Cambridge
Environmental
Research
Consultants

Air Pollution Health Impact Tool: Air quality modelling summary

Final report

Prepared for
Impact on Urban Health

18th July 2023

CERC

Report Information

CERC Job Number:	FM1362
Job Title:	Air Pollution Health Impact Tool: Air quality modelling summary
Prepared for:	Impact on Urban Health
Report Status:	Final
Report Reference:	FM1362/R3/23
Issue Date:	18th July 2023
Author(s):	Chetan Lad
Reviewer(s):	Sarah Strickland

Issue	Date	Comments
1	07/03/23	Draft report – incomplete
2	15/03/23	Full draft report
3	18/07/23	Final report (minor amendments)

Main File(s):	FM1362_CERC_IoUH_R3_18Jul23.pdf

Contents

1. Executive Summary

Cambridge Environmental Research Consultants Ltd (CERC) have developed a tool for assessing the air quality impact of measures, on behalf of Impact on Urban Health (IoUH), in conjunction with the London Boroughs of Lambeth and Southwark. The air quality modelling informing the tool calculations is summarised in this report.

We set up an air quality model for 2019 using the ADMS-Urban dispersion model, based on emissions and activity data from the London Atmospheric Emissions Inventory (LAEI) 2019 and verified against air quality monitoring across Lambeth and Southwark.

We calculated road traffic emissions using LAEI activity data using emission factors taken from the latest Department for Environment, Food and Rural Affairs (Defra) Emission Factor Toolkit (EFT v 10.1), modified to account for emission factor uncertainty in urban driving conditions.

We explicitly included the South East London CHP Energy Facility industrial source in the modelling. We took emission rates for all other sources from the LAEI 2019 and modelled them as aggregated grid sources for the whole of London.

The modelling used meteorological data from Heathrow Airport and background pollutant data obtained from rural monitoring sites. We took into account the variation in emissions during the day by applying a set of diurnal profiles to the road and grid sources.

We used the Advanced Street Canyon and Urban Canopy options in ADMS-Urban to take into account the impact of buildings on the dispersion of pollutants. We used the ADMS-Urban chemistry scheme in the dispersion calculations for the calculation of nitrogen dioxide (NO_2) concentrations.

We used the air quality model for 2019 to identify receptor locations for use in the air pollution tool. We based these receptors on the locations of educational establishments, health care and air quality monitoring sites, selecting them based on both modelled air pollution concentrations and the Ministry of Housing, Communities and Local Government's Index for Multiple Deprivation 2019 (IMD2019).

We based the tool inputs on air quality modelling for 2022. We modified traffic emissions for the 2019 model set-up to represent a 'post-pandemic' 2022 by applying the following changes:

- Traffic activity was modified using Office for National Statistics (ONS) experimental dataset for traffic camera data (1st December 2022 release); and
- The traffic fleet was modified using Transport for London (TfL) fleet projections from 2018 and taking into account the expansion of the Ultra Low Emission Zone (ULEZ) in October 2021.

All other inputs to the 2022 model set-up were the same as for the 2019 model set-up.

We carried out source apportionment modelling using the 2022 model set-up to identify the contribution of different source groups to total concentrations of nitrogen oxides (NO_x) and particulate matter (PM_{10} and $PM_{2.5}$) at the receptor locations. The source apportionment results informed the choice of measures for the tool and provided the source group contributions in the database for calculations within the tool.

In addition to source apportionment results, the tool database contains source- and receptor-specific secondary NO_2 factors for the calculation of total NO_2 concentrations with measures applied. These factors were derived from detailed modelling of 41 measures.

It is hoped that future iterations of the tool will link changes in air pollutant emissions or concentrations due to measures to health impacts. Anticipating these developments, we calculated pollutant emissions damage costs and local mortality burden based on modelled concentrations.

We summarised borough emissions and Defra's central damage costs for emissions of NO_x and $PM_{2.5}$. Based on damage cost values for road emissions in Inner London, the change in road transport emissions between the 2019 and 2022 models is estimated at between £15 million and £16 million. This cost saving represents the air pollution impacts of mortality, morbidity and non-health impacts.

Using a detailed impact pathways approach, we calculated local mortality burdens from modelled annual average NO_2 and $PM_{2.5}$ concentrations using the approach set out in Appendix A of the Public Health England guidance *Estimating local mortality burdens associated with particulate air pollution (April 2014)*. We used concentration response function (CRF) pairs for NO_2 and $PM_{2.5}$ from the 2018 COMEAP report *Associations of long-term average concentrations of nitrogen dioxide with mortality.*

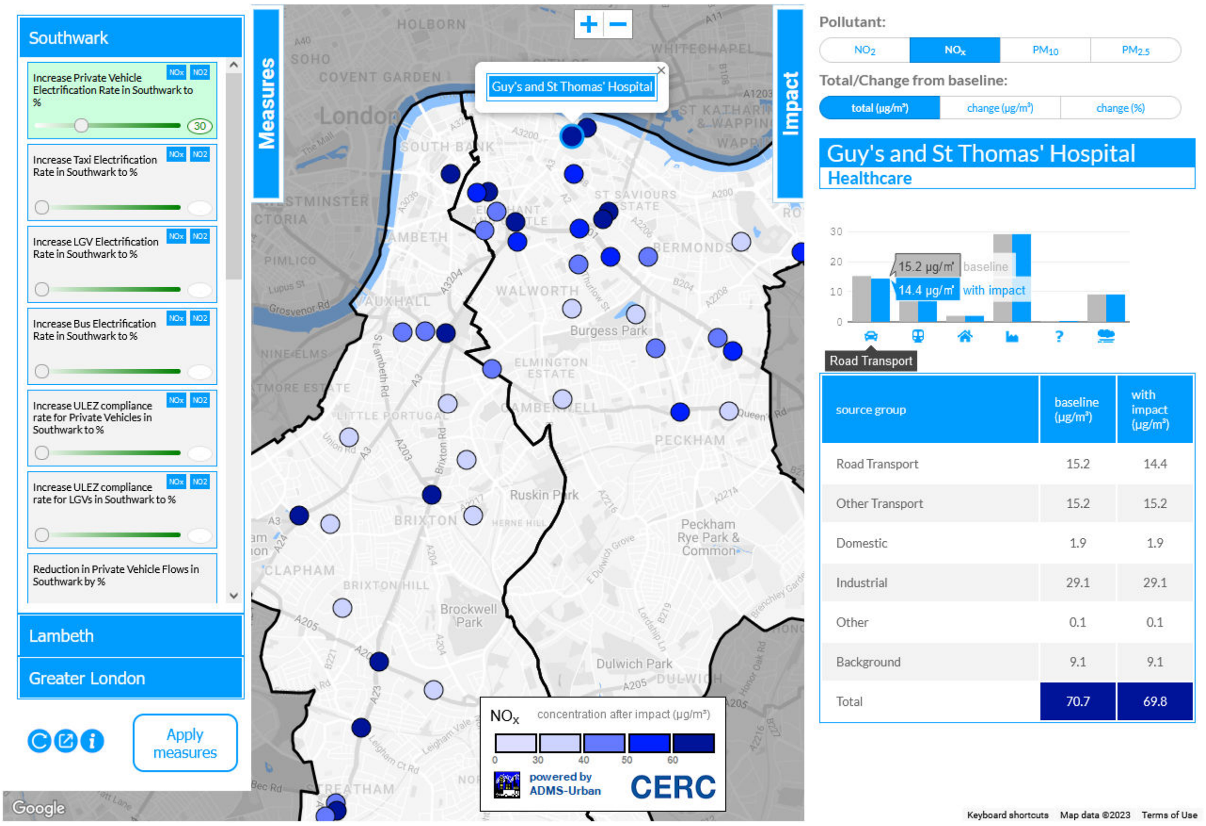
The estimated reduction local mortality burden between the 2019 and 2022 modelled concentrations is between 7 and 11 deaths per borough, 119 and 200 life-years lost, and £6.0 million and £10.1 million economic cost. This calculated cost saving only considers the air pollution impact on mortality.

2. Introduction

Impact on Urban Health (IoUH) and Lambeth and Southwark Councils have a shared ambition to reduce the harmful impact air pollution has on people's health, particularly those most at risk.

To aid the realisation of this ambition, IoUH commissioned Cambridge Environmental Research Consultants Ltd (CERC) to develop a tool for the assessment the impact of air pollution mitigation measures, for use by IoUH and council officers.

For a selection of receptors representing sensitive locations in areas of deprivation, the tool enables the impact of local (borough-wide) and regional (London-wide) air quality measures to be assessed, including the contribution of different source groups to total concentrations. The web interface for the tool is shown in Figure 2.1.



Southwark

Increase Private Vehicle Electrification Rate in Southwark to % — 30

Increase Taxi Electrification Rate in Southwark to %

Increase LGV Electrification Rate in Southwark to %

Increase Bus Electrification Rate in Southwark to %

Increase ULEZ compliance rate for Private Vehicles in Southwark to %

Increase ULEZ compliance rate for LGVs in Southwark to %

Reduction in Private Vehicle Flows in Southwark by %

Lambeth

Greater London

Pollutant: NO₂ | **NOₓ** | PM₁₀ | PM₂.₅

Total/Change from baseline: **total (µg/m³)** | change (µg/m³) | change (%)

Guy's and St Thomas' Hospital

Healthcare

15.2 µg/m³ baseline

14.4 µg/m³ with impact

source group	baseline (µg/m³)	with impact (µg/m³)
Road Transport	15.2	14.4
Other Transport	15.2	15.2
Domestic	1.9	1.9
Industrial	29.1	29.1
Other	0.1	0.1
Background	9.1	9.1
Total	70.7	69.8

Figure 2.1: Web interface of the tool

The main purpose of this report is to summarise the air quality modelling that forms the basis of the tool's calculation database.

For context, Section 3 presents relevant air quality standards and Section 4 summarises current local air quality across the two boroughs. The model set-up and emissions data are summarised in Sections 5 and 6.

Section 7 presents modelled concentrations for 2019 and the selection of receptor locations of the tool. Section 8 presents source apportionment results for 2022 and the derivation other inputs for the tool, including measures and calculation of secondary NO_2 factors. Finally, calculations relating to health impacts of air pollution are provided in Section 9.

A summary of the ADMS-Urban model is included as Appendix A.

3. Air quality standards

The Air Quality Standards Regulations 2010 sets out limit values and target values for concentrations of certain pollutants in air. *The Environment (Miscellaneous Amendments) (EU Exit) Regulations 2020* updated the 2010 regulations to set a new limit value for $PM_{2.5}$ of 20 µg/m^3. Local authorities are required to work towards air quality objectives. In doing so, they assist the Government in meeting the limit values. These limit values are presented in Table 3.1

Table 3.1 Air quality objectives (µg/m^3)

	Value	Description of standard
NO_2	200	Hourly mean not to be exceeded more than 18 times a calendar year (modelled as 99.79th percentile)
	40	Annual average
PM_{10}	50	24-hour mean not to be exceeded more than 35 times a calendar year (modelled as 90.41st percentile)
	40	Annual average
$PM_{2.5}$	20	Annual average

Furthermore, *Environmental Targets (Fine Particulate Matter) (England) Regulations 2023* sets $PM_{2.5}$ targets of 10 µg/m^3 for annual average concentrations and a 35% reduction in population exposure compared to a 2016 to 2018 baseline, by the end of 2040

The short-term objectives, i.e. those measured hourly or over 24 hours, are specified in terms of the number of times during a year that a concentration measured over a short period of time is permitted to exceed a specified value. For example, the concentration of NO_2 measured as the average value recorded over a one-hour period is permitted to exceed the concentration of 200 µg/m^3 up to 18 times per year. Any more exceedences than this during a one-year period would represent a breach of the objective.

It is convenient to model objectives of this form in terms of the equivalent percentile concentration value. A percentile is the concentration below which lie a specified percentage of concentration measurements. For example, consider the 98th percentile of one-hour concentrations over a year. Taking all of the 8760 one-hour concentration values that occur in a year, the 98th percentile value is the concentration below which 98% of those concentrations lie. Or, in other words, it is the concentration exceeded by 2% (100 – 98) of those hours, that is, 175 hours per year. Taking the NO_2 objective considered above, allowing 18 exceedences per year is equivalent to not exceeding for 8742 hours or for 99.79% of the year. This is therefore equivalent to the 99.79th percentile value. It is important to note that modelling exceedences of short term averages is generally not as accurate as modelling annual averages.

Table 3.2 gives examples from the London Local Air Quality Management technical guidance (LLAQM.TG(19))[1] of where the air quality objectives should apply. Note that this table differs from the equivalent table in Defra's national (outside London) guidance, LAQM. TG(22), includes clarifications that the annual average objective applies to school playgrounds and the grounds of hospitals and care homes.

Table 3.2: Examples of where the air quality objectives should apply, as provided in the technical guidance LLAQM.TG(19)

Averaging period	**Objectives should apply at:**	**Objectives should generally not apply at:**
Annual average	All locations where members of the public might be regularly exposed. Building facades of residential properties, schools (including all of playgrounds), hospitals (and their grounds), care homes (and their grounds) etc.	Building facades of offices or other places of work where members of the public do not have regular access. Hotels, unless people live there as their permanent residence. Gardens of residential properties Kerbside sites (as opposed to locations at the building facade), or any other location where public exposure is expected to be short term.
24-hour mean	All locations where the annual mean objective would apply, together with hotels. Gardens of residential properties (where relevant for public exposure e.g. seating or play areas)	Kerbside sites (as opposed to locations at the building facade), or any other location where public exposure is expected to be short term.
Hourly average	All locations where the annual mean and 24-hour mean objectives apply and: Kerbside sites (for example pavements of busy shopping streets). Those parts of car parks, bus stations and railway stations etc. Which are not fully enclosed, where members of the public might reasonably be expected to spend one hour or longer. Any outdoor locations where members of the public might reasonably expected to spend one hour or longer.	Kerbside sites where the public would not be expected to have regular access.

---

[1] https://www.london.gov.uk/sites/default/files/llaqm_technical_guidance_2019.pdf

4. Local air quality and sensitivity

4.1. Local Air Quality Management

Part IV of the Environment Act 1995[2] prescribes the Local Air Quality Review and Assessment process for local authorities. The Review and Assessment process requires local authorities to review local air quality and assess whether or not air quality objectives will be achieved. If it is predicted that these will not be achieved, an Air Quality Management Area must be designated and an Air Quality Action Plan put in place to improve air quality to acceptable levels.

The whole borough of Lambeth was declared an Air Quality Management Area (AQMA) in 2007, due to concentrations of NO_2 and PM_{10} exceeding the air quality objectives.

Southwark Council declared the northern part of the borough as an Air Quality Management Area (AQMA) in 2003, due to concentrations of NO_2 and PM_{10} exceeding the air quality objectives. The AQMA encompasses the entire northern part of the borough, extending from Rotherhithe to Walworth and Camberwell and up to the boundary on the River Thames. The Southwark AQMA was changed to a whole borough AQMA in 2023.

4.2. Air quality monitoring

This section presents a summary of the monitoring sites operational in Lambeth and Southwark in the year 2019. These data were used for the verification of the air quality model set-up. Monitoring data were taken from the councils' Air Quality Annual Status Reports or provided directly from the councils.

In 2019, Lambeth measured air pollutant concentrations across the borough using three continuous monitoring sites, providing hour by hour measurements of NO_2 and PM_{10}, and 51 diffusion tubes, providing monthly measurements of NO_2. Southwark measured air pollutant concentrations at three automatic monitoring sites, providing hour by hour measurements of NO_2 and PM_{10}, and at 82 diffusion tube locations, providing monthly measurements of NO_2.

The monitoring locations by type are shown in Figure 4.1 with the colour scale showing whether the air quality standard for annual average NO_2 concentrations was met in 2019. Since 2019, both boroughs have expanded their air quality monitoring networks, including an additional continuous monitor installed in Southwark at South Circular Road.

---

[2] http://www.legislation.gov.uk/ukpga/1995/25/pdfs/ukpga_19950025_en.pdf

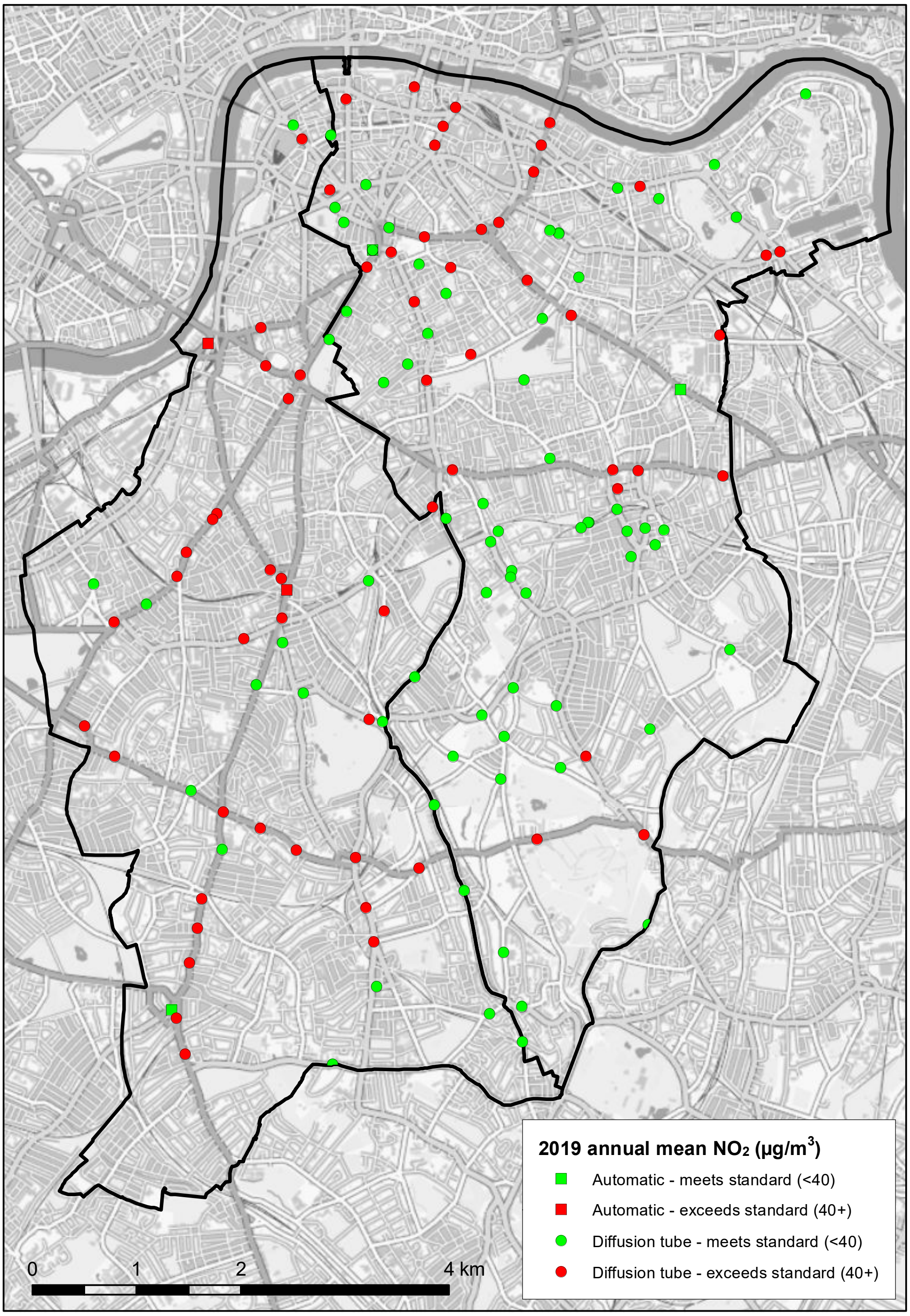


Figure 4.1: Air quality monitoring locations by type and compliance with annual mean NO_2 air quality standard of 40 µg/m^3

4.3. Air quality sensitivity

Housing, Communities and Local Government's Index for Multiple Deprivation 2019 (IMD2019) were used to identify areas across Lambeth and Southwark that likely to be most sensitivity poor air quality. Figure 4.2 shows Lowest Super Output Areas (LSOAs) across Lambeth and Southwark by IMD2019 deciles. In the 2019 dataset, there are 32,844 LSOAs in England, therefore each decile represents approximately 3,284 areas.

In Southwark, there are five LSOAs in the first decile, representing the most deprived areas in England, and one area in the tenth decile, representing the least deprived areas. In Lambeth, the LSOAs range from the second to ninth deciles. Across both boroughs, the mode is the third decile (91 out of 344 LSOAs).

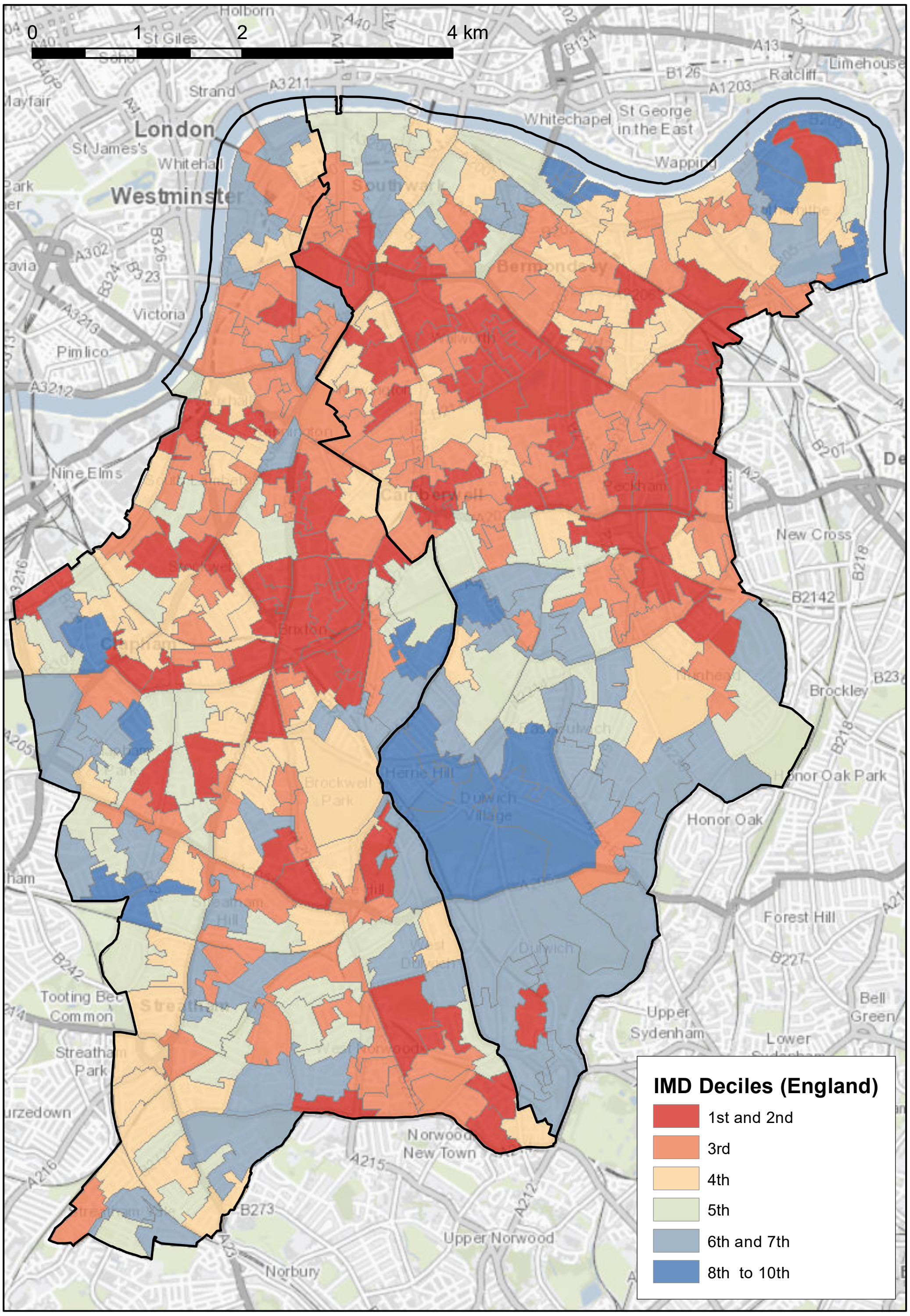


Figure 4.2: Lambeth and Southwark LSOAs, coloured by IMD2019 decile

5. Model set-up

We carried out modelling using the ADMS-Urban [3] model (version 5.0). The model uses the detailed emissions data described in Section 6, together with a range of other input data, to calculate the dispersion of pollutants. This section summarises the data and assumptions used in the modelling.

5.1. Surface roughness

A length scale parameter called the surface roughness length is used in the model to characterise the study area in terms of the effects it will have on wind speed and turbulence, which are key factors in the modelling. We used a value of 1 m to represent the modelled area, representing the built-up nature of the area.

5.2. Monin-Obukhov length

In urban and suburban areas, a significant amount of heat is emitted by buildings and traffic, which warms the air within and above a city. This is known as the urban heat island and its effect is to prevent the atmosphere from becoming very stable. In general, the larger the urban area the more heat is generated and the stronger the effect becomes.

In the ADMS-Urban model, the stability of the atmosphere is represented by the Monin-Obukhov parameter, which has the dimension of length. In very stable conditions it has a positive value of between 2 metres and 20 metres. In near neutral conditions its magnitude is very large, and it has either a positive or negative value depending on whether the surface is being heated or cooled by the air above it. In very convective conditions it is negative with a magnitude of typically less than 20 metres.

The effect of the urban heat island is that, in stable conditions, the Monin-Obukhov length will never fall below some minimum value; the larger the city, the larger the minimum value. We used a value of 75 metres in the modelling.

5.3. Urban canopy flow

The ADMS-Urban spatially-varying urban canopy flow option calculates changes in the vertical profiles of velocity and turbulence caused by the presence of buildings in an urban area, allowing the flow field within urban areas to be characterised on a neighbourhood-by-neighbourhood basis. The velocity and turbulence profiles are displaced by the building height, and flow within the building canopy is slowed by the buildings. Note that modelling spatially-varying urban canopy flow does not influence the urban heat island calculations described in Section 5.2.

---

[3] http://www.cerc.co.uk/environmental-software/ADMS-Urban-model.html

5.4. Street canyons

The presence of buildings either side of a road can introduce street canyon effects that result in pollutants becoming trapped, leading to increased pollutant concentrations. We took into account street canyon effects using the ADMS Advanced Canyon option, which makes use of detailed information for roadside buildings.

5.5. Meteorological data

We used a year of hourly sequential meteorological data measured at Heathrow in 2019 in the modelling. Table 5.1 shows the proportion of useable data and Table 5.2 summarises the data used in the modelling. To take account of the different surface characteristics at Heathrow, we used a surface roughness of 0.2 m for the meteorological site.

Table 5.1: Hours of meteorological data used in the modelling

Total number of hours used	8760
Number of hours with missing data	94
Percentage of hours used	98.9%

Table 5.2: Summary of meteorological data

	Minimum	**Maximum**	**Mean**
Temperature (°C)	-4.4	37.2	11.9
Wind speed (m/s)	0	16.5	4.0
Cloud cover (oktas)	0	8	5

The ADMS meteorological pre-processor, written by the Met Office, uses the data provided to calculate the parameters required by the program. Figure 5.1 presents a wind rose for the site, showing the frequency of occurrence of wind from different directions for a number of wind speed ranges.

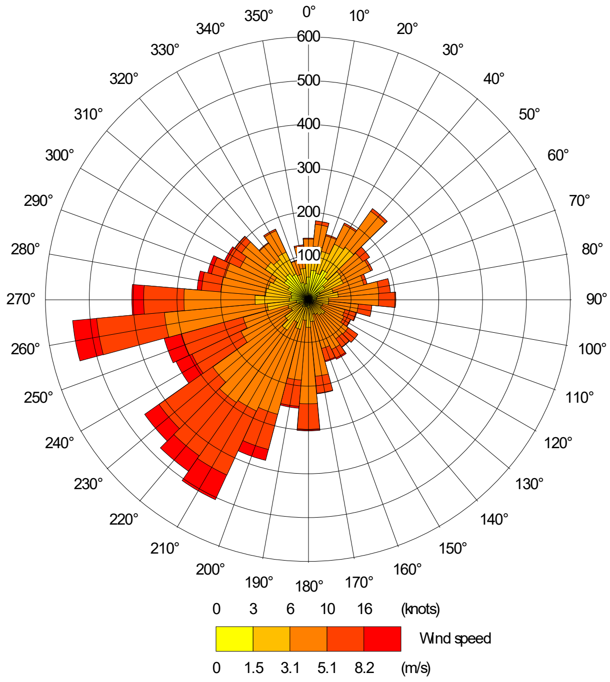


Figure 5.1: Wind rose for Heathrow 2019

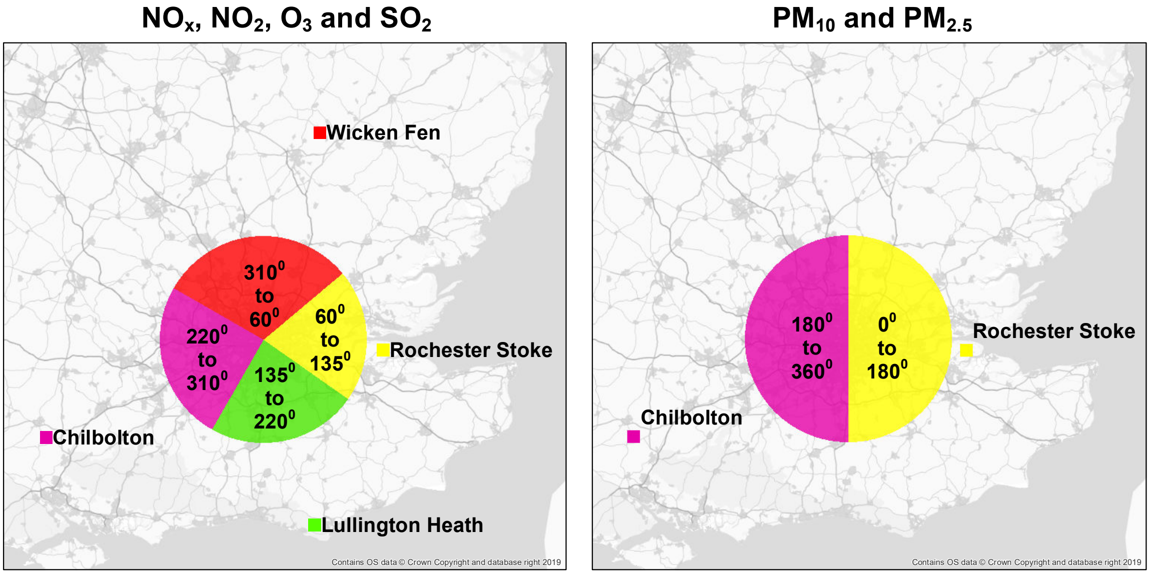
5.6. Background data

The air entering from outside of London contains a concentration of each pollutant being modelled. These background concentrations were estimated using measured data from the monitoring sites at Wicken Fen, Chilbolton Observatory, Lullington Heath and Rochester Stoke.

Nitrogen dioxide (NO_2) results from direct emissions from combustion sources together with chemical reactions in the atmosphere involving NO_2, nitric oxide (NO) and ozone (O_3). The combination of NO and NO_2 is referred to as nitrogen oxides (NO_x).

We took into account the chemical reactions taking place in the atmosphere using the Generic Reaction Set (GRS) of equations. These use hourly average background concentrations of NO_x, NO_2 and O_3, together with meteorological and modelled emissions data to calculate the NO_2 concentration at a given point.

We input hourly background data to the model to represent the concentrations in the air being blown into the city. We obtained NO_x, NO_2, O_3 and SO_2 concentrations from Rochester, Chilbolton Observatory, Lullington Heath and Wicken Fen. We obtained PM_{10}, $PM_{2.5}$ concentrations from Rochester and Chilbolton Observatory. The monitored concentration used for each hour is based upon the wind direction for that hour, as shown in Figure 5.2.



NO_x, NO_2, O_3 and SO_2

PM_{10} and $PM_{2.5}$

Figure 5.2: Wind direction segments used to calculate background concentrations

Table 5.3 summarises the annual statistics of the resulting background concentrations used in the modelling.

Table 5.3: Summary of 2019 background data used in the modelling (µg/m^3)

Statistic	**NO_x**	**NO_2**	**O_3**	**PM_{10}**	**$PM_{2.5}$**	**SO_2**
Annual average	9.1	7.3	55.1	13.4	9.5	0.9
Maximum	175	107	205	272	191	12

6. Emissions data

We compiled emissions inventories for oxides of nitrogen (NO_x), nitrogen dioxide (NO_2) and particulates (PM_{10} and $PM_{2.5}$) in CERC's emissions inventory toolkit, EMIT.

6.1. Traffic data

For major roads across London, we used LAEI 2019 road traffic data for 2019. We used ONS experimental traffic camera activity data[4] to adjust the 2019 levels to 2022, to be representative of 'post-pandemic' traffic levels.

The ONS data is part of a dataset for estimating economic activity and social change in real-time; the time series for London begins on the 11th March 2020. We used the 1st December 2022 release of this data, the most current at the time of use, in conjunction with Department for Transport (DfT) national road traffic statistics[5] for monthly variation in traffic activity (TRA305_B) to derive multipliers by vehicle type.

The estimated 2022 monthly traffic activity in London, as a proportion of 2019 levels are shown in Figure 6.1. We used the values for November, summarised in Table 6.1, to represent post-pandemic traffic activity.

Table 6.1: Traffic activity multipliers applied to 2019 data for 2022

	Motorcycles	**Cars & taxis**	**LGVs**	**Buses**	**HGVs**
2022 factor	88.9%	90.4%	99.4%	76.6%	92.7%

---

[4] https://www.ons.gov.uk/economy/economicoutputandproductivity/output/datasets/trafficcameraactivity

[5] https://www.gov.uk/government/statistical-data-sets/road-traffic-statistics-tra

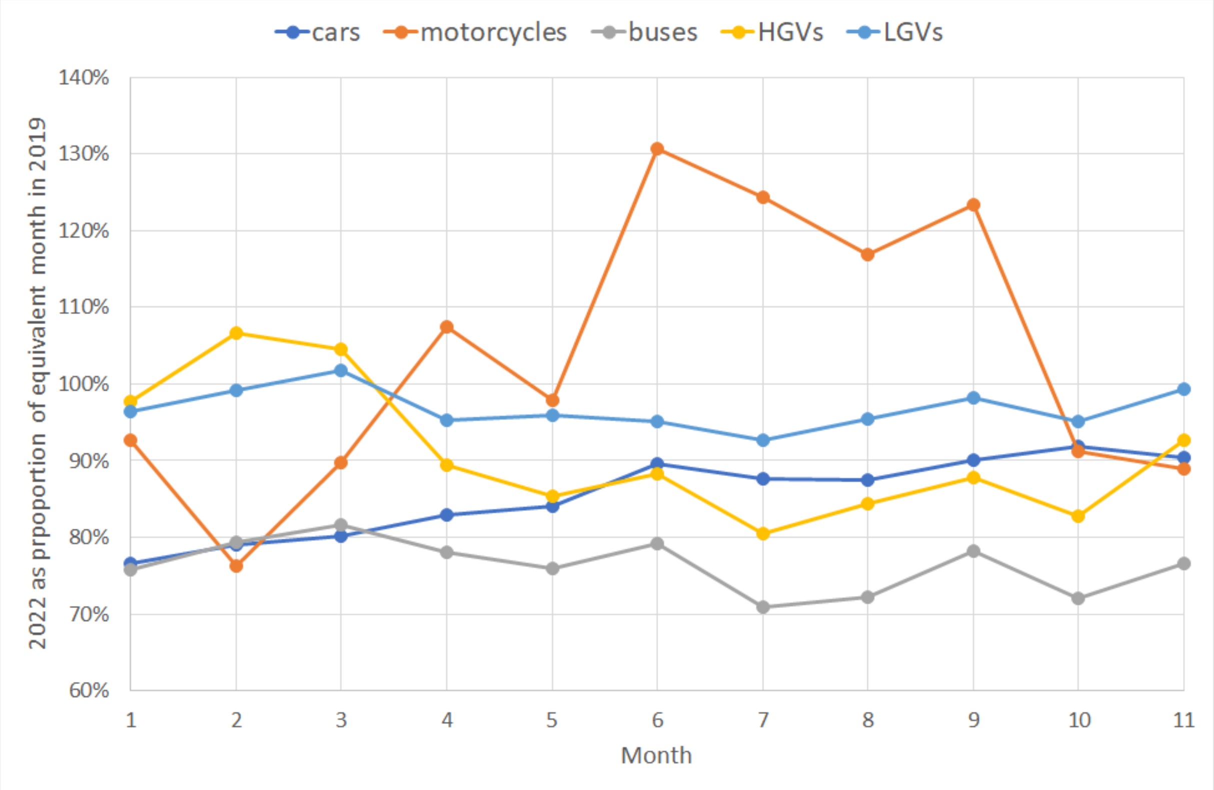


Figure 6.1: Monthly traffic activity in London, as a percentage of the equivalent month in 2019, derived from ONs traffic camera activity and DfT national traffic statistics

We modelled major roads within 750 m of model output points in detail; we modelled emissions from other minor roads and more distant major roads as a part of the aggregated grid source described in Section 6.7.

Activity data for minor roads are not included in LAEI 2019, therefore we adjusted LAEI 2016 using Department for Transport (DfT) traffic statistics by local authority[6]. The range in activity adjustments across London boroughs are shown in Figure 6.2. For Lambeth and Southwark, the calculated factors for cars & taxis were 99.1% and 97.8%, respectively, and for all other vehicles 97.1% and 95%, respectively. We then modified the calculated 2019 activity data for the 2022 set-up using the factors in Table 6.1.

---

[6] https://www.gov.uk/government/statistical-data-sets/tra89-traffic-by-local-authority

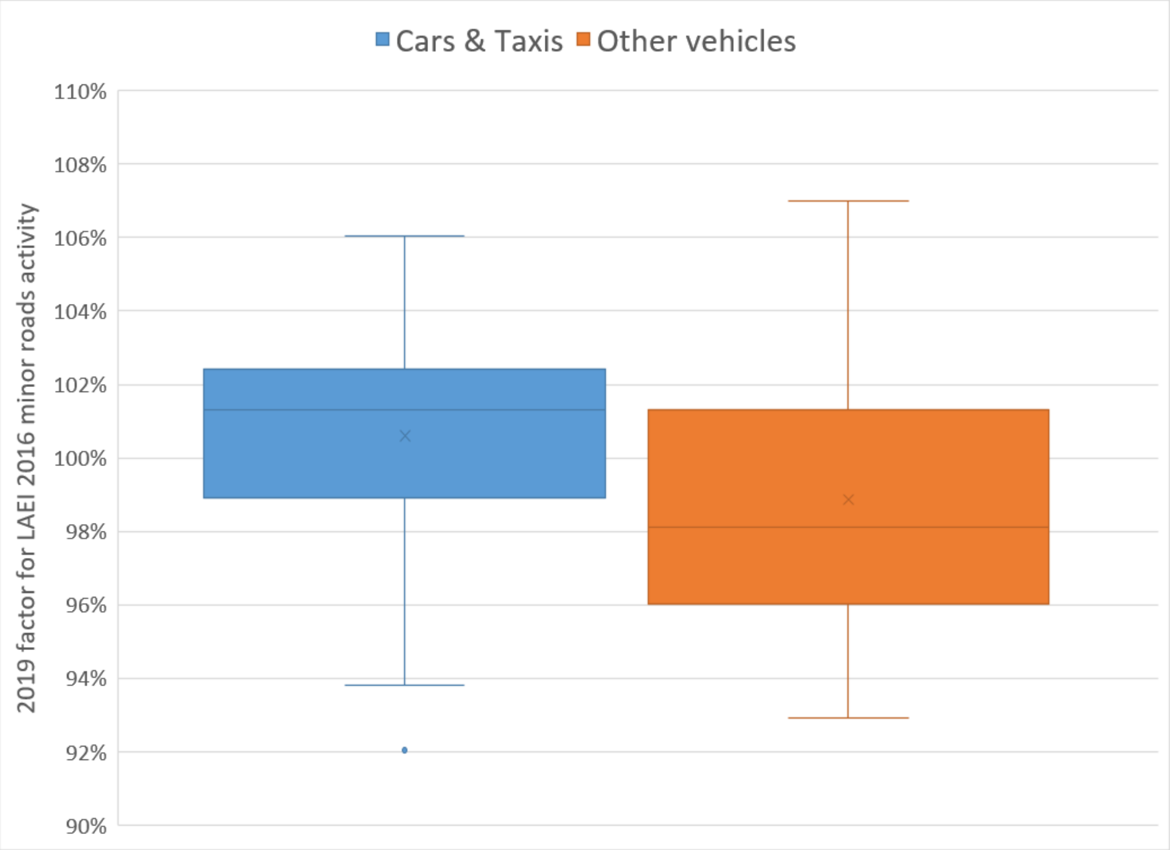


Figure 6.2: Box and whisker plots showing the range in borough-specific adjustments to LAEI 2016 minor road activity data for 2019

6.2. Traffic speeds

We took traffic speeds for major roads from LAEI 2019.

On minor roads, we used the following speed assumptions for the emission calculations[7]:

- 11 km/h in Central London;
- 19 km/h in Inner London; and
- 31 km/h in Outer London.

These speeds were the basis of road traffic emission calculations. We considered the variation of emissions across a day by applying the time-varying emission profiles shown in Section 6.5.

---

[7] https://www.london.gov.uk/questions/2019/19767

6.3. Traffic emission factors

We calculated traffic emissions of NO_x, NO_2 and PM_{10} from traffic flows and speeds using EFT v10.1 published by Defra[8]. This dataset comprises speed-emissions emission factors based on Euro vehicle emissions categories.

Note that there is uncertainty surrounding the current emissions estimates of NO_x in these factors. In order to address this discrepancy, we modified the NO_x emission factors based on published Remote Sensing Data (RSD) [9] [10] for vehicle NO_x emissions. We applied scaling factors to each vehicle category and Euro standard.

Concentrations of PM_{10} at roadside locations are affected by brake, tyre and road-wear, and concentrations of PM_{10} are also affected by resuspension. With the exception of resuspension, we calculated these non-exhaust road traffic emissions using EFT v10.1 emission factors. We took resuspension emission factors from a report produced by TRL Limited on behalf of Defra [11].

6.4. Road traffic fleet assumptions

The EFT v10.1 uses fleet data separated by the regions and road types. We classified London roads by region using definitions provided in LAEI 2019. With the exception of the bus fleet assumptions outlined in Section 6.4.1, we used the London fleets, in line with the regions defined in the LAEI for 2019. For 2022, we considered the expansion of the ULEZ.

Northern parts of Lambeth and Southwark fall within Central London, the area covered by the Congestion Charge Zone (CCZ), which also represents the area covered by Ultra Low Emission Zone (ULEZ) in 2019. For these parts of the borough, we used the Central London fleet.

Most of both boroughs fall within Inner London, the area between the CCZ and the North and South Circulars (A406 and A205). For 2019, we used the Inner London fleet for these parts of the borough.

The London fleet projections in EFT v10.1 are based on projections from TfL in 2018, before the confirmation of the expansion of the ULEZ to cover area within North and South Circulars; the ULEZ expansion came into force in October 2021. To account for the impact of the ULEZ, for 2022, we used the Central London fleet for Inner London roads.

---

[8] https://laqm.defra.gov.uk/review-and-assessment/tools/emissions-factors-toolkit.html

[9] Carslaw, D and Rhys-Tyler, G 2013: New insights from comprehensive on-road measurements of NO_x, NO_2 and NH_3 from vehicle emission remote sensing in London, UK. *Atmos. Env.* **81** pp 339–347.

[10] Davison, J., Rose, R.A., Farren, N.J., Wagner, R.L., Murrells, T.P. and Carslaw, D.C., 2021. Verification of a National Emission Inventory and Influence of On-road Vehicle Manufacturer-Level Emissions. Environmental Science & Technology, 55(8), pp.4452-4461.

[11] *Road vehicle non-exhaust particulate matter: final report on emission modelling*, TRL Limited Project Report PPR110 https://uk-air.defra.gov.uk/assets/documents/reports/cat15/0706061624_Report2__Emission_modelling.PDF

For roads beyond the North and South Circulars, we used the Outer London fleets for both modelled years. We also applied the Outer London fleets to non-GLA roads within the M25. We used the London Motorway fleets for the M25.

6.4.1. Bus fleet assumptions

Bus fleet projections in EFT 10.1 are shown in Figure 6.3. The projections for 2019 assume that 100% buses operating in Central London, 77% in Inner London and 66% in Outer London are Euro VI or better. The projections show a step change in 2020, where all buses across London become Euro VI or better.

According to TfL's bus fleet audit[12], by the end of the 2018/2019 financial year, 77.5% of buses across the whole of London were Euro VI standard or better, increasing to 93.4% by the end of 2019/2020.

To account for the accelerated uptake of newer bus technology, we applied the following assumptions to the modelled bus fleet for 2019:

- Use an average of the respective EFT 2019 and 2020 bus projections for roads in Inner and Outer London; and
- For Central London, use the EFT projection without modifications for 2019, since it is in line with TfL's bus fleet audit.

For 2022 emissions, we used the EFT fleets for 2022 without modifications.

---

[12] https://tfl.gov.uk/corporate/publications-and-reports/bus-fleet-data-and-audits

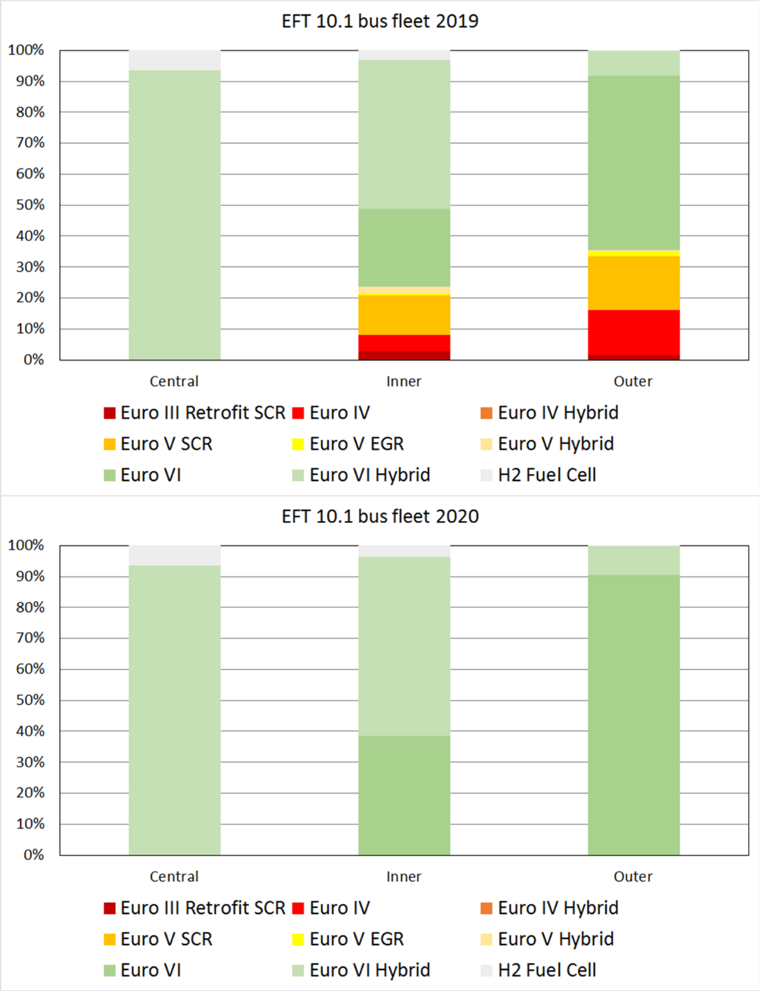


Figure 6.3: EFT 10.1 bus fleet projections for London regions for 2019 (top) and 2020 (bottom). Projections for Central, Inner and Outer London are shown.

6.5. Time-varying emissions profiles

We took into account the variation in emissions during the day by applying a set of diurnal profiles to the road and grid sources. We based time-varying emissions profiles on road traffic emissions in *Air pollution and emissions trends in London* [13], used in the compilation of the LAEI, as shown in Figure 6.4.

---

[13] *Air pollution and emissions trends in London*, King's College London, Environmental Research Group and Leeds University, Institute for Transport studies https://uk-air.defra.gov.uk/assets/documents/reports/cat05/1004010934_MeasurementvsEmissionsTrends.pdf

These emission profiles capture the changes in traffic volume, composition and speed throughout the day.

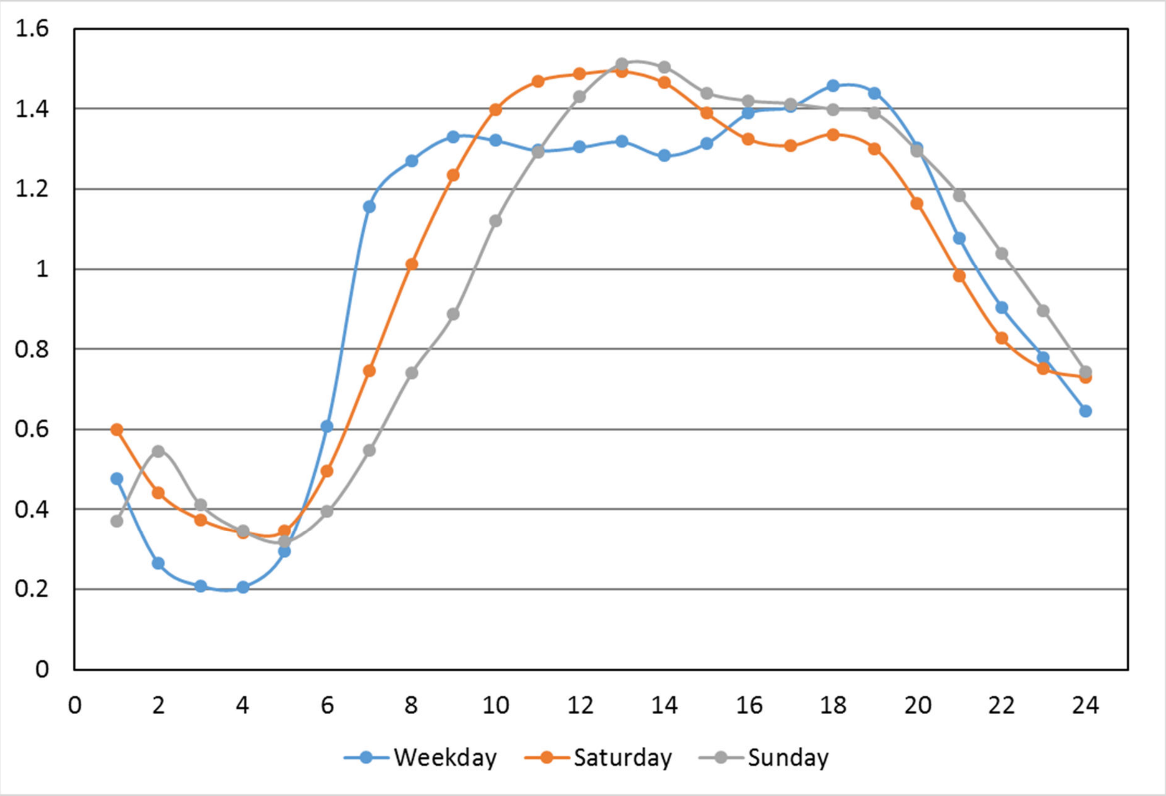


Figure 6.4: Diurnal profiles for road traffic emissions

We derived profiles for grid sources, as described in Section 6.7, from European Monitoring and Evaluation Programme (EMEP) emissions data, as shown in Figure 6.5.

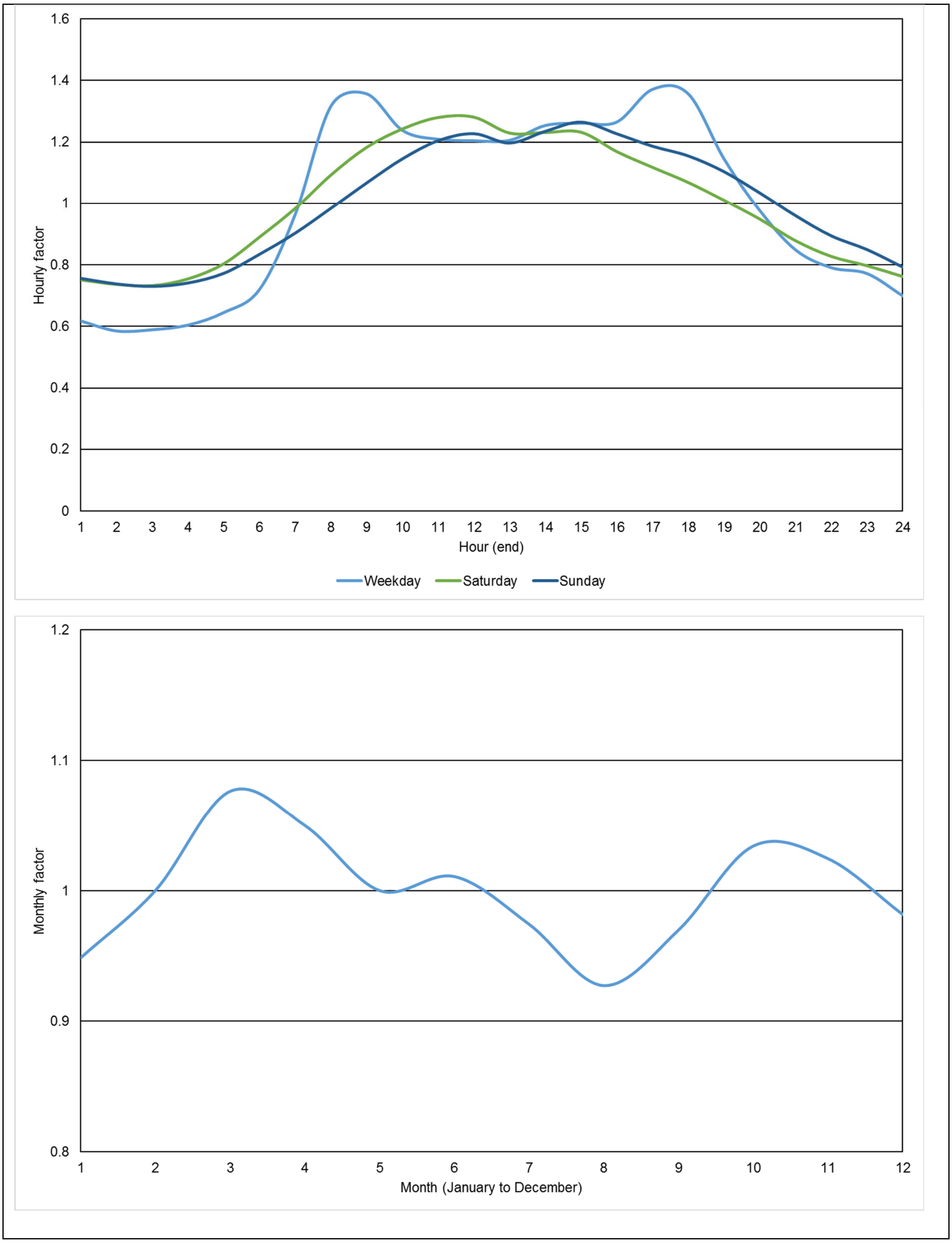


Figure 6.5: Diurnal (top) and monthly profiles (bottom) for grid source emissions

6.6. Industrial sources

We modelled the South East London Combined Heat and Power (SEL CHP) explicitly as an industrial point source. The modelled parameters are summarised in Table 6.2. We estimated the stack parameters based on the type of source and emission rates were obtained from the LAEI 2019.

Table 6.2: SEL CHP model parameters and emission rates

Location (x, y)	Height (m)	Diameter (m)	Exit velocity (m/s)	Temperature (°C)	NO_2 (g/s)	NO_x (g/s)	PM_{10} (g/s)	$PM_{2.5}$ (g/s)
535700, 178120	61	1.6	13.7	134	0.89	18.0	0.11	0.11

6.7. Other emissions

We took emission rates for all other sources from the LAEI 2019 and modelled them as aggregated 1-kilometre resolution grid sources covering the whole of London.

We derived hourly and monthly emissions profiles for the grid sources from European Monitoring and Evaluation Programme (EMEP) emissions data, as shown in Section 6.5.

7. 2019 modelled concentrations

This section presents modelled NO_2, PM_{10} and $PM_{2.5}$ concentrations for 2019 and the selection of receptor locations.

7.1. Model verification

We verified the model set-up against air quality monitoring at the locations shown in Section 4.2, a scatter plot comparing modelled and monitored annual average NO_2 concnetrations for 2019 is shown in Figure 7.1 . The modelled results are in line with results from recent modelling carried out for the assessment of Low Traffic Neighbourhoods (LTN) in the boroughs, with 85% of modelled concentrations within 25% of monitored values.

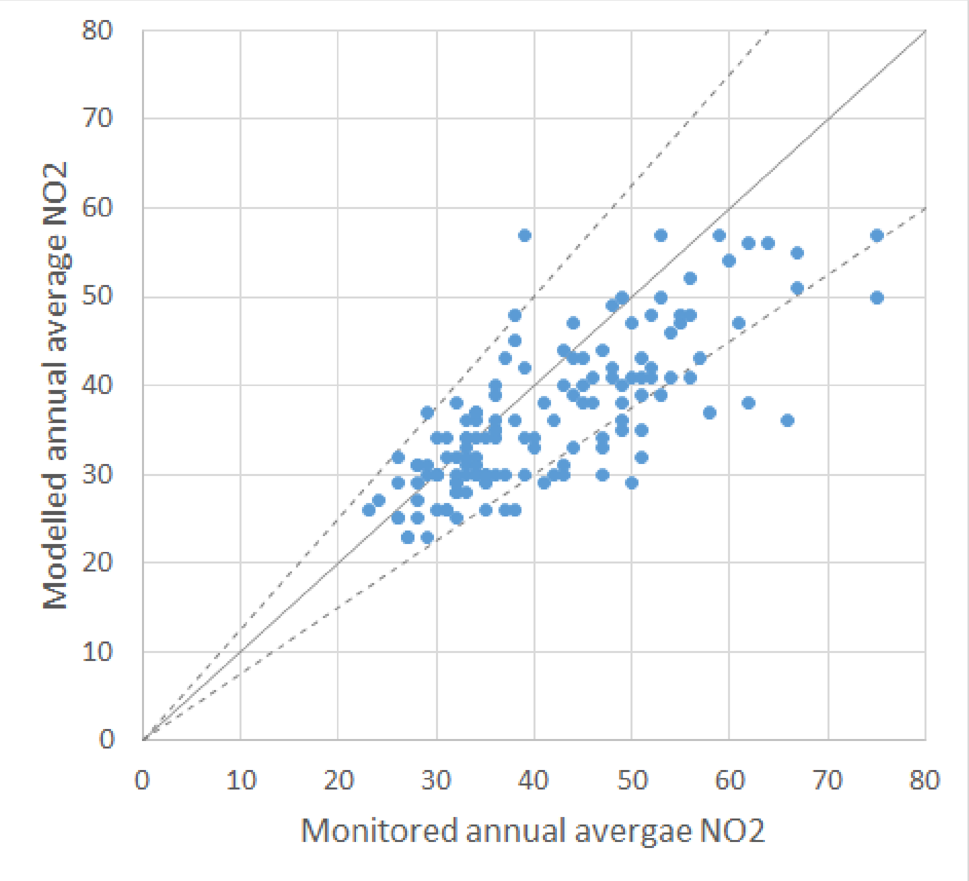


Figure 7.1: Comparison of modelled and monitored annual average NO_2 concentrations for 2019 (µg/m^3). The 1:1 line is shown as a solid line, with dash lines representing modelled values ±25% of monitored values

7.2. Contour maps

We calculated concentrations on a regular grid of receptors on a 50 m resolution and on a dense network of roadside, kerbside and building façade points. We used the additional set of receptors to represent the steep concentration gradient from the roadside to the building facades. We used the model output to generate 10 m resolution contour maps across the scheme area using the natural neighbour interpolation method.

Figure 7.2 shows modelled annual average NO_2 concentrations. The modelled concentrations exceed the air quality objective of 40 µg/m³ at locations close to major roads. Figure 7.3 and Figure 7.4 show the modelled annual average PM_{10} and $PM_{2.5}$ concentrations. Modelled concentrations largely meet the air quality objective of 40 µg/m³ and 20 µg/m³ across the boroughs. All pollutants show similar spatial trends, in that concentrations are generally higher concentrations in the north of the boroughs.

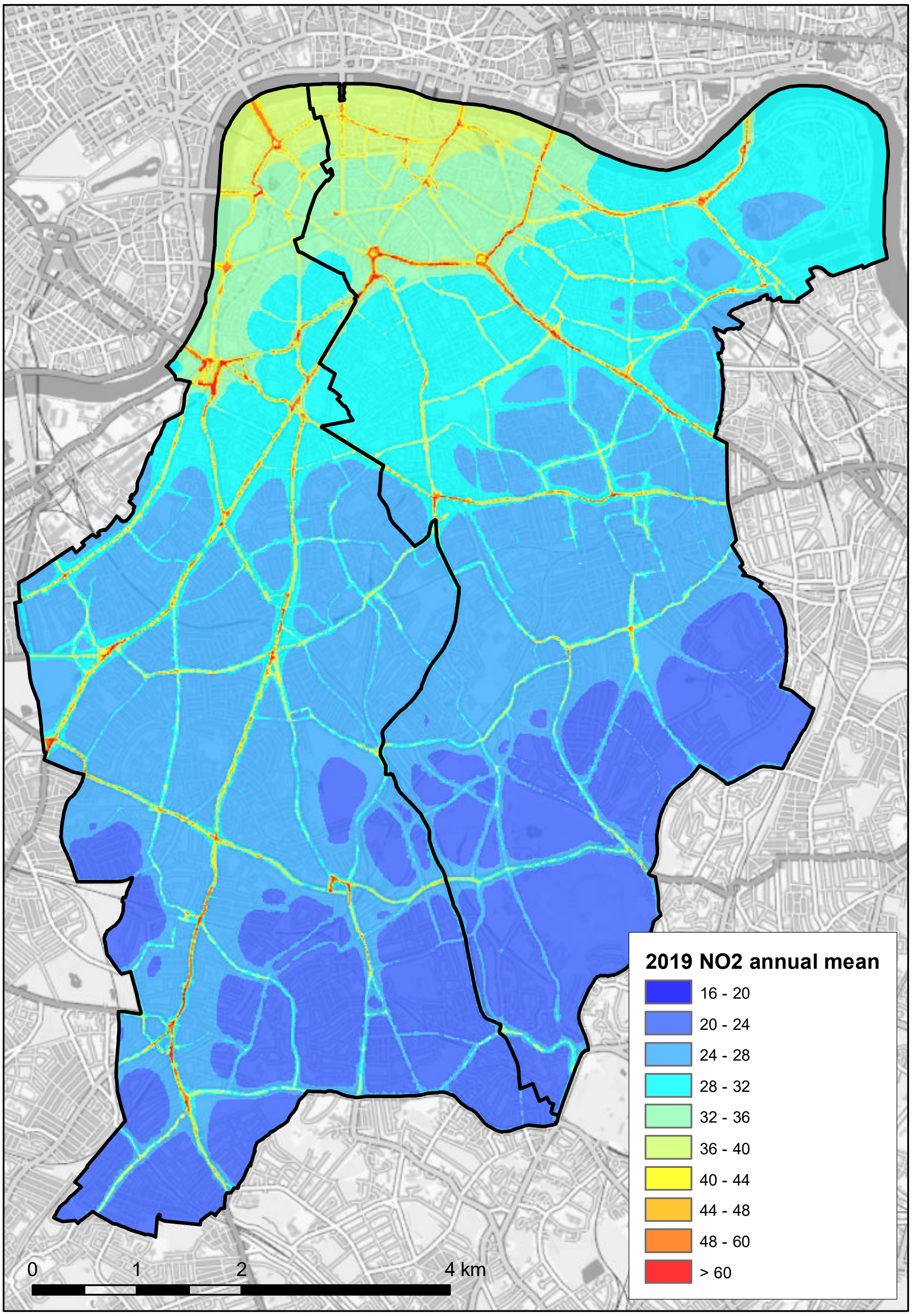


Figure 7.2: 2019 annual average NO$_2$ concentrations (µg/m^3)

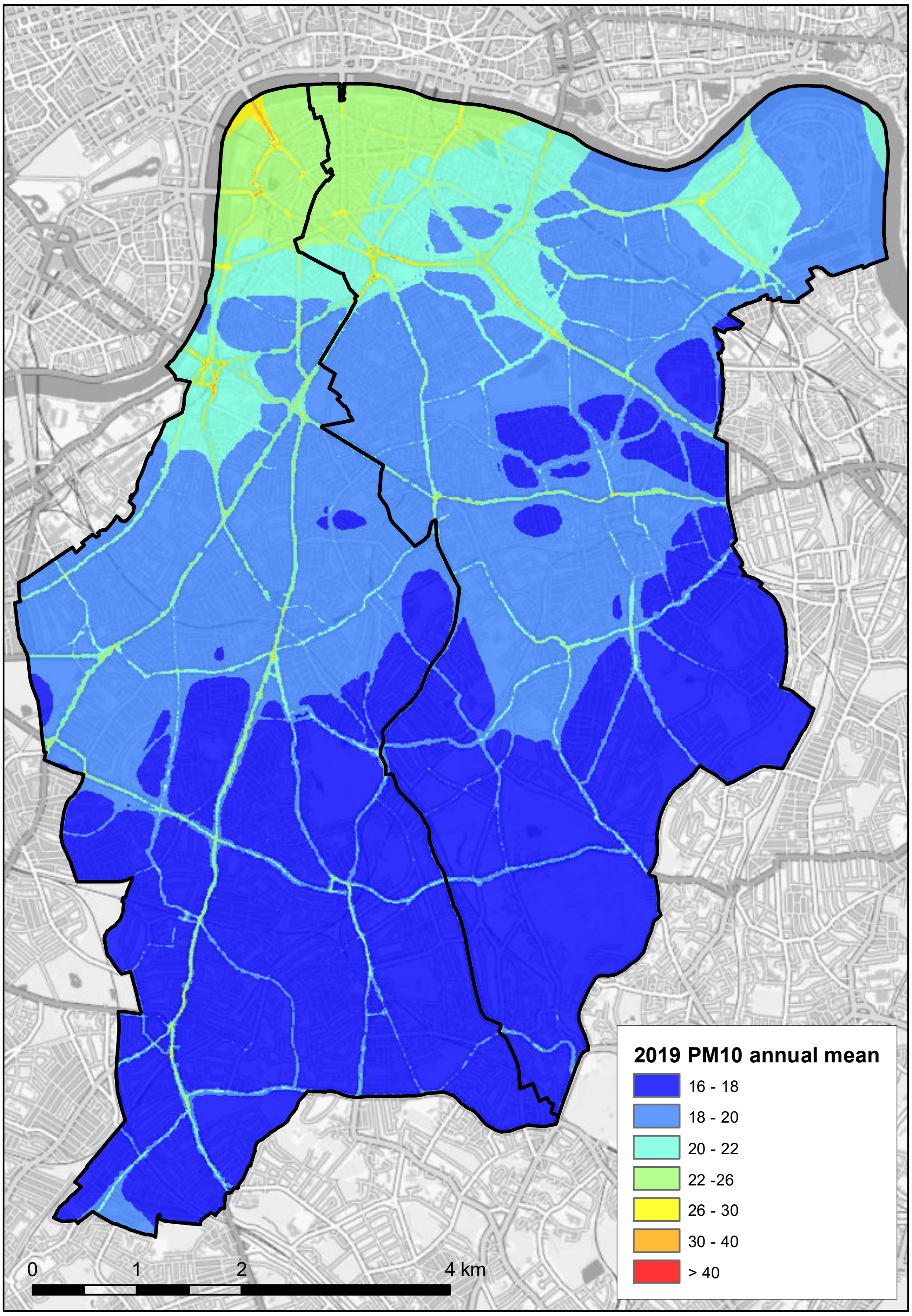


Figure 7.3: 2019 annual average PM_{10} concentrations (µg/m^3)

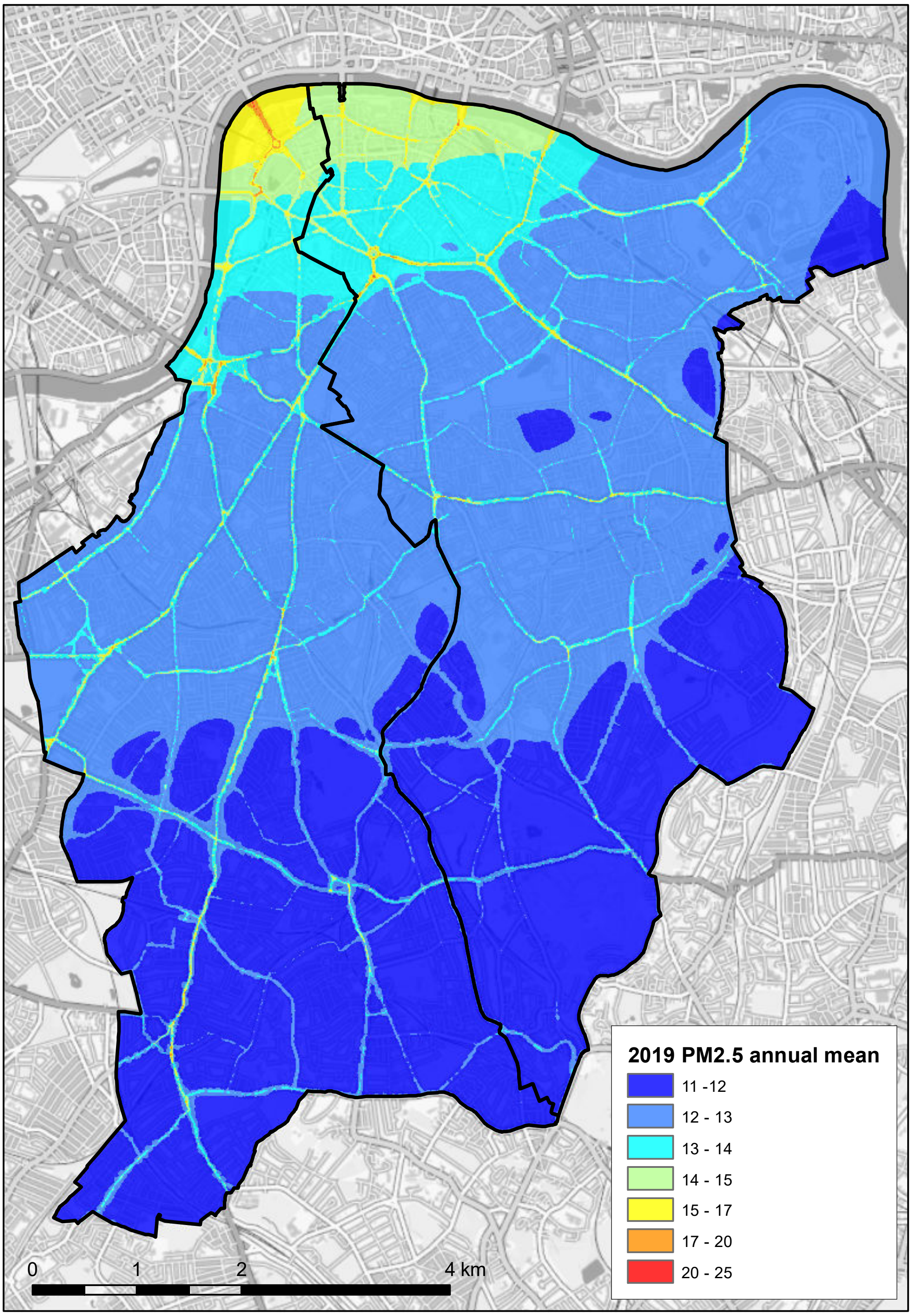


Figure 7.4: 2019 annual average $PM_{2.5}$ concentrations (µg/m^3)

7.3. Receptor location identification

We identified priority sensitive receptors in Lambeth and Southwark according to risk from air pollution exposure, focusing on areas of deprivation.

We used educational establishments and health care locations, as users of these facilities are likely to be those most susceptible to the impacts of air pollution. In addition, we used 2019 air quality monitor locations, for areas of worst case exposure. In order to use locations representative of long-term exposure to air pollution, locations near major roads were set to the location of the nearest building façade.

For these location types, we extracted modelled annual average NO_2 concentrations for 2019 and the IMD2019 values for LSOA that it is located. Using these metrics, initial screening of receptor locations used the following criteria:

- Educational establishments located in LOSA with an IMD2019 Rank of less than 10,000 (approximately first three deciles) with modelled concentrations at the boundary of 35 µg/m^3 or more. Higher education establishments excluded.
- Potential long-stay health care establishments i.e. care homes and hospitals, with modelled concentrations at the boundary of 29.5 µg/m^3. IMD2019 Rank not used but a value of 15,000 was considered
- Monitoring locations located in LOSA with an IMD2019 Rank of less than 10,000 with modelled concentrations at the nearest modelled building façade of 40 µg/m^3 or more.

Figure 7.5 shows locations from the initial screening. The screening led to a northern bias in the receptor locations with some duplications on the types of environments represented; in addition there were no receptors in areas of high deprivation in parts of Brixton, Camberwell, Stockwell, Tulse Hill / Streatham Hill and West Norwood.

To refine the receptor location set, we removed eight monitor location based receptors, primarily in the northern parts of the boroughs, and two health care receptors around Tooting Bec Gardens and Ambleside Avenue in Lambeth. We improved the coverage by adding 11 receptor at school locations, seven in Lambeth and three in Southwark. Figure 7.6 shows the final receptor locations

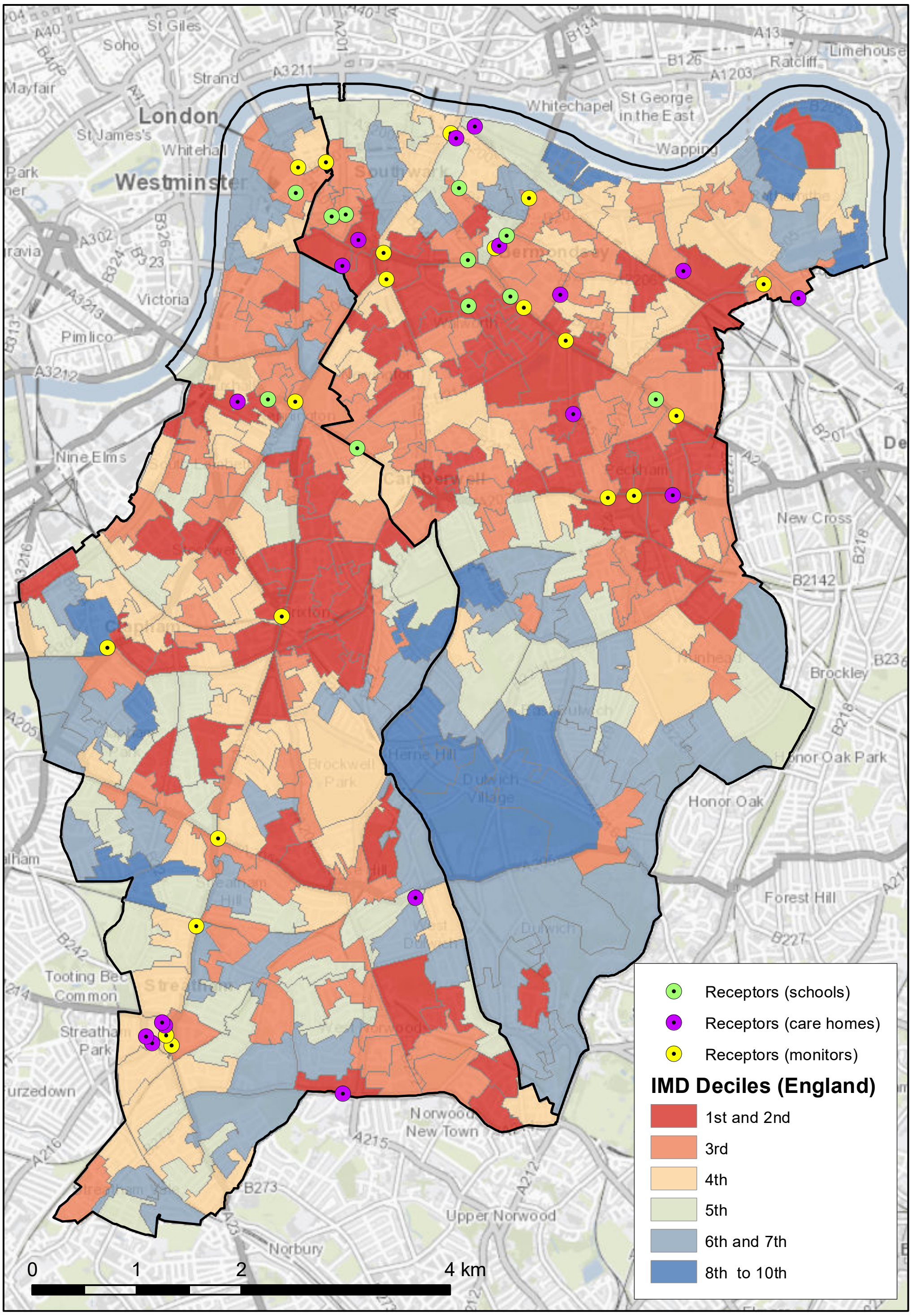


Figure 7.5: Initial screening receptor locations

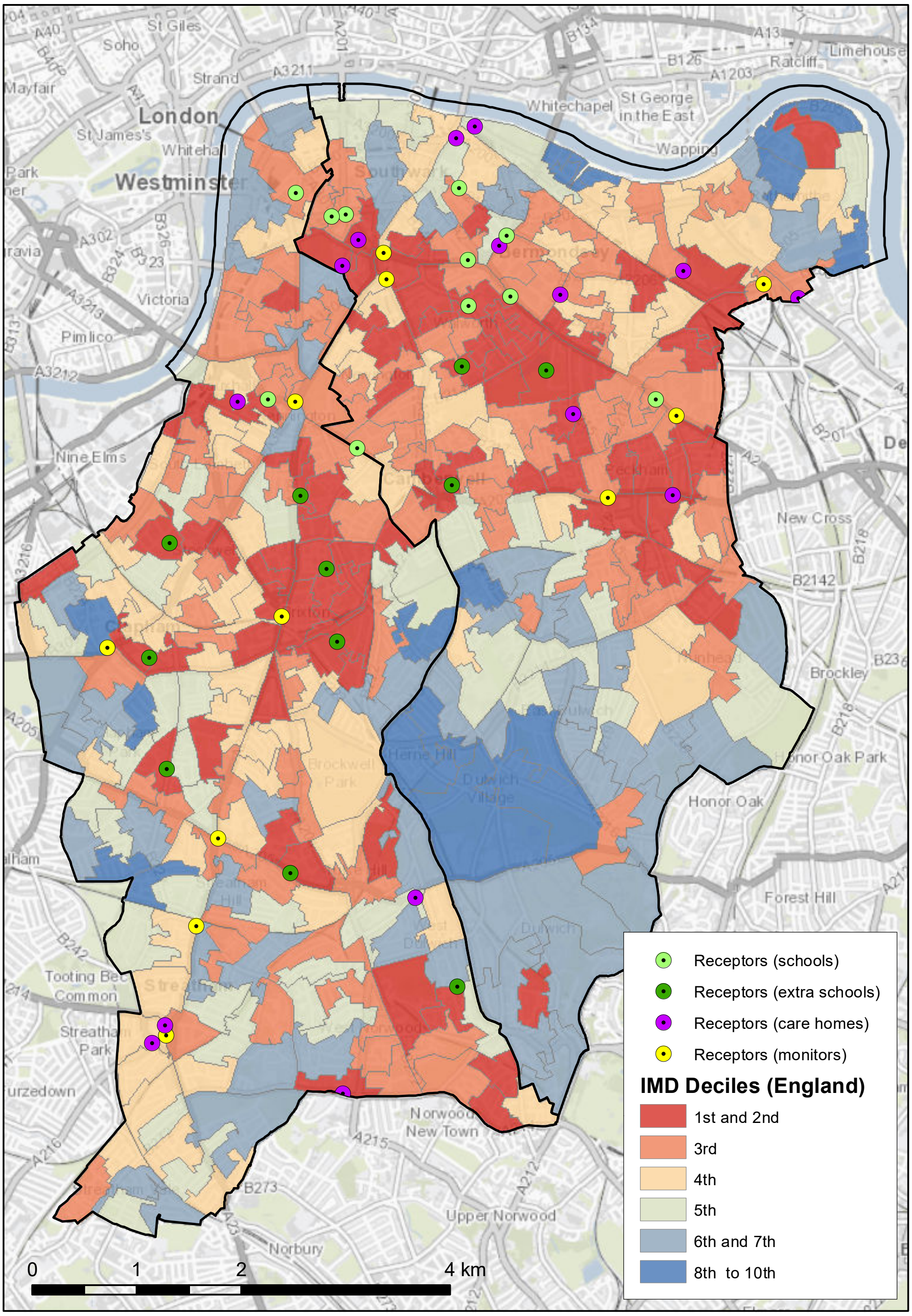


Figure 7.6: Final receptor locations

8. 2022 modelled concentrations

8.1. Contour maps

Figure 8.1 shows modelled annual average NO_2 concentrations for 2022. Equivalent figures for annual average PM_{10} and $PM_{2.5}$ concentrations are shown in Figure 8.2 and Figure 8.3. The reduction in road traffic emissions leads to lower modelled pollution concentrations for 2022, when compared to 2019. The spatial trends are largely similar across modelled years with generally higher pollutant concentrations in the north of the boroughs.

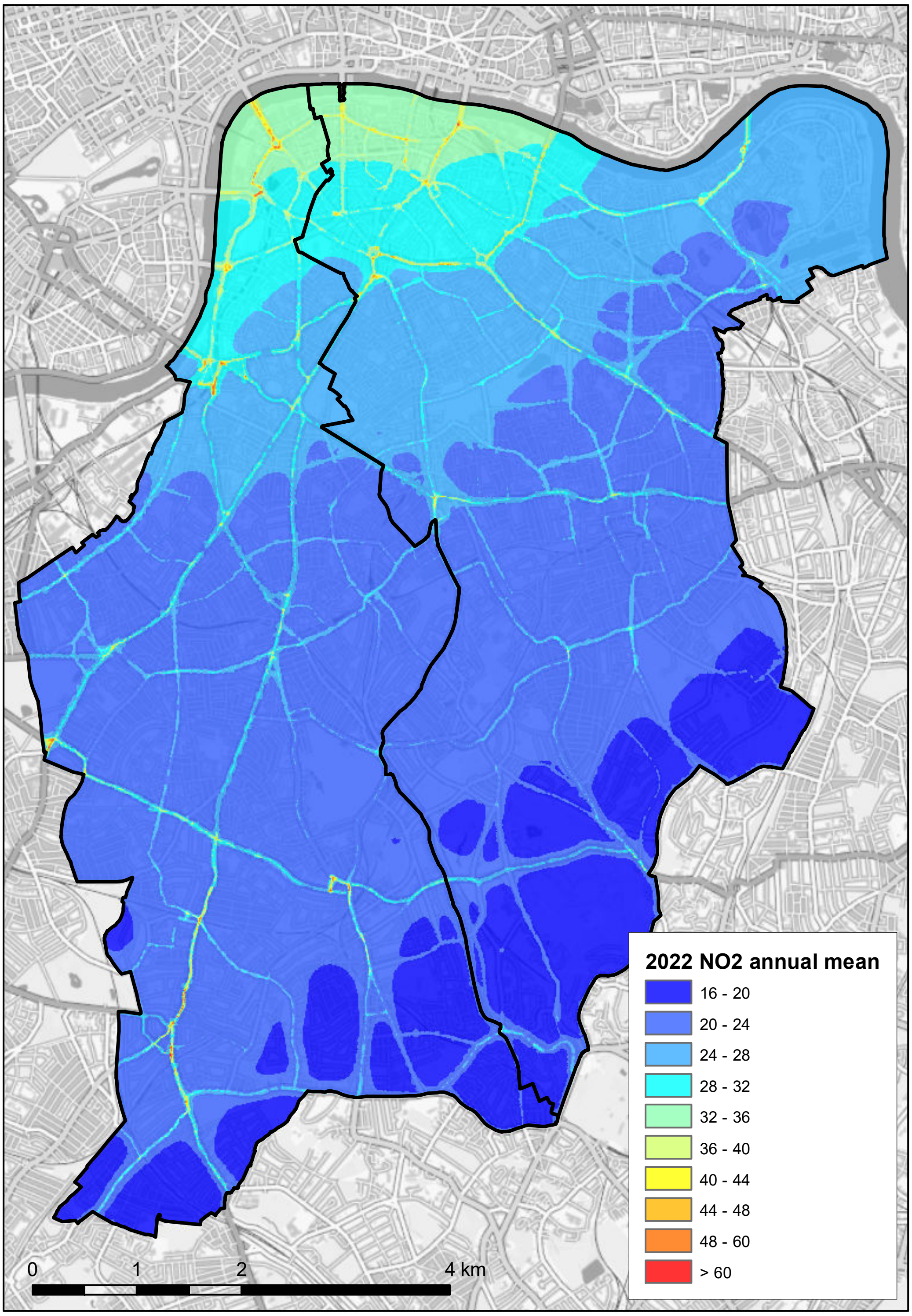


Figure 8.1: 2022 annual average NO_2 concentrations ($\mu g/m^3$)

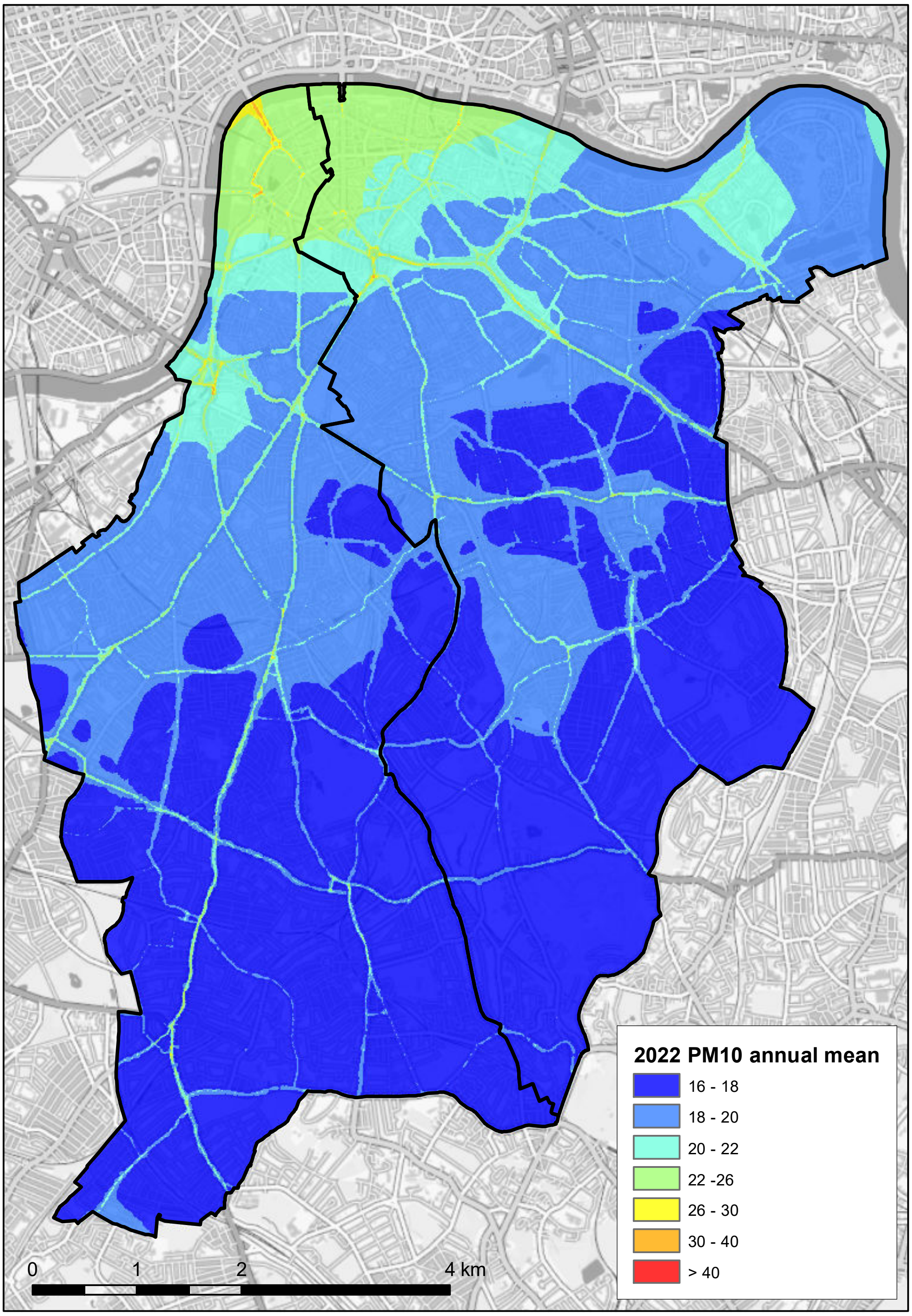


Figure 8.2: 2022 annual average PM_{10} concentrations (µg/m^3)

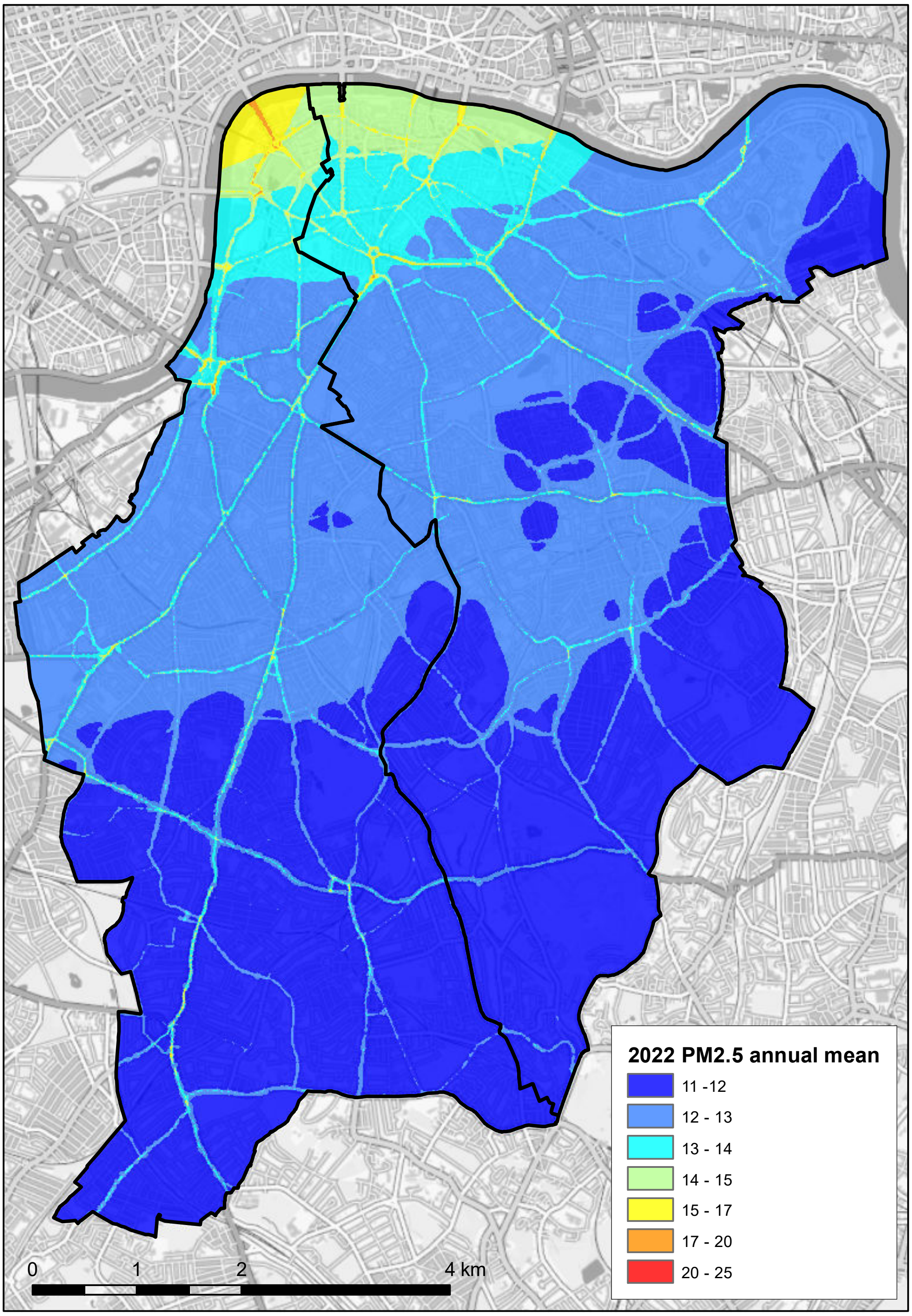


Figure 8.3: 2022 annual average $PM_{2.5}$ concentrations (µg/m^3)

8.2. Source apportionment

8.2.1. NO_x

Figure 8.4 shows total NO_x concentrations averaged across the 48 receptor locations, by major source group. The largest contributors to NO_x concentrations are road transport and commercial & industry emissions.

The breakdown of road transport NO_x concentrations by vehicle type in Figure 8.5 considers ULEZ compliance for private vehicles and light goods vehicles, and engine technology for taxis – split into internal combustion engine (ICE) and zero emission capable (ZEC) taxis. The average across receptor locations shows significant contributions from most vehicle types. Sources of NO_x are largely local, with on average 21% of road NO_x concentrations originating from sources outside of Lambeth and Southwark.

Figure 8.6 shows that the breakdown of NO_x concentrations by industrial source groups. The dominant source is gas combustion for industrial heat and power. On average just under half (48%) the contribution of commercial & industry to NO_x concentrations is from sources outside the two boroughs. Regulatory powers are available to the councils to control for Non-Road Mobile Machinery (NRMM) emissions in their borough.

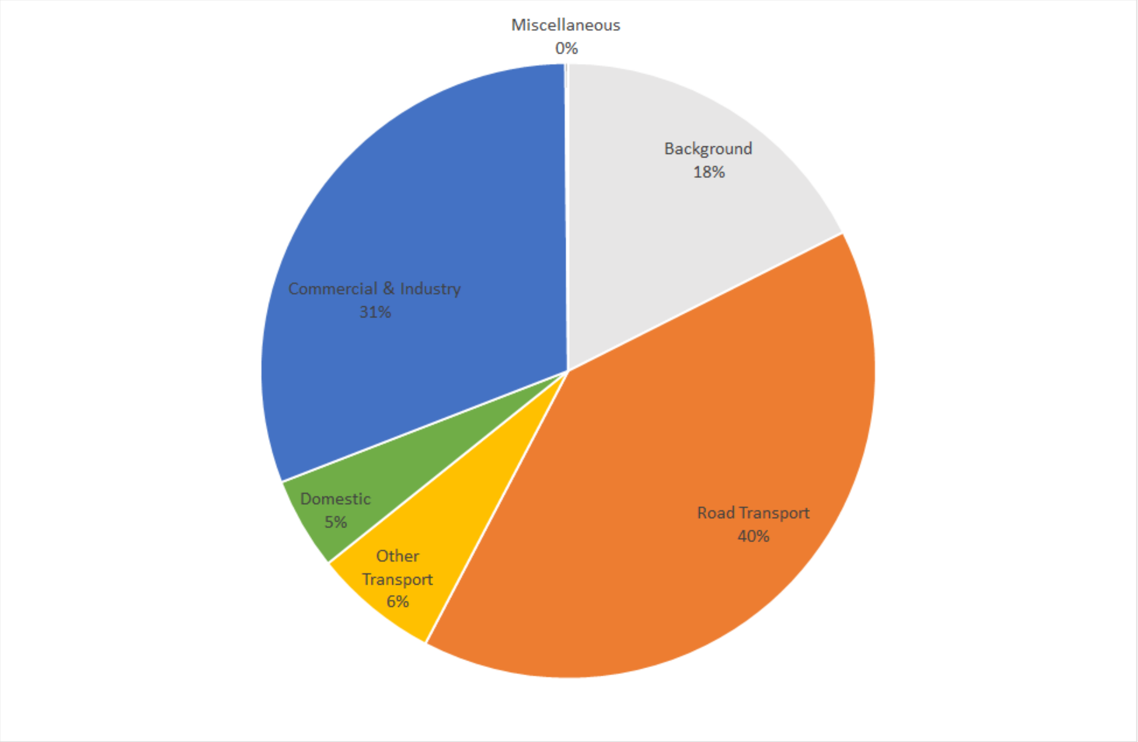


Figure 8.4: Average breakdown of total NO_x concentrations at receptor locations

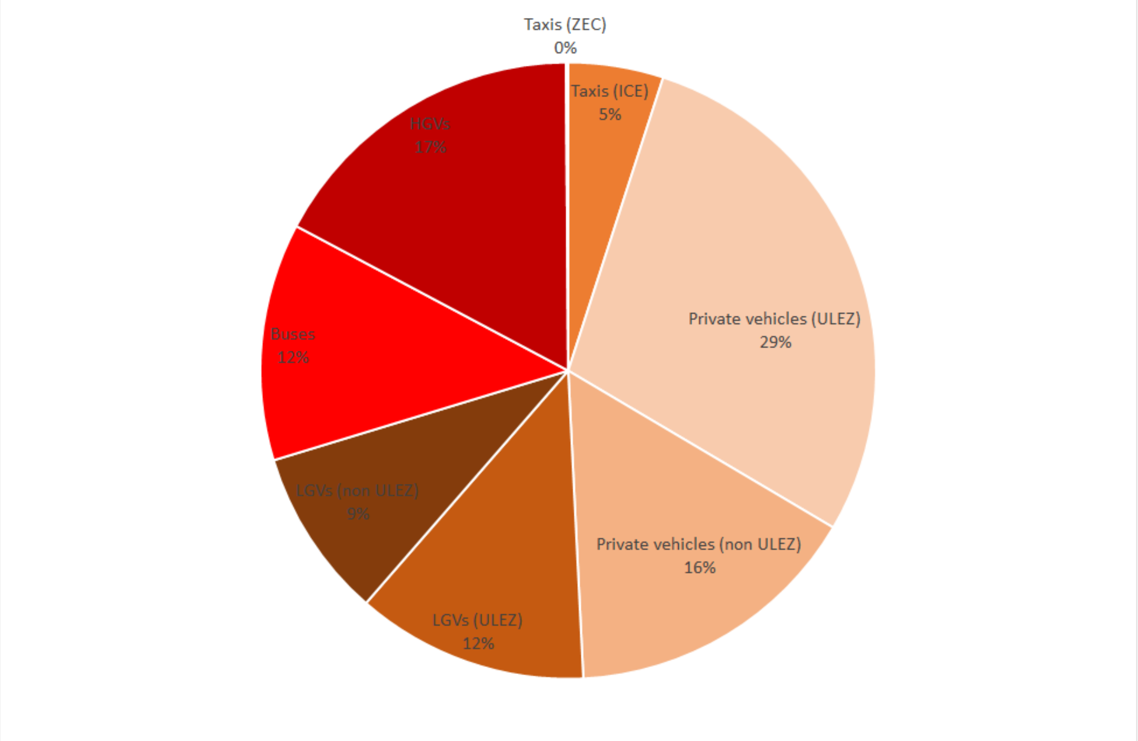


Figure 8.5: Average breakdown of road transport NO_x concentrations at receptor locations

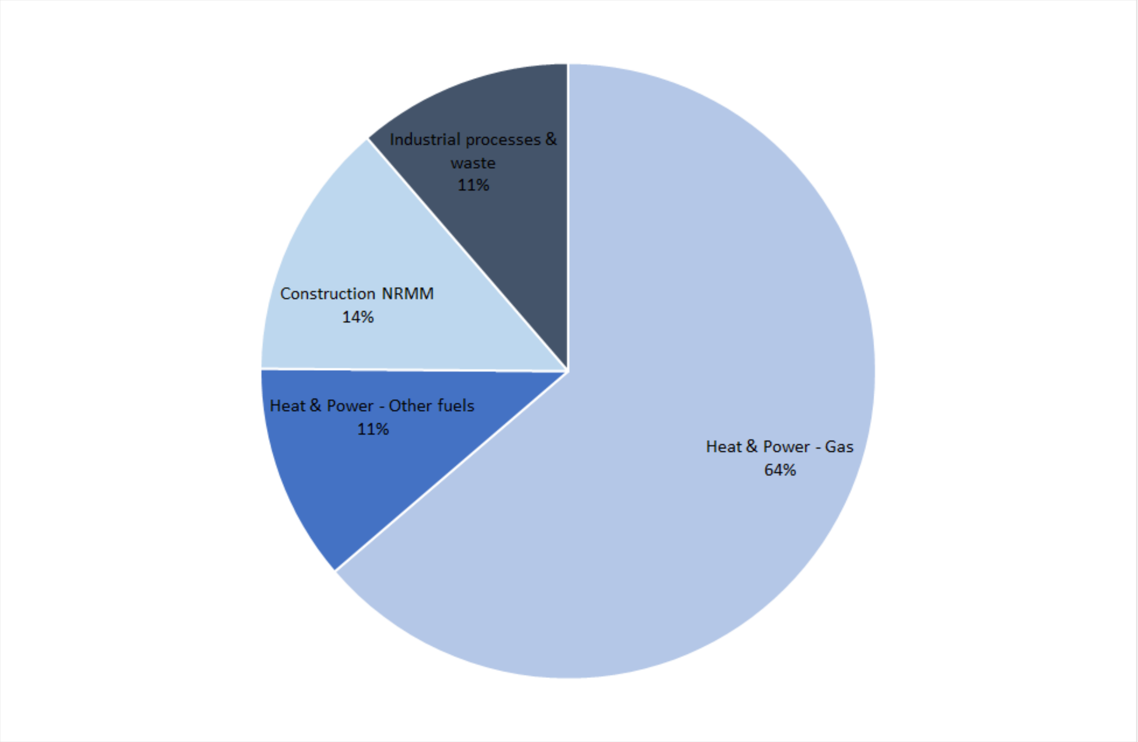


Figure 8.6: Average breakdown of industrial NO_x concentrations at receptor locations

8.2.2. PM_{10}

As shown in Figure 8.7, on average 66% of PM_{10} concentrations at receptor locations is background, representing the contribution from sources outside of London (the area covered by the LAEI).

Since non-exhaust emissions dominate PM_{10} concentrations from road transport, we did not consider engine technology in the breakdown by vehicle type, in Figure 8.8. As for NO_x, all vehicle types are relatively significant contributors.

Figure 8.9 shows construction dust and commercial cooking dominate contributions from industrial sources. The boroughs are expected to have some regulatory control over these sources.

Figure 8.10 shows solid and liquid fuel combustion is the largest source of domestic PM_{10} concentrations.

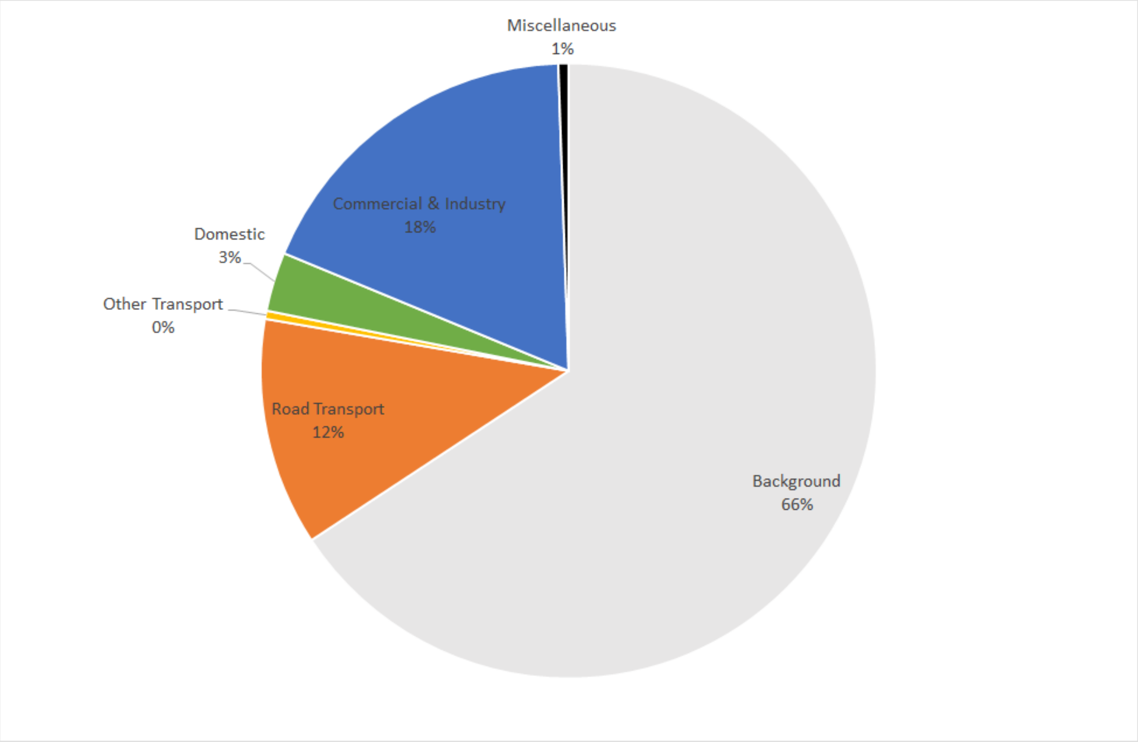


Figure 8.7: Average breakdown of total PM_{10} concentrations at receptor locations

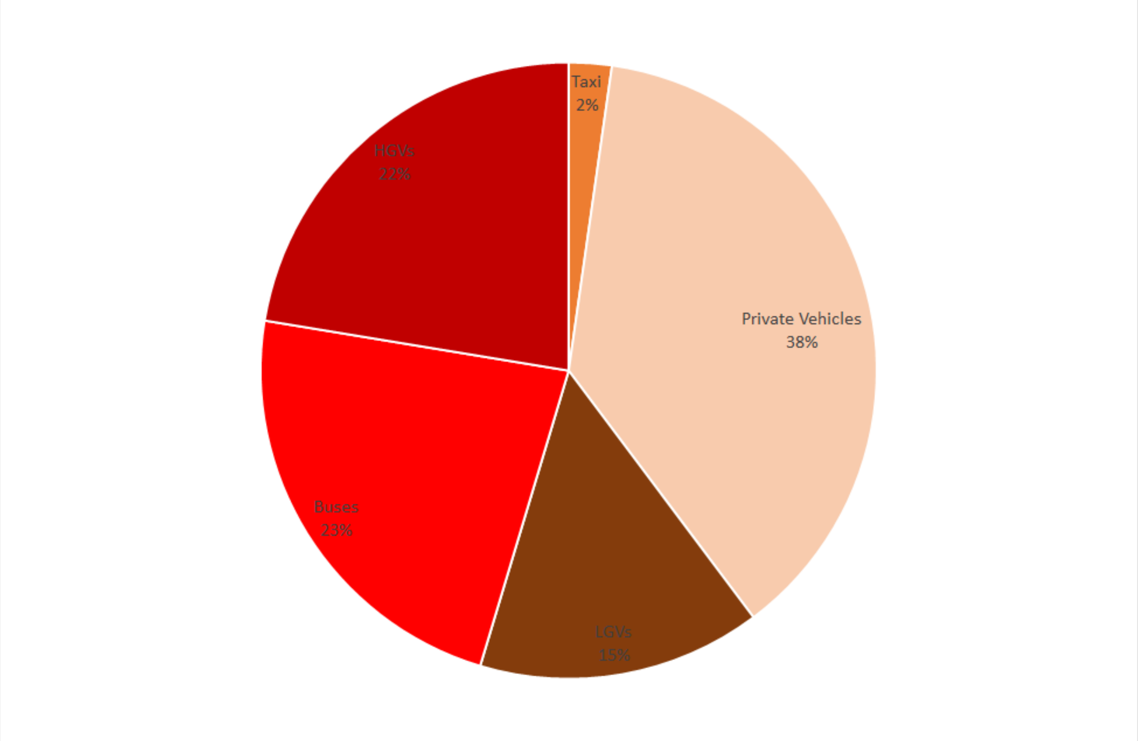


Figure 8.8: Average breakdown of road transport PM_{10} concentrations at receptor locations

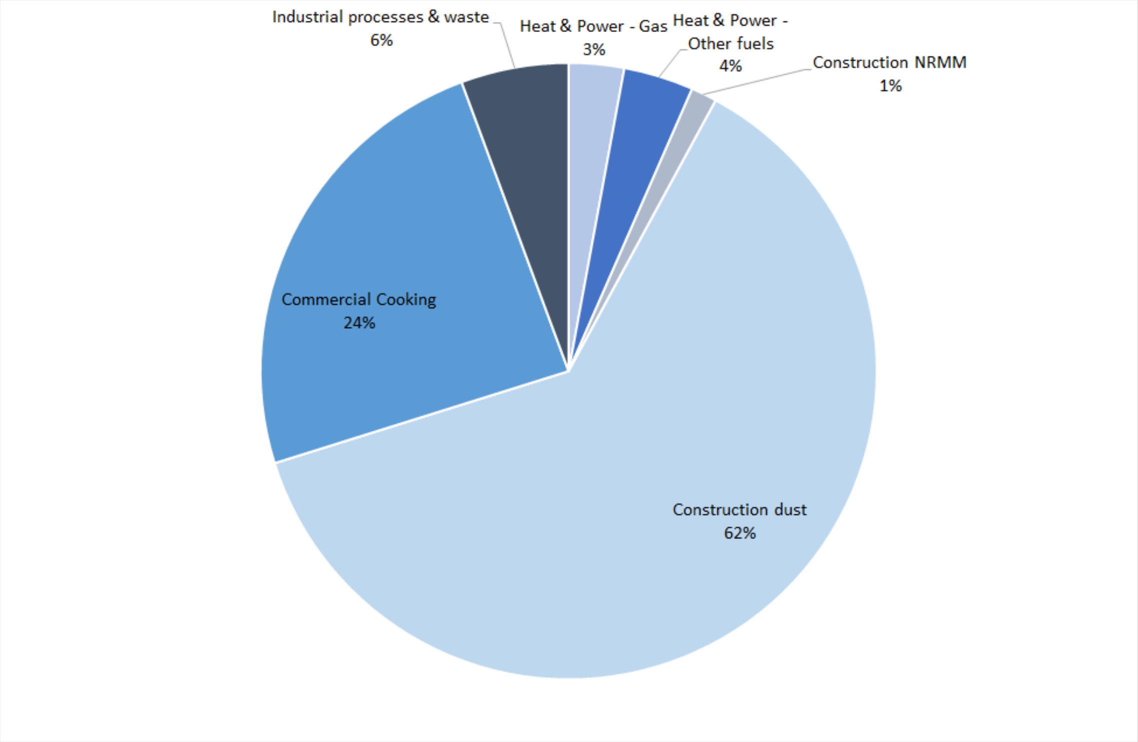


Figure 8.9: Average breakdown of industrial PM_{10} concentrations at receptor locations

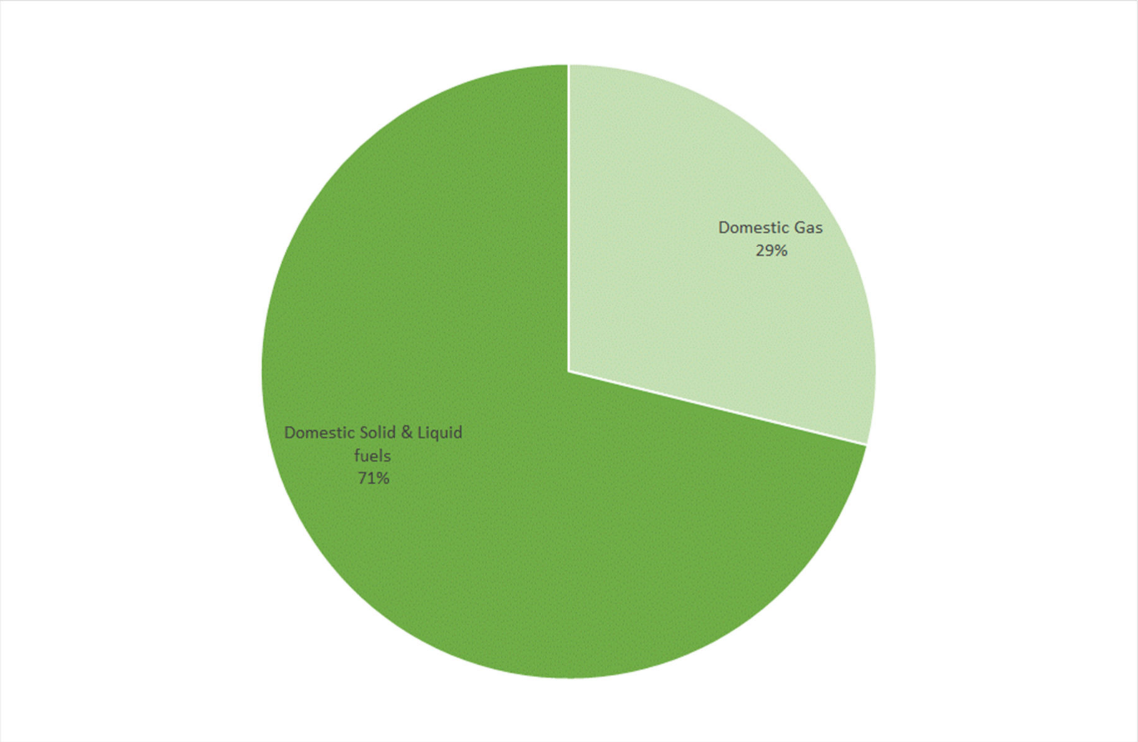


Figure 8.10: Average breakdown of domestic PM_{10} concentrations at receptor locations

8.2.3. $PM_{2.5}$

Source apportionment results for $PM_{2.5}$ concentrations, average across receptor locations are summarised Figure 8.11 to Figure 8.14.

As with PM_{10}, background is the largest source of concentrations, there is relatively significant contribution from all vehicle types to total road $PM_{2.5}$ concentrations and the domestic emissions contribution is dominated by solid and liquid fuel combustion. Commercial cooking is the largest contributor from industrial sources.

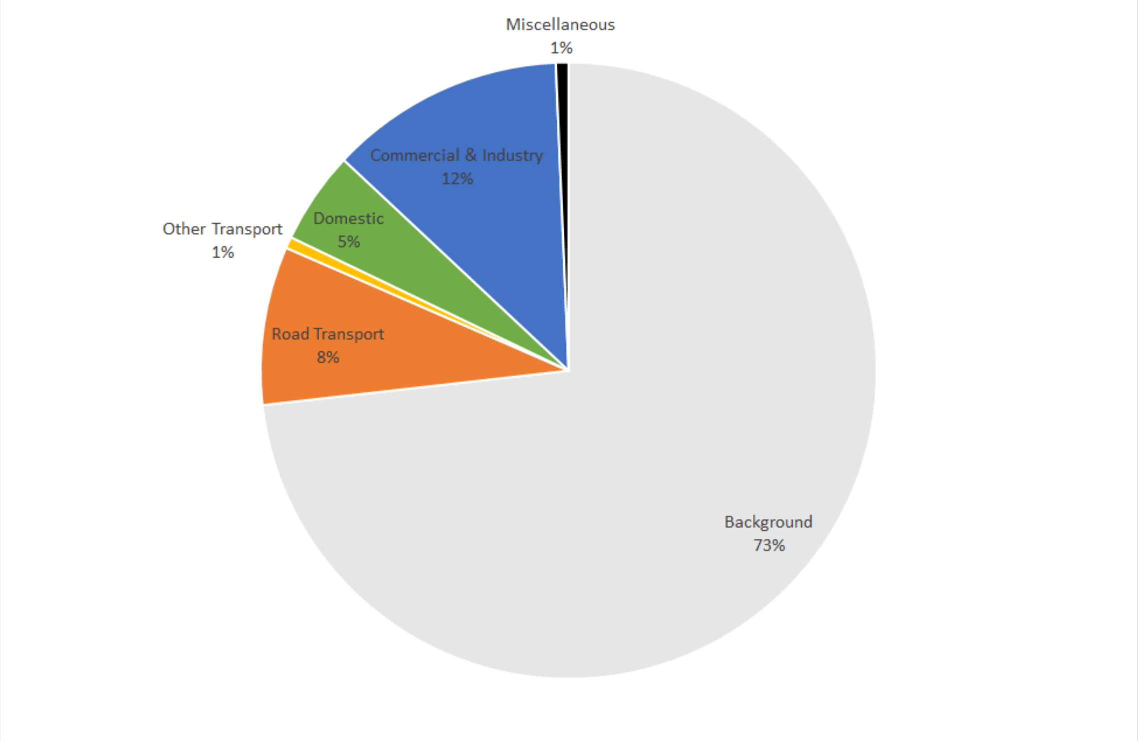


Figure 8.11: Average breakdown of total $PM_{2.5}$ concentrations at receptor locations

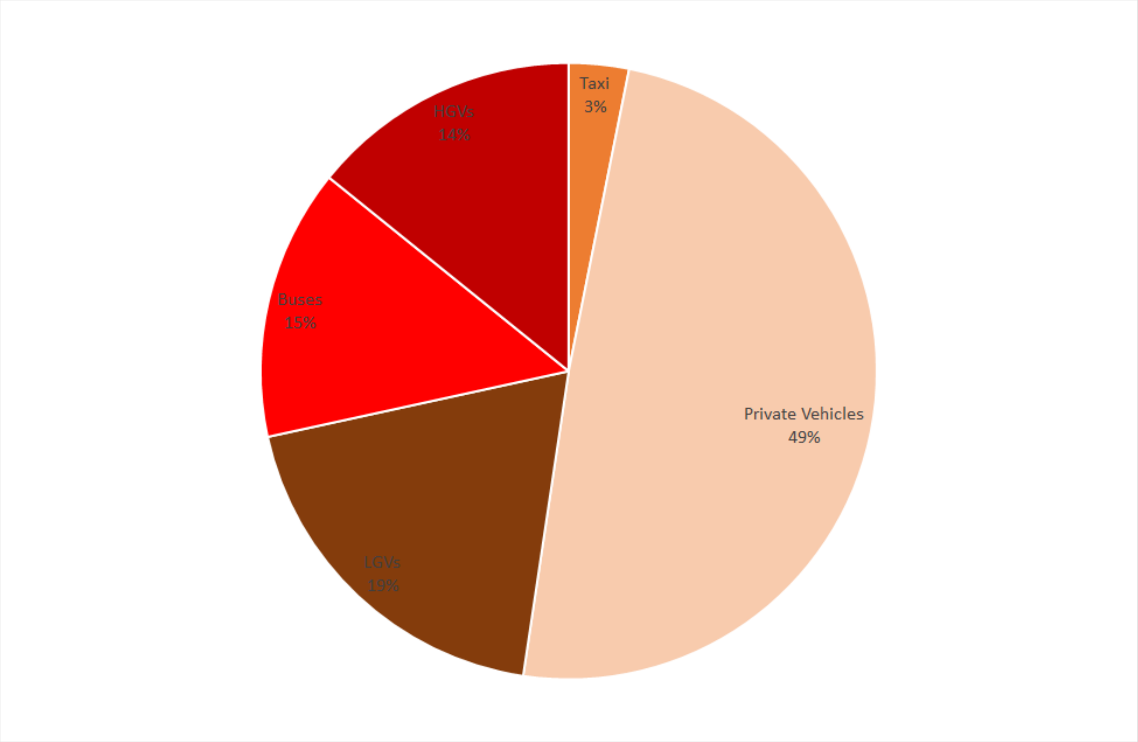


Figure 8.12: Average breakdown of road tranpsortc$PM_{2.5}$ concentrations at receptor locations

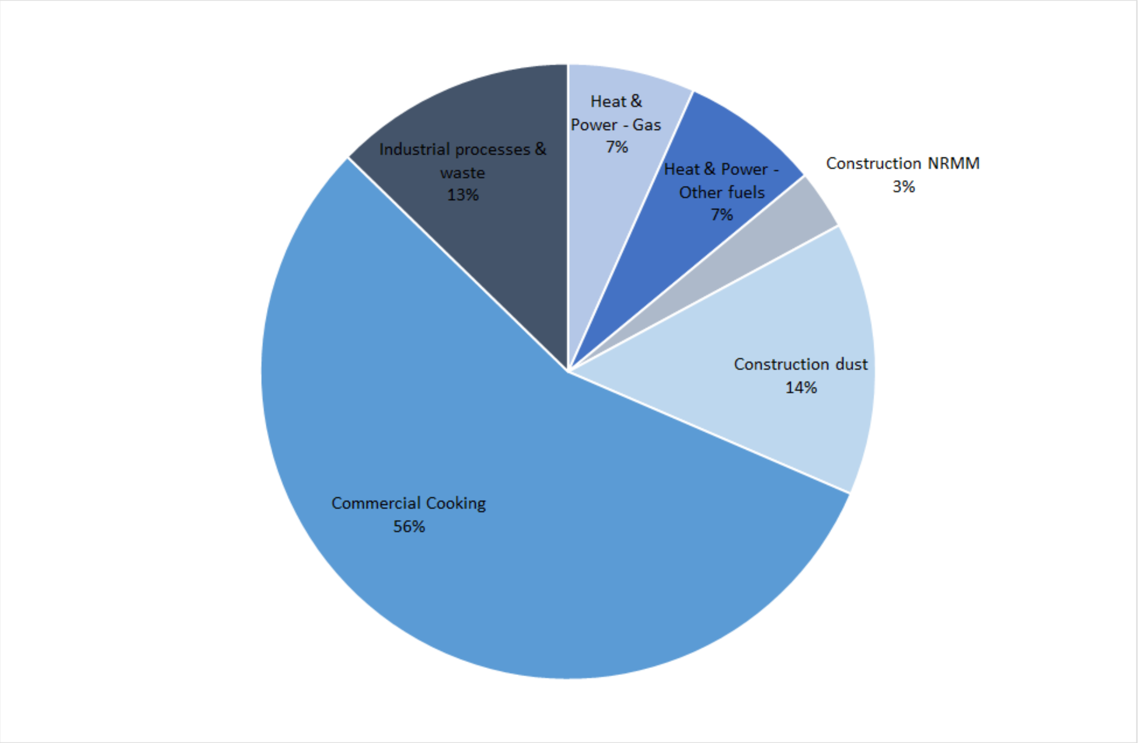


Figure 8.13: Average breakdown of industrial $PM_{2.5}$ concentrations at receptor locations

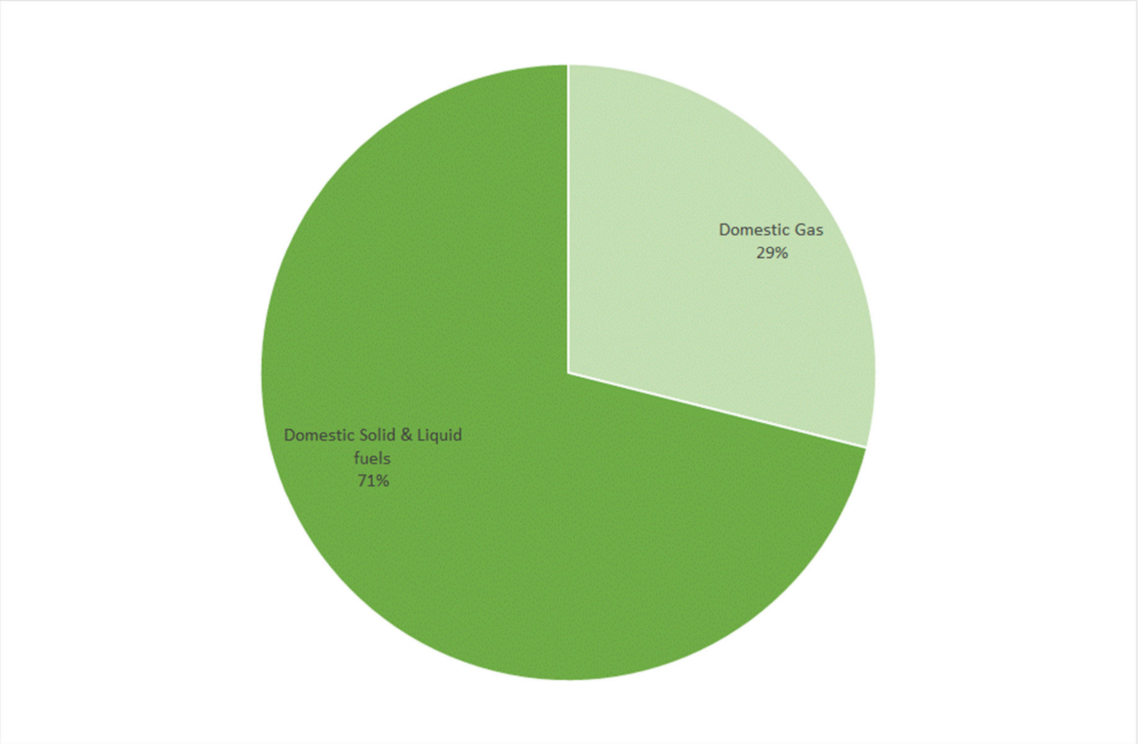


Figure 8.14: Average breakdown of domestic $PM_{2.5}$ concentrations at receptor locations

8.3. Air pollution measures

Table 8.1 shows measures for the tool, as agreed with the project team. Measures with local geographical extents were selected based on the impact of local measures and the level of local authority control for source emissions.

Table 8.1: Summary of tool measures

Type of measure	Source groups affected	Geographical extents	Pollutants
Vehicle electrification	Private vehicles Taxis LGVs Buses	Lambeth Southwark Rest of London	NO_x & NO_2
ULEZ compliance rate	Private vehicles LGVs		
Change vehicle flows	Private vehicles Taxis LGVs Buses HGVs		NO_x, NO_2, PM_{10} & $PM_{2.5}$
Change in domestic emissions	Domestic gas Domestic solid and liquid fuels	Lambeth Southwark Rest of London	NO_x, NO_2, PM_{10} & $PM_{2.5}$
Change in industrial emissions	Construction NRMM	Lambeth Southwark Rest of London	NO_x, NO_2, PM_{10} & $PM_{2.5}$
	Construction dust		PM_{10} & $PM_{2.5}$
	Commercial cooking		
	Heat & Power – Gas	Whole of London	NO_x, NO_2, PM_{10} & $PM_{2.5}$
	Heat & Power – Other fuels		
	Industrial processes and waste		
Change in other transport emissions	Other transport	Whole of London	NO_x, NO_2, PM_{10} & $PM_{2.5}$
Change in miscellaneous emissions	Miscellaneous		

8.4. Derivation of secondary NO_2 factors

The contribution of source groups to NO_x, PM_{10} and $PM_{2.5}$ concentrations is linear, such that a 50% reduction in emissions from a source would lead to a 50% reduction in contribution of the source group to total concentrations of these pollutants. Consequently results from the source apportionment modelling are used directly in the tool's calculation of the impact of measures.

Total NO_2 concentrations will be dependent on direct emissions of the pollutant form sources, primary NO_2, and additional component created from chemical reactions of nitrogen oxide (NO) with ozone in the atmosphere. This secondary component will be dependent on the source characteristics, the distance and relative locations of sources and receptors, and the total concentrations of NO_x and NO_2.

In order for the tool to estimate total NO_2 concentrations, we explicitly modelled a number of measures using the ADMS-Urban chemistry, in order to calculate factors for NO conversion as input to the tool. These measures were modelled in detail:

- 25% and 75% reduction in domestic gas combustion in Lambeth, Southwark and the rest of London
- 25% and 75% reduction in domestic solid and liquid fuels combustion in Lambeth, Southwark and the Rest of London
- 25% and 75% reduction in industrial heat and power gas combustion across the whole of London
- 25% and 75% reduction in industrial heat and power other fuels combustion across the whole of London
- 25% and 75% reduction in road traffic in Lambeth, Southwark and the rest of London
- 25% and 75% reduction in private vehicles in Lambeth, Southwark and the rest of London
- 25% and 75% reduction in HGVs in Lambeth, Southwark and the rest of London
- 50% reduction in Construction Non-Road Mobile Machinery (NRMM) in Lambeth, Southwark and Rest of London
- 50% reduction in industrial processes and waste emissions across the whole of London
- 50% reduction in other transport emissions across the whole of London
- 50% reduction in miscellaneous (accidental fires, agriculture and forestry) emissions across the whole of London
- 100% reduction in road traffic in Greater London (inclusive reduction in Lambeth, Southwark and rest of London)

For each measure, the change in NO_x and primary NO_2 concentrations can be calculated from source apportionment results, therefore the residual change in NO_2 concentration is assigned to change in secondary NO_2 concentrations, from which the secondary NO_2 factors were derived. These secondary NO_2 factors are multipliers for primary NO concentrations i.e. NO before reactions to form NO_2.

The sensitivity and specificity of the secondary factors were identified from the test runs. The main conclusions are:

- The secondary NO_2 factors are receptor and source group dependent, therefore different factors are required for each combination
- The secondary NO_2 factors are dependent on source arrangement and spatial characteristics. The secondary NO_2 factors are typically larger for more distant sources

- There is some dependence for the secondary NO_2 factors on the strength of measure, but is more pronounced for small changes in NO_x concentrations.
- The secondary NO_2 factors are dependent on f-NO_2 but assuming the factors are independent of f-NO_2 provide reasonable estimates.
- For large reductions in NO_x concentrations i.e. 100% reduction in road traffic, the tool overestimates NO_2 concentrations, when compared to detailed chemistry with ADMS-Urban, therefore the impact of measures is likely to be conservative (smaller reduction concentrations). A ceiling was added to the NO_2 / NO_x ratio calculated by the tool to ensure consistency with background levels

The range of secondary NO_2 factors by source group are in shown Figure 8.15. Typically, local sources have large ranges for the secondary NO_2 factors, reflecting that the sources can be close or distant from the receptor, especially for road transport sources. Compared to Southwark sources, Lambeth sources are typically upwind for most receptors, therefore the range of factors for Lambeth source groups is typically larger when compared to Southwark sources. The range of factors for Rest of London or whole of London source groups is much narrower, when compared to the exclusively local source groups.

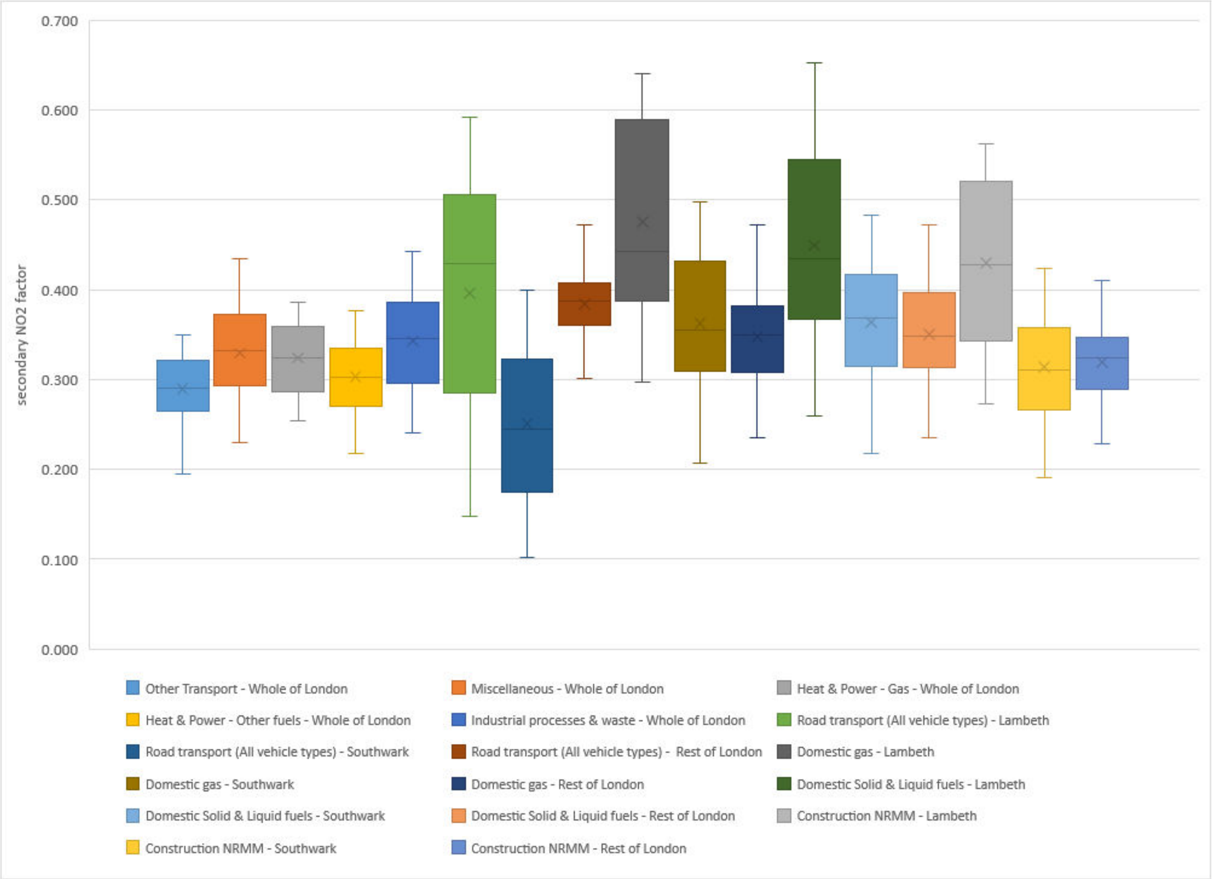


Figure 8.15: Range of secondary NO_2 factors by source group

9. Health impact calculations

Defra's guidance[14] recommends two techniques for assessing the impact of air quality:

- A damage costs approach[15] is recommended for impacts of less than £50 million; and
- An impact pathways approach (IPA) when the air quality impacts are more than £50 million or the main objective of the policy or project is changes in air quality.

In this section, we demonstrate calculations for both approaches.

9.1. Damage costs approach

The damage costs approach assesses the air quality impact through the change in emissions. The Defra guidance provides sector damage costs for $PM_{2.5}$ and NO_x. Table 9.1 and Table 9.2 summarise Lambeth and Southwark emissions for 2022, alongside central damage cost (2022 prices) from Table 10 and 12 of the Defra guidance.

The sectors (source groups_ for the damage costs are included in the tables. For transport emissions, damage costs are sector- and location-specific, therefore the Inner London values are presented alongside Central and Outer London values. For industrial processes and waste emissions, the damage cost values are presented for industrial area sources and for Part A category 6. This category, for large industrial sources, represents emissions from a stack height of between 50 m and 100 m, located in an area with an average population density of more than 1000 persons per square km.

The modelled emissions for SEL CHP, located close to the Southwark boundary, are approximately half the total industrial process and waste $PM_{2.5}$ emissions for Southwark and approximately three times the borough's sector NO_x emissions.

As described in Section 6, between the model set-up for 2019 and 2022, we only modified road transport emissions. The change in modelled emissions is between 3 tonnes and 3.5 tonnes per borough for $PM_{2.5}$ and approximately 230 tonnes per borough for NO_x. Applying the damage cost values for Inner London road emissions gives a damage cost *saving* of between £15 million and £16 million. Note that the damage costs calculations consider the mortality, morbidity and non-health impacts of air pollution.

---

[14] https://www.gov.uk/government/publications/assess-the-impact-of-air-quality

[15] https://www.gov.uk/government/publications/assess-the-impact-of-air-quality/air-quality-appraisal-damage-cost-guidance

Table 9.1: $PM_{2.5}$ emissions and central damage costs by source group, 2022

Source group	**Lambeth $PM_{2.5}$ (tonne/y)**	**Southwark $PM_{2.5}$ (tonne/y)**	**Central damage cost (£/tonne)**
Private vehicles	6.44	6.47	*(Road Inner)* 450,215 *(Road Central)* 472,656 *(Road Outer)* 246,942
LGVs	2.23	2.40	
Taxis	0.31	0.51	
Buses	1.50	1.65	
HGVs	1.42	1.33	
Domestic gas	5.95	4.85	*(Domestic)* 84,629
Domestic solid and liquid fuels	13.43	9.96	
Construction NRMM	1.27	1.26	*(Off road)* 53,014
Construction dust	3.48	5.72	
Commercial cooking	13.08	22.61	*(Commercial)* 59,509
Heat & Power – Gas	1.95	3.36	
Heat & Power – Other fuels	1.40	2.74	
Industrial processes & waste	2.69	2.51	*(Part A cat 6)* 17,707 *(Area)* 76,354
Other transport	1.23	3.76	*(Rail Inner)* 421,032 *(Rail Central)* 428,863 *(Rail Outer)* 238,024
Miscellaneous	1.96	2.52	*(Other)* 76,354

Table 9.2: NO_x emissions and central damage costs by source group, 2022

Source Group	**Lambeth NO_x (tonne/y)**	**Southwark NO_x (tonne/y)**	**Central damage cost (£/tonne)**
Private vehicles *(not ULEZ compliant)*	46.3	31.1	*(Road Inner)* 60,239 *(Road Central)* 63,239 *(Road Outer)* 33,064
Private vehicles *(ULEZ compliant)*	67.8	76.2	
LGVs *(not ULEZ complaint)*	22.3	19.7	
LGVs *(ULEZ compliant)*	25.5	29.7	
Taxis *(Internal Combustion Engines)*	9.3	15.6	
Taxis *(Zero Emissions Capable)*	0.2	0.4	
Buses	24.1	23.3	
HGVs	34.0	26.3	
Domestic gas	81.2	62.4	*(Domestic)* 12,881
Domestic solid and liquid fuels	3.7	2.7	
Construction NRMM	52.4	54.0	*(Off road)* 7,881
Heat & Power – Gas	183.1	316.0	*(Commercial)* 16,583
Heat & Power – Other fuels	21.9	43.7	
Industrial processes & waste	5.3	9.2	*(Part A cat 6)* 4,356 *(Area)* 8,635
Other transport	47.4	147.4	*(Rail Inner)* 56,808 *(Rail Central)* 56,456 *(Rail Outer)* 33,029
Miscellaneous	0.9	1.3	*(Other)* 3,678

9.2. Impact pathways approach - local mortality burden

The Defra guidance considers an Impact Pathways Approach (IPA) the best practice approach of valuing changes in air quality. This approach requires output from dispersion modelling, e.g. ADMS-Urban modelling, to estimate the impact of changes in air pollutant concentrations.

Local mortality burden of air pollution calculations consider the health impact of long-term (chronic) exposure. They include the calculation of the number of deaths attributable to air pollution, the associated life-years lost and economic cost based annual average concentrations of NO_2 and $PM_{2.5}$.

The mortality burden is assessed using the approach set out in Appendix A of the Public Health England guidance *Estimating local mortality burdens associated with particulate air pollution (April 2014)*[16]. This guidance uses concentration response functions (CRFs), which relate the increased risk of mortality to a given change in pollutant concentrations; specifically, it assumes that an increment of 10 µg/m³ in the annual concentration of $PM_{2.5}$ will increase the mortality risk by 6%.

The mortality burden of air quality will actually be a consequence of exposure to both NO_2 and $PM_{2.5}$. The 2018 COMEAP report *Associations of long-term average concentrations of nitrogen dioxide with mortality*[17] recommends revised CRFs for anthropogenic $PM_{2.5}$ and NO_2, which are adjusted from the single-pollutant CRFs to avoid double counting air quality effects from different pollutants. The report recommends using pairs of CRFs for $PM_{2.5}$ and NO_2 taken from four studies, as shown in Table 9.3, with the results from the two pollutants added for each study.

Table 9.3: Coefficients for use in burden calculations

Pollutant	Jerrett et al (2013)	Fischer et al (2015)	Beelen et al (2014)	Crouse et al (2015)
NO_2	1.019	1.016	1.011	1.020
$PM_{2.5}$	1.029	1.033	1.053	1.019

We carried out mortality burden calculations for Lower Layer Super Output Areas (LSOAs), each representing an area with a population of approximately 1,500. There are 344 LSOAs covering the scheme area. The Office for National Statistics (ONS) publishes population[18, 19] and death data split by age for each LSOA[20]; data for 2019 were used for the calculations.

---

[16] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/332854/PHE_CRCE_010.pdf

[17] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/734799/COMEAP_NO2_Report.pdf

[18] https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/lowersuperoutputareamidyearpopulationestimates

[19] https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationestimatesforukenglandandwalesscotlandandnorthernireland

[20] https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/adhocs/12626deathsbylowerlayersuperoutputarealsoaenglandandwalesmidyear2001to2019

For each LSOA, the relative risk for each pollutant wass calculated as

$$RR(c) = R^{c/10} ,$$

where R is the relative risk, as given in Table 9.3, and c is the average pollutant concentration for that LSOA calculated from the concentration contour maps, presented in Sections 7.2 and 8.1.

The attributable fraction was then calculated as

$$AF = (RR-1)/RR.$$

The number of attributable deaths in each LSOA was then calculated by multiplying the attributable fraction by the number of deaths over 30 years of age. The total number of attributable deaths is the sum of the attributable deaths in each LSOA.

The total loss in life-years due to air pollution for each LSOA was calculated by multiplying the attributable deaths for each 5-year age band by the corresponding expected life expectancy for each age group. The 2017–2019 life expectancy data for Lambeth and Southwark were taken from the ONS[21].

The economic cost was calculated by multiplying the life-years lost by a value for a life year lost. The recommended value in the Defra guidance[22] is £50,800 at 2022 prices.

Table 9.4 summarises mortality burden estimates by borough for 2019 and 2022, at 2022 prices.

The estimated number of attributable deaths is calculated to be between 92 and 126 deaths per borough across the two years. The total loss in life-years due to air pollution is between 1497 and 2030 life-years per borough. The estimated economic cost is between £76 million and £107 million per borough, at 2022 prices.

The estimated reduction local mortality burden between the 2019 and 2022 modelled concentrations is between 7 and 11 deaths per borough, 119 and 200 life-years lost, and an economic cost *saving* of between £6.0 million and £10.1 million. Note that this calculation considers the mortality burden of long-term exposure.

---

[21] https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/healthandlifeexpectancies/datasets/lifeexpectancyestimatesallagesuk

[22] https://www.gov.uk/government/publications/assess-the-impact-of-air-quality/air-quality-appraisal-impact-pathways-approach

Table 9.4: Summary of mortality burden calculations

Year	Borough	Metric	Air pollution burden coefficients			
			Beelan *et al* (2014)	**Crouse *et al* (2015)**	**Fischer *et al* (2015)**	**Jerrett *et al* (2013)**
2019	Lambeth	Attributable Deaths	126	105	113	117
		Life-years lost	2030	1687	1821	1890
		Economic cost (£, 2022 prices)	103,137,942	85,692,168	92,513,893	96,023,404
	Southwark	Attributable Deaths	123	104	112	116
		Life-years lost	2101	1775	1902	1980
		Economic cost (£, 2022 prices)	106,736,661	90,173,897	96,598,905	100,574,983
2022	Lambeth	Attributable Deaths	119	93	103	106
		Life-years lost	1911	1497	1663	1707
		Economic cost (£, 2022 prices)	97,094,404	76,066,511	84,461,566	86,691,724
	Southwark	Attributable Deaths	116	92	102	105
		Life-years lost	1976	1575	1734	1786
		Economic cost (£, 2022 prices)	100,358,865	80,017,004	88,100,276	90,728,637

APPENDIX A: Summary of ADMS-Urban

ADMS-Urban is a scientifically advanced but practical air pollution modelling tool, which has been developed to provide high resolution calculations of pollution concentrations for all sizes of study area relevant to the urban environment. The model can be used to look at concentrations near a single road junction or over a region extending across the whole of a major city. ADMS-Urban is used worldwide to assess air quality impact for a wide range of planning and policy studies, incorporating elements such as Low Emission Zones, traffic management, clean vehicle technologies and modal shift. In the UK, it is used extensively for air quality review and assessment carried out by local government.

The following is a summary of the capabilities and validation of ADMS-Urban. More details can be found on the CERC web site[23].

ADMS-Urban is a development of the Atmospheric Dispersion Modelling System (ADMS), which has been developed to investigate the impacts of emissions from industrial facilities. ADMS-Urban allows full characterisation of the wide variety of emissions in urban areas, including an extensively validated road traffic emissions model. It also includes a number of other features, which include consideration of:

- the effects of vehicle movement on the dispersion of traffic emissions;
- the behaviour of material released into street-canyons;
- the chemical reactions occurring between nitrogen oxides, ozone and Volatile Organic Compounds (VOCs);
- the pollution entering a study area from beyond its boundaries;
- the effects of complex terrain on the dispersion of pollutants;
- the effects of the urban canopy on the dispersion of pollutants; and
- the effects of a building on the dispersion of pollutants emitted nearby.

Further details of these features are provided below.

Studies of extensive urban areas are necessarily complex, requiring the manipulation of large amounts of data. To allow users to cope effectively with this requirement, ADMS-Urban runs in Windows 10 and Windows 8 environments. The manipulation of data is further facilitated by the ADMS-Urban Mapper, which allows for the visualisation and manipulation of geospatial information, and by the CERC Emissions Inventory Toolkit, EMIT.

---

[23] https://www.cerc.co.uk/environmental-software/ADMS-Urban-model.html

Dispersion Modelling

ADMS and ADMS-Urban use boundary layer similarity profiles to parameterise the variation of turbulence with height within the boundary layer, and the use of a skewed-Gaussian distribution to determine the vertical variation of pollutant concentrations in the plume under convective conditions.

The main dispersion modelling features of ADMS-Urban are as follows:
- ADMS-Urban is an **advanced dispersion model** in which the boundary layer structure is characterised by the height of the boundary layer and the Monin-Obukhov length, a length scale dependent on the friction velocity and the heat flux at the surface. This method supersedes methods based on Pasquill Stability Categories, as used in, for example, the US models Caline and ISC. Concentrations are calculated hour by hour and are fully dependent on prevailing weather conditions.
- For convective conditions, a **non-Gaussian vertical profile of concentration** allows for the skewed nature of turbulence within the atmospheric boundary layer, which can lead to high concentrations near to the source.
- A **meteorological processor** calculates boundary layer parameters from a variety of input data, typically including date and time, wind speed and direction, surface temperature and cloud cover. Meteorological data may be raw, hourly averaged or statistically analysed data.

Emissions

Emissions into the atmosphere across an urban area typically come from a wide variety of sources. There are likely to be emissions from road traffic, as well as from domestic heating systems and industrial emissions from chimneys. To represent the full range of emissions configurations, the explicit source types available within ADMS-Urban are:
- **Roads**, for which emissions are specified in terms of vehicle flows and the additional initial dispersion caused by moving vehicles is also taken into account.
- **Industrial points**, for which plume rise and stack downwash are included in the modelling.
- **Areas**, where a source or sources is best represented as uniformly spread over an area.
- **Volumes**, where a source or sources is best represented as uniformly spread throughout a volume.

In addition, sources can also be modelled as a regular grid of emissions. This allows the contributions of large numbers of minor sources to be efficiently included in a study while the majority of the modelling effort is used for the relatively few significant sources.

ADMS-Urban can be used in conjunction with CERC's Emissions Inventory Toolkit, EMIT, which facilitates the management and manipulation of large and complex data sets into usable emissions inventories.

Presentation of Results

The results from the model can be based on a wide range of averaging times, and include rolling averages. Maximum concentration values and percentiles can be calculated where appropriate meteorological input data have been input to the model. This allows ADMS-Urban to be used to calculate concentrations for direct comparison with existing air quality limits, guidelines and objectives, in whatever form they are specified.

ADMS-Urban has an integrated Mapper which facilitates both the compilation and manipulation of the emissions information required as input to the model and the interpretation and presentation of the air quality results provided. ADMS-Urban can also be integrated with ArcGIS or MapInfo.

Complex Effects - Street Canyons

ADMS-Urban incorporates two methods for representing the effect of street canyons on the dispersion of road traffic emissions: a basic canyon method based on the *Operational Street Pollution Model (OSPM)*[24]*,* developed by the Danish National Environmental Research Institute (NERI); and an advanced street canyon module, developed by CERC. The basic canyon model was designed for simple symmetric canyons with height similar to width and assumes that road traffic emissions originate throughout the base of the canyon, i.e. that the emissions are spread across both the road and neighbouring pavements.

The advanced canyon model[25] was developed to overcome these limitations and is our model of choice. It represents the effects of channelling flow along and recirculating flow across a street canyon, dispersion out of the canyon through gaps in the walls, over the top of the buildings or out of the end of the canyon. It can take into account canyon asymmetry and restricts the emissions area to the road carriageway.

---

[24] Hertel, O., Berkowicz, R. and Larssen, S., 1990, 'The Operational Street Pollution Model (OSPM).' *18th International meeting of NATO/CCMS on Air Pollution Modelling and its Applications.* Vancouver, Canada, pp741-749.

[25] Hood C, Carruthers D, Seaton M, Stocker J and Johnson K, 2014. *Urban canopy flow field and advanced street canyon modelling in ADMS-Urban.* 16th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Varna, Bulgaria, September 2014. http://www.harmo.org/Conferences/Proceedings/_Varna/publishedSections/H16-067-Hood-EA.pdf

Complex Effects - Chemistry

ADMS-Urban includes the *Generic Reaction Set (GRS)*[26] atmospheric chemistry scheme. The original scheme has seven reactions, including those occurring between nitrogen oxides and ozone and parameterisations of the large number of reactions involving a wide range of Volatile Organic Compounds (VOCs). In addition, an eighth reaction has been included within ADMS-Urban for the situation when high concentrations of nitric oxide (NO) can convert to nitrogen dioxide (NO_2) using molecular oxygen. In addition to the basic GRS scheme, ADMS-Urban also includes a trajectory model[27] for use when modelling large areas. This permits the chemical conversions of the emissions and background concentrations upwind of each location to be properly taken into account.

Complex Effects - Terrain

As well as the effect that complex terrain has on wind direction and, consequently, pollution transport, it can also enhance turbulence and therefore increase dispersion. These effects are taken into account in ADMS-Urban using the FLOWSTAR[28] model developed by CERC.

Complex Effects – Urban Canopy

As wind approaches an urban area of relatively densely packed buildings, the wind profile is vertically displaced. The wind speed and turbulence levels are also reduced within the area of buildings. These effects are taken into account in ADMS-Urban by modifying the wind speed and turbulence profiles based on parameters describing the amount and size of buildings within an urban area.

Data Comparisons – Model Validation

ADMS-Urban is a development of the Atmospheric Dispersion Modelling System (ADMS), which is used throughout the UK by industry and the Environment Agency to model emissions from industrial sources. ADMS has been subject to extensive validation, both of individual components (e.g. point source, street canyon, building effects and meteorological pre-processor) and of its overall performance.

---

[26] Venkatram, A., Karamchandani, P., Pai, P. and Goldstein, R., 1994, 'The Development and Application of a Simplified Ozone Modelling System.' *Atmospheric Environment,* Vol 28, No 22, pp3665-3678.

[27] Singles, R.J., Sutton, M.A. and Weston, K.J., 1997, 'A multi-layer model to describe the atmospheric transport and deposition of ammonia in Great Britain.' In: *International Conference on Atmospheric Ammonia: Emission, Deposition and Environmental Impacts. Atmospheric Environment*, Vol 32, No 3.

[28] Carruthers D.J., Hunt J.C.R. and Weng W-S. 1988. 'A computational model of stratified turbulent airflow over hills – FLOWSTAR I.' Proceedings of Envirosoft. In: *Computer Techniques in Environmental Studies,* P. Zanetti (Ed) pp 481-492. Springer-Verlag.

ADMS-Urban has been extensively tested and validated against monitoring data for large urban areas in the UK and overseas, including London, Birmingham, Manchester, Glasgow, Riga, Cape Town, Hong Kong and Beijing, as part of projects supported by local governments and research organisations. A summary of model validation studies is available online[29]. CERC have co-authored[30] a number of papers presenting results from ADMS-Urban, and other organisations have published the outcomes of their applications of the model[31].

---

[29] www.cerc.co.uk/Validation

[30] www.cerc.co.uk/CERCCoAuthorPublications

[31] www.cerc.co.uk/CERCSoftwarePublications