sipson	0.15	0.08	0.51	0.04	0.78
Harlington	0.15	0.05	0.26	0.03	0.48
Oxford Ave	0.22	0.04	0.43	0.04	0.73
Hayes	0.06	0.02	0.14	0.01	0.23
Cranford	0.11	0.03	0.18	0.02	0.33
Hatton Cross	0.39	0.09	0.49	0.08	1.05
PerimA	0.12	0.10	0.33	0.12	0.66
PerimB	0.25	0.10	0.80	0.07	1.22
PerimC	0.32	0.09	0.46	0.05	0.92
PerimD	0.52	0.08	0.39	0.06	1.05
PerimE	0.39	0.06	0.74	0.05	1.24
PerimF	0.46	0.14	0.59	0.07	1.27
PerimG	0.21	0.23	0.47	0.11	1.02
PerimH	0.14	0.16	0.78	0.11	1.20
M4A	0.03	0.03	1.00	0.01	1.07
M4B	0.03	0.03	0.91	0.01	0.99
M4C	0.09	0.03	0.80	0.02	0.94
M4D	0.08	0.02	0.76	0.02	0.88

b) New EFs

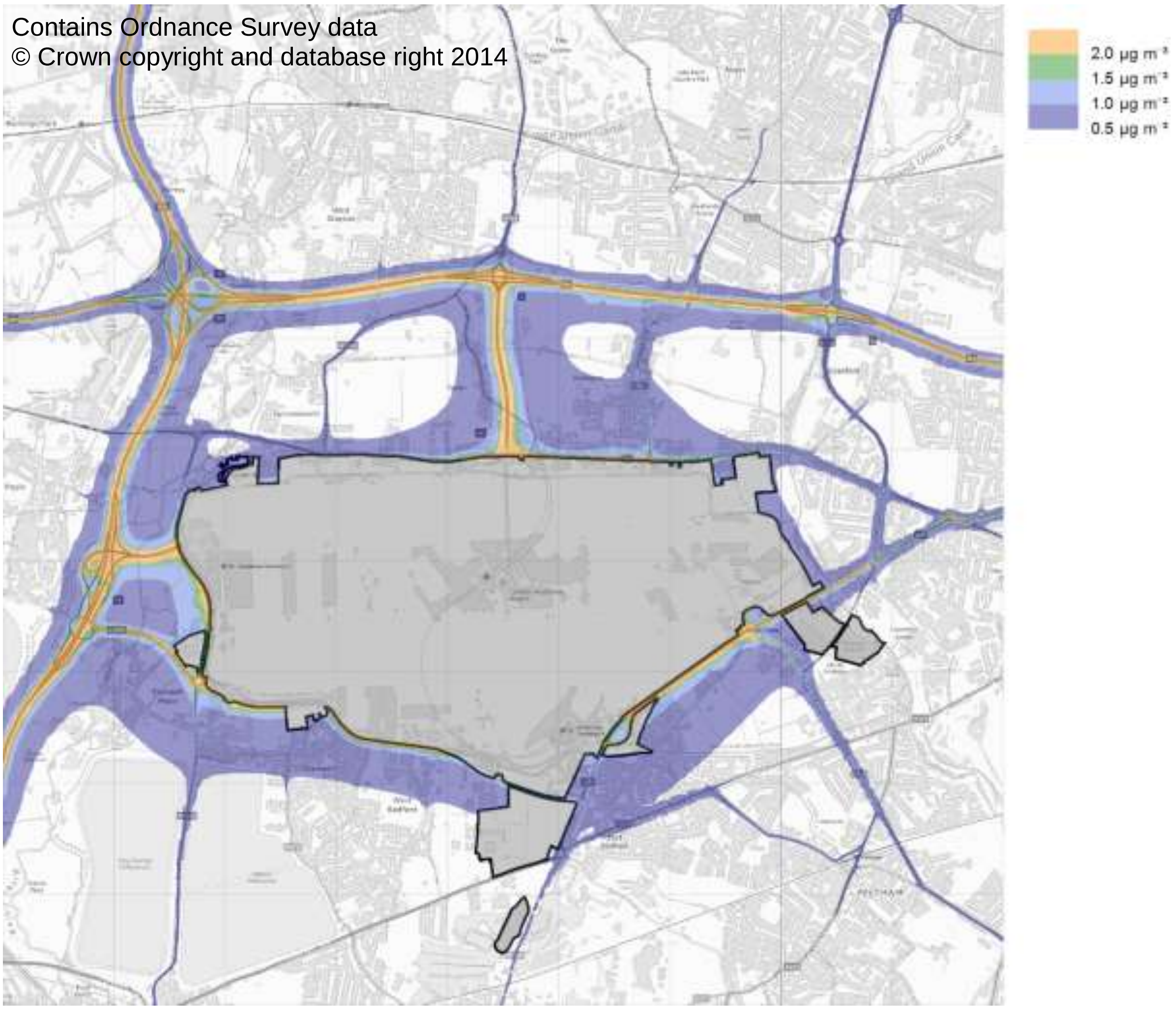
Receptor	Annual mean PM_{10} contribution (µg m^{-3})				
	Aircraft[a]	Apron[b]	Road traffic	Other[c]	Total
LHR2	1.39	0.12	1.96	0.05	3.52
Oaks Rd	0.22	0.17	0.39	0.03	0.82
Green Gates	0.12	0.07	0.33	0.02	0.54
Colnbrook	0.05	0.02	0.22	0.01	0.30
Harmondsworth	0.05	0.04	0.28	0.01	0.39
Hillingdon	0.05	0.03	1.08	0.01	1.17
Sipson	0.15	0.08	0.59	0.02	0.85
Harlington	0.15	0.05	0.30	0.02	0.51
Oxford Ave	0.22	0.04	0.49	0.03	0.78
Hayes	0.06	0.02	0.16	0.01	0.25
Cranford	0.11	0.03	0.20	0.02	0.35
Hatton Cross	0.39	0.09	0.58	0.05	1.11
PerimA	0.12	0.10	0.38	0.06	0.66
PerimB	0.25	0.11	0.93	0.04	1.33
PerimC	0.32	0.10	0.53	0.03	0.98
PerimD	0.52	0.09	0.45	0.03	1.09
PerimE	0.39	0.07	0.84	0.03	1.33
PerimF	0.46	0.15	0.69	0.05	1.35
PerimG	0.21	0.24	0.55	0.05	1.05
PerimH	0.14	0.17	0.92	0.08	1.32
M4A	0.03	0.03	1.18	0.01	1.25
M4B	0.03	0.03	1.08	0.01	1.15
M4C	0.09	0.03	0.95	0.01	1.08
M4D	0.08	0.02	0.89	0.01	1.01

[a] Aircraft main engines (including engine testing), brake wear and tyre wear
[b] APU and GSE emissions
[c] Car parking and stationary sources

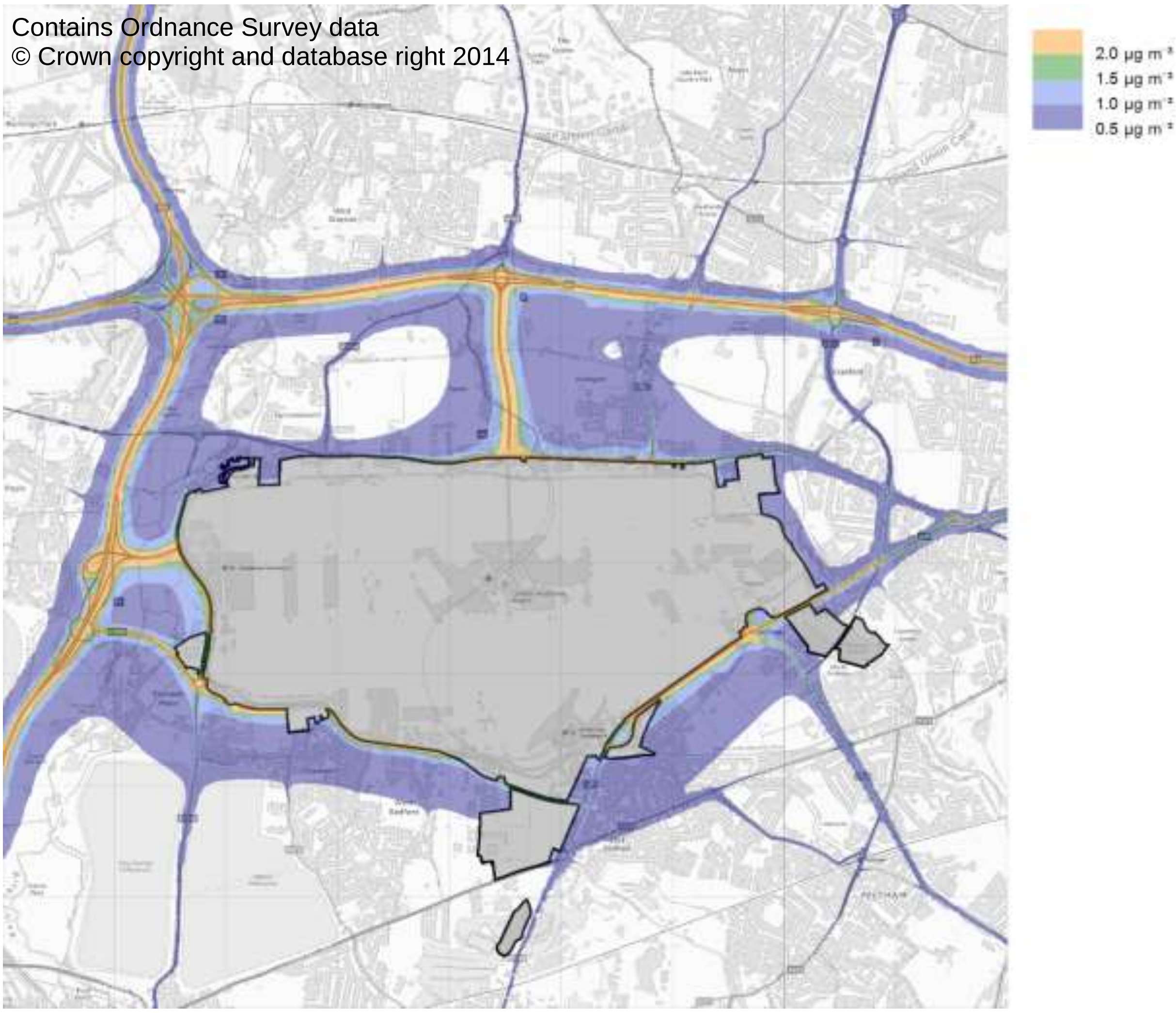
Figure 27 displays the spatial variation of the airport-related contribution to annual mean PM_{10} concentrations around the airport, showing that the contribution at non-roadside receptor locations drops below 1 µg m^{-3} within about 100 m of the airport boundary. Along the M4 and M25, the contribution at drops below 1 µg m^{-3} within about 100 m of the motorway. Contour plots of total PM_{10} and $PM_{2.5}$ concentrations are given in Appendix A.

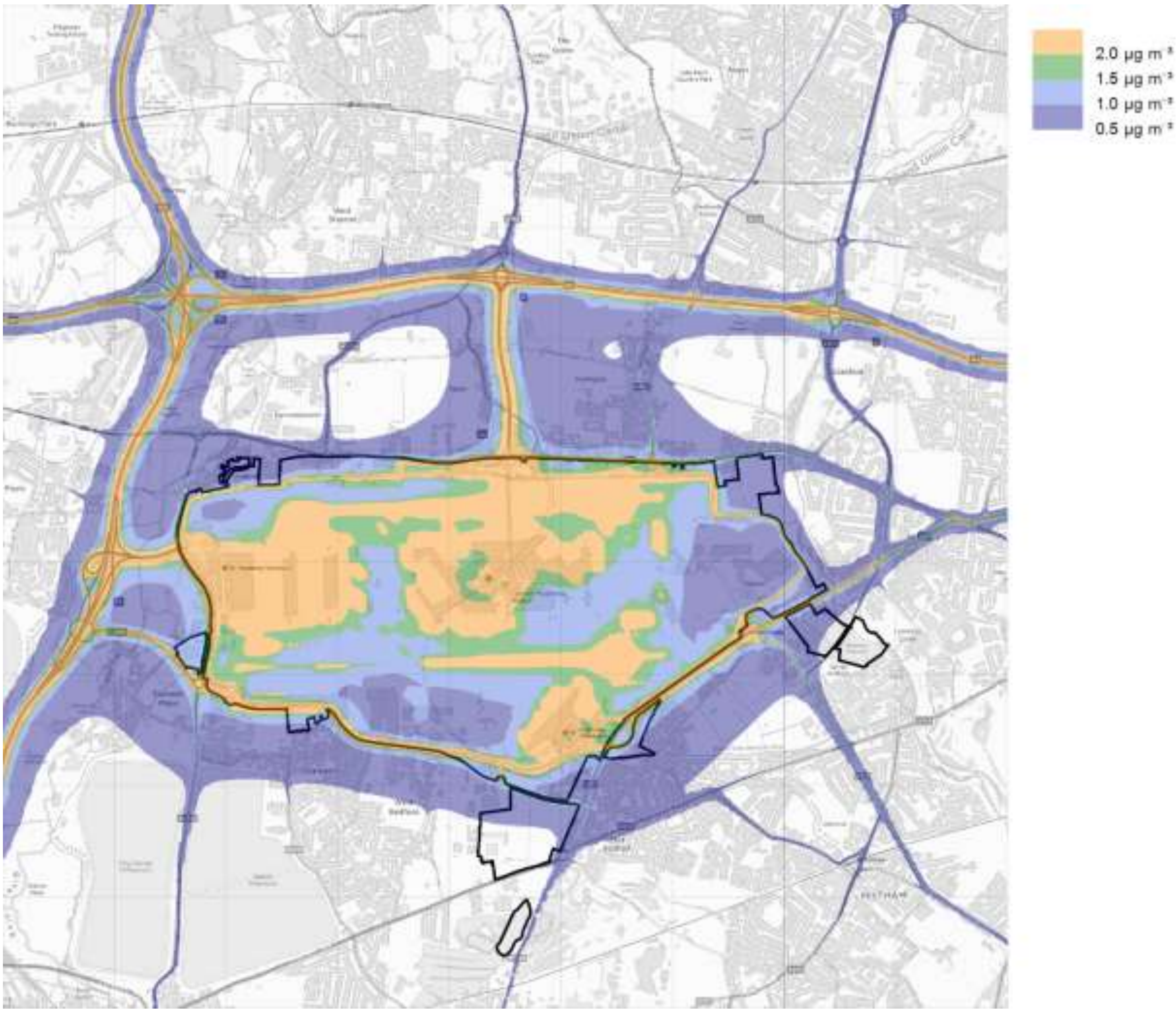
Figure 27: Airport-related contribution[a] to annual mean PM_{10} concentration in 2013

a) Old EFs



b) New EFs


Contains Ordnance Survey data
© Crown copyright and database right 2014
2.0 µg m⁻³
1.5 µg m⁻³
1.0 µg m⁻³
0.5 µg m⁻³



[a] Includes aircraft, APUs, GSE, airport-related traffic on the road network, car parking and stationary sources

5.5.2 Non-airport PM

The contribution from non-airport sources is relatively constant across the set of receptor locations, with the consequence that the total concentration is also relatively constant. Even so, it is instructive to examine its contributions by source. Table 25 shows the pertinent breakdown, separately for PM_{10} and $PM_{2.5}$.

Table 25: Breakdown of the non-airport PM contribution by source category

a) Old EFs

Receptor	Annual mean PM_{10} contribution ($\mu g\ m^{-3}$)			Annual mean $PM_{2.5}$ contribution ($\mu g\ m^{-3}$)		
	Road traffic	Back-ground[a]	Total	Road traffic	Back-ground[a]	Total
LHR2	1.4	18.3	19.7	0.8	13.7	14.5
Oaks Rd	0.6	18.3	19.0	0.4	13.8	14.2
Green Gates	1.1	18.4	19.5	0.7	13.9	14.5
Colnbrook	1.0	18.7	19.6	0.6	14.0	14.6
Harmondsworth	0.9	18.4	19.3	0.6	13.9	14.4
Hillingdon	2.9	18.4	21.3	1.8	13.8	15.6
Sipson	0.7	18.3	19.1	0.4	13.8	14.2
Harlington	1.3	18.4	19.7	0.8	13.8	14.5
Oxford Ave	1.5	18.3	19.9	0.9	13.7	14.6
Hayes	1.7	18.6	20.3	1.0	13.9	14.9
Cranford	1.0	18.4	19.4	0.6	13.7	14.3
Hatton Cross	1.5	18.4	19.8	0.8	13.7	14.6
PerimA	1.5	18.3	19.9	0.9	13.8	14.7
PerimB	1.1	18.3	19.4	0.6	13.8	14.4
PerimC	1.0	18.3	19.3	0.6	13.7	14.3
PerimD	1.0	18.3	19.4	0.6	13.7	14.3
PerimE	2.4	18.3	20.8	1.4	13.7	15.1
PerimF	1.7	18.4	20.0	1.0	13.7	14.7
PerimG	3.1	18.4	21.5	1.8	13.8	15.5
PerimH	1.7	18.3	20.1	1.0	13.8	14.8
M4A	3.1	18.4	21.5	1.9	13.9	15.7
M4B	2.9	18.4	21.3	1.7	13.8	15.6
M4C	3.4	18.5	21.9	2.1	13.8	15.9
M4D	3.3	18.5	21.8	2.0	13.8	15.8

b) New EFs

Receptor	Annual mean PM_{10} contribution ($\mu g\ m^{-3}$)			Annual mean $PM_{2.5}$ contribution ($\mu g\ m^{-3}$)		
	Road traffic	Back-ground[a]	Total	Road traffic	Back-ground[a]	Total
LHR2	1.7	18.3	20.0	1.0	13.7	14.7
Oaks Rd	0.7	18.3	19.1	0.4	13.8	14.2
Green Gates	1.3	18.4	19.7	0.8	13.9	14.6
Colnbrook	1.1	18.7	19.8	0.7	14.0	14.7
Harmondsworth	1.1	18.4	19.5	0.6	13.9	14.5
Hillingdon	3.4	18.4	21.8	2.1	13.8	15.9
Sipson	0.9	18.3	19.2	0.5	13.8	14.3
Harlington	1.5	18.4	19.9	0.9	13.8	14.6
Oxford Ave	1.8	18.3	20.1	1.0	13.7	14.7
Hayes	1.9	18.6	20.6	1.2	13.9	15.0
Cranford	1.2	18.4	19.6	0.7	13.7	14.4
Hatton Cross	1.7	18.4	20.0	1.0	13.7	14.7
PerimA	1.8	18.3	20.1	1.0	13.8	14.8
PerimB	1.3	18.3	19.6	0.8	13.8	14.5
PerimC	1.1	18.3	19.4	0.7	13.7	14.4
PerimD	1.2	18.3	19.5	0.7	13.7	14.4
PerimE	2.8	18.3	21.1	1.6	13.7	15.3
PerimF	1.9	18.4	20.3	1.1	13.7	14.8
PerimG	3.6	18.4	21.9	2.0	13.8	15.8
PerimH	2.0	18.3	20.3	1.2	13.8	14.9
M4A	3.6	18.4	22.0	2.2	13.9	16.1
M4B	3.4	18.4	21.8	2.0	13.8	15.9
M4C	4.1	18.5	22.5	2.4	13.8	16.2
M4D	3.9	18.5	22.3	2.3	13.8	16.1

[a] Sources from the LAEI and NAEI not already included in the airport and road network source categories

Clearly, the background contribution is dominant and virtually constant across the area of interest, reflecting the fact that background sources are distant and coarsely defined spatially. The small distance of some of the receptor locations from the M4 or other major roads leads to the comparatively large contribution at these sites from road vehicles on the network.

5.5.3 Comparison with 2008/9

Table 26 compares annual mean PM concentrations for 2013 and 2008/9 at the continuous monitors. A more detailed version of the table, giving a breakdown of the different source contributions, is given in Appendix A.

Table 26: Comparison of modelled PM concentrations for 2013 and 2008/9

a) Old EFs

Receptor	2013 concentration (µg m^{-3})		Fractional difference from 2008/9 (%)	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
LHR2	23.0	16.6	-3.6	17.9
Oaks Rd	19.7	14.7	-2.9	24.3
Green Gates	20.0	14.9	-2.7	24.6
Colnbrook	19.9	14.8	-1.8	26.5
Harmondsworth	19.7	14.6	-3.0	24.8
Hillingdon	22.3	16.2	-4.0	18.1
Sipson	19.9	14.7	-4.4	21.8
Harlington	20.2	14.8	-2.7	23.5
Oxford Ave	20.6	15.1	-3.0	22.4
Hayes	20.6	15.1	-5.3	17.9
Cranford	19.8	14.5	-2.8	23.7
Hatton Cross	20.9	15.3	-2.9	21.9

b) New EFs

Receptor	2013 concentration (µg m^{-3})		Fractional difference from 2008/9 (%)	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
LHR2	23.5	16.9	-1.7	19.7
Oaks Rd	19.9	14.8	-2.2	24.9
Green Gates	20.2	15.0	-1.8	25.5
Colnbrook	20.1	14.9	-0.9	27.5
Harmondsworth	19.8	14.7	-2.1	25.7
Hillingdon	23.0	16.6	-1.1	21.0
Sipson	20.0	14.8	-3.5	22.7
Harlington	20.4	15.0	-1.6	24.6
Oxford Ave	20.9	15.2	-1.7	23.7
Hayes	20.8	15.2	-4.1	19.0
Cranford	19.9	14.6	-2.0	24.6
Hatton Cross	21.2	15.4	-1.5	23.2

[a] Fractional Difference (%) = 100 * (2013 value – 2008/9 value) / 2008/9 value

The total modelled concentrations of PM_{10} are lower in 2013 than in 2008/9; however the total modelled $PM_{2.5}$ is higher in 2013. The main reason for the increase in $PM_{2.5}$ is the high contribution from the rural background term, which in turn derives from high concentrations measured at the rural Rochester Stoke monitoring station in easterlies. Concentrations of $PM_{2.5}$ at this station were appreciably higher in 2013 than in 2011/2012, which in turn were higher than the longer term trend from 1999–2009, for unknown reasons[55].

Other than the rural contribution to $PM_{2.5}$, the picture for PM is similar to that for NO_x. Contributions from almost all sources are lower in 2013 than in 2008/9 for the old road traffic emission factor related modelling. However, modelling related to the new road traffic related emission factors has an increased contribution from roads compared to 2008/9. The

55 Conolly C (2014) Kent and Medway Air Quality Monitoring Network: Annual Report 2013. http://www.kentair.org.uk/documents/KMAQMN_2013_Issue_1_2-7-14.pdf. Retrieved 7 August 2014.

contribution from aircraft main engines (i.e. excluding APUs) reflects a small rise in emissions but also a higher fraction of easterly operations in 2013, meaning that receptor locations to the west of the airfield (e.g. Green Gates) tend to have an increase from this source relative to 2008/9, while receptor locations to the east (e.g. LHR2) tend to have a decrease.

Overall, though, the on-airport contribution is lower in 2013 than in 2008/9, largely due to the steep reductions in emissions from APUs and GSE.

6 Monitoring results

While a detailed comparison of the modelling results with monitoring is described in the model evaluation report[56], it is useful to present a brief comparison here.

Table 27 presents a summary of measurements at the continuous monitoring sites. Figure 28 shows the measured NO_2 concentrations overlaid on a contour map of modelled NO_2.

Table 27: Measured concentrations at the continuous monitors

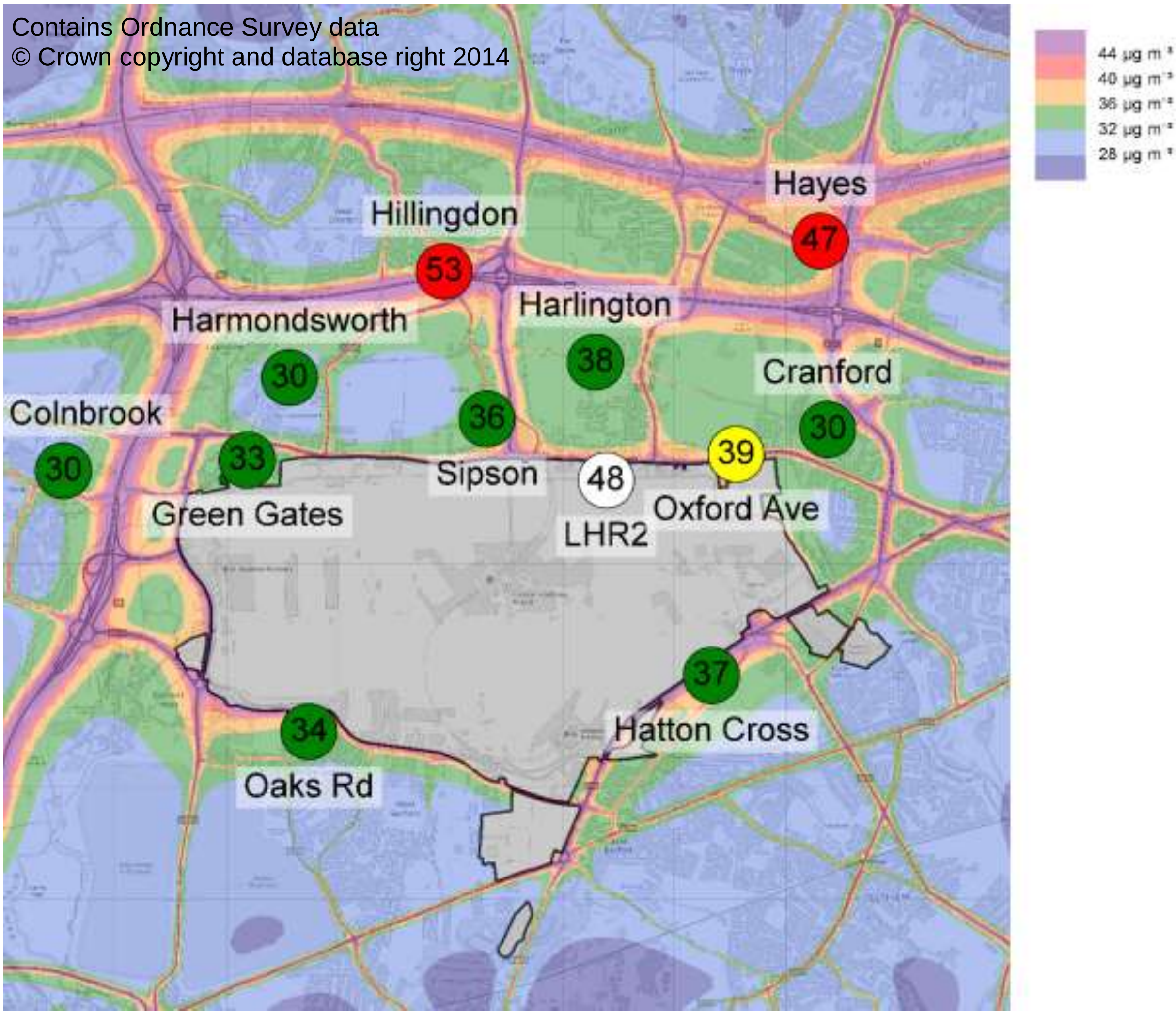
Receptor	NO_x ($\mu g\ m^{-3}$)	NO_2 ($\mu g\ m^{-3}$)	PM_{10} ($\mu g\ m^{-3}$)	$PM_{2.5}$ ($\mu g\ m^{-3}$)
LHR2	105.7	47.9	26.1	10.9
Oaks Rd	58.1	34.2	21.6	10.0
Green Gates	63.4	33.5	20.7	10.1
Colnbrook	51.1	29.6	18.9	NM
Harmondsworth	55.2	30.3	21.9	NM
Hillingdon	107.5	52.8	NM	NM
Sipson	62.6	36.5	NM	NM
Harlington	65.5	37.5	19.9	13.8
Oxford Ave	75.6	39.2	21.3	NM
Hayes	117.1	47.0	29.3	NM
Cranford	51.1	30.1	19.4	NM
Hatton Cross	70.1	37.2	20.9	NM

[a] NM = Not Monitored.
[b] Measurements where data capture is below 90% are shaded grey.

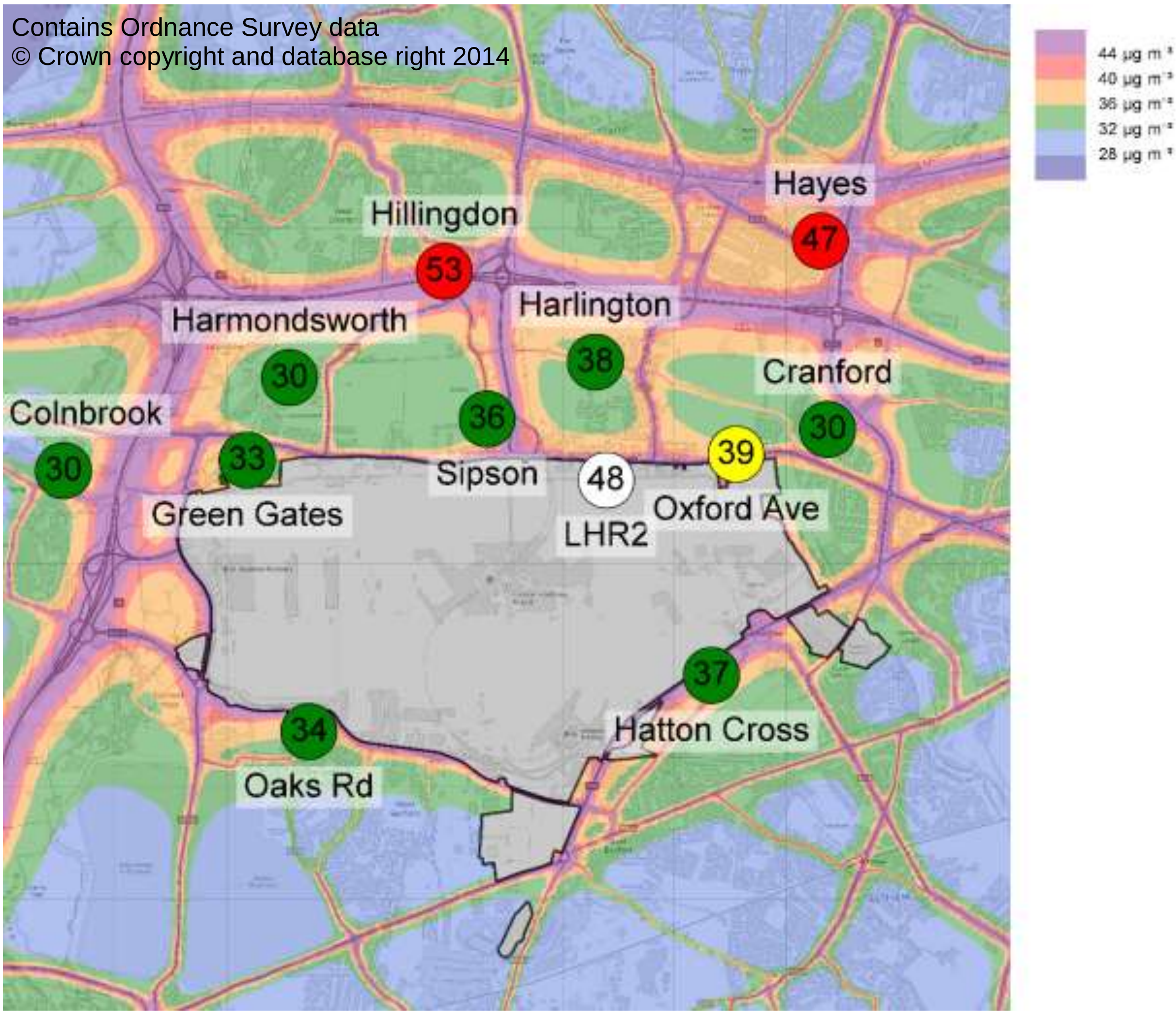
56 Ricardo-AEA (2014) Heathrow Airport 2013 Air Quality Assessment: Model Evaluation, Draft Report November 2014.

Figure 28: Modelled and measured annual mean NO_2 concentrations in 2013

a) Old EFs Unadjusted



b) New EFs Adjusted

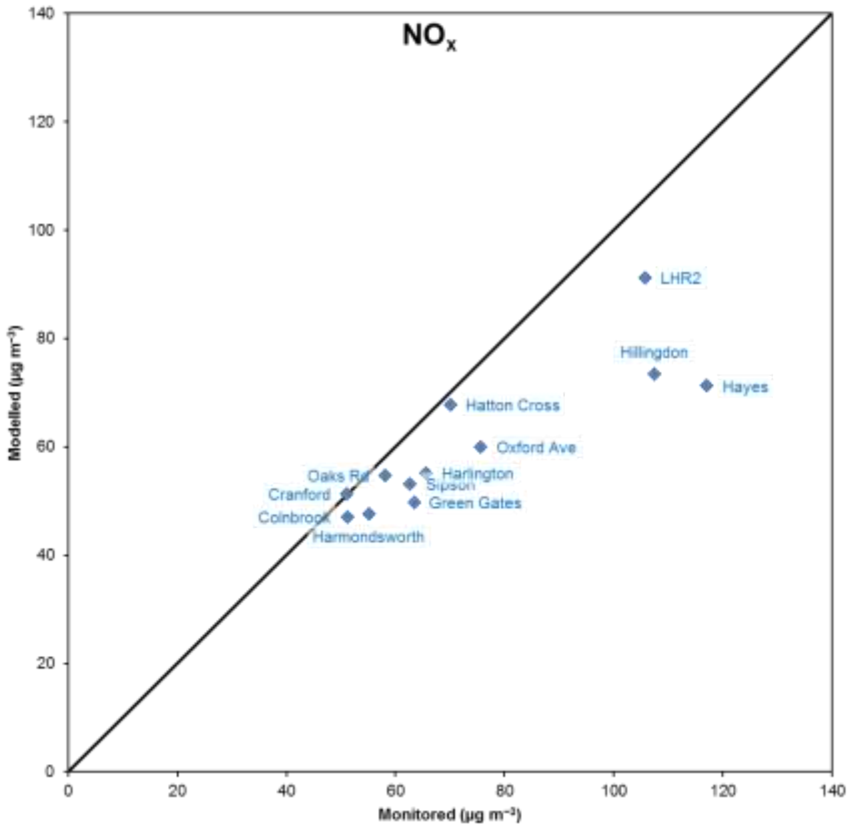


[a] Contours show modelled concentrations. Spot values at monitoring locations are measured NO_2 concentrations in µg m^{-3}.
● Exceeds EU limit value (40 µg m^{-3} or more).
● Close to EU limit value (38 µg m^{-3} to 40 µg m^{-3}).
● Meets EU limit value (below 38 µg m^{-3}).
○ EU limit value does not apply.

Figures 29 to 32 show a comparison between modelled and measured concentrations for NO_x, NO_2, PM_{10} and $PM_{2.5}$. For NO_x and NO_2, modelled results are shown before and after scaling. It can be seen that NO_x concentrations are generally underpredicted by the modelling, but modelled NO_2 concentrations are very close to measured values at most receptor locations (exceptions being Hillingdon and Hayes). PM_{10} is generally underpredicted, while $PM_{2.5}$ is overpredicted at all locations where it is monitored. This is discussed further in the model evaluation report.

Figure 29: Modelled versus measured NO_x concentrations

a) Old EFs



b) New EFs

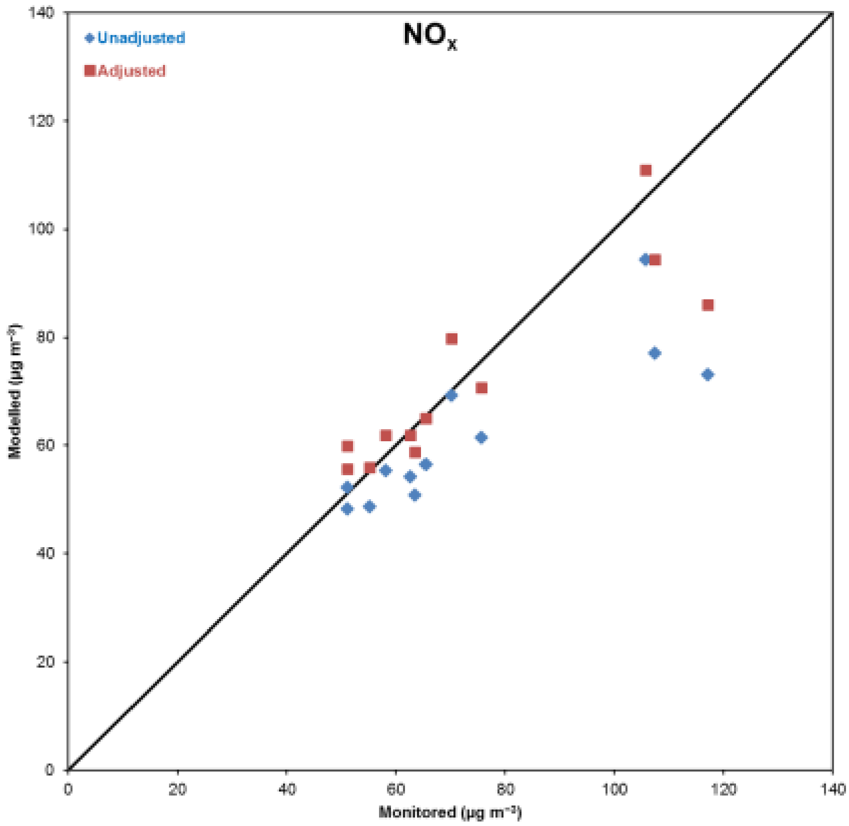
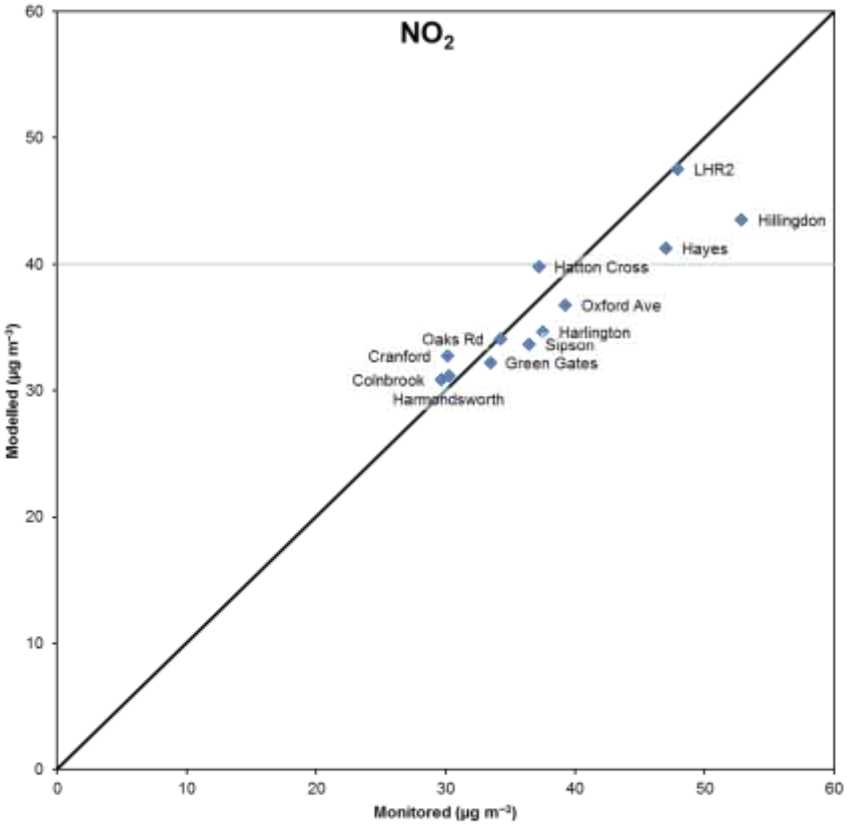


Figure 30: Modelled versus measured NO_2 concentrations

a) Old EFs



b) New EFs

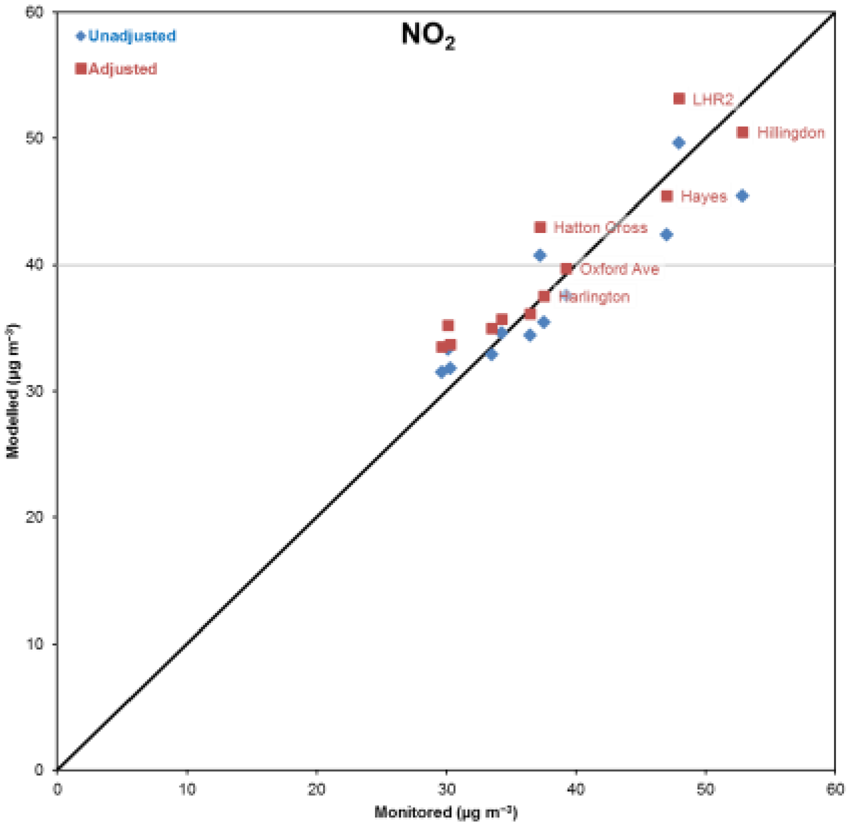
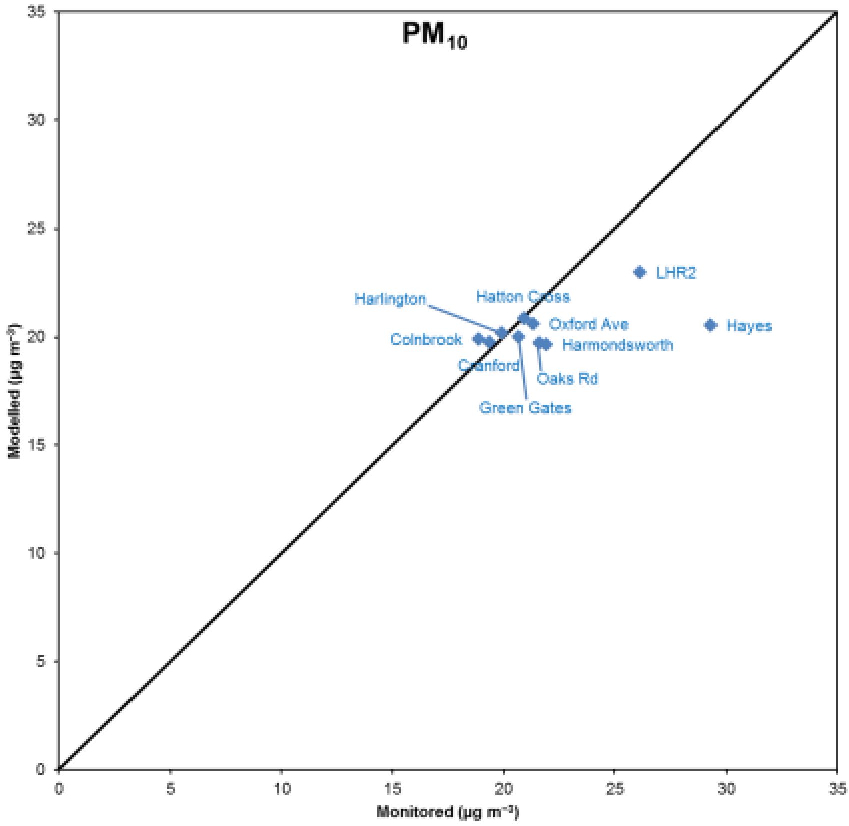


Figure 31: Modelled versus measured PM_{10} concentrations

a) Old EFs



b) New EFs

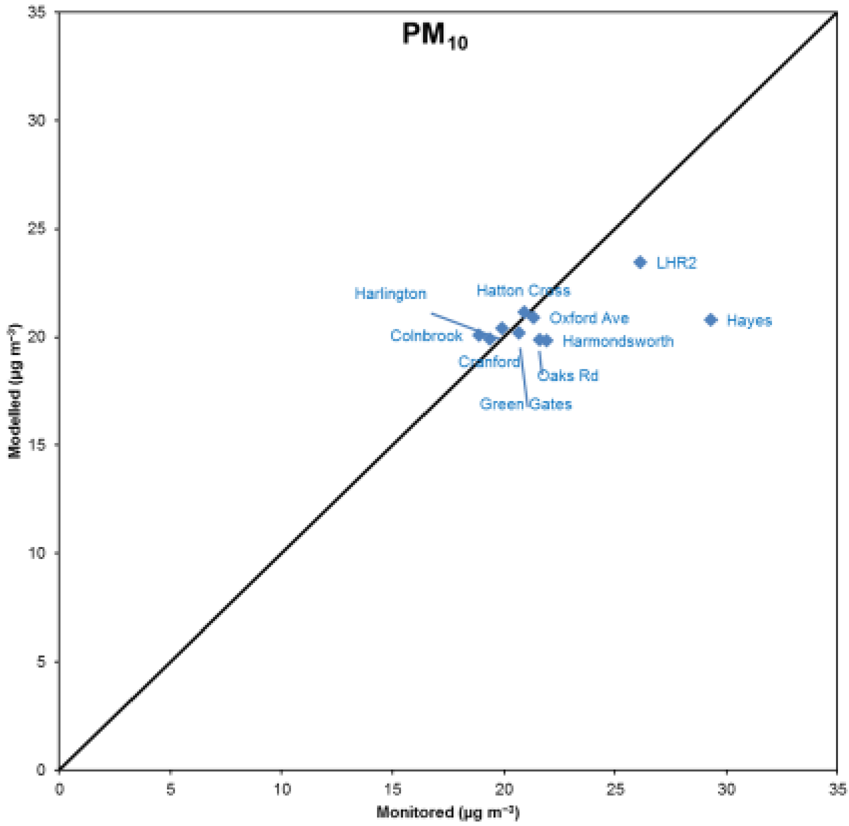
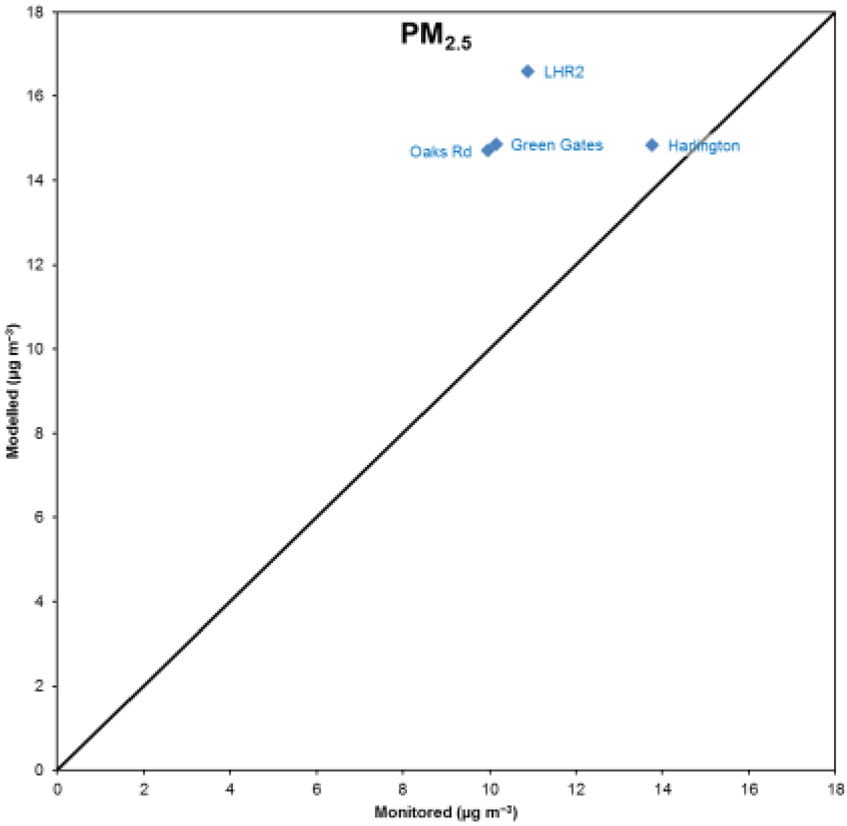
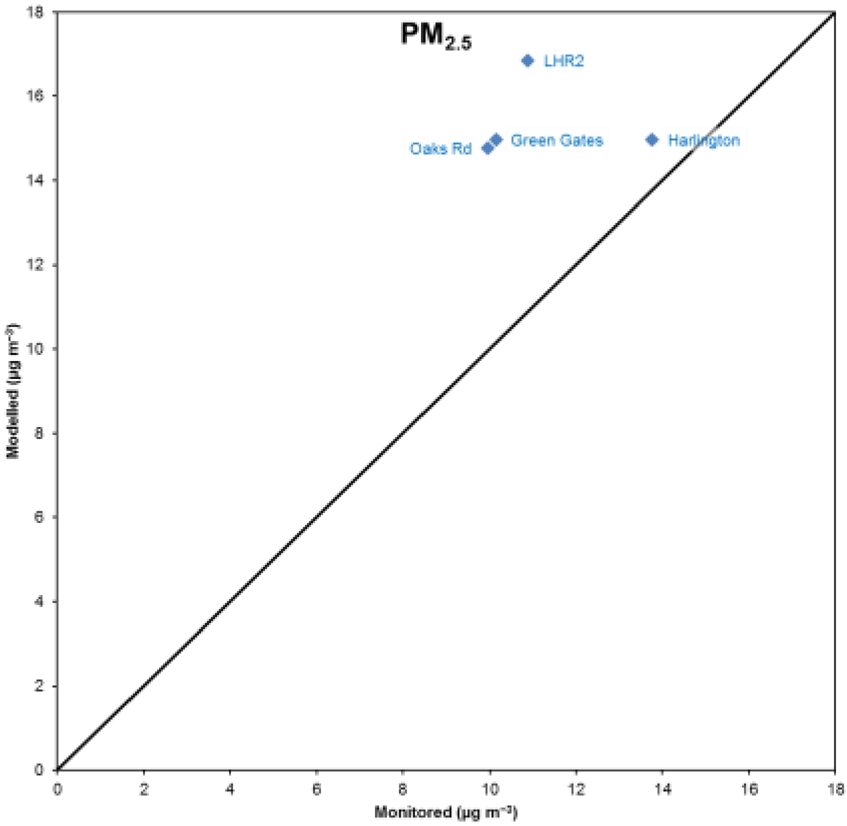


Figure 32: Modelled versus measured $PM_{2.5}$ concentrations

a) Old EFs



b) New EFs



Acknowledgements

The authors thank Liz Hegarty, David Vowles, Luke Cox, Peter Rafano, Nigel Stroud, Andy Cameron and Chris Joyce from Heathrow Airport along with any colleagues supporting them. We also that Duncan Younger (AECOM), Jay Parsons (Airport Energy), Kevin Tucker (Helios), Tom Cunnington (TfL), and the The Met Office.

Appendix A Further results

A.1 Road network

Table A1: Vehicle km and emissions on the road network by vehicle type

a) Old EFs

	Vehicle km (million)	NOx (tonne)	PM_{10} (tonne)	$PM_{2.5}$ (tonne)	CO_2 (kilotonne)
Airport-related traffic					
Cars	447.53	145.15	27.37	15.72	66.93
Taxis	6.91	3.76	0.55	0.38	1.86
Motorcycles	4.93	1.09	0.28	0.16	0.58
LGV	60.97	45.61	5.08	3.24	14.12
Buses	8.07	36.49	1.01	0.59	5.39
Coaches	2.92	16.55	0.33	0.20	2.45
Rigid HGV	28.89	86.92	3.15	1.98	17.88
Artic HGV	4.24	14.98	0.59	0.38	3.84
Airport-related total	**564.47**	**350.55**	**38.37**	**22.65**	**113.05**
Non-airport traffic					
Cars	2050.93	678.08	127.08	72.77	318.76
Taxis	27.07	15.13	2.19	1.51	7.46
Motorcycles	23.50	4.96	1.35	0.80	2.75
LGV	352.86	271.90	30.42	19.32	83.25
Buses	24.64	131.47	3.30	1.96	18.47
Coaches	8.33	56.91	1.04	0.63	7.79
Rigid HGV	135.15	430.09	15.19	9.73	85.88
Artic HGV	19.12	73.01	2.69	1.74	17.87
Non-airport total	2641.60	1661.51	183.26	108.46	542.24
Total	**3206.06**	**2012.07**	**221.63**	**131.11**	**655.29**

b) New EFs

	Vehicle km (million)	NOx (tonne)	PM_{10} (tonne)	$PM_{2.5}$ (tonne)	CO_2 (kilotonne)
Airport-related					
Cars	447.53	166.64	30.65	17.46	66.85
Taxis	6.91	6.53	0.65	0.45	1.86
Motorcycles	4.93	1.12	0.30	0.17	0.58
LGV	60.97	51.55	5.86	3.79	13.39
Buses	8.07	44.29	1.37	0.80	6.84
Coaches	2.92	16.51	0.52	0.33	2.45
Rigid HGV	28.89	84.81	4.48	2.80	17.77
Artic HGV	4.24	15.37	0.80	0.51	4.19
Airport-related total	**564.47**	**386.82**	**44.63**	**26.32**	**113.91**
Non-airport					
Cars	2051.80	777.76	142.27	80.87	318.51
Taxis	27.07	26.19	2.61	1.82	7.46
Motorcycles	23.52	5.11	1.43	0.84	2.75
LGV	352.90	307.97	34.53	22.14	79.25
Buses	24.72	159.84	4.41	2.63	23.01
Coaches	8.35	56.86	1.63	1.07	7.81
Rigid HGV	135.16	421.73	21.32	13.44	85.45
Artic HGV	19.12	74.34	3.65	2.36	19.48
Non-airport total	2642.64	1829.76	211.86	125.17	543.72
Total	**3207.11**	**2216.58**	**256.49**	**151.49**	**657.62**

A.2 NO_x emissions

Table A2: Annual NO_x emissions for 2013 and fractional change from 2008/9 values

a) Old EFs

Source category	Emissions (tonnes/year)[a]	Fractional Difference[b] %
On-Airport		
Aircraft	4285.76	-4.0
Ground level	1524.36	-6.7
Taxi-out	237.53	10.6
Hold	225.63	35.3
Take-off roll	681.80	-5.8
Landing roll	41.04	0.7
Taxi-in	153.51	12.7
APU	182.05	-47.7
Engine testing	2.80	-16.1
Elevated	2761.41	-2.5
Initial climb	773.17	-12.0
Climb-out	1393.60	-1.1
Approach	594.64	9.5
Ground support equipment	177.40	-31.9
Road vehicles	136.70	-1.2
Off-road vehicles	40.70	-66.7
Car parks etc.	12.05	-34.0
Public car parks[c]	8.02	-31.0
Staff car parks	1.87	-63.1
Taxis (TFP, forecourts)	2.17	36.8
Stationary sources	85.83	-69.7
Heating plant	85.78	-69.8
Fire Training Ground	0.05	-63.4
Off-Airport		
Landside road network	2012.07	-18.3
Airport-related traffic	350.55	NA[d]
Non-airport traffic	1661.51	NA[d]

b) New EFs

Source category	Emissions (tonnes/year)[a]	Fractional Difference[b] %
On-Airport		
Aircraft	4285.76	-4.0
Ground level	1524.36	-6.7
Taxi-out	237.53	10.6
Hold	225.63	35.3
Take-off roll	681.80	-5.8
Landing roll	41.04	0.7
Taxi-in	153.51	12.7
APU	182.05	-47.7
Engine testing	2.80	-16.1
Elevated	2761.41	-2.5
Initial climb	773.17	-12.0
Climb-out	1393.60	-1.1
Approach	594.64	9.5
Ground support equipment	186.79	-28.3
Road vehicles	146.08	5.5
Off-road vehicles	40.70	-66.7
Car parks etc.	11.98	-34.5
Public car parks[c]	8.07	-30.5
Staff car parks	1.73	-65.8
Taxis (TFP, forecourts)	2.17	36.8
Stationary sources	85.83	-69.7
Heating plant	85.78	-69.8
Fire Training Ground	0.05	-63.4
Off-Airport		
Landside road network	2216.58	-10.0
Airport-related traffic	386.82	NA[d]
Non-airport traffic	1829.76	NA[d]

[a] Values quoted to 0.01 tonne for convenience in taking ratios etc. and should not be taken as indicative of the precision of the estimates
[b] Fractional Difference = 100 * (2013 value – 2008/9 value) / 2008/9 value
[c] Includes car rental
[d] The 2008/9 data does not separate airport-related and non-airport road traffic emissions

Table A3: Ground-level aircraft NO_x emissions[a] by aircraft type

	2013			2008/9		
	NO_x (t/year)	%	NO_x/cycle[b] (kg/cycle)	NO_x (t/year)	%	NO_x/cycle[b] (kg/cycle)
Small/Light	1.67	0.1	1.09	6.44	0.5	0.71
Airbus A318	0.78	0.1	1.58	0.13	0.0	1.26
Airbus A319	112.81	8.4	2.35	92.14	7.2	2.21
Airbus A320	143.70	10.7	2.34	100.85	7.9	2.22
Airbus A321	79.74	6.0	3.27	81.26	6.3	3.00
Boeing 737	24.10	1.8	2.25	30.32	2.4	2.14
Boeing 757	10.11	0.8	3.20	37.36	2.9	3.96
Other Medium	2.37	0.2	1.66	11.65	0.9	2.00
Airbus A300/310	5.19	0.4	5.92	8.99	0.7	4.87
Airbus A330	70.54	5.3	7.79	58.73	4.6	8.76
Airbus A340	92.21	6.9	14.61	160.27	12.5	13.09
Boeing 747	211.78	15.8	13.08	293.48	22.9	13.08
Boeing 767	108.99	8.1	6.54	85.22	6.6	6.00
Boeing 777	387.14	28.9	12.79	302.44	23.6	11.27
Boeing 787	6.41	0.5	6.37	0.00	0.0	NA
Other Heavy	0.05	0.0	9.68	0.75	0.1	8.67
Airbus A380	81.93	6.1	18.35	12.15	0.9	16.05
Total Small/Light	1.67	0.1	1.09	6.44	0.5	0.71
Total Medium	373.61	27.9	2.50	353.69	27.6	2.46
Total Heavy	882.31	65.9	10.98	909.87	71.0	10.79
Total Super	81.93	6.1	18.35	12.15	0.9	16.05
Total	1339.51	100.0	5.68	1282.15	100.0	5.39

[a] Omits APU and engine testing emissions
[b] 'Cycle' = arrival plus departure (2 movements)

A.3 NO_x and NO_2 concentrations

Table A4: Contributions to 2013 NO_x concentrations, and fractional difference from 2008/9

(I) On-airport sources

a) Old EFs Unadjusted

Receptor	2013 concentration contribution (µg m^{-3})				Fractional difference from 2008/9 (%)			
	Aircraft[a]	APUs	GSE	Misc airport[b]	Aircraft	APUs	GSE	Misc airport
LHR2	21.60	1.48	1.51	0.82	-14.2	-55.0	-59.0	-13.2
Oaks Rd	9.20	1.95	2.13	0.63	9.1	-42.9	-37.9	-35.1
Green Gates	2.05	0.82	0.85	0.50	23.7	-32.1	-40.5	38.5
Colnbrook	1.54	0.26	0.27	0.13	38.7	-25.4	-42.0	-10.9
Harmondsworth	1.40	0.49	0.51	0.23	18.6	-38.0	-48.2	-12.2
Hillingdon	1.79	0.39	0.40	0.18	-1.1	-49.5	-49.0	-39.1
Sipson	4.97	0.97	1.01	0.48	-9.4	-55.5	-55.6	-31.6
Harlington	4.77	0.60	0.62	0.28	-10.4	-55.1	-58.4	-47.8
Oxford Ave	9.22	0.49	0.52	0.55	-4.5	-63.3	-66.8	-46.9
Hayes	2.49	0.21	0.22	0.16	-5.7	-59.4	-64.3	-57.2
Cranford	4.28	0.31	0.33	0.36	-11.7	-64.4	-67.8	-61.7
Hatton Cross	13.53	1.09	1.16	1.22	16.9	-58.6	-59.5	-37.3

b) New EFs Adjusted

Receptor	2013 concentration contribution (µg m^{-3})				Fractional difference from 2008/9 (%)			
	Aircraft[a]	APUs	GSE	Misc airport[b]	Aircraft	APUs	GSE	Misc airport
LHR2	21.60	1.48	1.59	0.65	-14.2	-55.0	-56.6	-31.4
Oaks Rd	9.20	1.95	2.25	0.45	9.1	-42.9	-34.4	-54.5
Green Gates	2.05	0.82	0.90	0.28	23.7	-32.1	-37.1	-21.1
Colnbrook	1.54	0.26	0.29	0.09	38.7	-25.4	-38.7	-37.3
Harmondsworth	1.40	0.49	0.54	0.15	18.6	-38.0	-45.2	-43.1
Hillingdon	1.79	0.39	0.42	0.13	-1.1	-49.5	-46.1	-55.5
Sipson	4.97	0.97	1.06	0.37	-9.4	-55.5	-53.1	-47.5
Harlington	4.77	0.60	0.65	0.22	-10.4	-55.1	-56.0	-59.3
Oxford Ave	9.22	0.49	0.55	0.45	-4.5	-63.3	-64.8	-56.1
Hayes	2.49	0.21	0.24	0.14	-5.7	-59.4	-62.3	-63.4
Cranford	4.28	0.31	0.35	0.31	-11.7	-64.4	-66.0	-66.5
Hatton Cross	13.53	1.09	1.23	1.05	16.9	-58.6	-57.1	-46.1

[a] Excluding APU contribution
[b] Car parking, heating plant and fire training ground

(II) Off-airport sources and total

a) Old EFs Unadjusted

Receptor	2013 concentration contribution (µg m^{-3})				Fractional difference from 2008/9 (%)			
	Road traffic	NAEI/ LAEI	Rural	Total NO_x	Road traffic	NAEI/ LAEI	Rural	Total NO_x
LHR2	32.28	20.57	12.94	91.20	-8.2	-19.1	-9.4	-15.5
Oaks Rd	8.50	19.31	12.94	54.66	-11.1	-18.0	-9.4	-14.1
Green Gates	11.98	20.59	12.94	49.73	-21.8	-16.7	-9.4	-15.7
Colnbrook	10.59	21.33	12.94	47.06	-21.6	-12.0	-9.4	-13.0
Harmondsworth	10.33	21.76	12.94	47.67	-26.4	-19.1	-9.4	-18.5
Hillingdon	33.94	23.78	12.94	73.41	-25.0	-22.9	-9.4	-21.9
Sipson	11.08	21.62	12.94	53.08	-16.5	-21.7	-9.4	-19.3
Harlington	12.98	22.92	12.94	55.11	-4.0	-23.4	-9.4	-17.0
Oxford Ave	15.17	21.11	12.94	60.00	-13.5	-20.2	-9.4	-16.5
Hayes	23.89	31.32	12.94	71.24	-23.5	-20.7	-9.4	-20.1
Cranford	11.21	21.82	12.94	51.25	-8.4	-23.0	-9.4	-18.0
Hatton Cross	18.16	19.62	12.94	67.73	-3.8	-21.0	-9.4	-12.1

b) New EFs Adjusted

Receptor	2013 concentration contribution (µg m^{-3})				Fractional difference from 2008/9 (%)			
	Road traffic	NAEI/ LAEI	Rural	Total NO_x	Road traffic	NAEI/ LAEI	Rural	Total NO_x
LHR2	49.22	23.40	12.94	110.88	39.9	-8.0	-9.4	2.7
Oaks Rd	12.87	22.21	12.94	61.86	34.5	-5.7	-9.4	-2.8
Green Gates	18.37	23.41	12.94	58.77	20.0	-5.3	-9.4	-0.3
Colnbrook	16.33	24.27	12.94	55.71	20.8	0.1	-9.4	3.0
Harmondsworth	15.91	24.57	12.94	56.01	13.3	-8.7	-9.4	-4.2
Hillingdon	52.14	26.61	12.94	94.42	15.2	-13.7	-9.4	0.4
Sipson	17.14	24.43	12.94	61.89	29.1	-11.5	-9.4	-5.9
Harlington	20.01	25.78	12.94	64.97	47.9	-13.8	-9.4	-2.2
Oxford Ave	23.06	24.01	12.94	70.73	31.6	-9.2	-9.4	-1.5
Hayes	35.70	34.31	12.94	86.03	14.3	-13.1	-9.4	-3.5
Cranford	16.90	24.82	12.94	59.90	38.0	-12.4	-9.4	-4.2
Hatton Cross	27.39	22.59	12.94	79.82	45.2	-9.1	-9.4	3.6

Table A5 presents NO_2/NO_x ratios at the continuous monitors, and how they are different from the 2008/9 modelling. In 2013, the highest ratios are found at Green Gates, Colnbrook and Harmondsworth, in line with the low estimated NO_x concentrations there. In general, higher NO_x concentrations are associated with lower NO_2/NO_x ratios, although in 2013 the NO_2/NO_x ratio at Hillingdon is relatively high because road vehicles emit a relatively large proportion of primary NO_2. The ratios are somewhat higher in 2013 than in 2008/9 for similar NO_x concentrations; this is believed to be mainly because road vehicles emit a higher fraction of NO_x as primary NO_2 in 2013.

Table A5: Comparison of NO_2/NO_x ratios in 2013 and 2008/9

a) Old EFs Unadjusted

Receptor	2013 NO_2/NO_x ratio	Fractional difference from 2008/9 (%)
LHR2	0.52	11.7
Oaks Rd	0.62	9.2
Green Gates	0.65	9.8
Colnbrook	0.66	8.0
Harmondsworth	0.65	10.7
Hillingdon	0.59	18.4
Sipson	0.63	11.9
Harlington	0.63	11.3
Oxford Ave	0.61	11.2
Hayes	0.58	14.5
Cranford	0.64	10.9
Hatton Cross	0.59	9.5

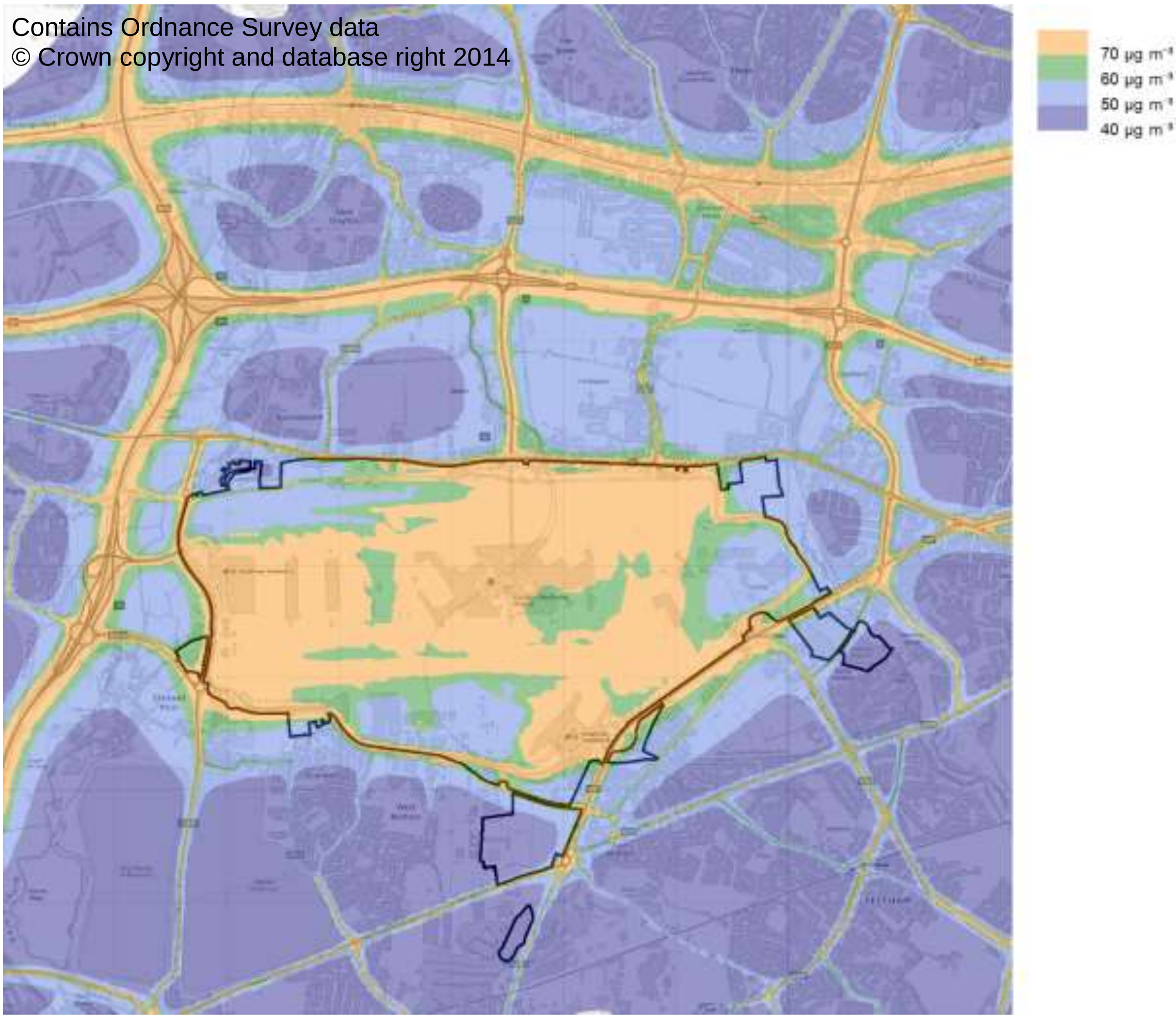
b) New EFs Adjusted

Receptor	2013 NO_2/NO_x ratio	Fractional difference from 2008/9 (%)
LHR2	0.48	2.7
Oaks Rd	0.58	1.0
Green Gates	0.60	0.9
Colnbrook	0.60	-0.9
Harmondsworth	0.60	1.9
Hillingdon	0.54	6.8
Sipson	0.58	3.2
Harlington	0.58	2.3
Oxford Ave	0.56	2.0
Hayes	0.53	4.4
Cranford	0.59	1.9
Hatton Cross	0.54	0.4

[a] Fractional Difference (%) = 100 * (2013 value – 2008/9 value) / 2008/9 value

Figure A1: Total annual mean NO_x concentration in 2013

a) Old EFs Unadjusted



b) New EFs Adjusted

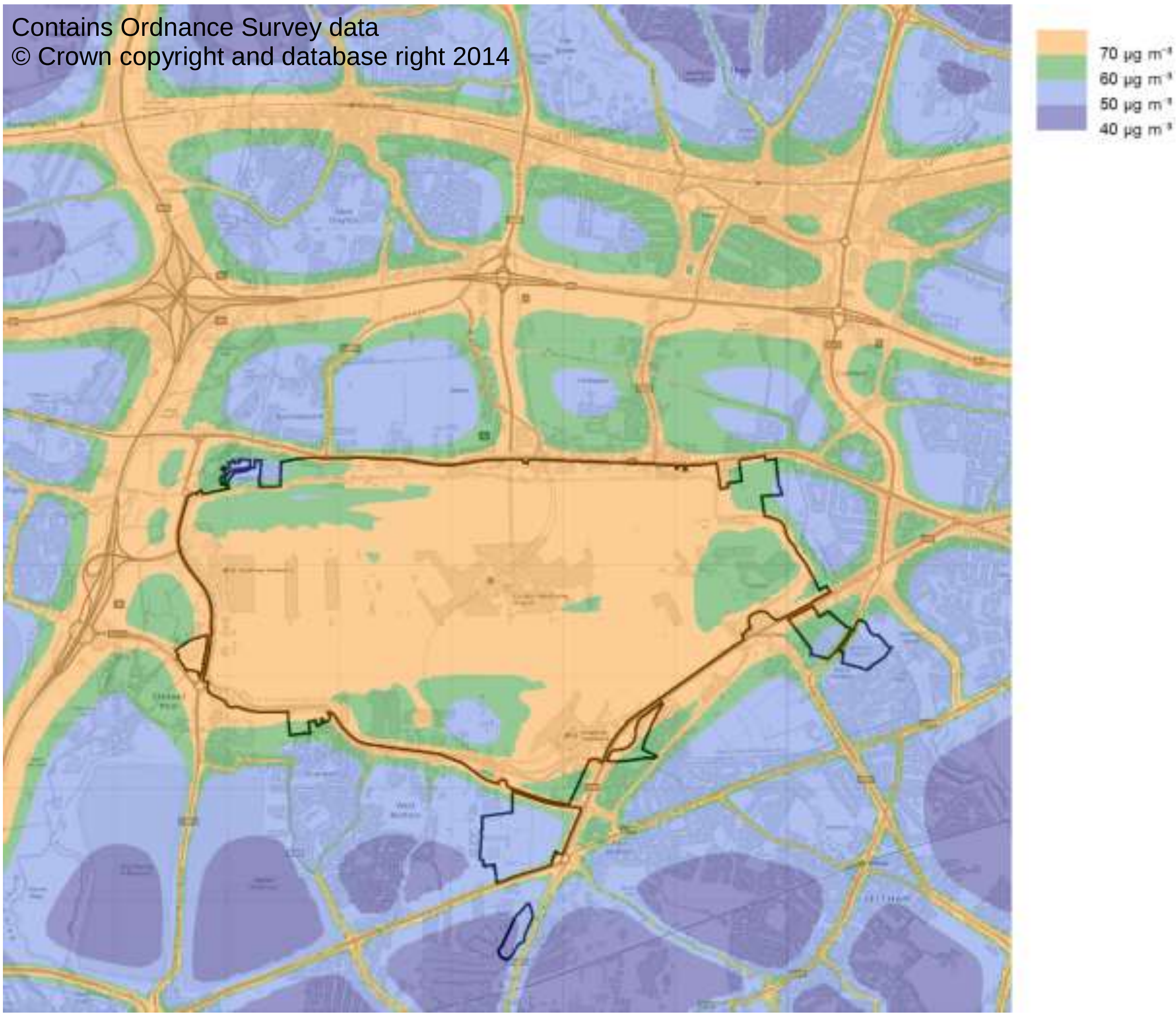
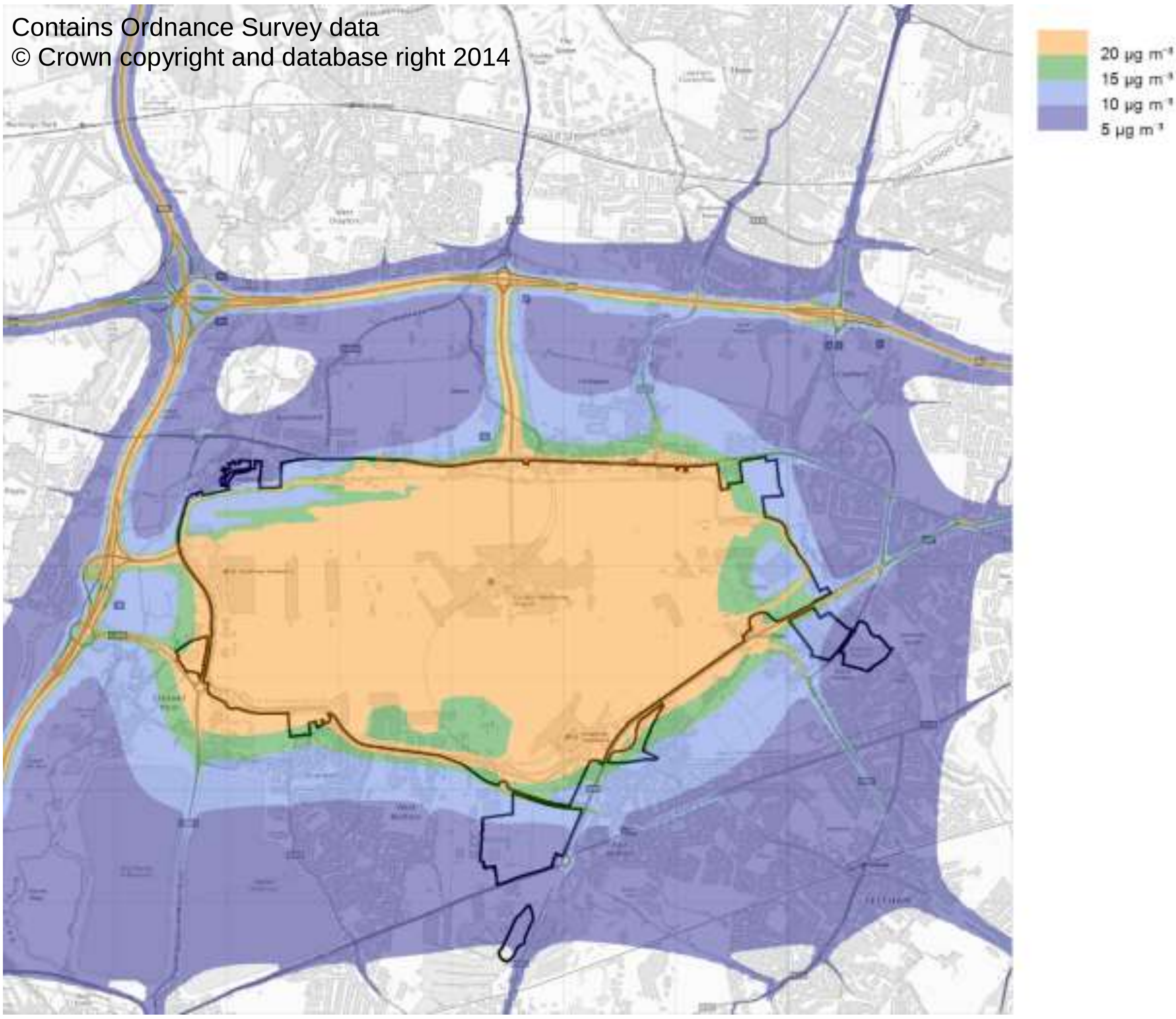
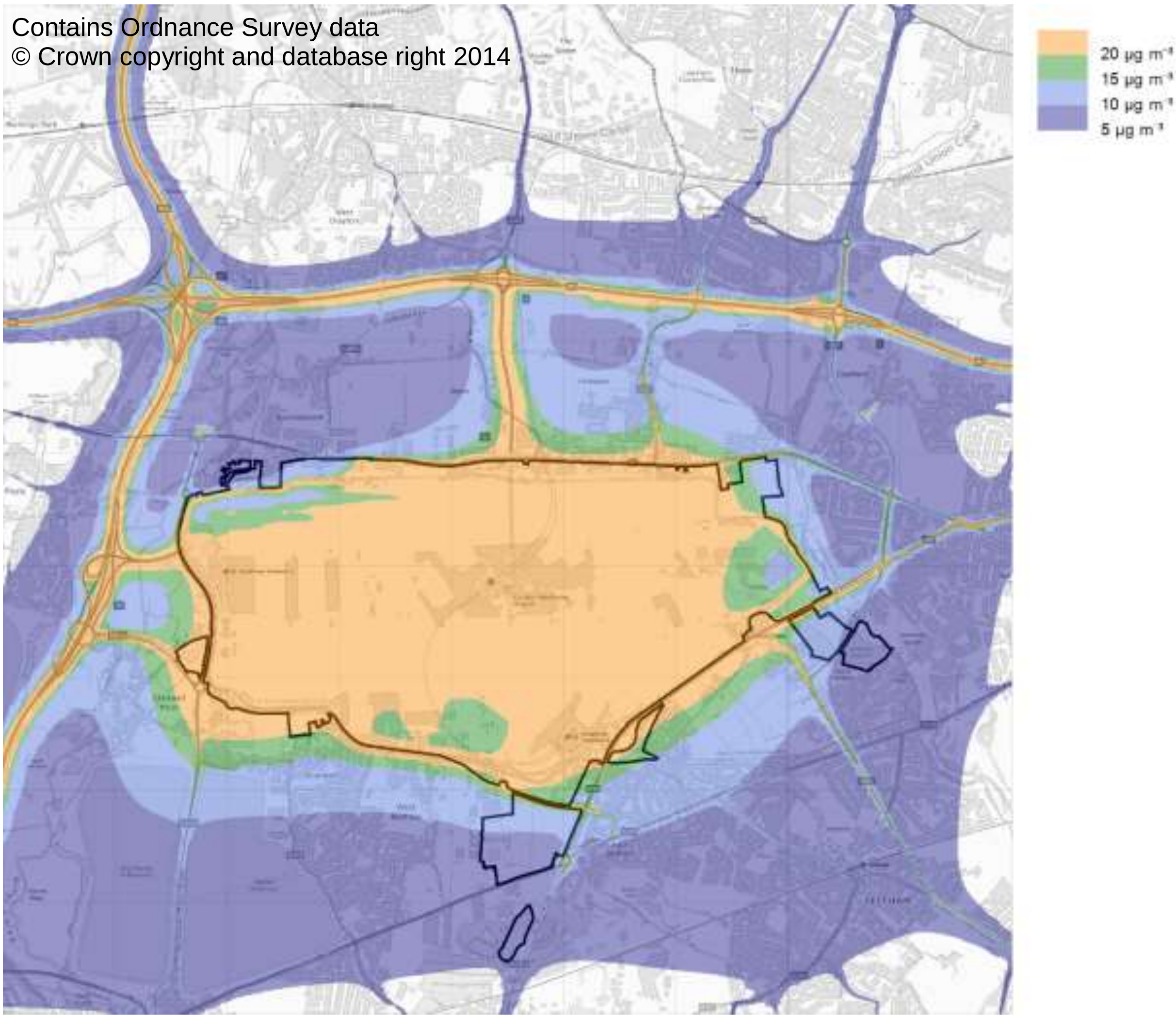


Figure A2: Airport-related contribution[a] to annual mean NO_x concentrations in 2013

a) Old EFs Unadjusted



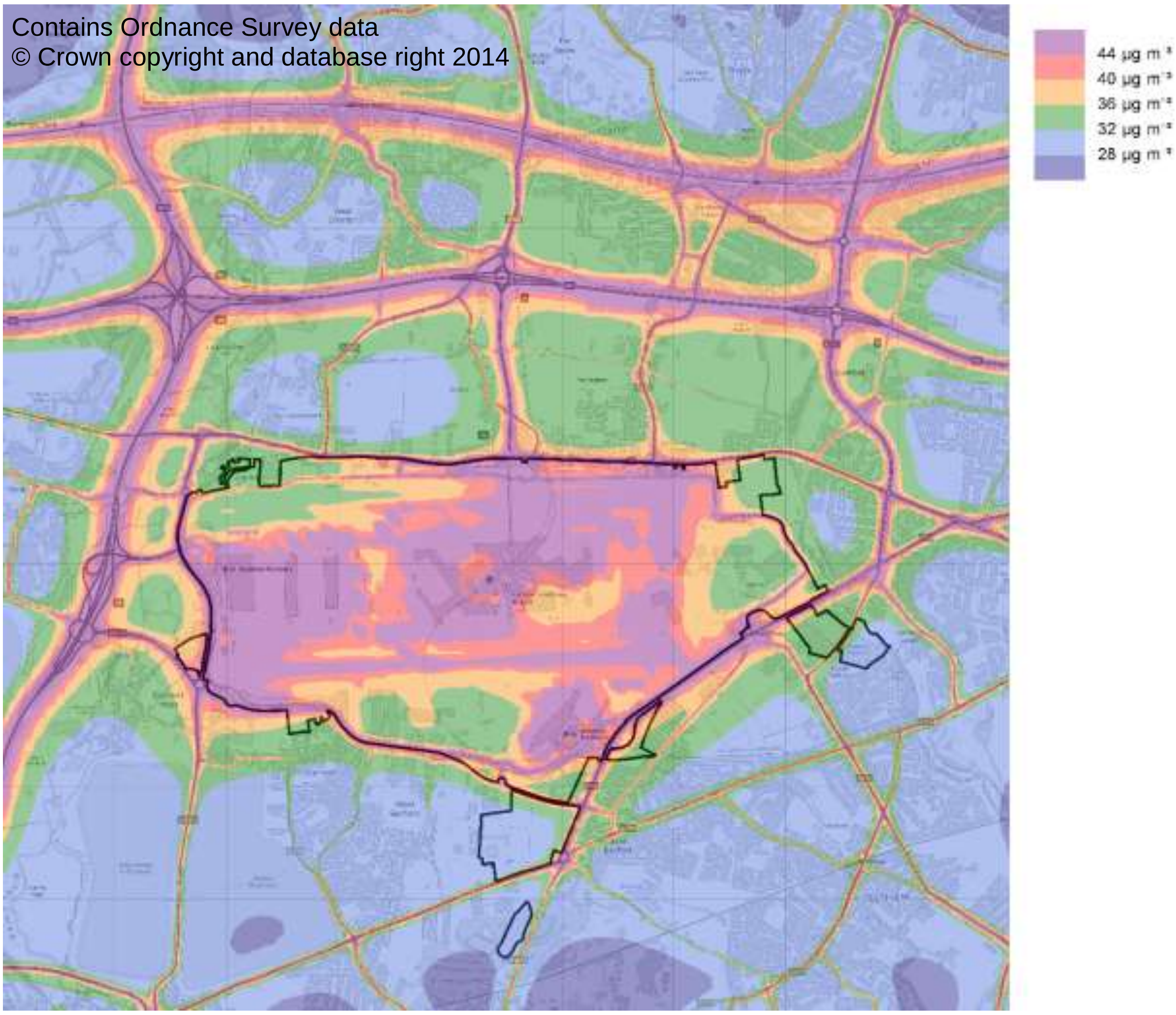
b) New EFs Adjusted



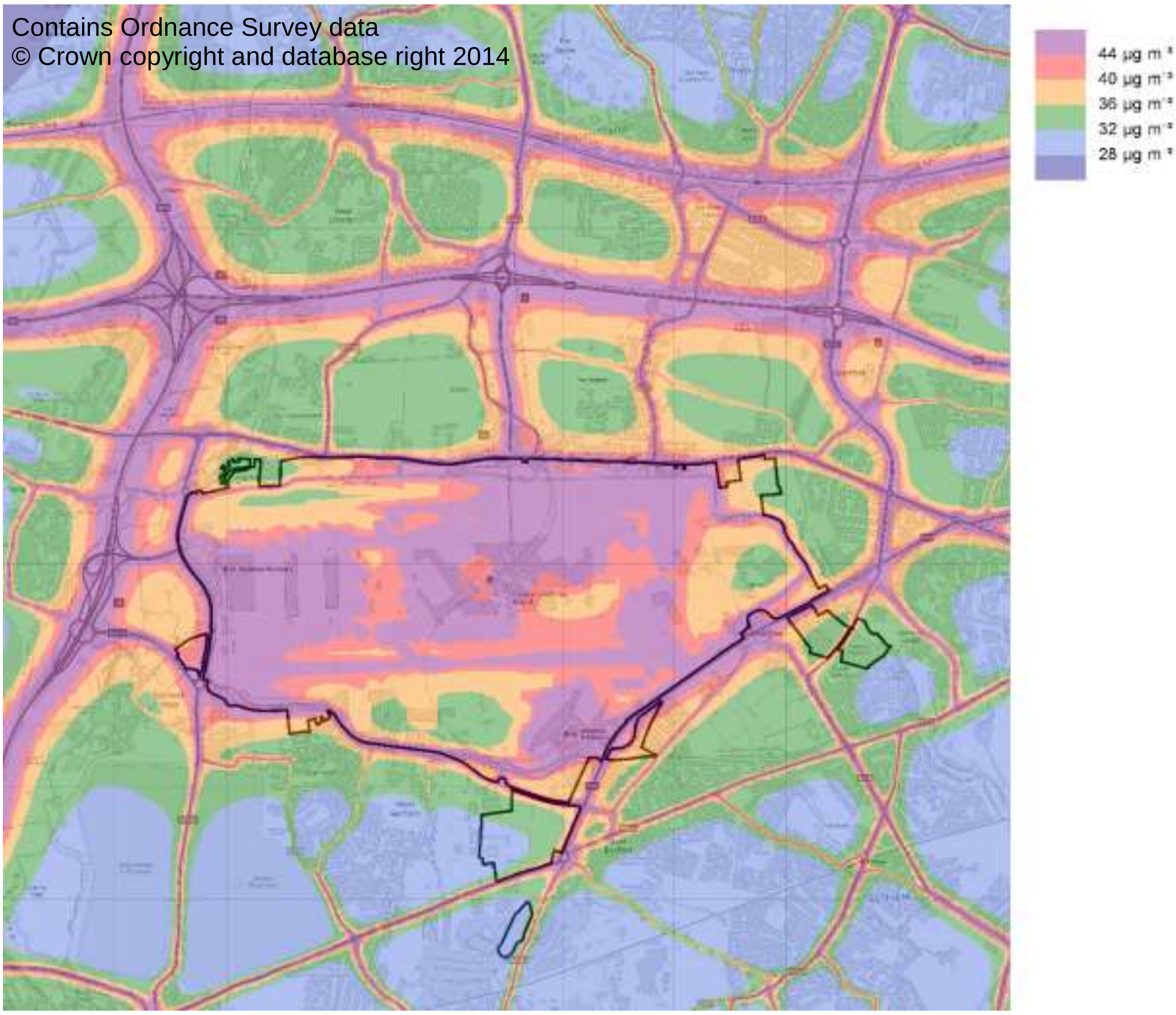
[a] Includes aircraft, APUs, GSE, airport-related traffic on the road network, car parking and stationary sources

Figure A3: Annual mean NO_2 concentrations in 2013

a) Old EFs Unadjusted



b) New EFs Adjusted



A.4 PM_{10} and $PM_{2.5}$ emissions

Table A6: Annual PM_{10} emissions for 2013 and fractional change from 2008/9 values

a) Old EFs

Source category	Emissions (tonnes/year)[a]			Fractional Difference[b] %		
	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
On-Airport						
Aircraft	50.97			-1.2		
Ground level		35.51			-3.0	
Taxi-out			4.90			7.9
Hold			4.62			33.7
Take-off roll			3.34			-3.9
Landing roll			0.55			-3.7
Tyre wear			6.10			1.2
Brake wear			9.25			1.2
Taxi-in			3.18			8.1
APU			3.52			-44.9
Engine testing			0.06			-13.8
Elevated		15.46			3.2	
Initial climb			3.27			-4.2
Climb out			6.50			3.3
Approach			5.69			7.8
Ground support equipment	10.95			-48.9		
Exhaust		5.76			-67.6	
Road			2.42			-55.5
Off-road			3.34			-72.9
Fugitives		5.19			40.7	
Road			4.49			50.5
Off-road			0.70			-0.7
Car parks etc.	1.43			-12.8		
Exhaust		0.55			-26.8	
Public car parks[c]			0.34			-1.6
Staff car parks			0.10			-32.4
Taxis			0.11			-57.7
Fugitives		0.88			-0.8	
Public car parks[c]			0.76			8.6
Staff car parks			0.10			-39.4
Taxis			0.01			4.5
Stationary sources	6.88			-73.6		
Heating plant		6.87			-73.6	
Fire Training Ground		0.00			-63.4	
Off-airport						
Landside road network	256.49			7.2		
Airport-related traffic		44.63			NA[d]	
Non-airport traffic		211.86			NA[d]	

b) New EFs

Source category	Emissions (tonnes/year)[a]	Fractional Difference[b] %
On-Airport		
Aircraft	50.97	-1.2
Ground level	35.51	-3.0
Taxi-out	4.90	7.9
Hold	4.62	33.7
Take-off roll	3.34	-3.9
Landing roll	0.55	-3.7
Tyre wear	6.10	1.2
Brake wear	9.25	1.2
Taxi-in	3.18	8.1
APU	3.52	-44.9
Engine testing	0.06	-13.8
Elevated	15.46	3.2
Initial climb	3.27	-4.2
Climb out	6.50	3.3
Approach	5.69	7.8
Ground support equipment	10.95	-48.9
Exhaust	5.76	-67.6
Road	2.42	-55.5
Off-road	3.34	-72.9
Fugitives	5.19	40.7
Road	4.49	50.5
Off-road	0.70	-0.7
Car parks etc.	1.43	-12.8
Exhaust	0.55	-26.8
Public car parks[c]	0.34	-1.6
Staff car parks	0.10	-32.4
Taxis	0.11	-57.7
Fugitives	0.88	-0.8
Public car parks[c]	0.76	8.6
Staff car parks	0.10	-39.4
Taxis	0.01	4.5
Stationary sources	6.88	-73.6
Heating plant	6.87	-73.6
Fire Training Ground	0.00	-63.4
Off-airport		
Landside road network	256.49	7.2
Airport-related traffic	44.63	NA[d]
Non-airport traffic	211.86	NA[d]

[a] Values quoted to 0.01 tonne for convenience in taking ratios etc. and should not be taken as indicative of the precision of the estimates
[b] Fractional Difference = 100 * (2013 value – 2008/9 value) / 2008/9 value
[c] Includes car rental
[d] The 2008/9 data does not separate airport-related and non-airport road traffic emissions

Table A7: Annual $PM_{2.5}$ emissions for 2013 and fractional change from 2008/9 values

a) Old EFs

Source category	Emissions (tonnes/year)[a]	Fractional Difference[b] %
On-Airport		
Aircraft	43.57	-1.6
Ground level	28.11	-4.0
Taxi-out	4.90	7.9
Hold	4.62	33.7
Take-off roll	3.34	-3.9
Landing roll	0.55	-3.7
Tyre wear	4.27	1.2
Brake wear	3.68	1.2
Taxi-in	3.18	8.1
APU	3.52	-44.9
Engine testing	0.06	-13.8
Elevated	15.46	3.2
Initial climb	3.27	-4.2
Climb out	6.50	3.3
Approach	5.69	7.8
Ground support equipment	7.87	-58.2
Exhaust	5.44	-67.9
Road	2.30	-55.5
Off-road	3.14	-73.4
Fugitives	2.43	29.9
Road	2.13	41.2
Off-road	0.30	-17.0
Car parks etc.	0.97	-13.3
Exhaust	0.52	-22.1
Public car parks[c]	0.32	5.3
Staff car parks	0.10	-28.0
Taxis	0.10	-55.2
Fugitives	0.45	-0.1
Public car parks[c]	0.39	9.4
Staff car parks	0.05	-39.0
Taxis	0.01	5.2
Stationary sources	6.88	-73.6
Heating plant	6.87	-73.6
Fire Training Ground	0.00	-63.4
Off-airport		
Landside road network	151.49	-2.9
Airport-related traffic	26.32	NA[d]
Non-airport traffic	125.17	NA[d]

b) New EFs

Source category	Emissions (tonnes/year)[a]			Fractional Difference[b] %		
On-Airport						
Aircraft	43.57			-1.6		
Ground level		28.11			-4.0	
Taxi-out			4.90			7.9
Hold			4.62			33.7
Take-off roll			3.34			-3.9
Landing roll			0.55			-3.7
Tyre wear			4.27			1.2
Brake wear			3.68			1.2
Taxi-in			3.18			8.1
APU			3.52			-44.9
Engine testing			0.06			-13.8
Elevated		15.46			3.2	
Initial climb			3.27			-4.2
Climb out			6.50			3.3
Approach			5.69			7.8
Ground support equipment	7.87			-58.2		
Exhaust		5.44			-67.9	
Road			2.30			-55.5
Off-road			3.14			-73.4
Fugitives		2.43			29.9	
Road			2.13			41.2
Off-road			0.30			-17.0
Car parks etc.	0.97			-13.3		
Exhaust		0.52			-22.1	
Public car parks[c]			0.32			5.3
Staff car parks			0.10			-28.0
Taxis			0.10			-55.2
Fugitives		0.45			-0.1	
Public car parks[c]			0.39			9.4
Staff car parks			0.05			-39.0
Taxis			0.01			5.2
Stationary sources	6.88			-73.6		
Heating plant		6.87			-73.6	
Fire Training Ground		0.00			-63.4	
Off-airport						
Landside road network	151.49			-2.9		
Airport-related traffic		26.32			NA[d]	
Non-airport traffic		125.17			NA[d]	

[a] Values quoted to 0.01 tonne for convenience in taking ratios etc. and should not be taken as indicative of the precision of the estimates
[b] Fractional Difference = 100 * (2013 value – 2008/9 value) / 2008/9 value
[c] Includes car rental
[d] The 2008/9 data does not separate airport-related and non-airport road traffic emissions

Table A8: Ground-level aircraft exhaust PM[a] emissions[b] by aircraft type

	2013			2008/9		
	PM (t/year)	%	PM/cycle[c] (kg/cycle)	PM (t/year)	%	PM/cycle[c] (kg/cycle)
Small/Light	0.063	0.4	0.041	0.130	0.9	0.014
Airbus A318	0.014	0.1	0.028	0.003	0.0	0.026
Airbus A319	2.793	16.8	0.058	2.228	14.9	0.054
Airbus A320	3.142	18.9	0.051	2.044	13.6	0.045
Airbus A321	1.381	8.3	0.057	1.218	8.1	0.045
Boeing 737	0.341	2.1	0.032	0.400	2.7	0.028
Boeing 757	0.128	0.8	0.040	0.386	2.6	0.041
Other Medium	0.045	0.3	0.031	0.338	2.3	0.058
Airbus A300/310	0.067	0.4	0.076	0.132	0.9	0.072
Airbus A330	0.561	3.4	0.062	0.602	4.0	0.090
Airbus A340	0.712	4.3	0.113	1.408	9.4	0.115
Boeing 747	2.828	17.0	0.175	3.077	20.5	0.137
Boeing 767	0.945	5.7	0.057	0.806	5.4	0.057
Boeing 777	2.945	17.8	0.097	2.125	14.2	0.079
Boeing 787	0.042	0.3	0.042	0.000	0.0	NA
Other Heavy	0.001	0.0	0.138	0.009	0.1	0.104
Airbus A380	0.581	3.5	0.130	0.075	0.5	0.099
Total Small/Light	0.063	0.4	0.041	0.130	0.9	0.014
Total Medium	7.844	47.3	0.052	6.617	44.2	0.046
Total Heavy	8.100	48.8	0.101	8.159	54.5	0.097
Total Super	0.581	3.5	0.130	0.075	0.5	0.099
Total	16.588	100.0	0.070	14.981	100.0	0.063

[a] For aircraft exhaust emissions, $PM_{2.5}$ and PM_{10} are assumed the same
[b] Omits APU, engine testing, brake wear and tyre wear emissions
[c] Cycle = arrival plus departure (2 movements)

A.5 PM_{10} and $PM_{2.5}$ concentrations

Table A9: Contributions to 2013 PM_{10} concentrations, and fractional difference from 2008/9

(I) On-airport sources

a) Old EFs

Receptor	2013 concentration contribution (µg m^{-3})				Fractional difference from 2008/9 (%)			
	Aircraft[a]	APUs	GSE	Misc airport[b]	Aircraft	APUs	GSE	Misc airport
LHR2	1.39	0.03	0.09	0.10	-11.5	-56.9	-70.2	60.8
Oaks Rd	0.22	0.04	0.13	0.06	-8.2	-40.3	-55.0	16.4
Green Gates	0.12	0.02	0.05	0.05	12.6	-27.6	-56.8	106.4
Colnbrook	0.05	0.01	0.02	0.01	36.0	-21.7	-57.9	26.1
Harmondsworth	0.05	0.01	0.03	0.02	13.3	-36.0	-62.4	29.5
Hillingdon	0.05	0.01	0.02	0.02	5.9	-47.1	-63.0	-15.6
Sipson	0.15	0.02	0.06	0.04	-0.7	-53.3	-67.8	-6.2
Harlington	0.15	0.01	0.04	0.03	-4.0	-55.1	-69.8	-24.1
Oxford Ave	0.22	0.01	0.03	0.04	-14.2	-61.9	-75.9	-15.8
Hayes	0.06	0.00	0.01	0.01	-8.7	-58.0	-74.1	-27.7
Cranford	0.11	0.01	0.02	0.02	-18.0	-62.8	-76.6	-28.8
Hatton Cross	0.39	0.02	0.07	0.08	1.2	-54.9	-70.6	12.9

b) New EFs

Receptor	2013 concentration contribution (µg m^{-3})				Fractional difference from 2008/9 (%)			
	Aircraft[a]	APUs	GSE	Misc airport[b]	Aircraft	APUs	GSE	Misc airport
LHR2	1.39	0.03	0.09	0.05	-11.5	-56.9	-68.8	-21.6
Oaks Rd	0.22	0.04	0.13	0.03	-8.2	-40.3	-52.8	-37.1
Green Gates	0.12	0.02	0.05	0.02	12.6	-27.6	-54.8	-14.7
Colnbrook	0.05	0.01	0.02	0.01	36.0	-21.7	-55.9	-34.4
Harmondsworth	0.05	0.01	0.03	0.01	13.3	-36.0	-60.6	-38.5
Hillingdon	0.05	0.01	0.03	0.01	5.9	-47.1	-61.2	-53.3
Sipson	0.15	0.02	0.06	0.02	-0.7	-53.3	-66.2	-45.1
Harlington	0.15	0.01	0.04	0.02	-4.0	-55.1	-68.4	-53.5
Oxford Ave	0.22	0.01	0.03	0.03	-14.2	-61.9	-74.7	-47.5
Hayes	0.06	0.00	0.01	0.01	-8.7	-58.0	-72.9	-49.6
Cranford	0.11	0.01	0.02	0.02	-18.0	-62.8	-75.5	-51.1
Hatton Cross	0.39	0.02	0.07	0.05	1.2	-54.9	-69.2	-25.5

[a] Excluding APU contribution
[b] Car parking, heating plant and fire training ground

(II) Off-airport sources and total

a) Old EFs

Receptor	2013 concentration contribution (µg m^{-3})				Fractional difference from 2008/9 (%)			
	Road traffic	NAEI/ LAEI	Rural	Total	Road traffic	NAEI/ LAEI	Rural	Total
LHR2	3.12	2.28	16.02	23.02	-0.8	51.6	-7.0	-3.6
Oaks Rd	0.96	2.32	16.02	19.75	-2.7	56.5	-7.0	-2.9
Green Gates	1.39	2.35	16.02	20.01	-9.5	53.3	-7.0	-2.7
Colnbrook	1.17	2.63	16.02	19.91	-7.0	54.6	-7.0	-1.8
Harmondsworth	1.16	2.37	16.02	19.66	-10.1	48.4	-7.0	-3.0
Hillingdon	3.80	2.39	16.02	22.30	-8.5	39.7	-7.0	-4.0
Sipson	1.25	2.32	16.02	19.86	-6.6	29.6	-7.0	-4.4
Harlington	1.58	2.36	16.02	20.19	6.4	39.0	-7.0	-2.7
Oxford Ave	1.97	2.32	16.02	20.62	-5.5	57.2	-7.0	-3.0
Hayes	1.86	2.60	16.02	20.56	-25.4	40.7	-7.0	-5.3
Cranford	1.18	2.40	16.02	19.76	-10.0	56.9	-7.0	-2.8
Hatton Cross	1.96	2.33	16.02	20.87	-4.8	59.6	-7.0	-2.9

b) New EFs

Receptor	2013 concentration contribution (µg m^{-3})				Fractional difference from 2008/9 (%)			
	Road traffic	NAEI/ LAEI	Rural	Total	Road traffic	NAEI/ LAEI	Rural	Total
LHR2	3.62	2.28	16.02	23.47	15.1	51.6	-7.0	-1.7
Oaks Rd	1.11	2.32	16.02	19.88	13.1	56.5	-7.0	-2.2
Green Gates	1.61	2.35	16.02	20.20	4.9	53.3	-7.0	-1.8
Colnbrook	1.37	2.63	16.02	20.10	8.5	54.6	-7.0	-0.9
Harmondsworth	1.35	2.37	16.02	19.84	5.0	48.4	-7.0	-2.1
Hillingdon	4.47	2.39	16.02	22.97	7.7	39.7	-7.0	-1.1
Sipson	1.45	2.32	16.02	20.04	8.3	29.6	-7.0	-3.5
Harlington	1.82	2.36	16.02	20.41	22.3	39.0	-7.0	-1.6
Oxford Ave	2.26	2.32	16.02	20.90	8.6	57.2	-7.0	-1.7
Hayes	2.11	2.60	16.02	20.82	-15.2	40.7	-7.0	-4.1
Cranford	1.36	2.40	16.02	19.93	3.7	56.9	-7.0	-2.0
Hatton Cross	2.27	2.33	16.02	21.15	10.2	59.6	-7.0	-1.5

Table A10: Contributions to 2013 $PM_{2.5}$ concentrations, and fractional difference from 2008/9

(I) On-airport sources

a) Old EFs

Receptor	2013 concentration contribution (µg m^{-3})				Fractional difference from 2008/9 (%)			
	Aircraft[a]	APUs	GSE	Misc airport[b]	Aircraft	APUs	GSE	Misc airport
LHR2	0.90	0.03	0.07	0.07	-10.5	-56.9	-73.7	43.0
Oaks Rd	0.16	0.04	0.10	0.05	-5.0	-40.3	-60.2	-4.2
Green Gates	0.08	0.02	0.04	0.04	11.8	-27.6	-61.8	78.9
Colnbrook	0.04	0.01	0.01	0.01	37.4	-21.7	-62.8	3.6
Harmondsworth	0.03	0.01	0.02	0.02	16.0	-36.0	-66.8	8.2
Hillingdon	0.03	0.01	0.02	0.01	4.7	-47.1	-67.3	-31.1
Sipson	0.10	0.02	0.05	0.03	-0.6	-53.3	-71.5	-20.6
Harlington	0.10	0.01	0.03	0.02	-3.3	-55.1	-73.3	-35.1
Oxford Ave	0.17	0.01	0.02	0.03	-10.2	-61.9	-78.7	-21.4
Hayes	0.05	0.00	0.01	0.01	-5.7	-58.0	-77.1	-36.0
Cranford	0.08	0.01	0.02	0.02	-15.4	-62.8	-79.3	-35.6
Hatton Cross	0.29	0.02	0.05	0.06	4.6	-54.9	-74.0	-1.8

b) New EFs

c)	2013 concentration contribution (µg m^{-3})				Fractional difference from 2008/9 (%)			
Receptor	Aircraft[a]	APUs	GSE	Misc airport[b]	Aircraft	APUs	GSE	Misc airport
LHR2	0.90	0.03	0.07	0.04	-10.5	-56.9	-74.6	-23.7
Oaks Rd	0.16	0.04	0.10	0.03	-5.0	-40.3	-61.5	-41.4
Green Gates	0.08	0.02	0.04	0.02	11.8	-27.6	-63.1	-17.9
Colnbrook	0.04	0.01	0.01	0.01	37.4	-21.7	-64.0	-39.3
Harmondsworth	0.03	0.01	0.02	0.01	16.0	-36.0	-67.9	-42.1
Hillingdon	0.03	0.01	0.02	0.01	4.7	-47.1	-68.4	-56.8
Sipson	0.10	0.02	0.05	0.02	-0.6	-53.3	-72.5	-47.4
Harlington	0.10	0.01	0.03	0.01	-3.3	-55.1	-74.2	-55.6
Oxford Ave	0.17	0.01	0.02	0.02	-10.2	-61.9	-79.4	-45.0
Hayes	0.05	0.00	0.01	0.01	-5.7	-58.0	-77.9	-51.1
Cranford	0.08	0.01	0.01	0.01	-15.4	-62.8	-80.1	-51.1
Hatton Cross	0.29	0.02	0.05	0.05	4.6	-54.9	-74.9	-27.5

[a] Excluding APU contribution
[b] Car parking, heating plant and fire training ground

(II) Off-airport sources and total

a) Old EFs

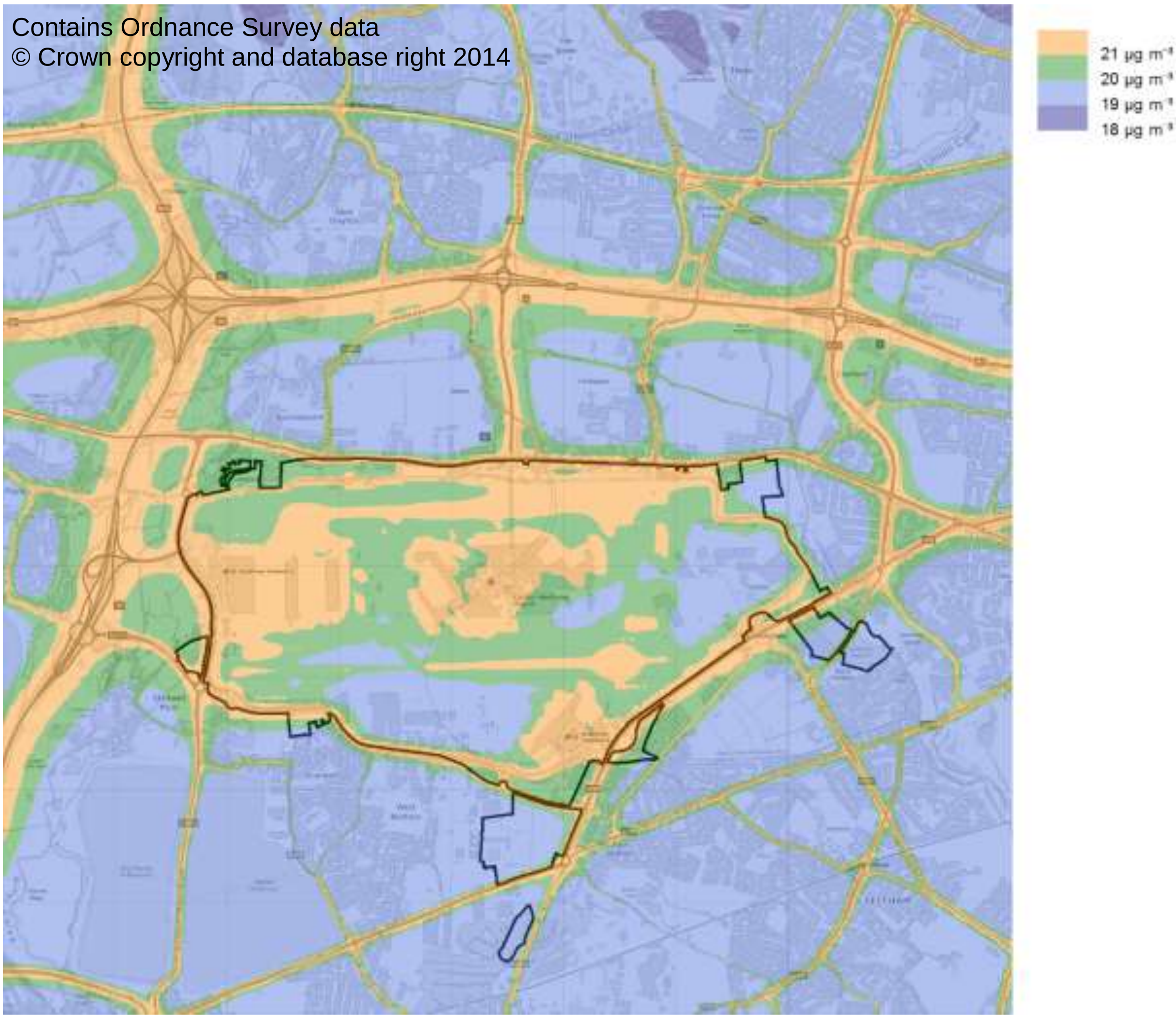
Receptor	2013 concentration contribution (µg m^{-3})				Fractional difference from 2008/9 (%)			
	Road traffic	NAEI/ LAEI	Rural	Total	Road traffic	NAEI/ LAEI	Rural	Total
LHR2	1.80	1.17	12.55	16.59	-10.3	11.7	30.3	17.9
Oaks Rd	0.56	1.25	12.55	14.70	-10.5	20.3	30.3	24.3
Green Gates	0.83	1.31	12.55	14.86	-16.9	21.9	30.3	24.6
Colnbrook	0.71	1.50	12.55	14.82	-14.5	27.2	30.3	26.5
Harmondsworth	0.70	1.30	12.55	14.64	-18.0	17.1	30.3	24.8
Hillingdon	2.31	1.26	12.55	16.19	-17.0	7.1	30.3	18.1
Sipson	0.74	1.22	12.55	14.70	-14.1	-1.4	30.3	21.8
Harlington	0.93	1.21	12.55	14.84	-2.3	3.3	30.3	23.5
Oxford Ave	1.13	1.16	12.55	15.08	-12.1	12.5	30.3	22.4
Hayes	1.13	1.31	12.55	15.06	-34.4	0.5	30.3	17.9
Cranford	0.69	1.18	12.55	14.54	-17.4	10.2	30.3	23.7
Hatton Cross	1.12	1.17	12.55	15.27	-12.2	14.6	30.3	21.9

b) New EFs

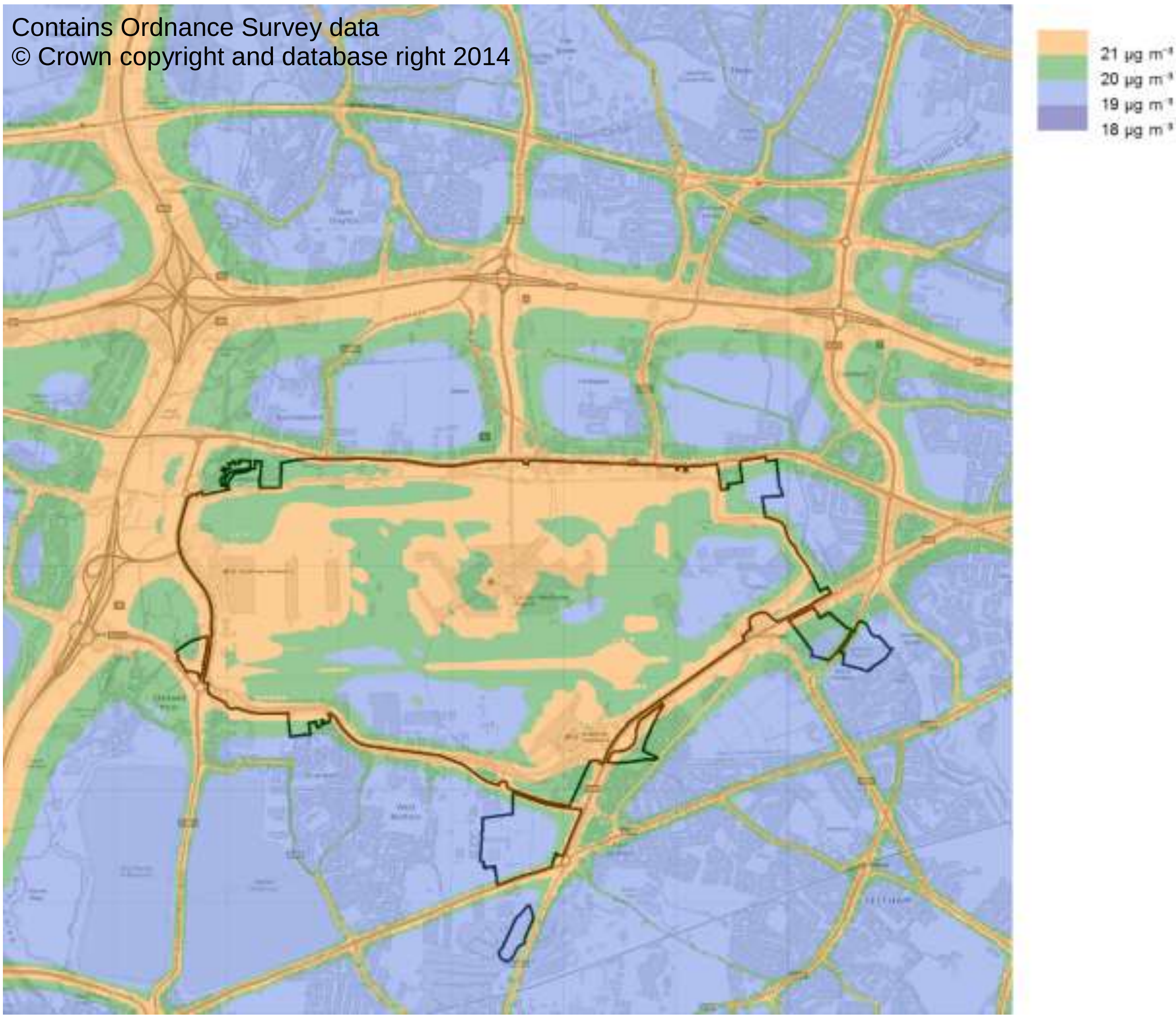
Receptor	2013 concentration contribution (µg m^{-3})				Fractional difference from 2008/9 (%)			
	Road traffic	NAEI/ LAEI	Rural	Total	Road traffic	NAEI/ LAEI	Rural	Total
LHR2	2.10	1.17	12.55	16.86	4.6	11.7	30.3	19.7
Oaks Rd	0.65	1.25	12.55	14.78	4.2	20.3	30.3	24.9
Green Gates	0.96	1.31	12.55	14.97	-3.9	21.9	30.3	25.5
Colnbrook	0.82	1.50	12.55	14.93	-0.6	27.2	30.3	27.5
Harmondsworth	0.82	1.30	12.55	14.74	-4.6	17.1	30.3	25.7
Hillingdon	2.71	1.26	12.55	16.59	-2.6	7.1	30.3	21.0
Sipson	0.86	1.22	12.55	14.81	-0.4	-1.4	30.3	22.7
Harlington	1.07	1.21	12.55	14.98	12.5	3.3	30.3	24.6
Oxford Ave	1.30	1.16	12.55	15.24	1.0	12.5	30.3	23.7
Hayes	1.28	1.31	12.55	15.20	-25.9	0.5	30.3	19.0
Cranford	0.80	1.18	12.55	14.64	-4.7	10.2	30.3	24.6
Hatton Cross	1.30	1.17	12.55	15.43	2.1	14.6	30.3	23.2

Figure A4: Total annual mean PM_{10} concentration in 2013

a) Old EFs



b) New EFs


Contains Ordnance Survey data
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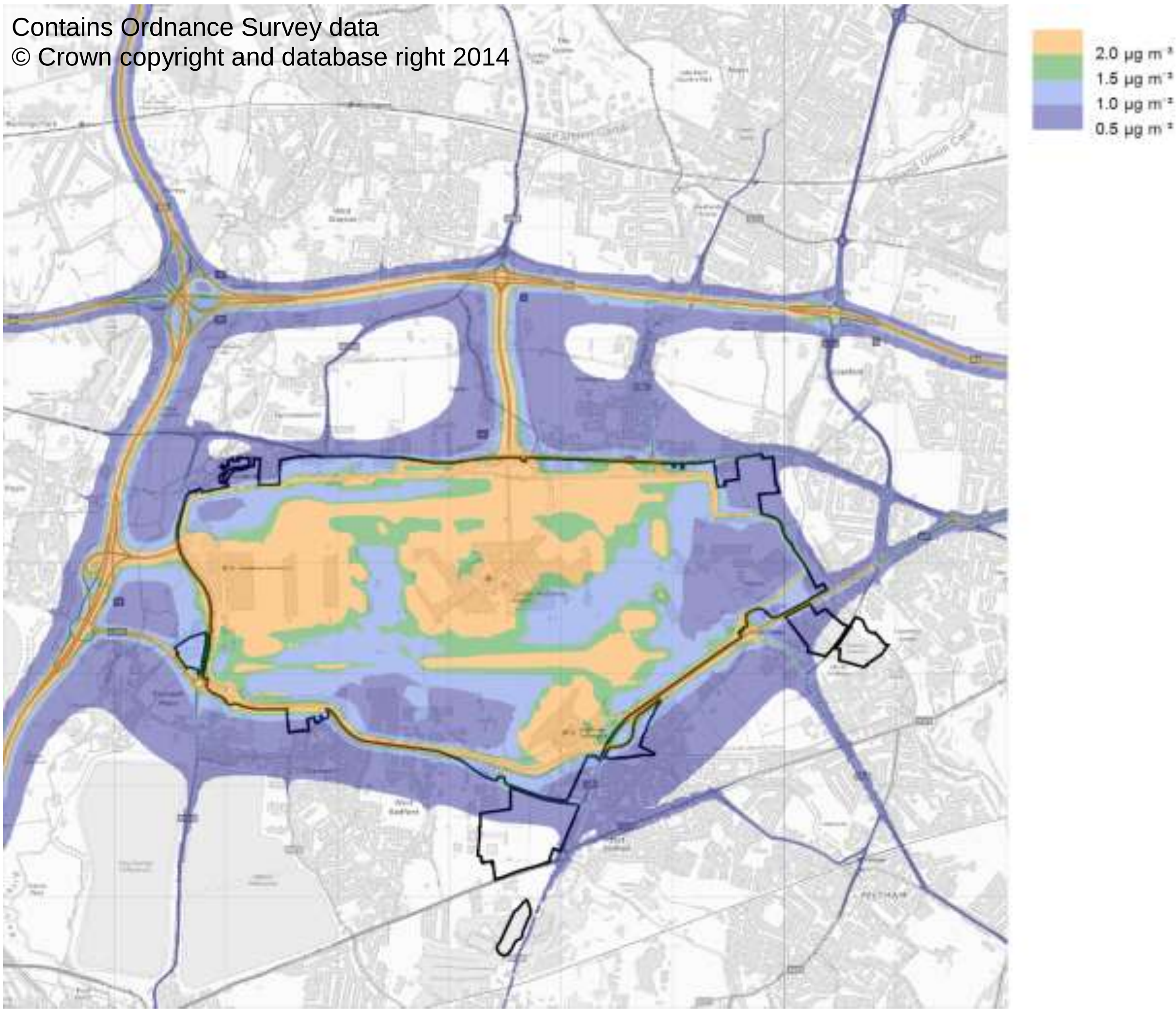
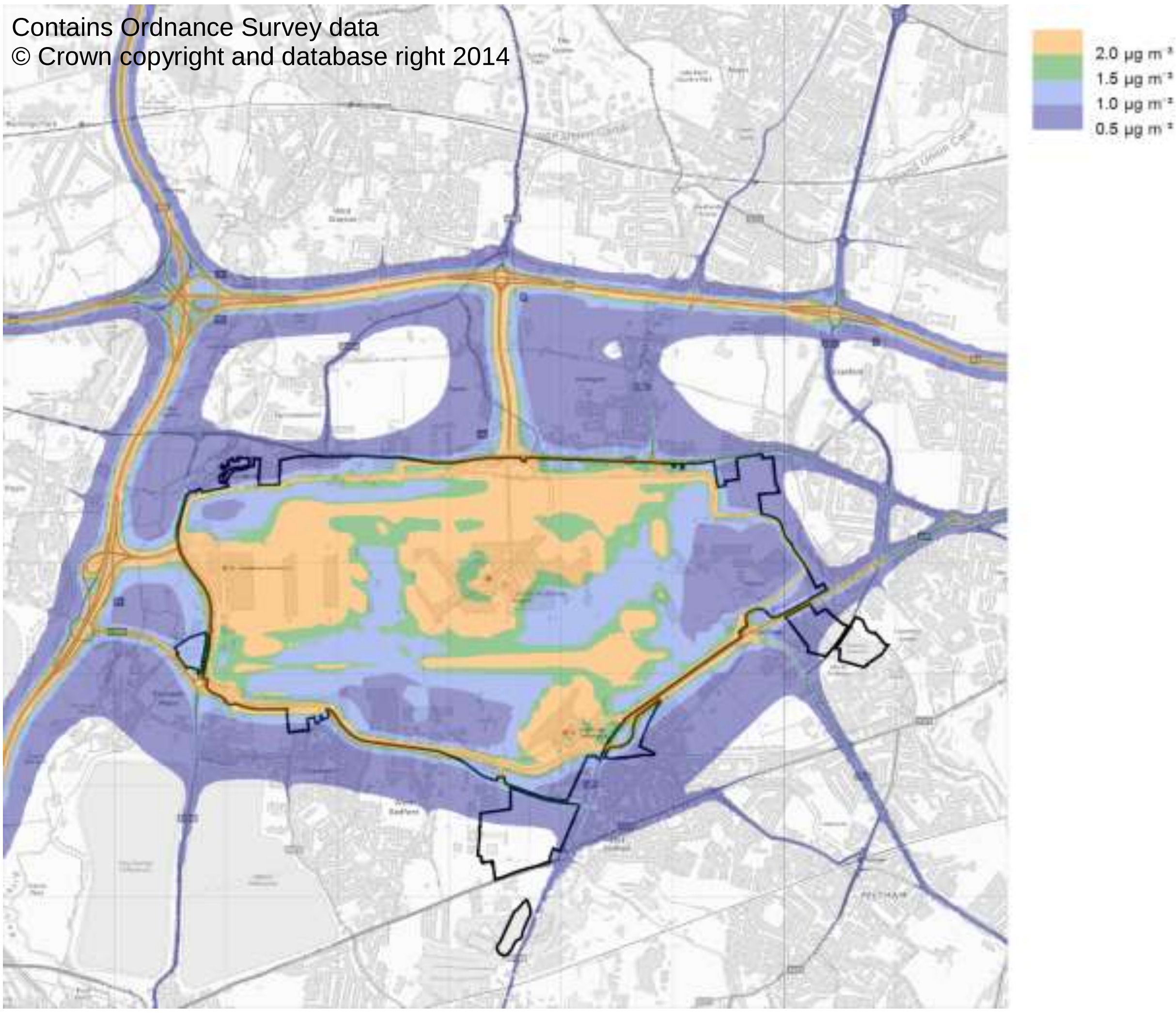
21 µg m⁻³
20 µg m⁻³
19 µg m⁻³
18 µg m⁻³

Figure A5: Airport-related contribution[a] to annual mean PM_{10} concentration in 2013

a) Old EFs



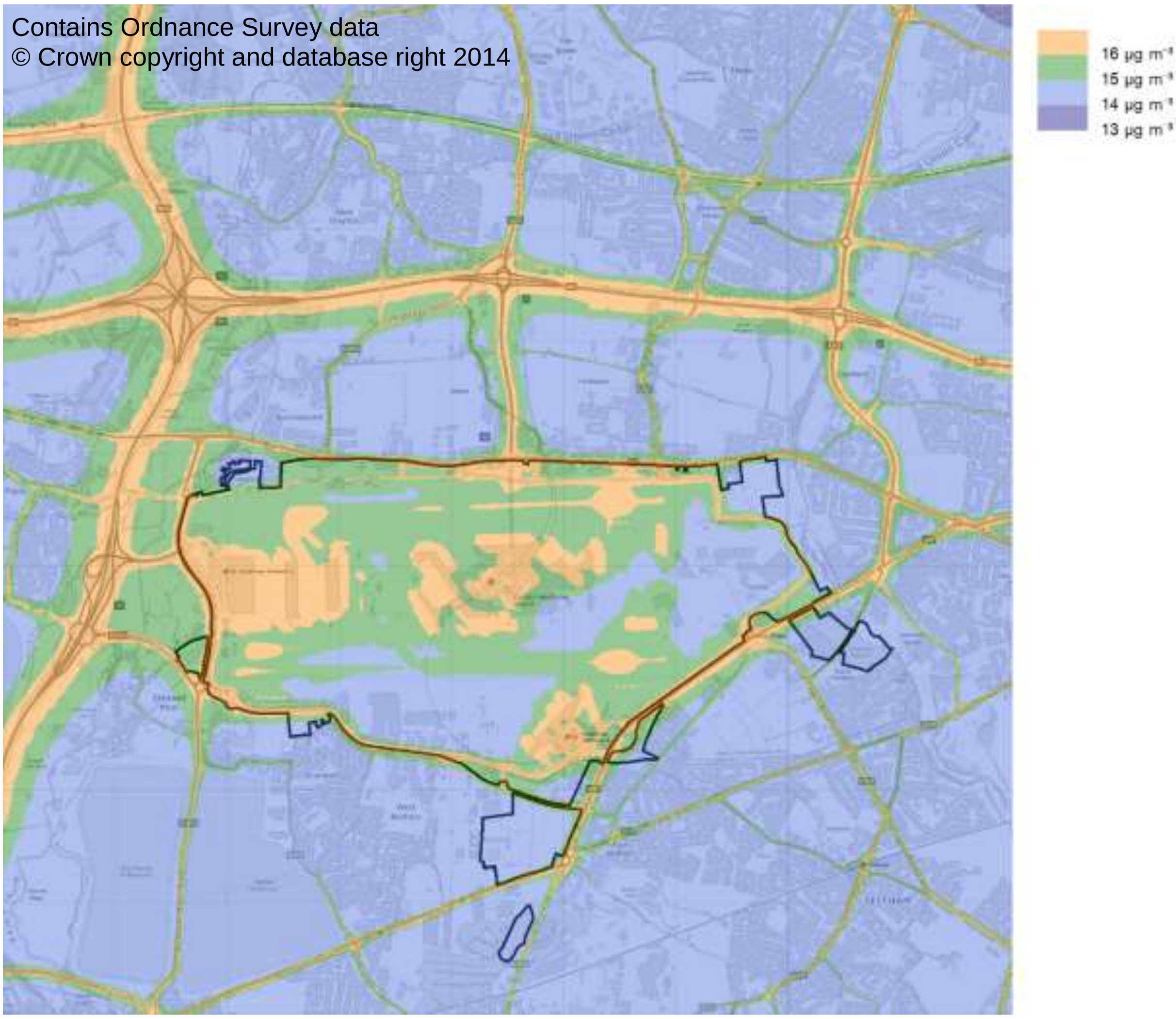
b) New EFs



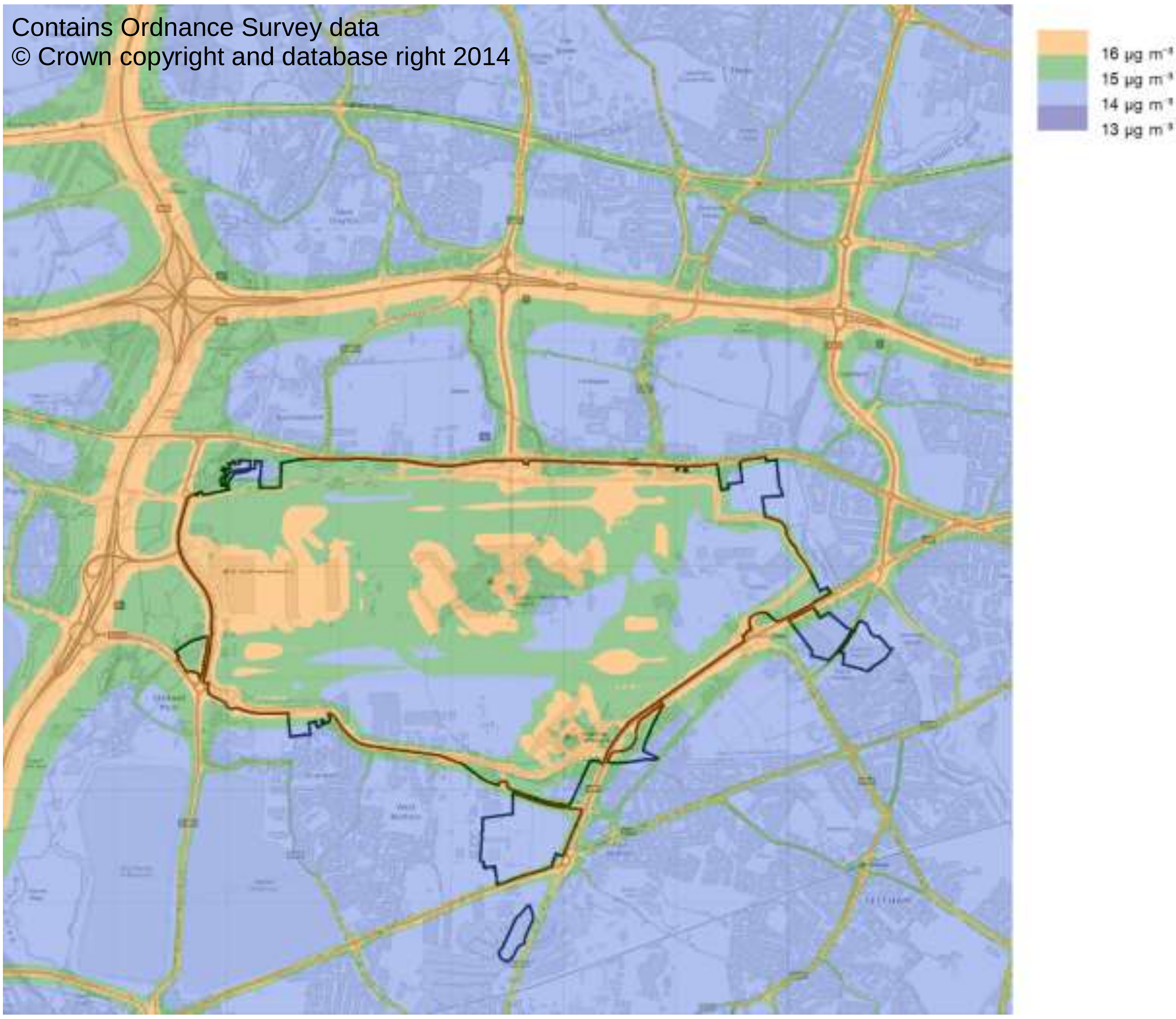
[a] Includes aircraft, APUs, GSE, airport-related traffic on the road network, car parking and stationary sources

Figure A6: Total annual mean $PM_{2.5}$ concentration in 2013

a) Old EFs



b) New EFs


Contains Ordnance Survey data
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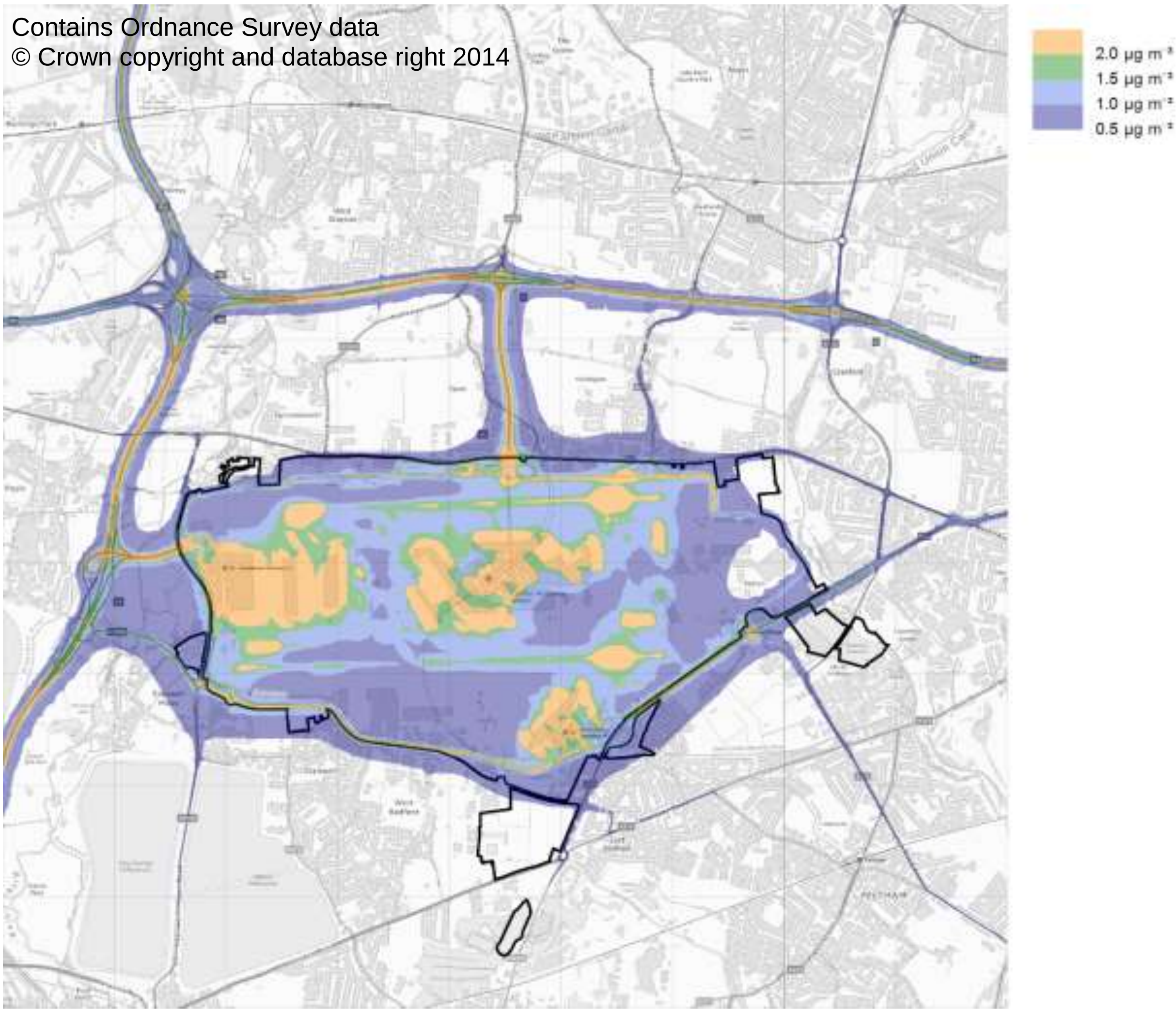
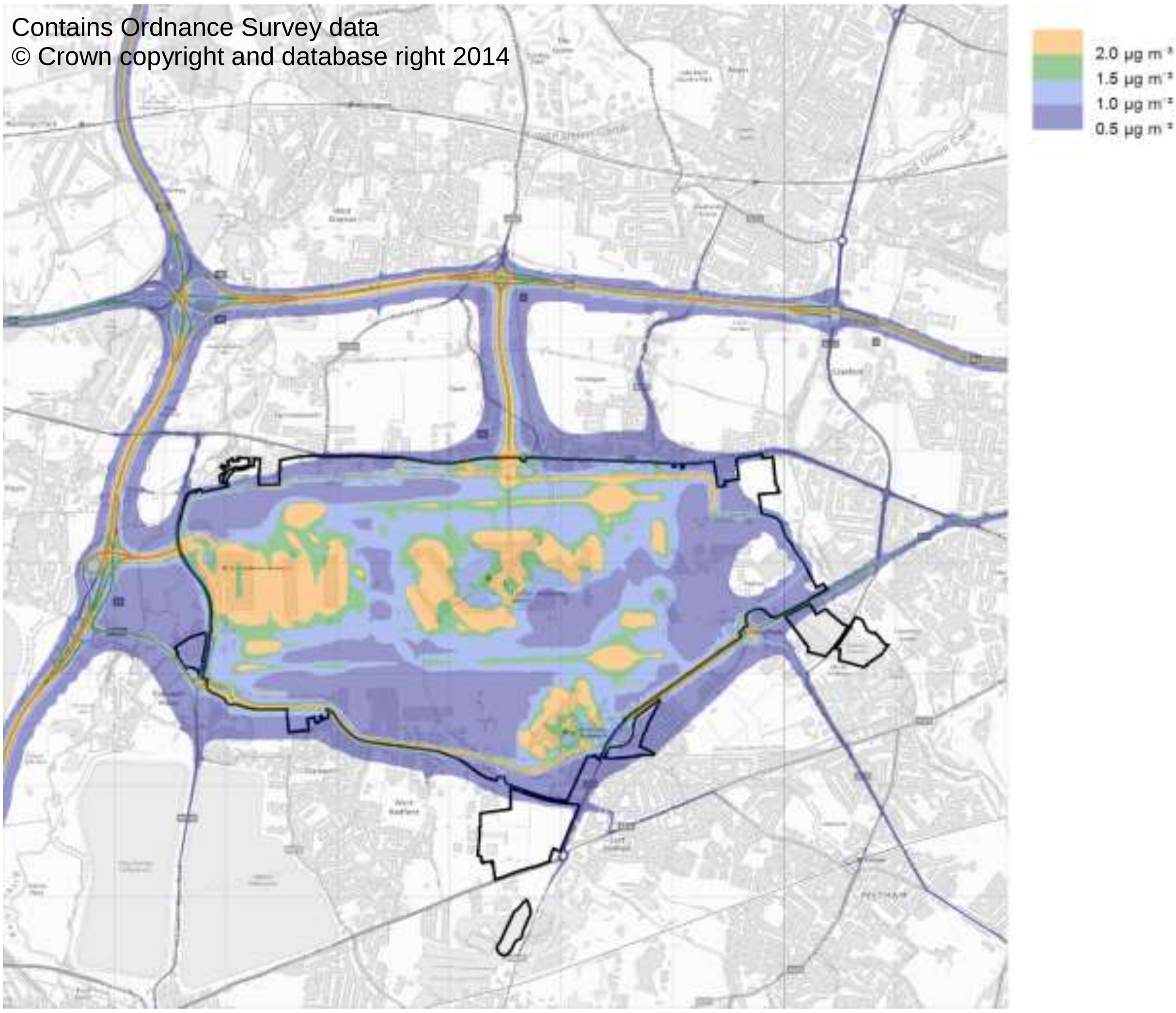
16 µg m⁻³
15 µg m⁻³
14 µg m⁻³
13 µg m⁻³

Figure A7: Airport-related contribution[a] to annual mean $PM_{2.5}$ concentration in 2013

a) Old EFs



b) New EFs



[a] Includes aircraft, APUs, GSE, airport-related traffic on the road network, car parking and stationary sources

A.6 CO_2 emissions

Table A11: Annual CO_2 emissions for 2013 and fractional change from 2008/9 values

a) Old EFs

Source category	Emissions (kilotonnes/year)[a]			Fractional Difference[b] %		
On-Airport						
Aircraft	1047.82			2.7		
Ground level		596.46			1.7	
Taxi-out			161.15			11.5
Hold			152.63			35.4
Take-off roll			92.26			-0.1
Landing roll			19.77			0.5
Taxi-in			105.45			15.7
APU			63.98			-48.5
Engine testing			1.21			-24.6
Elevated		451.36			4.0	
Initial climb			89.27			-3.6
Climb-out			177.13			5.6
Approach			184.96			6.4
Ground support equipment	30.64			-9.3		
Road vehicles		24.38			4.1	
Off-road vehicles		6.26			-39.6	
Car parks etc.	3.57			NA		
Public car parks[c]		2.61			NA	
Staff car parks		0.36			NA	
Taxis (TFP, forecourts)		0.59			NA	
Stationary sources	52.36			NA		
Heating plant		52.31			NA	
Fire Training Ground		0.05			NA	
Off-Airport						
Landside road network	655.29			NA		
Airport-related traffic		113.05			NA	
Non-airport traffic		542.24			NA	

b) New EFs

Source category	Emissions (kilotonnes/year)[a]	Fractional Difference[b] %
On-Airport		
Aircraft	1047.82	2.7
Ground level	596.46	1.7
Taxi-out	161.15	11.5
Hold	152.63	35.4
Take-off roll	92.26	-0.1
Landing roll	19.77	0.5
Taxi-in	105.45	15.7
APU	63.98	-48.5
Engine testing	1.21	-24.6
Elevated	451.36	4.0
Initial climb	89.27	-3.6
Climb-out	177.13	5.6
Approach	184.96	6.4
Ground support equipment	30.72	-9.1
Road vehicles	24.46	4.4
Off-road vehicles	6.26	-39.6
Car parks etc.	3.57	NA
Public car parks[c]	2.61	NA
Staff car parks	0.36	NA
Taxis (TFP, forecourts)	0.59	NA
Stationary sources	52.36	NA
Heating plant	52.31	NA
Fire Training Ground	0.05	NA
Off-Airport		
Landside road network	657.62	NA
Airport-related traffic	113.91	NA
Non-airport traffic	543.72	NA

[a] Values quoted to 0.01 kilotonne for convenience in taking ratios etc. and should not be taken as indicative of the precision of the estimates
[b] Fractional Difference = 100 * (2013 value – 2008/9 value) / 2008/9 value
[c] Includes car rental

Table A12: LTO aircraft CO_2 emissions[a] by aircraft type

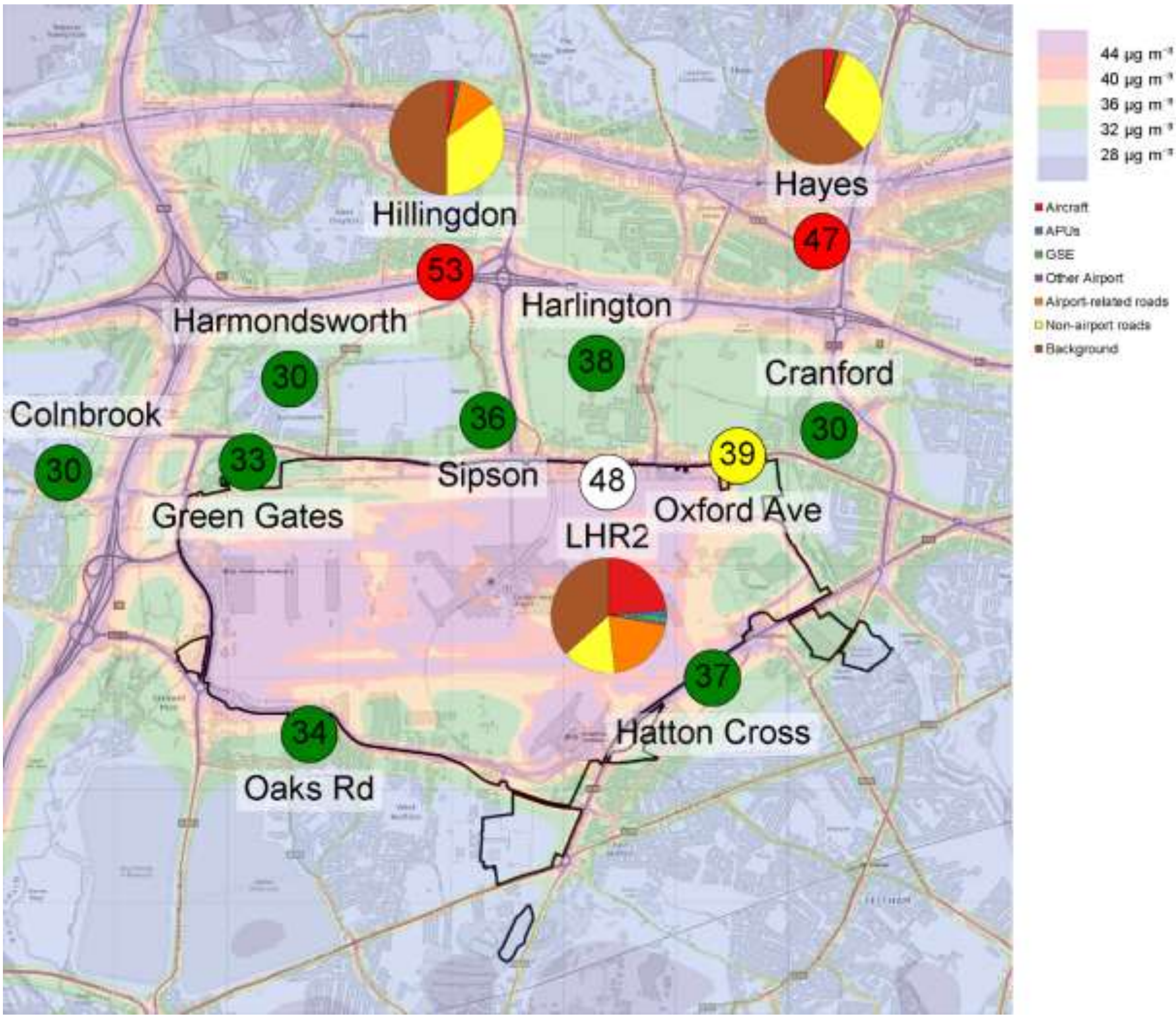
	2013			2008/9		
	CO_2 (kt/year)	%	CO_2/cycle[b] (t/cycle)	CO_2 (kt/year)	%	CO_2/cycle[b] (t/cycle)
Small/Light	2.09	0.2	1.37	7.05	0.7	0.78
Airbus A318	0.98	0.1	1.96	0.17	0.0	1.62
Airbus A319	107.29	8.0	2.23	83.00	6.5	1.99
Airbus A320	142.41	10.6	2.32	92.28	7.2	2.03
Airbus A321	68.07	5.1	2.79	63.39	4.9	2.34
Boeing 737	22.80	1.7	2.13	29.04	2.3	2.05
Boeing 757	10.54	0.8	3.34	28.96	2.3	3.07
Other Medium	2.71	0.2	1.91	12.64	1.0	2.17
Airbus A300/310	4.26	0.3	4.86	7.43	0.6	4.03
Airbus A330	56.26	4.2	6.21	37.23	2.9	5.55
Airbus A340	58.43	4.4	9.25	104.33	8.1	8.52
Boeing 747	179.38	13.4	11.08	222.79	17.4	9.93
Boeing 767	80.76	6.0	4.85	63.29	4.9	4.45
Boeing 777	229.67	17.1	7.59	181.15	14.1	6.75
Boeing 787	4.88	0.4	4.85	0.00	0.0	NA
Other Heavy	0.04	0.0	8.28	0.60	0.0	6.92
Airbus A380	54.32	4.1	12.16	8.88	0.7	11.73
Total Small/Light	2.09	0.2	1.37	7.05	0.7	0.78
Total Medium	354.80	26.5	2.37	309.46	24.1	2.15
Total Heavy	613.67	45.8	7.64	616.83	48.1	7.31
Total Super	54.32	4.1	12.16	8.88	0.7	11.73
Total	1024.88	76.6	4.34	942.22	73.7	3.96

[a] Omits APU and engine testing emissions
[b] 'Cycle' = arrival plus departure (2 movements)

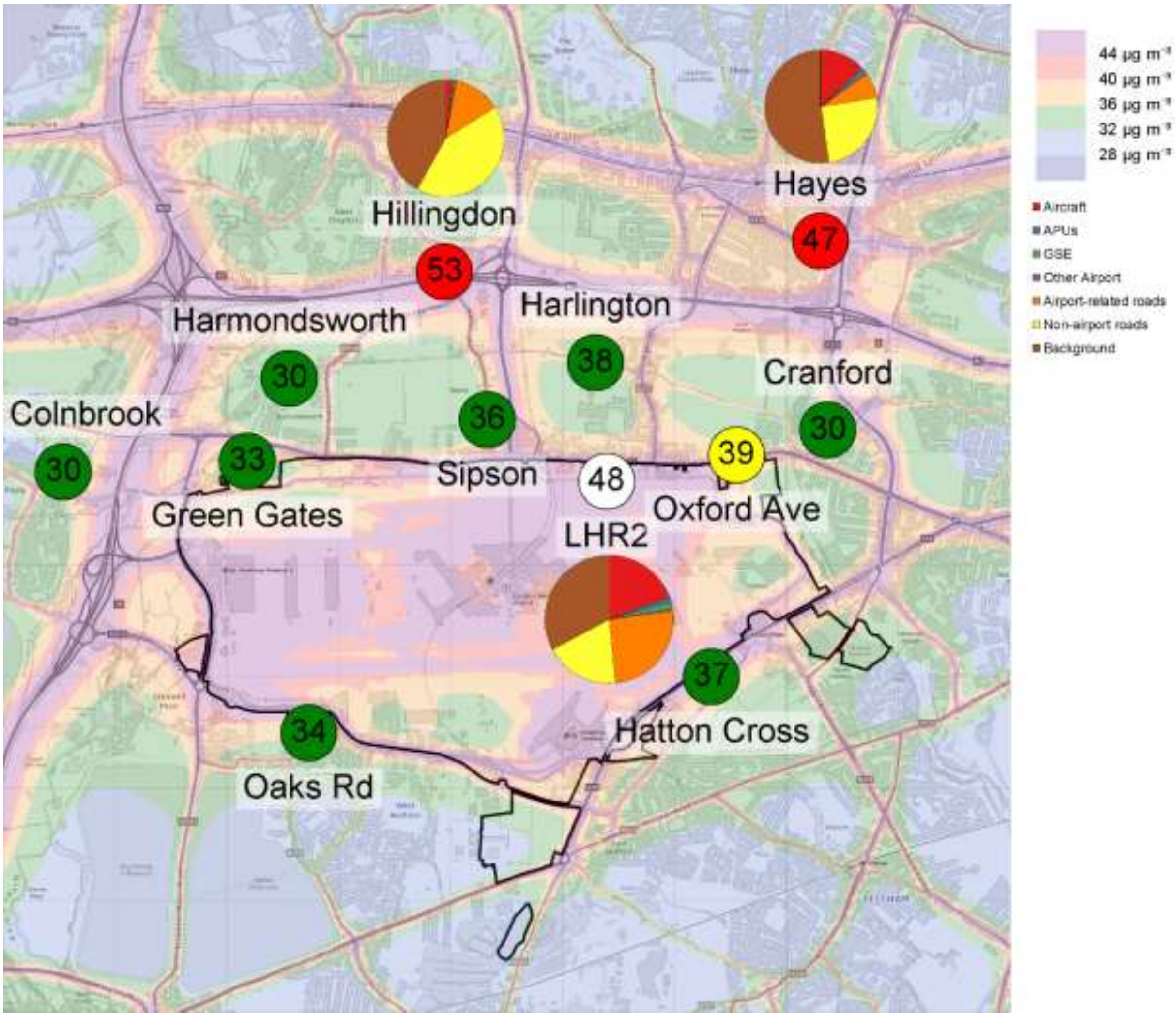
A.7 Monitoring results

Figure A8: Modelled and measured annual mean NO_2 concentrations in 2013, with source apportionment at key receptors

a) Old EFs Unadjusted



b) New EFs Adjusted



[a] Contours show modelled concentrations. Spot values at monitoring locations are measured NO_2 concentrations in µg m^{-3}. Source apportionments (pie charts) are derived from modelling at Hillingdon, Hayes and LHR2.

- ● Exceeds EU limit value (40 µg m^{-3} or more).
- ● Close to EU limit value (38 µg m^{-3} to 40 µg m^{-3}).
- ● Meets EU limit value (below 38 µg m^{-3}).
- ○ EU limit value does not apply.

Figure A9: Modelled and measured NO_x concentrations at key receptors

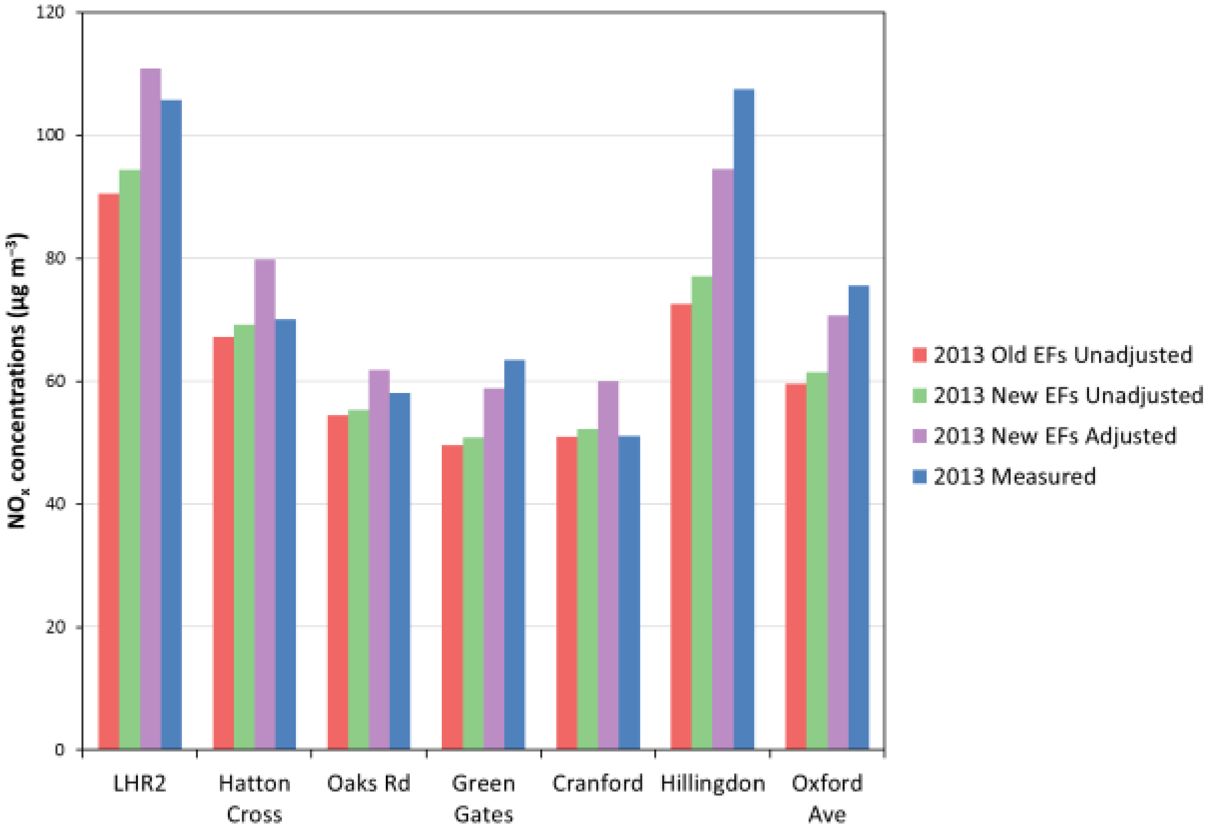
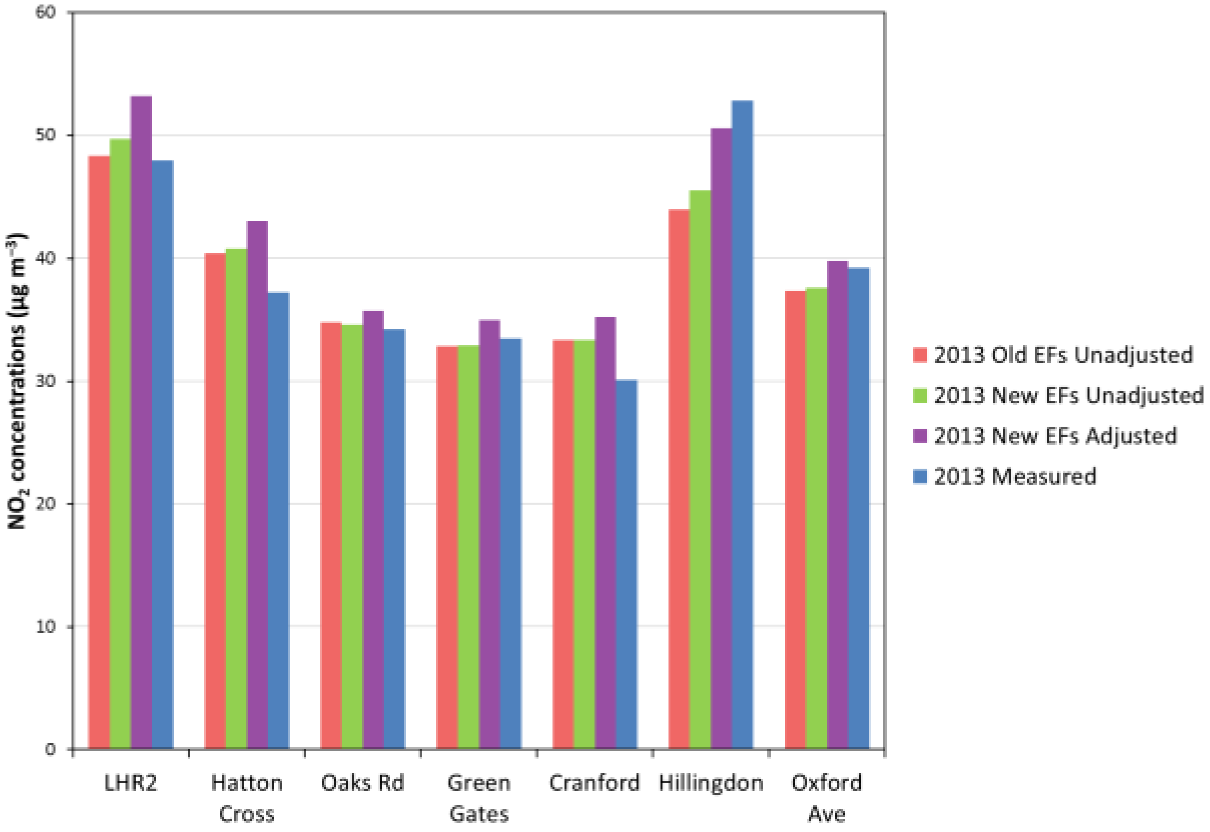


Figure A10: Modelled and measured NO_2 concentrations at key receptors



A.8 Example road speed related emission curves (NOx)

Other similar speed emission curves exist for other pollutants.

Figure A11: LDV speed emission curves using new road emission factors for 2013

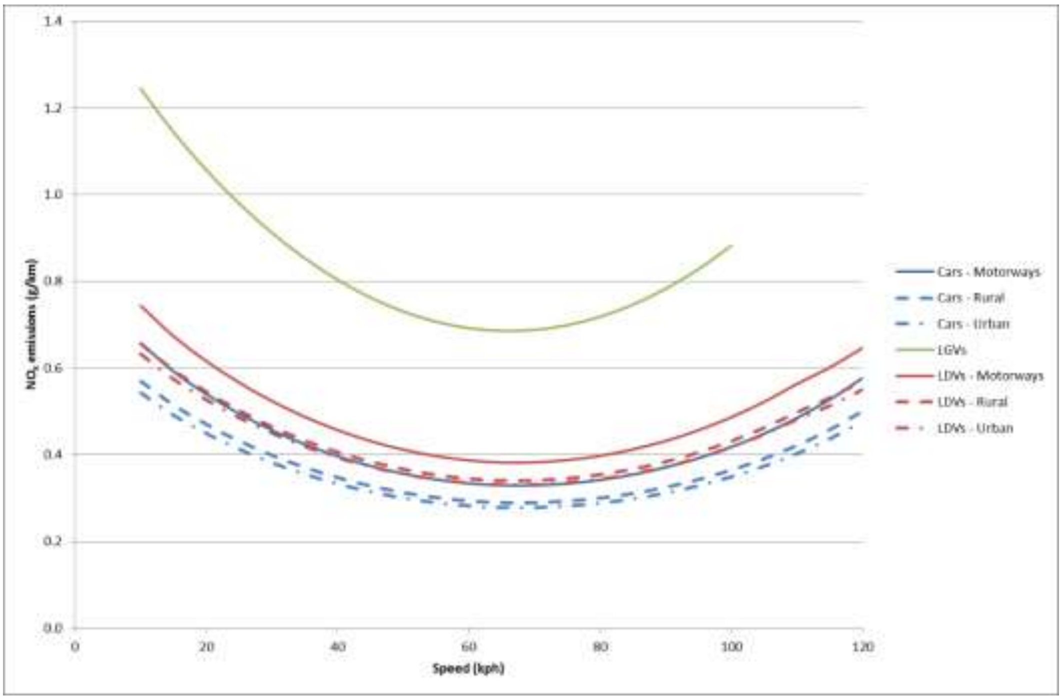
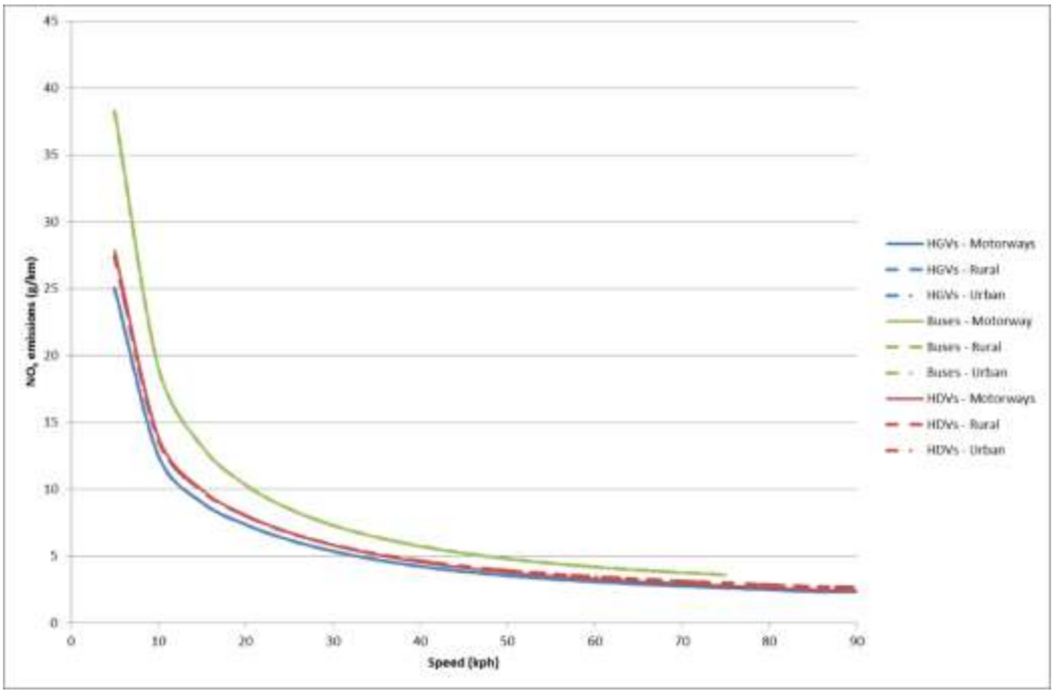


Figure A12: HDV speed emission curves using new road emission factors for 2013



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