Oxford Source Apportionment Study

Report for Oxford City Council
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Abbreviations

Abbreviation	Explanation
AADT	Annual Average Daily Traffic
AQAP	Air Quality Action Plan
AQMA	Air Quality Management Area
AQO	Air Quality Objective
AQS	Air Quality Strategy
ASR	Annual Status Report
AURN	Automatic Urban and Rural Network
BEIS	UK Department for Business, Energy & Industrial Strategy
CAZ	Clean Air Zone
EEA	European Environment Agency
EFT	Emissions Factor Toolkit
EMEP	European Monitoring and Evaluation Programme
GIS	Geographic Information System
HGV	Heavy Goods Vehicle
IAQM	Institute of Air Quality Management
LAQM	Local Air Quality Management
LES	Low Emission Strategy
LEZ	Low Emission Zone
LGV	Light Goods Vehicle
OCC	Oxford City Council
NAEI	National Atmospheric Emissions Inventory
NO_2	Nitrogen dioxide
NOx	Nitrogen oxides (NO + NO_2)
NTEM	National Trip End Model
NTS	National Travel Survey
PHI	Priority Habitat Inventory, a GIS dataset from Natural England
$PM_{2.5}$	Particulate matter 2.5 micrometres or less in diameter
PM_{10}	Particulate matter 10 micrometres or less in diameter
RMSE	Root Mean Square Error
TEMPro	Trip End Model Presentation Program
ZEZ	Zero Emission Zone

1 Introduction

Oxford City Council (OCC) will soon be required to deliver a new Air Quality Action Plan (AQAP) in order to reduce concentrations of air pollutants and exposure to air pollution; thereby positively impacting on the health and quality of life of residents and visitors to the city. It will be developed in recognition of the legal requirement on the local authority to work towards Air Quality Strategy (AQS) objectives under Part IV of the Environment Act 1995 and relevant regulations made under that part and to meet the requirements of the Local Air Quality Management (LAQM) statutory process. The AQAP measures are intended to be targeted towards the predominant sources of emissions within OCC's area. A source apportionment exercise is therefore required to identify the percentage source contributions of emission sources in the city.

The city of Oxford, in common with many urban areas throughout the United Kingdom, is subject to poor air quality in some areas of the city, particularly in areas with high levels of road traffic. In the city, nitrogen dioxide (NO_2) continues to be the pollutant of most concern, and transport is the most significant source of emissions of oxides of nitrogen (NOx). The most recent Air Quality Annual Status Report (ASR) reports that road traffic accounts for 75% of NOx emissions in the city.

The current City of Oxford Air Quality Management Area (AQMA) covers a citywide area and was declared for NO_2 in 2010. Air quality in Oxford continues to improve owing in part to the following measures/schemes:

- Introduction of a Low Emission Zone (LEZ) for buses in the city in 2014 and the retrofit of several buses to cleaner Euro VI engines.
- In January 2019, Oxford City Council, and Oxfordshire County Council published updated proposals for a Zero Emission Zone (ZEZ) in Oxford city centre. From 2020, under the proposals, all non-zero emission vehicles could be banned during certain hours from parking and loading on the public highway in an inner zone, while in a larger zone the requirement will be Euro VI for buses. Citywide taxi emissions standards will apply from 2020, with increasingly improving standards to 2025.

This study will focus on concentrations of NO_2, the main pollutant of concern, however particulate matter (PM_{10} and $PM_{2.5}$) will also be included in the emissions modelling and a complementary PM source apportionment provided. These dispersion model outputs will be used in conjunction with Defra air pollution background concentration maps to:

- Carry out source apportionment to understand the contribution of all sources of emissions to exceedances of the air quality objectives within the AQMA.
- Identify the reduction in pollutant emissions required to attain the NO_2 annual mean objective within the AQMA to determine the scale of effort likely to be required.

Oxford City Council and Oxfordshire County Council are seeking to introduce a new LEZ for buses to be a minimum of Euro VI standard. The Low Emission Zone aims to improve air quality by reducing toxic emissions as part of the councils' Zero Emission Zone proposals.[1] Source apportionment will therefore be carried out for two scenarios:

- A baseline 2018 fleet generated using RapidEMS/pyCOPERT and localised bus information.
- A fleet which assumes all buses in the modelling domain have been upgraded to Euro VI standard.

The results will then be compared to determine the estimated reductions in emissions, as well as total modelled concentrations of NOx, PM_{10} and $PM_{2.5}$ arising from the Euro VI bus upgrades. In order to correspond with LAQM guidance, we will focus on localised pollution hotspots with an emphasis on locations where relevant human exposure is present.

[1] https://www.oxford.gov.uk/news/article/1088/new_low_emission_zone_for_buses_in_oxford

2 Method Statement

2.1 Update of existing model

Emission and concentration outputs representative of 2018 were generated within the City of Oxford AQMA. This was achieved by updating the 2015 base year scenario from the previous Oxford Zero Emission Zone Feasibility and Implementation Study[2] using the following methodology:

- Traffic flows (AADT) were scaled using the Trip End Model Presentation Program (TEMPro)[3]; the growth factor from 2015 to 2018 was **1.0331**;
- Road traffic emissions were generated by updating the vehicle fleet to be representative of 2018 and applying the most up to date COPERT[4] emissions factors;
- City wide concentration contour maps were generated using Ricardo's RapidAIR modelling system and application of 2018 meteorological data;
- The most up to date 2018 Defra air pollution background concentration maps were used; and
- The model was validated using 2018 air quality monitoring data.[5]

2.2 Air dispersion modelling methodology

The RapidAIR Urban Air Quality Modelling Platform was used to predict air pollutant concentrations for this study. This is Ricardo Energy & Environment's proprietary modelling system developed for urban air pollution assessment. It was set up for this study based on the model that was used previously in the Oxford Zero Emission Zone Feasibility and Implementation Study[2].

RapidAIR has been developed to provide graphic and numerical outputs which are comparable with other models used widely in the United Kingdom. The model approach is based on three elements:

- Road traffic emissions model conducted using fleet specific COPERT 5 (via the Defra EfT) algorithms to prepare grams/kilometre/second (g km^{-1} s^{-1}) emission rates of air pollutants originating from traffic sources.
- Convolution of an emissions grid with dispersion kernels derived from the USEPA AERMOD[6] model, at resolutions ranging from 1 m to 20 m. AERMOD provides the algorithms which govern the dispersion of the emissions and is an accepted international model for road traffic studies.
- The kernel based RapidAIR model running in GIS software to prepare dispersion fields of concentration for further analysis with a set of decision support tools coded by us in Python/arcpy.

RapidAIR includes an automated meteorological processor based on AERMET which obtains and processes meteorological data of a format suitable for use in AERMOD. Surface meteorological data is obtained from the NOAA online repository[7] and upper air data is downloaded from the NOAA Radiosonde database.[8]

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[2] Oxford Zero Emission Zone Feasibility and Implementation Study, Ricardo Energy & Environment, July 2017, available online at https://www.oxford.gov.uk/downloads/file/4019/zero_emission_zone_feasibility_study_october_2017
[3] https://www.gov.uk/government/publications/tempro-downloads
[4] http://naei.beis.gov.uk/data/ef-transport
[5] https://www.oxford.gov.uk/downloads/file/6429/air_quality_annual_status_report_2018
[6] https://www3.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod
[7] ftp://ftp.ncdc.noaa.gov/pub/data/noaa
[8] https://www.esrl.noaa.gov/roabs/

The model produces high resolution concentration fields at the city scale (down to a 1 m scale) so is ideal for spatially detailed compliance modelling. The combination of an internationally recognised model code and careful parameterisation matching international best practice makes RapidAIR ideal for this study. A validation study has been conducted in London using the same datasets as the 2011 Defra air quality model inter-comparison study.[9] Using the LAEI (London Atmospheric Emissions Inventory) 2008 data and the measurements for the same time period the model performance is consistent (and across some metrics performs better) than other modelling solutions currently in use in the UK.[10] This validation study has been published in *Environmental Modelling and Software*, in partnership with the University of Strathclyde.[11]

2.3 Model validation for identification of hotspots

The initial model was used for identification of NO_2 hotspots for source apportionment (see Section 2.4) and was run for a national fleet generated in RapidEMS/pyCOPERT.

A combination of automatic monitoring and diffusion tube NO_2 measurements within the City of Oxford AQMA (63 in total) were used for model verification. The modelled vs measured concentrations at each of the monitoring locations were compared. Refinements were subsequently made to the model inputs to improve model performance where possible, and a linear adjustment factor of **0.9989** was calculated for the road emissions component of the NOx model (see Appendix 1).

Total NOx was calculated as the sum of the adjusted NOx road contribution from RapidAIR and the Defra 2018 background maps (with main road sources removed from the background map). Total NO_2 concentrations were derived using the following equation (see Appendix 1 for further details):

$$(NO_2 \text{ in } \mu g/m^3) = -0.001221(NOx \text{ in } \mu g/m^3)^2 + 0.5813(NOx \text{ in } \mu g/m^3) + 3.919$$

To evaluate model performance and uncertainty, the Root Mean Square Error (RMSE) for the observed vs predicted NO_2 annual mean concentrations was calculated, as detailed in Technical Guidance LAQM.TG(16). This guidance indicates that an RMSE of up to 4 $\mu g/m^3$ is ideal, and an RMSE of up to 10 $\mu g/m^3$ is acceptable. In this case the RMSE was calculated at **6.5 $\mu g/m^3$**, which is acceptable.

2.4 Selection of locations for source apportionment

Source apportionment allows us to gain a better understanding of the nature of vehicles resulting in exceedances along roads in Oxford. A review was undertaken to determine the most appropriate locations for the source apportionment. This was based on the maximum NO_2 concentration predicted for 2018 within the City of Oxford AQMA, using a national fleet, as well as the measured results at diffusion tube locations in 2018.

Total NO_2 concentrations generated by the 2018 model were used in combination with 2018 monitoring data to identify pollutant hot spot locations within the City of Oxford AQMA at which to conduct source apportionment. Hot spots are areas of high pollutant concentrations where relevant human exposure is present and were identified using the following methodology:

- Monitoring locations which showed a high concentration of NO_2 relative to the national air quality objectives (AQOs).

[9] https://uk-air.defra.gov.uk/research/air-quality-modelling?view=intercomparison

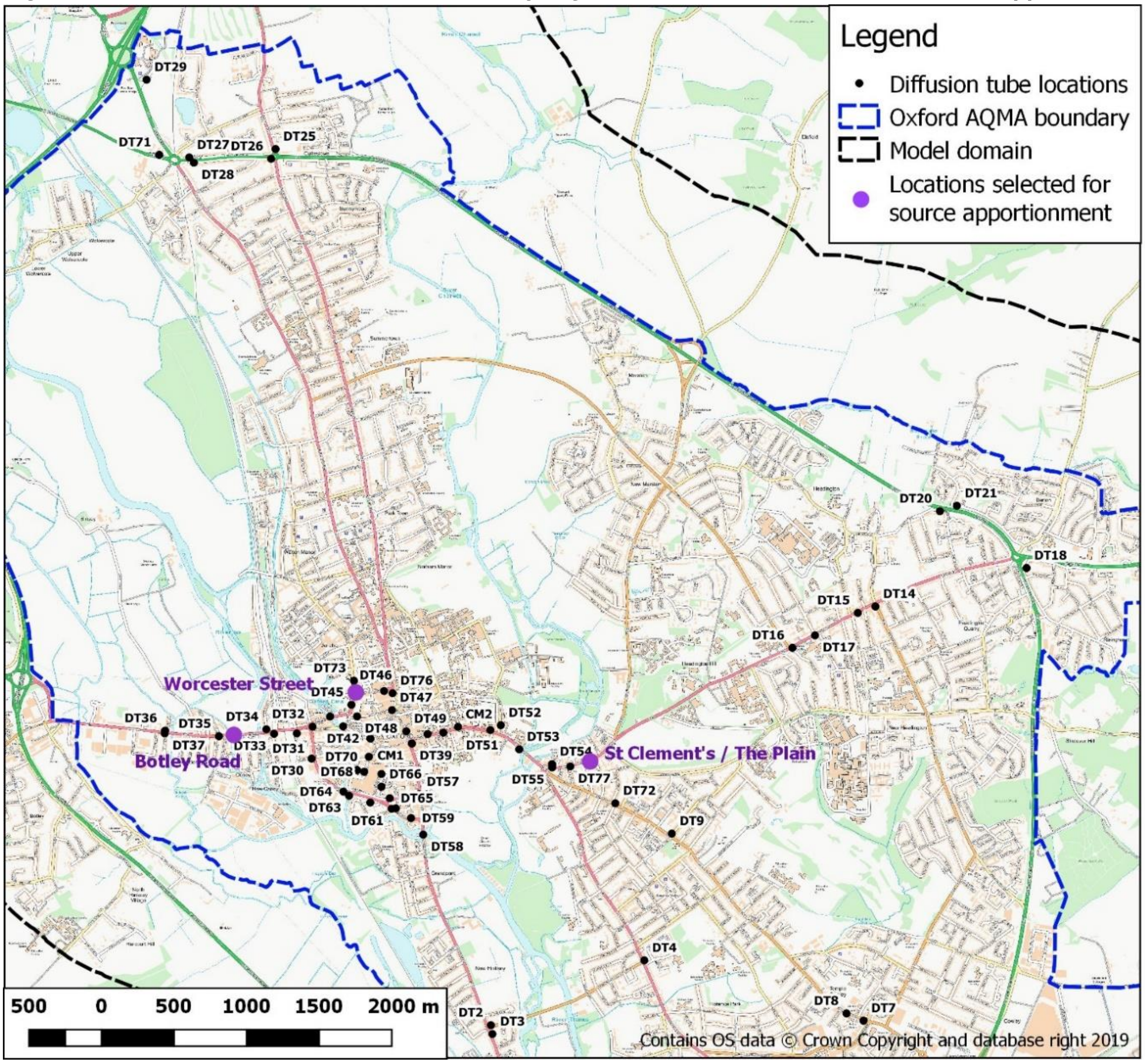
[10] The 2008 LAEI dataset was used in this context as a benchmarking study, to compare the performance of RapidAIR to other modelling systems. The 2008 LAEI dataset was not used as an input in the current modelling study.

[11] Masey, Nicola, Scott Hamilton, and Iain J. Beverland. "Development and evaluation of the RapidAIR® dispersion model, including the use of geospatial surrogates to represent street canyon effects." *Environmental Modelling & Software* (2018). DOI: https://doi.org/10.1016/j.envsoft.2018.05.014

- Extraction of high modelled NO_2 concentrations at locations of relevant exposure.
- Discussion and review of findings with OCC and confirmation of the three locations for source apportionment.

The three locations chosen for source apportionment are shown in Figure 2-1.

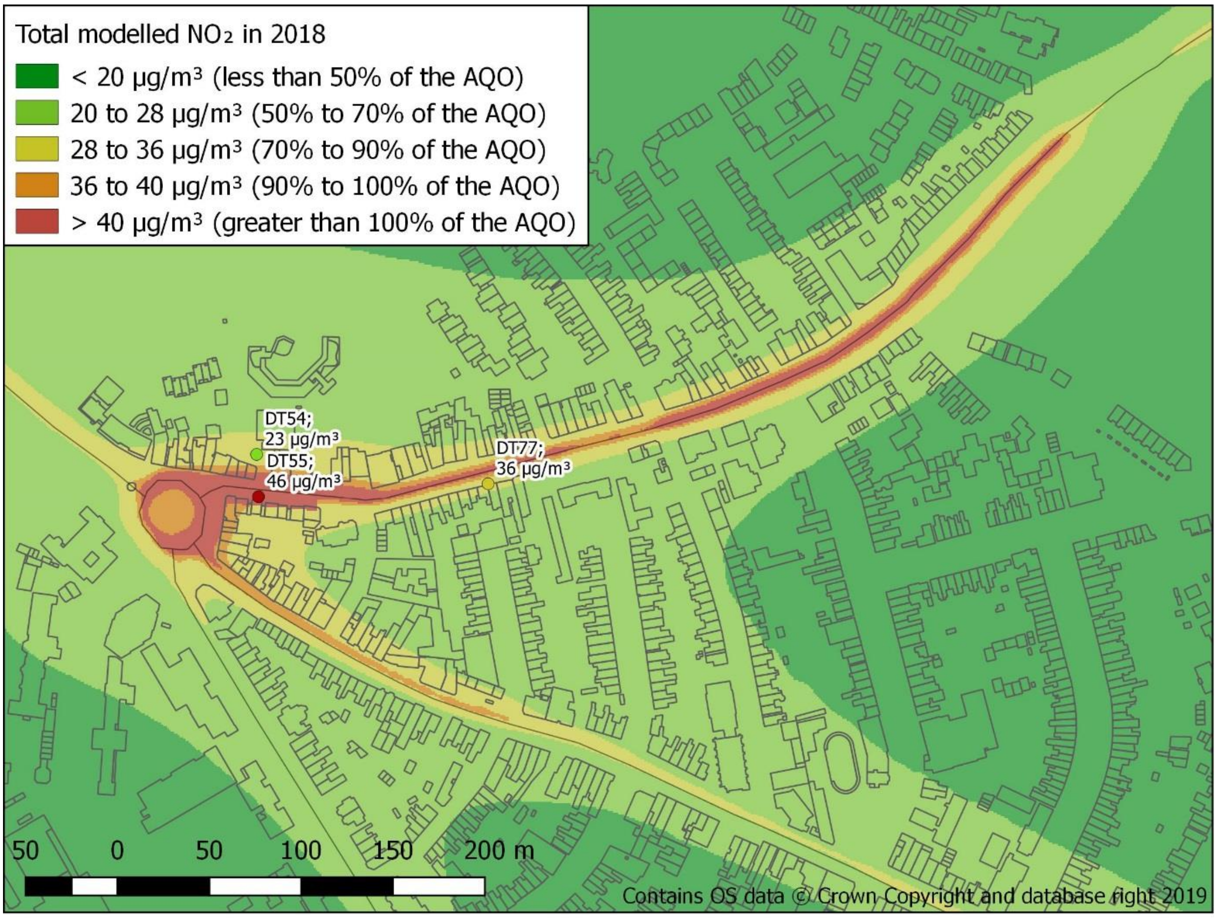
Figure 2-1 Diffusion tubes within the Oxford City AQMA and locations selected for source apportionment



The evidence underpinning the three chosen locations is presented in the text and figures below, which show the modelled concentrations of NO_2 in 2018 (using the national fleet) and diffusion tube locations labelled with the corresponding measured annual mean NO_2 concentration in 2018.

St Clement's / The Plain roundabout. The highest modelled concentrations occur around DT55 (52 μg/m³), for which the measured NO_2 also exceeded the AQO in 2018 (46 μg/m³). This diffusion tube is located in a street canyon and adjacent to a busy roundabout. The figure below shows concentrations above the AQO at locations relevant for human exposure. Source apportionment at the location of DT55 would likely be representative of the rest of St Clement's Street / the A420, where the modelled concentrations remain high.

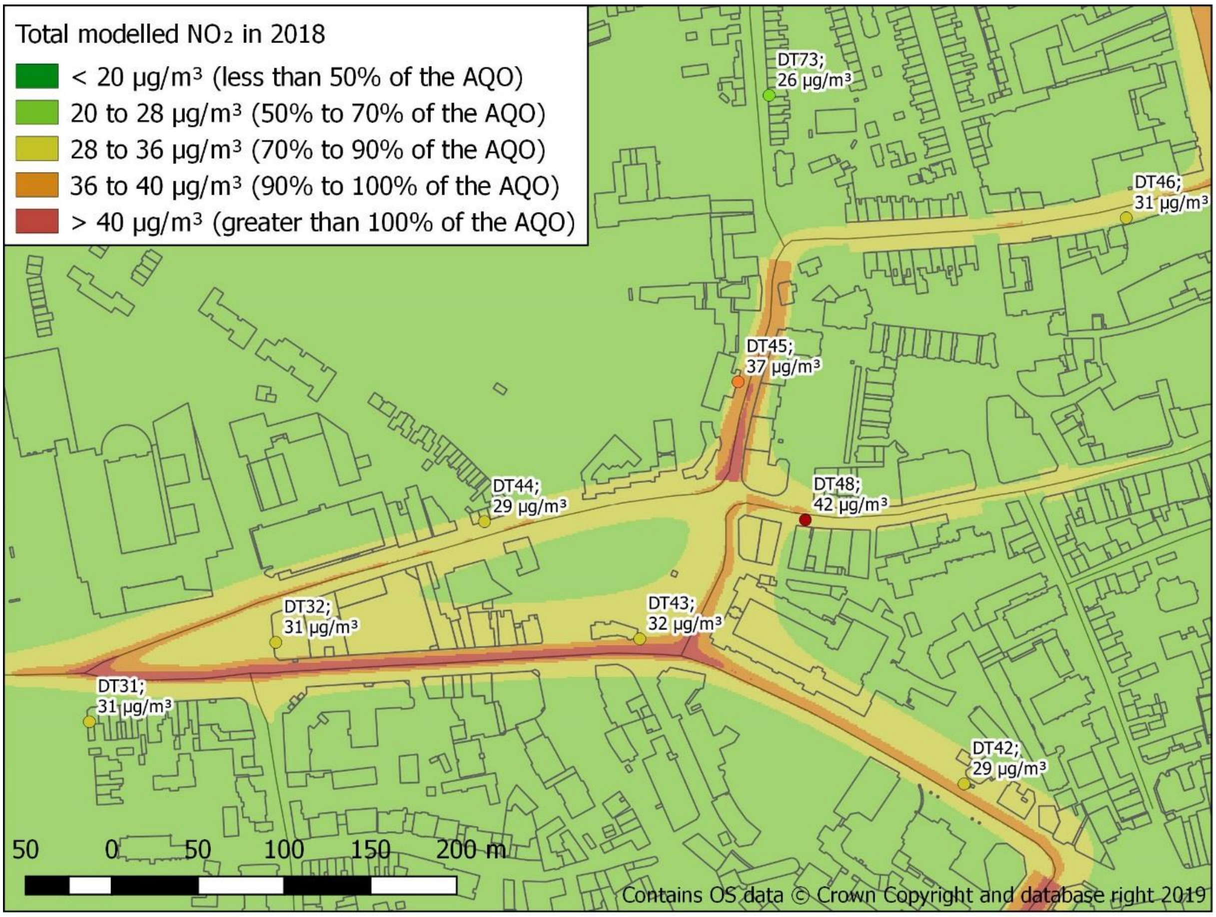
Figure 2-2 Modelled total NO_2 concentrations (2018) at St Clement's / The Plain. Diffusion tubes are labelled with the measured annual mean NO_2 for 2018.



George Street / Park End Street / Worcester Street area. This system of roads showed exceedances of the AQO in the modelling, although the majority of these were in the centre of the road, so are less relevant for human exposure. Diffusion tubes 32, 42, 43, 44 and 48 appear to be in locations with good dispersion (i.e. not in street canyons). DT45 is likely to be in the worst location for dispersion and is in a street canyon; the modelled and measured concentrations were both 37 µg/m³. DT43 is located next to a bar (so relevant for human exposure) and had a high modelled NO_2 concentration (37 µg/m³), however, the measured concentration is lower (32 µg/m³). DT48 had a high measured NO_2 concentration (42 µg/m³) in 2018, but as mentioned the dispersion in the general area appears to be good, which is supported by the modelled results.

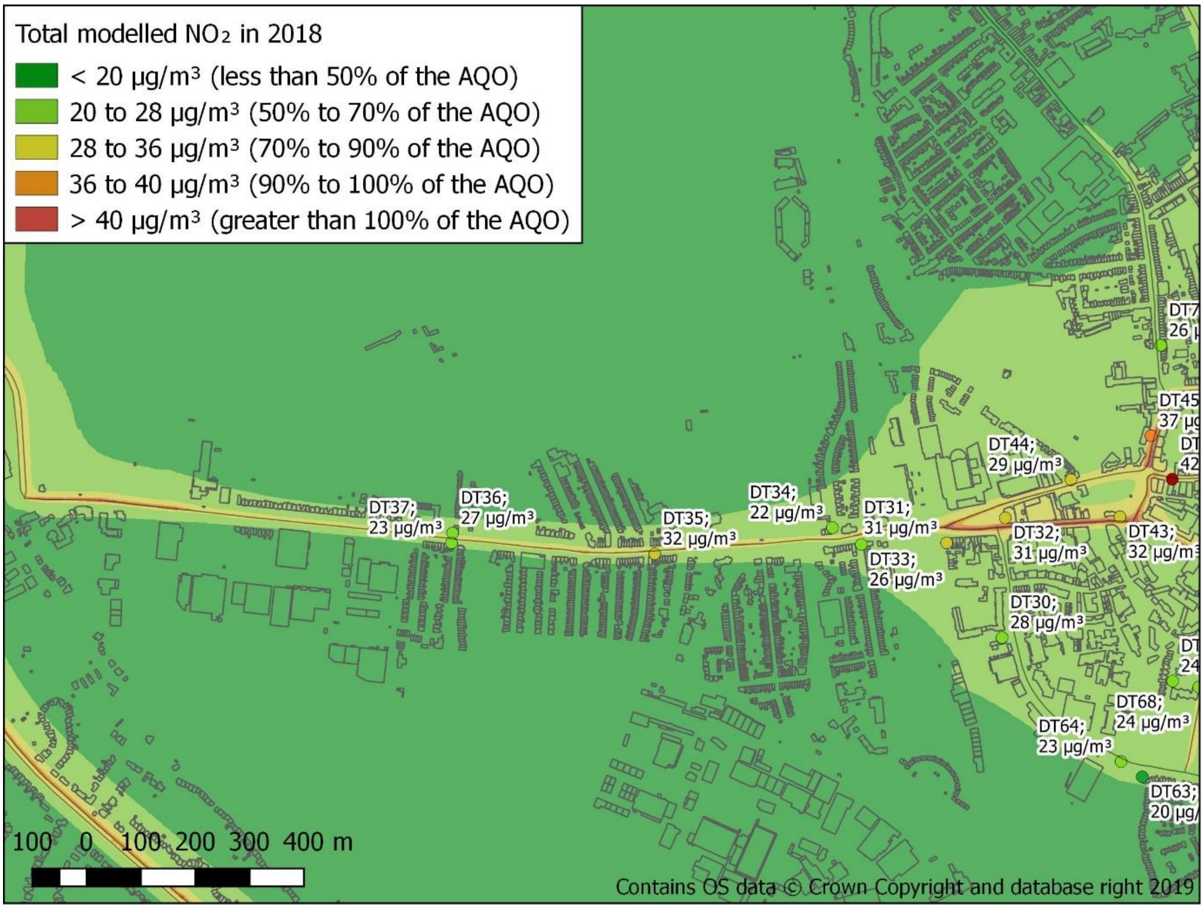
Of all the roads in this figure, source apportionment on the A4144 (Worcester Street, DT45) was our recommendation as it is in a street canyon as well as being a location relevant for human exposure.

Figure 2-3 Modelled total NO_2 concentrations (2018) at George Street, Park End and Worcester Street. Diffusion tubes are labelled with the measured annual mean NO_2 for 2018.



Botley Road. This location was recommended by the Council as a location for source apportionment. Botley Road is one of the major routes into the city with significant levels of traffic and high levels of human exposure from nearby houses. The chosen link had the greatest AADT of the three locations selected for source apportionment. There is regular congestion and queueing which has led to measured NO_2 concentrations within 20% of the AQO.

Figure 2-4 Modelled total NO_2 concentrations (2018) along Botley Road. Diffusion tubes are labelled with the measured annual mean NO_2 for 2018.

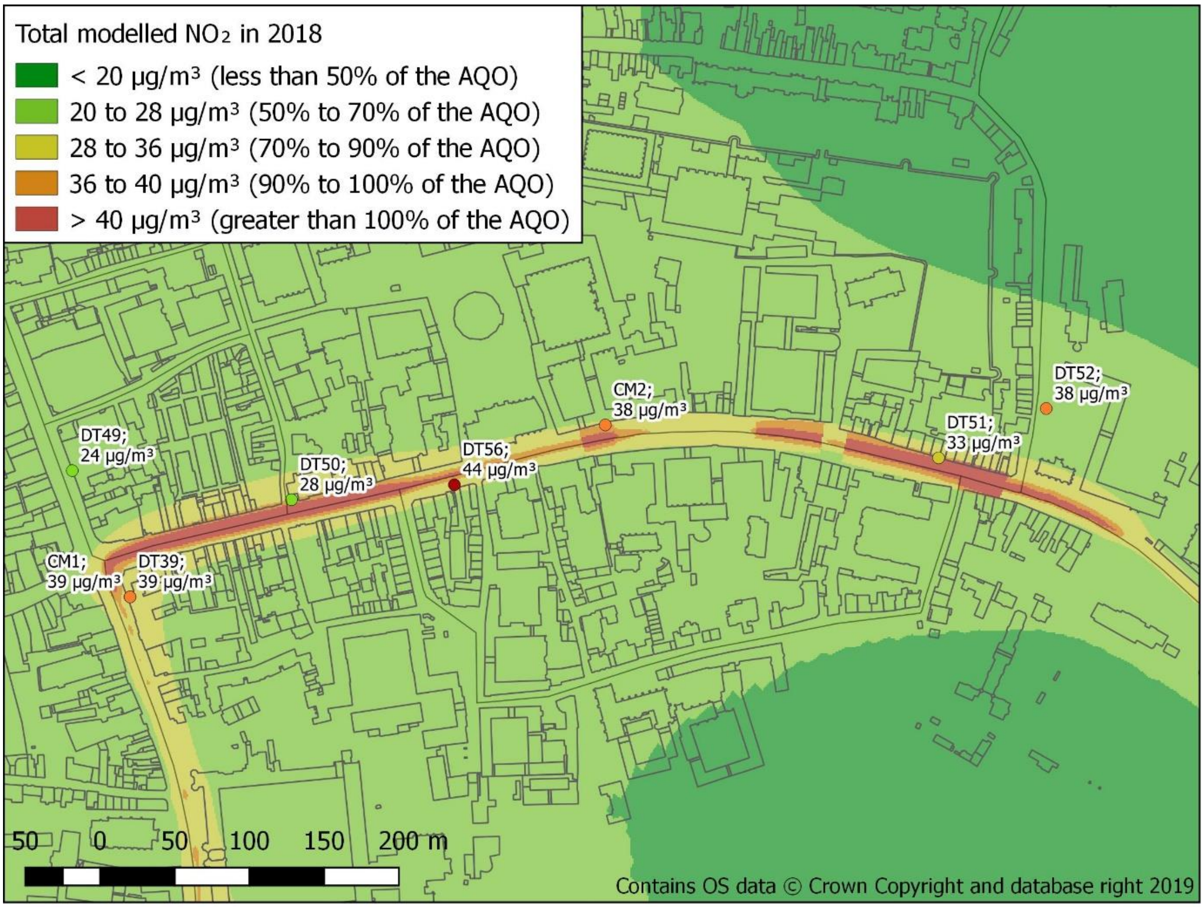


The following locations were also considered for source apportionment:

High Street. On the High Street there are a number of locations that would be suitable for source apportionment. The road link nearest DT51 in the figure below had a modelled concentration of 41 µg/m³ in 2018 and a measured concentration of 33 µg/m³ in 2018. High modelled NO_2 concentrations (greater than 90% of the AQO) extend into buildings around this location, which is relevant for human exposure. Although there are high modelled concentrations around DT50 (38 µg/m³) the measured concentration in 2018 was significantly lower; 28 µg/m³. This is likely due to better dispersion in this location than at DT51. Similarly, CM2 had high modelled and measured concentrations in 2018 (37 µg/m³ and 38 µg/m³ respectively), however, the surrounding area appears to have better dispersion as the concentrations drop off quickly from the diffusion tube location.

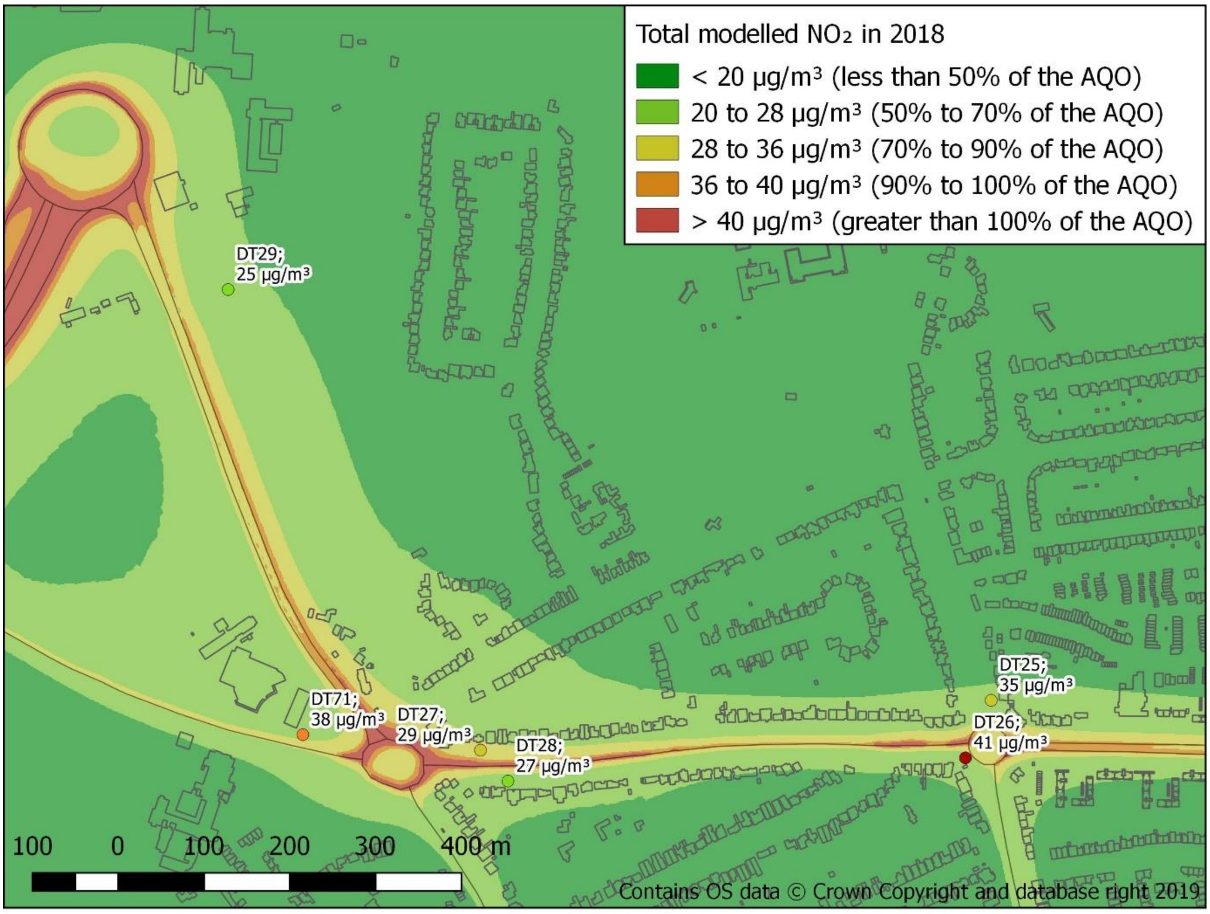
DT39 and DT56 both had very high measured concentrations in 2018 (44 µg/m³ and 39 µg/m³ respectively) however the modelling suggests these concentrations again decrease with distance from the centre of the road. We also anticipated that the source apportionment study would confirm that almost all the emissions along the High Street come from buses. Therefore, other locations were deemed more useful to target.

Figure 2-5 Modelled total NO_2 concentrations (2018) along the High Street. Diffusion tubes are labelled with the measured annual mean NO_2 for 2018.



Roundabouts near Cutteslowe. This location was considered as the NO_2 measurement for DT26 exceeded the AQO in 2018 (41 µg/m³). However, the diffusion tube is on a roundabout; increased NO_2 concentrations would be expected here but the potential for human exposure is low as the exceedances do not extend to the houses nearby. Additionally, the modelled concentrations in 2018 are significantly lower in this location and the surrounding area as shown in the figure below. The location is not in a street canyon and there is good dispersion.

Figure 2-6 Modelled total NO_2 concentrations (2018) at Cutteslowe. Diffusion tubes are labelled with the measured annual mean NO_2 for 2018.

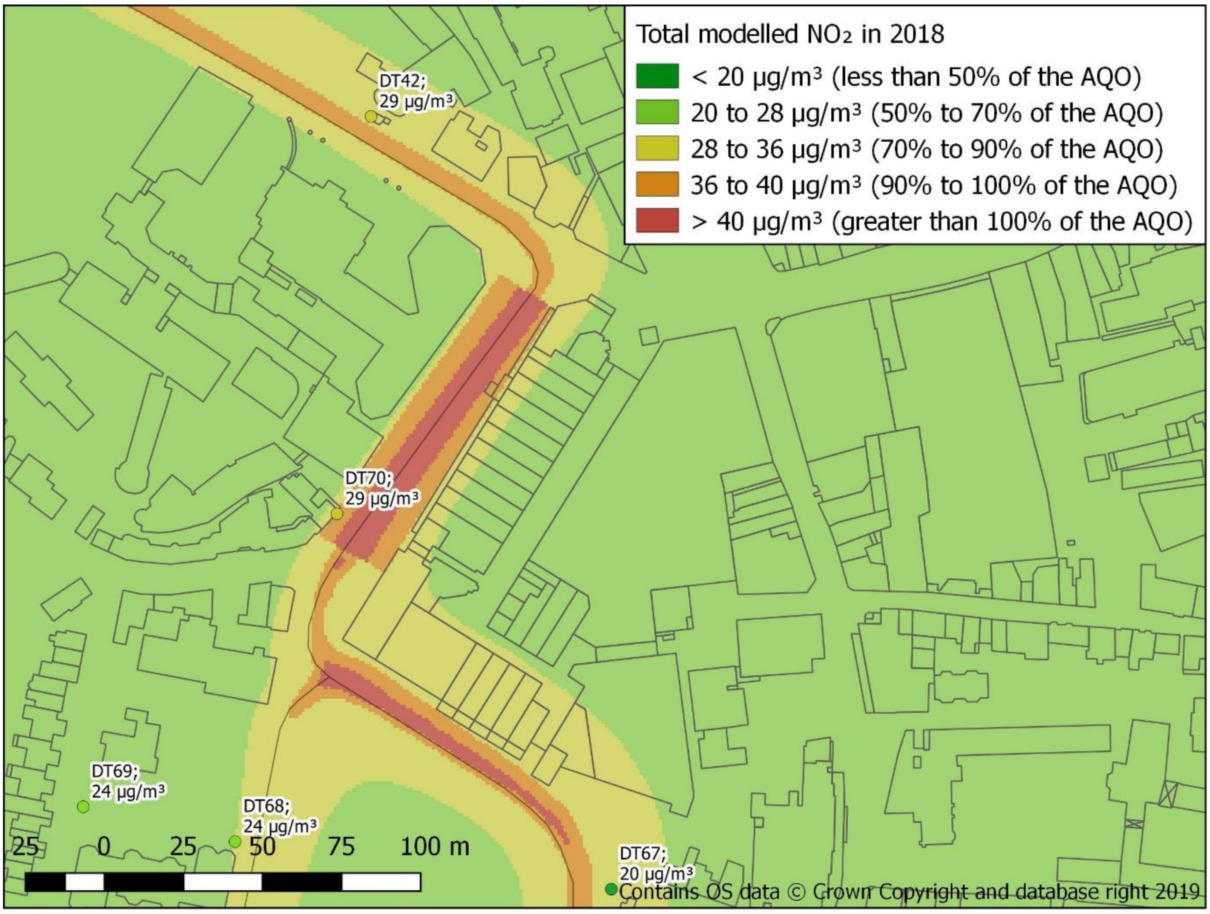


Speedwell Street. Both of the relevant diffusion tubes, DT57 and DT65, had modelled NO_2 concentrations within 10% of the AQO in 2018. Their measured concentrations were 35 µg/m³ and 30 µg/m³ and they are not located in a street canyon. Although the modelled concentrations are high, there appears to be relatively good dispersion in this location, and the exceedances do not extend to the nearby buildings.

Figure 2-7 Modelled total NO_2 concentrations (2018) at Speedwell Street. Diffusion tubes are labelled with the measured annual mean NO_2 for 2018.

Castle Street. DT70 in the figure below had a modelled NO_2 concentration of 38 µg/m³ in 2018, however, the measured concentration was only 29 µg/m³. We have modelled this as a street canyon, but despite the tall buildings the road is quite wide and may allow for better dispersion than the model predicts. The diffusion tube is located adjacent to the Westgate shopping centre and so is relevant for human exposure, which is the main reason why this location was considered.

Figure 2-8 Modelled total NO_2 concentrations (2018) at Castle Street. Diffusion tubes are labelled with the measured annual mean NO_2 for 2018.



2.5 Model validation for source apportionment

Following identification of NO_2 hotspots within the modelling domain, for which the model used a national fleet, the model was refined in order to more accurately represent the situation in Oxford City AQMA. Localised bus information was incorporated from the Oxford ZEZ Feasibility and Implementation Study[2] and additional information was provided directly from Oxford City Council.[12]

Again, a combination of automatic monitoring and diffusion tube NO_2 measurements within the City of Oxford AQMA (63 in total) were used for model verification. The modelled vs measured concentrations at each of the monitoring locations were compared. Refinements were subsequently made to the model inputs to improve model performance where possible, and a linear adjustment factor of **0.9258** was calculated for the road emissions component of the NOx model (see Appendix 2).

To evaluate model performance and uncertainty, the Root Mean Square Error (RMSE) for the observed vs predicted NO_2 annual mean concentrations was calculated, as detailed in Technical Guidance LAQM.TG(16). This guidance indicates that an RMSE of up to 4 $\mu g/m^3$ is ideal, and an RMSE of up to 10 $\mu g/m^3$ is acceptable. In this case the RMSE was calculated at **6.7 $\mu g/m^3$**, which is acceptable.

There are only two monitoring locations for PM_{10} and one monitoring location for $PM_{2.5}$ within the City of Oxford AQMA, and it was therefore not possible to compare measured vs modelled concentrations for PM_{10} or $PM_{2.5}$ to generate an adjustment factor. We have adopted an approach based on Section 7.527 of the Technical Guidance LAQM.TG(16)[13] which suggests that, in the absence of measured data for model verification of a traffic pollutant, it may be appropriate to apply the adjustment factor derived from another traffic pollutant to the pollutant that does not have any monitoring data available. RapidAIR was used to generate PM_{10} and $PM_{2.5}$ concentrations arising from road traffic sources across the study area, and these values were subsequently multiplied by **0.9258** to obtain adjusted PM_{10} and $PM_{2.5}$ road contribution values.

2.6 Source apportionment and determination of required reduction for compliance

Once the pollution hot spots were identified, the source apportionment process was performed using emissions data for the nearest road link to each worst-case receptor. Emission sources were separated into road sources by vehicle type, as well as background sources. Source apportionment of background sources can be found in Appendix 3.

Oxford City Council and Oxfordshire County Council are seeking to introduce a new LEZ for buses to be a minimum of Euro VI standard. Source apportionment was therefore carried out for two scenarios:

- A baseline 2018 fleet generated using RapidEMS/pyCOPERT and localised bus information.
- A fleet which assumes all buses in the modelling domain have been upgraded to Euro VI standard.

Table 2-1 compares the national fleet, Oxford ZEZ fleet and St Clement's fleet for buses.

The source apportionment results are presented as percentage contributions and concentration values in Sections 3.1 and 3.2 for scenarios using a baseline 2018 fleet, and a fleet with all buses upgraded to Euro VI, respectively. The results were then compared to determine the estimated reductions in

[12] Email received from Oxford City Council, 28/11/2019.
[13] https://laqm.defra.gov.uk/documents/LAQM-TG16-February-18-v1.pdf

emissions, as well as total modelled concentrations of NOx/NO_2, PM_{10} and $PM_{2.5}$, arising from the Euro VI bus upgrades.

The modelled pollution hot spot concentrations were compared to the national AQOs in order to determine what reductions are required to achieve compliance, presented in Section 3.3.

Table 2-1 Euro standards for the national, Oxford ZEZ and St Clement's bus fleets

Bus Euro Standard	% of bus fleet		
	National	Oxford ZEZ	St Clement's
Pre-Euro I	0%	0.0%	0.0%
Euro I	0%	0.0%	0.0%
Euro II	2%	0.0%	0.0%
Euro III	10%	0.0%	0.0%
Euro IV	9%	0.0%	0.0%
Euro V EGR	7%	15.6%	10.5%
Euro V SCR	22%	46.6%	31.5%
Euro VI	49%	37.8%	58.0%

Sources of NOx, PM_{10} and $PM_{2.5}$ across the City of Oxford have been apportioned using data from the National Atmospheric Emissions Inventory (NAEI) and are presented in Appendix 4.

3 Results from Source Apportionment

3.1 Source apportionment for the base 2018 year

Source apportionment was completed for the three locations identified in Section 2.4. The analysis for the base 2018 fleet uses data from the Oxford ZEZ feasibility study for the Worcester Street and Botley Road source apportionment locations. To consider the effect of running only Euro VI buses at St Clement's, specific bus information was gathered from bus operators regarding the Euro standards of the buses operating at this location. This information was collected at the end of 2017 and is therefore considered accurate for 2018. The information was fed into RapidEMS and used to generate emissions for buses. All other vehicles were assumed to be the same as the national fleet.

Table 3-1, Table 3-4 and Table 3-7 show the source apportionment in terms of percentage contribution of the major vehicle types to the total modelled vehicular NOx, NO_2, PM_{10} and $PM_{2.5}$ emissions. The percentage emissions are also presented in pie charts.

Table 3-2, Table 3-5 and Table 3-8 show the source apportionment in terms of the amount of modelled NOx, NO_2, PM_{10} and $PM_{2.5}$ originating from each of these sources (in µg m^{-3}).

Table 3-3, Table 3-6 and Table 3-9 show the source apportionment in terms of the amount of measured NO_2 attributed to each of these sources (in µg m^{-3}).

Along **St Clement's Street / The Plain** emissions are dominated by buses, which contribute more than half the emissions for all three pollutants from vehicles. In particular, 69.9% of NOx emissions are attributed to buses. Cars are the next largest contributor at approximately 20 – 30%, followed by LGVs. Reliable taxi information was unavailable for this location; therefore, it is assumed that taxi emissions are included in the emissions from petrol and diesel cars. In terms of contribution to the total modelled concentrations of each pollutant, buses make up more than half the total modelled concentration of NOx/NO_2, with the background contributing just over 20% of total NOx. For PM_{10} and $PM_{2.5}$ the background concentrations are considerably more than the road contribution, which is the case for all three locations. Looking at the breakdown of total measured NO_2 (46.0 µg m^{-3}), the background accounts for 10.5 µg m^{-3} and buses account for 24.8 µg m^{-3}. Diesel cars account for 6.0 µg m^{-3}, however petrol cars only account for 0.7 µg m^{-3}.

On **Worcester Street**, roughly 40 – 50% of the emissions come from cars. Approximately 25% of emissions are from LGVs in the case of NOx and PM_{10}; for $PM_{2.5}$ this rises to 36%. In contrast to St Clement's / The Plain, only 18% of NOx/NO_2 emissions and 9% of PM_{10}/$PM_{2.5}$ emissions are attributed to buses. Rigid HGVs contribute approximately 5% of PM emissions and 8% of NOx emissions. Worcester Street was the only study location with taxi information; taxis and Hackney cabs together attributed to approximately 5% of emissions of all modelled pollutants. Background NOx makes up just over 40% of the total modelled NOx/NO_2 concentration, with cars contributing around 25%. Again, for PM_{10} and $PM_{2.5}$ the background concentrations are considerably greater than the road contribution to the total modelled concentrations. Examining the breakdown of total measured NO_2 (37.0 µg m^{-3}), the background concentration is higher than for St Clement's, at 15.8 µg m^{-3}. Buses account for just 3.9 µg m^{-3} at this location. Diesel cars account for 8.1 µg m^{-3} and LGVs account for 5.3 µg m^{-3}.

For **Botley Road**, cars are again the largest contributor to emissions: 34.9% for NOx/NO_2, 46.4% for PM_{10} and 38.3% for $PM_{2.5}$. Buses contributed around 30% of NOx emissions, falling to just under 20% for PM_{10} and $PM_{2.5}$. LGVs contributed 23.7% and 28.2% of NOx and PM_{10} emissions respectively, but for $PM_{2.5}$ this rose to 37.6%. HGVs were the next largest contributor. Reliable taxi information was unavailable for this location; therefore, it is assumed that taxi emissions are included in the emissions from petrol and diesel cars. Considering the total modelled concentrations, in a similar way to Worcester

Street, background NOx made up around 40% of the total modelled NOx/NO_2. As with the other two locations, background PM_{10} and $PM_{2.5}$ made up nearly the entire modelled concentration of those pollutants. Again, looking at the breakdown of total measured NO_2 (32.0 µg m^{-3}), the background concentration is almost the same as Worcester street: 15.8 µg m^{-3}. Buses account for 5.1 µg m^{-3} of total NO_2, as do diesel cars.

Source apportionment using the national fleet showed that bus NOx emissions on Worcester Street and Botley Road were actually lower using the national bus fleet then when to the Oxford ZEZ bus fleet was used. However, on St Clement's Street the NOx emissions from buses are lower than if the national bus fleet was used. Table 2-1 shows that the relative proportions of Euro VI buses used in the national bus fleet and the St Clement's bus fleet (49% and 58.0% respectively) are greater than those used in the Oxford ZEZ bus fleet (37.8%). The ZEZ bus fleet contains a greater proportion of Euro V buses than the other two bus fleets. This suggests that the upgrade from Euro V to Euro VI brings the reduction in NOx emissions, and in the case of the national bus fleet the larger proportion of Euro VI buses outweighs the small proportions of buses older than Euro V.

General trends include:

- Diesel cars contributed a higher proportion of NOx emissions than petrol cars.
- Rigid HGVs contributed significantly more NOx, PM_{10} and $PM_{2.5}$ emissions than artic HGVs.
- In locations where taxi information was available, diesel taxis contributed a higher proportion of NOx emissions than petrol taxis, and taxis contributed a higher proportion of emissions than Hackney cabs.
- For PM_{10} and $PM_{2.5}$ the background concentrations are considerably more than the road contribution. This is not the case for NOx.

St Clement's / The Plain:

Table 3-1 Source apportionment for all road transports on St Clement's / The Plain (%) for the baseline fleet, 2018

	Cars		Motorcycles	Buses	HGVs (rigid)	HGVs (artic)	LGVs	Total
	Petrol	Diesel						
NOx	2.0%	16.9%	0.1%	69.9%	3.2%	0.1%	7.7%	100.0%
PM_{10}	29.3%		0.5%	56.7%	2.8%	0.1%	10.6%	100.0%
$PM_{2.5}$	25.7%		0.5%	56.2%	2.5%	0.1%	15.0%	100.0%

Table 3-2 Source apportionment for all road transports on St Clement's / The Plain (µg m^{-3}) for the baseline fleet, 2018 (NO_2 concentrations derived from the NOx to NO_2 calculator)

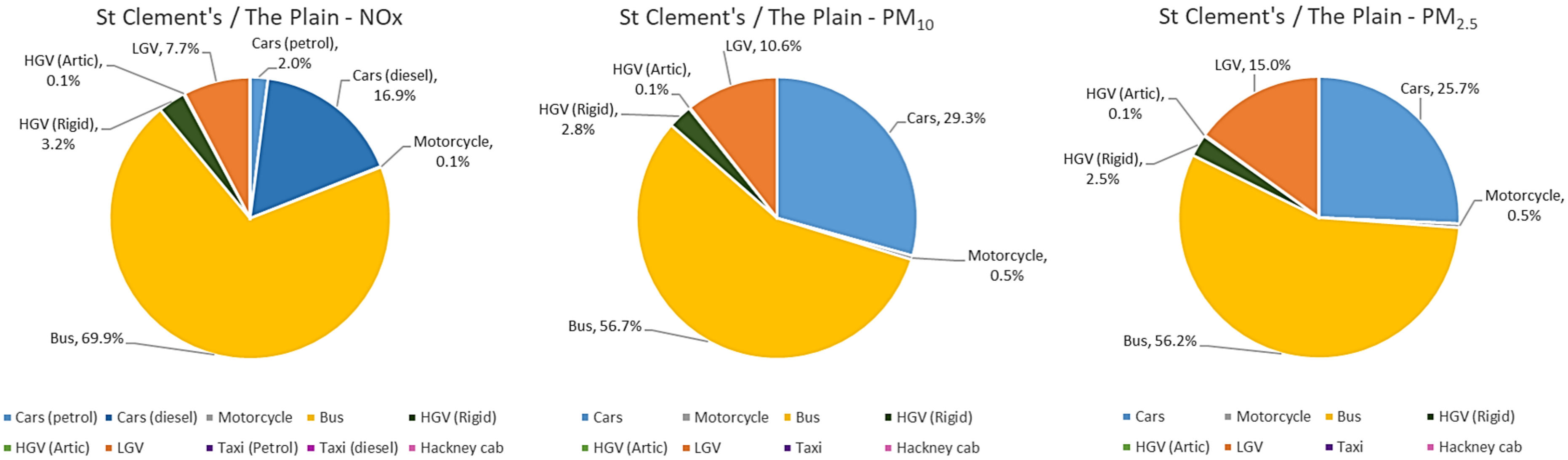
	Background	Cars		Motorcycles	Buses	HGVs (rigid)	HGVs (artic)	LGVs	Total Modelled Pollutant	Modelled NO_2
		Petrol	Diesel							
NOx	21.1	1.5	12.2	0.1	50.2	2.3	0.1	5.5	92.9	48.0
PM_{10}	15.1	1.1		0.0	2.2	0.1	0.0	0.4	19.0	
$PM_{2.5}$	10.4	0.7		0.0	1.5	0.1	0.0	0.4	13.0	

Table 3-3 Source apportionment for all road transports on St Clement's / The Plain (µg m^{-3}) for the baseline fleet, 2018 (NO_2 concentration measured at DT55 in 2018)

	Background*	Cars		Motorcycles	Buses	HGVs (rigid)	HGVs (artic)	LGVs	Total Measured NO_2
		Petrol	Diesel						
NO_2	10.5	0.7	6.0	0.0	24.8	1.1	0.0	2.7	46.0

*Background NO_2 was estimated by applying the same percentage of NOx that is background in the modelled results, to the total measured NO_2.

Figure 3-1 Pie chart representation of source apportionment for all road transports on St Clement's / The Plain (%) for the baseline fleet, 2018



Worcester Street:

Table 3-4 Source apportionment for all road transports on Worcester Street (%) for the baseline fleet, 2018

	Cars		Motorcycles	Buses	HGVs (rigid)	HGVs (artic)	LGVs	Taxis		Hackney Carriages	Total
	Petrol	Diesel						Petrol	Diesel		
NOx	4.6%	38.3%	0.2%	18.4%	8.2%	0.9%	25.1%	0.3%	2.5%	1.5%	100.0%
PM_{10}	51.6%		0.9%	9.2%	5.5%	0.7%	27.0%	3.4%		1.6%	100.0%
$PM_{2.5}$	43.1%		0.9%	9.2%	4.9%	0.6%	36.4%	2.8%		2.1%	100.0%

Table 3-5 Source apportionment for all road transports on Worcester Street (µg m^{-3}) for the baseline fleet, 2018 (NO_2 concentrations derived from the NOx to NO_2 calculator)

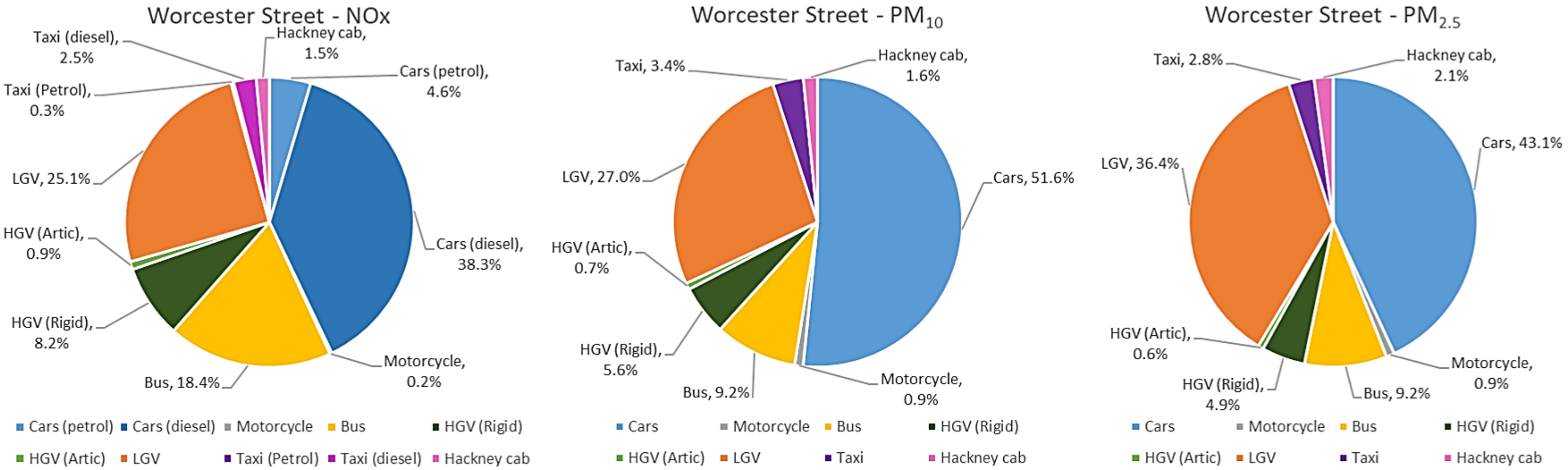
	Background	Cars		Motorcycles	Buses	HGVs (rigid)	HGVs (artic)	LGVs	Taxis		Hackney Carriages	Total Modelled Pollutant	Modelled NO_2
		Petrol	Diesel						Petrol	Diesel			
NOx	26.9	1.7	13.8	0.1	6.6	2.9	0.3	9.0	0.1	0.9	0.5	62.9	36.0
PM_{10}	15.1	1.3		0.0	0.2	0.1	0.0	0.7	0.1		0.0	17.	
$PM_{2.5}$	10.4	0.8		0.2	0.1	0.0	0.6	0.0	0.0		0.0	12.1	

Table 3-6 Source apportionment for all road transports on Worcester Street (µg m^{-3}) for the baseline fleet, 2018 (NO_2 concentration measured at DT45 in 2018)

	Background*	Cars		Motorcycles	Buses	HGVs (rigid)	HGVs (artic)	LGVs	Taxis		Hackney Carriages	Total Measured NO_2
		Petrol	Diesel						Petrol	Diesel		
NO_2	15.8	1.0	8.1	0.1	3.9	1.7	0.2	5.3	0.1	0.5	0.3	37.0

*Background NO_2 was estimated by applying the same percentage of NOx that is background in the modelled results, to the total measured NO_2.

Figure 3-2 Pie chart representation of source apportionment for all road transports on Worcester Street (%) for the baseline fleet, 2018



Botley Road:

Table 3-7 Source apportionment for all road transports on Botley Road (%) for the baseline fleet, 2018

	Cars		Motorcycles	Buses	HGVs (rigid)	HGVs (artic)	LGVs	Total
	Petrol	Diesel						
NOx	3.8%	31.1%	0.1%	31.3%	8.8%	1.2%	23.7%	100.0%
PM_{10}	46.4%		0.4%	17.3%	6.6%	1.1%	28.2%	100.0%
$PM_{2.5}$	38.3%		0.3%	17.2%	5.7%	0.9%	37.6%	100.0%

Table 3-8 Source apportionment for all road transports on Botley Road (µg m^{-3}) for the baseline fleet, 2018 (NO_2 concentrations derived from the NOx to NO_2 calculator)

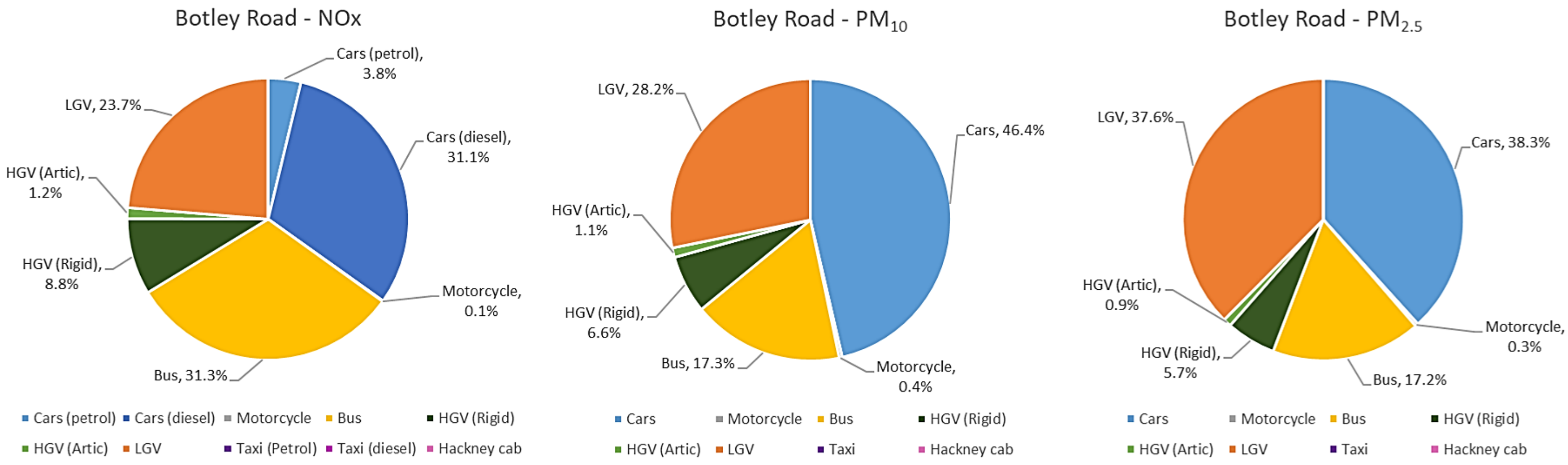
	Background	Cars		Motorcycles	Buses	HGVs (rigid)	HGVs (artic)	LGVs	Total Modelled Pollutant	Modelled NO_2
		Petrol	Diesel							
NOx	19.7	0.8	6.3	0.0	6.4	1.8	0.3	4.8	44.9	25.3
PM_{10}	15.1	0.7		0.0	0.3	0.1	0.0	0.4	16.8	
$PM_{2.5}$	10.2	0.4		0.0	0.2	0.1	0.0	0.4	11.3	

Table 3-9 Source apportionment for all road transports on Botley Road (µg m^{-3}) for the baseline fleet, 2018 (NO_2 concentration measured at DT35 in 2018)

	Background*	Cars		Motorcycles	Buses	HGVs (rigid)	HGVs (artic)	LGVs	Total Measured NO_2
		Petrol	Diesel						
NO_2	15.7	0.6	5.1	0.0	5.1	1.4	0.2	3.9	32.0

*Background NO_2 was estimated by applying the same percentage of NOx that is background in the modelled results, to the total measured NO_2.

Figure 3-3 Pie chart representation of source apportionment for all road transports on Botley Road (%) for the baseline fleet, 2018



3.2 Source apportionment including the Euro VI Bus Low Emission Zone (LEZ)

Source apportionment was again completed for the three locations identified in Section 2.4, this time assuming all buses in the modelling domain were Euro VI standard.

Table 3-10, Table 3-12 and Table 3-14 show the source apportionment in terms of percentage contribution of the major vehicle types to the total vehicular NOx, PM_{10} and $PM_{2.5}$ emissions. The percentage emissions again are presented in pie charts.

Table 3-11, Table 3-13 and Table 3-15 show the source apportionment in terms of the amount of NOx, PM_{10} and $PM_{2.5}$ originating from each of these sources (in µg m^{-3}).

Figure 3-7 to Figure 3-9 show the total modelled NO_2 concentrations at each of the source apportionment locations. They compare the modelled results for run 1, with the baseline fleet for 2018, and run 2, with all buses upgraded to Euro VI standard. This demonstrates the estimated reduction in each pollutant arising from the upgrade of all buses to Euro VI standard.

At **St Clement's Street / The Plain** bus emissions contributed approximately 70% of NOx/NO_2 and 56% of PM emissions using the 2018 baseline fleet. With all buses upgraded to Euro VI, this is estimated to decrease to around 30% of NOx emissions and just under 50% of PM emissions. Cars then become the largest contributor to NOx at approximately 45% of emissions; they also contribute around 35% of PM emissions. LGVs remain the next highest contributor for all pollutants. In terms of contribution to the total concentrations of each pollutant, buses contribute less than 20% of the total modelled concentration of NOx/NO_2, and the background contributes approximately 40% of total NOx. Decreases in total modelled concentration are significantly greater for NOx than for PM_{10} or $PM_{2.5}$.

On **Worcester Street** cars remain the largest contributor to emissions, however, with the bus upgrade this is even more pronounced. More than 50% of the emissions come from cars, except in the case of $PM_{2.5}$ at around 45%. In the case of NOx and PM_{10} approximately 30% of emissions are from LGVs; for $PM_{2.5}$ this rises to 38%. A smaller proportion of emissions were attributed to buses for Worcester Street than St Clement's using the 2018 baseline fleet, however, reductions in emissions from buses were still observed. For NOx a decrease from 18.4% to 2.7% of emissions was seen and for PM a decrease of around one third is seen. Background NOx still makes up just under half of the total modelled NOx concentration, with buses contributing less than 2%.

For **Botley Road**, the percentage emissions from cars increase to approximately 50% with the bus upgrade. Buses contributed 31% of NOx emissions, falling to just under 20% for PM_{10} and $PM_{2.5}$ using the 2018 baseline fleet – taking the bus upgrades into account they contributed around 5% of NOx emissions and 10% of PM emissions. Considering the total modelled concentrations, background NOx made up more than half of the total modelled NOx and buses only contributed 2.5%.

In all cases, the bus upgrades would significantly reduce NOx emissions and total modelled NOx/NO_2 concentrations in comparison to PM_{10} and $PM_{2.5}$.

St Clement's / The Plain:

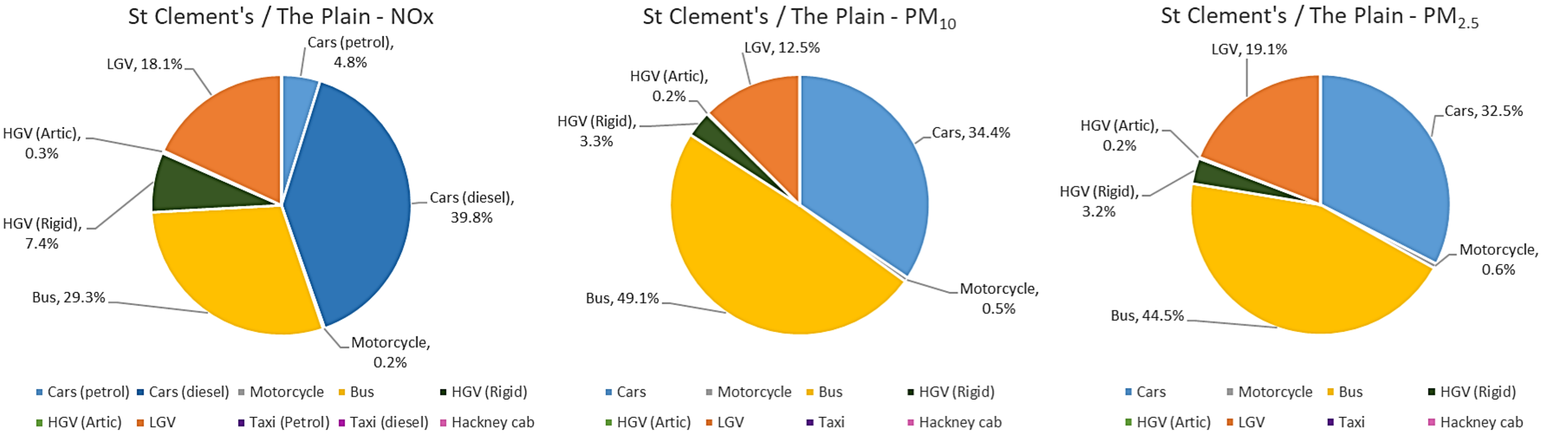
Table 3-10 Source apportionment for all road transports on St Clement's / The Plain (%) for 2018, assuming all buses are Euro VI standard

	Cars		Motorcycles	Buses	HGVs (rigid)	HGVs (artic)	LGVs	Total
	Petrol	Diesel						
NOx	4.8%	39.8%	0.2%	29.3%	7.4%	0.3%	18.1%	100.0%
PM_{10}	34.4%		0.5%	49.1%	3.3%	0.2%	12.5%	100.0%
$PM_{2.5}$	32.5%		0.6%	44.5%	3.2%	0.2%	19.1%	100.0%

Table 3-11 Source apportionment for all road transports on St Clement's / The Plain (µg m^{-3}) for 2018 (NO_2 concentrations derived from the NOx to NO_2 calculator), assuming all buses are Euro VI standard

	Background	Cars		Motorcycles	Buses	HGVs (rigid)	HGVs (artic)	LGVs	Total Modelled Pollutant	Modelled NO_2
		Petrol	Diesel							
NOx	21.1	1.5	12.1	0.1	8.9	2.3	0.1	5.5	51.6	30.8
PM_{10}	15.1	1.2		0.0	1.7	0.1	0.0	0.4	18.6	
$PM_{2.5}$	10.4	0.7		0.0	1.0	0.1	0.0	0.4	12.6	

Figure 3-4 Pie chart representation of source apportionment for all road transports on St Clement's / The Plain (%) for 2018, assuming all buses are Euro VI standard



Worcester Street:

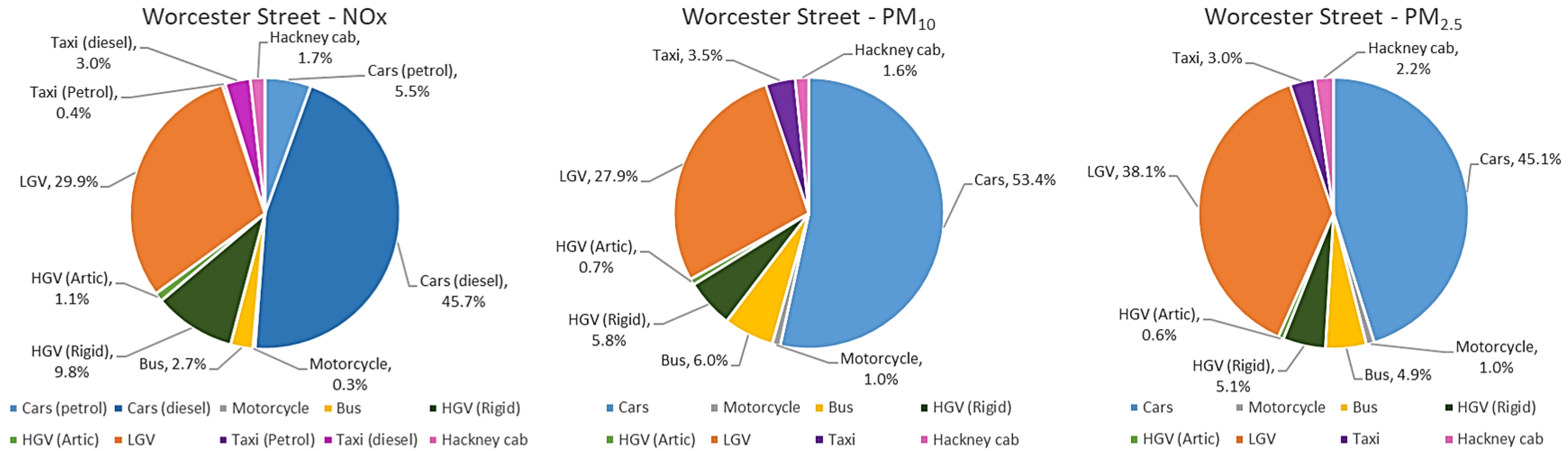
Table 3-12 Source apportionment for all road transports at Worcester Street (%) for 2018, assuming all buses are Euro VI standard

	Cars		Motorcycles	Buses	HGVs (rigid)	HGVs (artic)	LGVs	Taxis		Hackney Carriages	Total
	Petrol	Diesel						Petrol	Diesel		
NOx	5.5%	45.7%	0.3%	2.7%	9.8%	1.1%	29.9%	0.4%	3.0%	1.7%	100.0%
PM_{10}	53.4%		1.0%	6.0%	5.8%	0.7%	27.9%	3.5%		1.6%	100.0%
$PM_{2.5}$	45.1%		1.0%	4.9%	5.1%	0.6%	38.1%	3.0%		2.2%	100.0%

Table 3-13 Source apportionment for all road transports at Worcester Street (µg m^{-3}) for 2018 (NO_2 concentrations derived from the NOx to NO_2 calculator), assuming all buses are Euro VI standard

	Background	Cars		Motorcycles	Buses	HGVs (rigid)	HGVs (artic)	LGVs	Taxis		Hackney Carriages	Total Modelled Pollutant	Modelled NO_2
		Petrol	Diesel						Petrol	Diesel			
NOx	26.9	1.7	14.0	0.1	0.8	3.0	0.3	9.2	0.1	0.9	0.5	57.6	33.7
PM_{10}	15.1	1.4		0.0	0.2	0.1	0.0	0.7	0.1		0.0	17.7	
$PM_{2.5}$	10.4	0.8		0.1	0.1	0.0	0.7	0.1	0.1		0.0	12.1	

Figure 3-5 Pie chart representation of source apportionment for all road transports at Worcester Street (%) for 2018, assuming all buses are Euro VI standard



Botley Road:

Table 3-14 Source apportionment for all road transports at Botley Road (%) for 2018, assuming all buses are Euro VI standard

	Cars		Motorcycles	Buses	HGVs (rigid)	HGVs (artic)	LGVs	Total
	Petrol	Diesel						
NOx	5.2%	42.9%	0.1%	5.2%	12.1%	1.7%	32.7%	100.0%
PM_{10}	49.5%		0.4%	11.7%	7.1%	1.2%	30.1%	100.0%
$PM_{2.5}$	41.8%		0.4%	9.5%	6.2%	1.0%	41.1%	100.0%

Table 3-15 Source apportionment for all road transports at Botley Road (μg m^{-3}) for 2018 (NO_2 concentrations derived from the NOx to NO_2 calculator), assuming all buses are Euro VI standard

	Background	Cars		Motorcycles	Buses	HGVs (rigid)	HGVs (artic)	LGVs	Total Modelled Pollutant	Modelled NO_2
		Petrol	Diesel							
NOx	19.7	0.8	7.0	0.0	0.9	2.0	0.3	5.3	36.0	23.3
PM_{10}	15.1	0.7		0.0	0.2	0.1	0.0	0.3	16.6	
$PM_{2.5}$	10.2	0.4		0.0	0.1	0.1	0.0	0.4	11.2	

Figure 3-6 Pie chart representation of source apportionment for all road transports at Botley Road (%) for 2018, assuming all buses are Euro VI standard

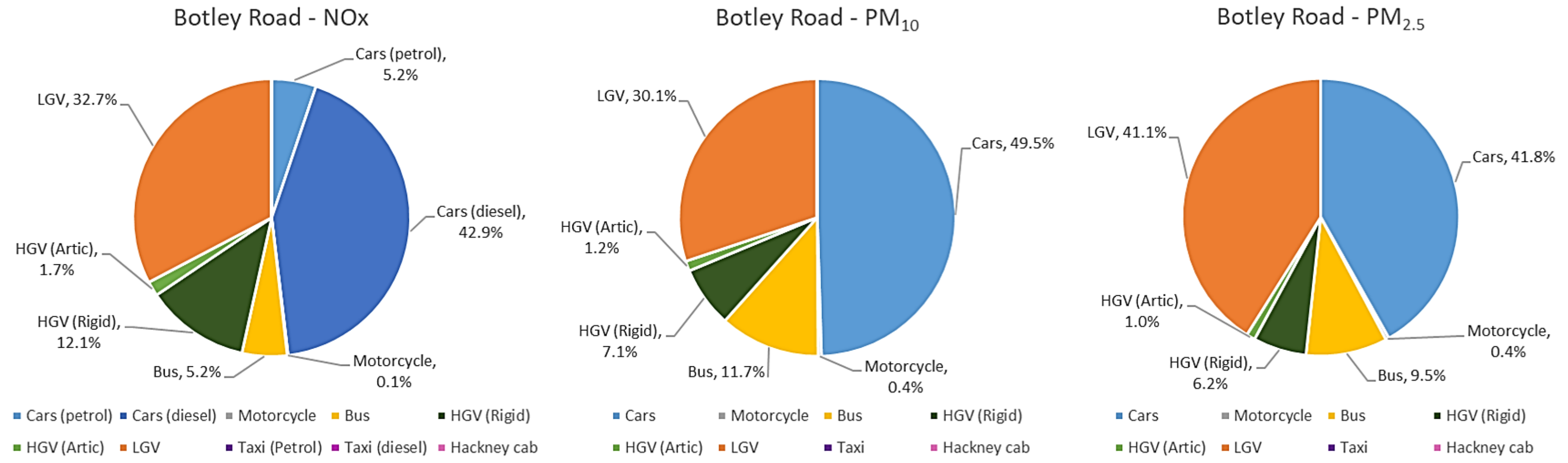


Figure 3-7 Modelled total NO_2 concentrations (2018) at St Clement's / The Plain using (a) baseline 2018 fleet and (b) updated bus fleet

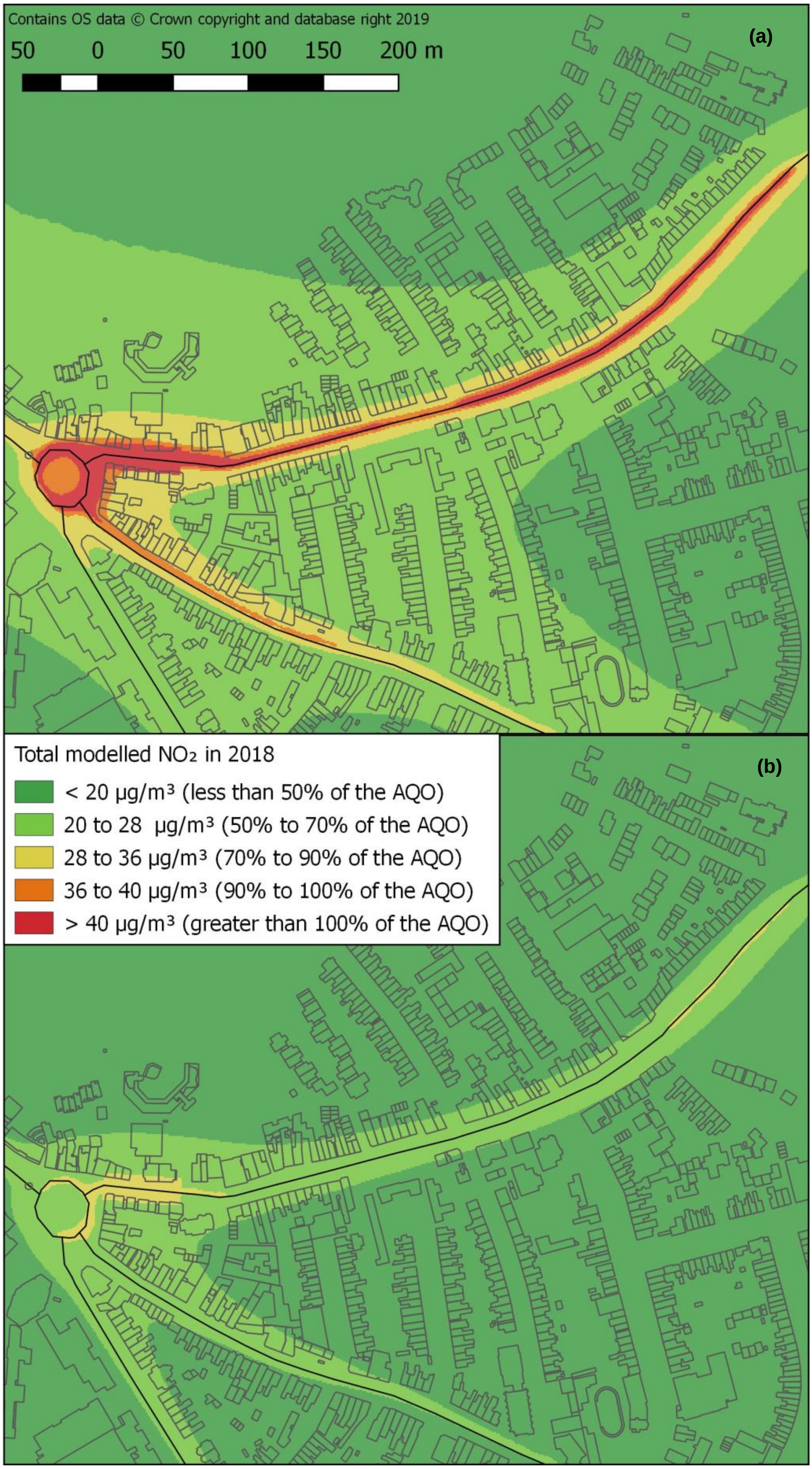


Figure 3-8 Modelled total NO_2 concentrations (2018) at Worcester Street using (a) baseline 2018 fleet and (b) updated bus fleet

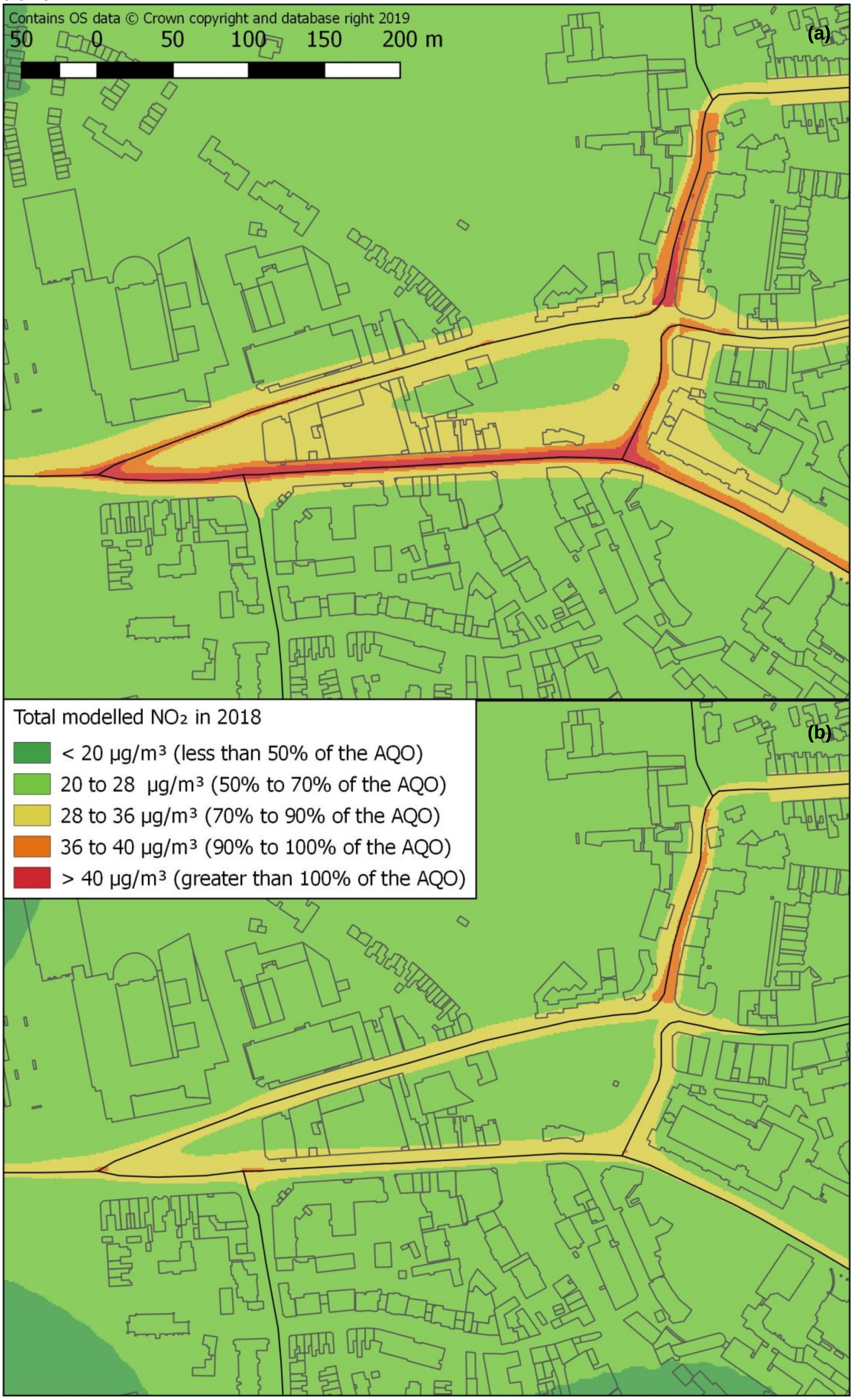
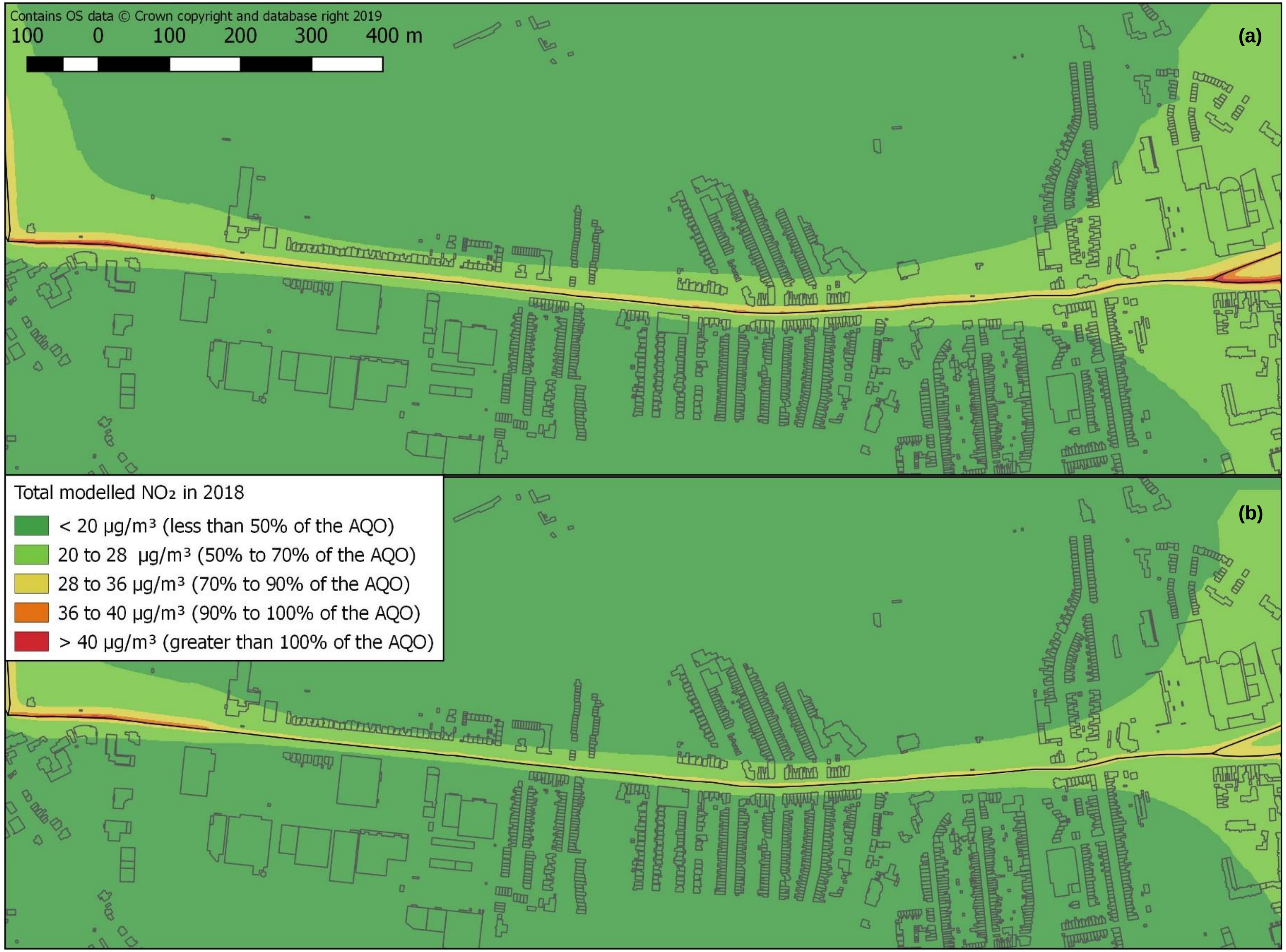


Figure 3-9 Modelled total NO_2 concentrations (2018) at Botley Road using (a) baseline 2018 fleet and (b) updated bus fleet



3.3 Required reduction in emissions

Of the three locations identified for source apportionment, only one had a measured NO_2 annual mean exceeding the AQO (St Clement's / The Plain, DT55). However, there are three additional monitoring locations within The City of Oxford AQMA that measured NO_2 annual exceedances in 2018. The required reduction in emissions to achieve compliance with the NO_2 annual mean AQO at each of these locations is presented in Table 3-16.

Table 3-16 Nitrogen dioxide concentrations measured within The City of Oxford AQMA and the required NOx emissions from road traffic required to achieve compliance

Code	Location	NO_2 measured in 2018, μg m^{-3}	NOx background, μg m^{-3}	Roadside NOx from NO_2 calculator, μg m^{-3}	Road NOx to achieve compliance, μg m^{-3}	Road NOx reduction required, μg m^{-3}	Road NOx reduction required, %
DT26	Cutteslowe	41	17.0	59.0	56.5	2.5	4.2
DT48	George St	42	26.4	50.6	45.8	4.8	9.5
DT55	St Clement's	46	21.1	66.7	51.8	14.9	22.4
DT56	High St	44	24.9	57.3	47.5	9.8	17.0

All four locations were considered for source apportionment as outlined in Section 2.4.

For DT48, DT55 and DT56 it has been identified that the major contributor to emissions is likely to be buses. In the case of DT55 (St Clement's Street) this was shown via this source apportionment study. For DT56 on the High Street, local knowledge suggests that the majority of traffic travelling along the High Street is buses; this is backed up by the traffic data used in the modelling. For DT48 (George Street) this diffusion tube is located directly opposite the entrance to the Oxford Bus Station, as well as adjacent to four-way traffic lights. The combination of these factors leads to congestion and idling, contributing to the high measured NO_2 concentration.

The required reduction in emissions for St Clement's Street / The Plain to achieve compliance with the NO_2 annual mean AQO is 14.9 μg m^{-3}, or 22.4%. The source apportionment identified buses as by far the largest contributor to emissions, so reduction in emissions should be focused on buses. Source apportionment was not carried out for George Street or the High Street, however local knowledge suggests that the respective 9.5% and 17.0% reductions in road NOx required to achieve NO_2 compliance should also focus on buses. Source apportionment was not completed for Cutteslowe (DT26) however the diffusion tube is located very close to a roundabout, which may make it difficult to reduce emissions. The required reduction in road NOx to achieve compliance would be 4.2%, or 2.5 μg/m^3.

A comparison of the source apportionment study results using the baseline fleet, and one assuming all Euro VI buses, demonstrates significant reductions in modelled NO_2 concentrations as a result of the bus upgrades. In particular, there is a predicted decrease in modelled NO_2 concentration from 48.0 μg/m^3 to 30.8 μg/m^3 (a reduction of 17.2 μg/m^3 or 36%) at St Clement's which brings the location well into compliance with the annual mean AQO. At Worcester Street and Botley Road, reductions of 2.3 μg/m^3 (6%) and 2.0 μg/m^3 (8%) NO_2 respectively were predicted. Although these locations were already below the annual mean AQO, any reduction is beneficial to human health.

4 Conclusions

A review was undertaken to determine the most appropriate locations for the source apportionment. This was based on the maximum NO_2 concentration predicted for 2018 within The City of Oxford AQMA using a national fleet, as well as the measured NO_2 concentrations at diffusion tubes in 2018. Discussion and review of these findings was undertaken with OCC and the three locations for source apportionment were confirmed to be:

- St Clement's / The Plain
- Worcester Street
- Botley Road

The results of the source apportionment were presented in terms of percentage contribution to modelled road emissions, as well as modelled concentrations of NOx, NO_2 PM_{10} and $PM_{2.5}$, and measured NO_2 concentrations at the diffusion tube in 2018. Two runs were completed, one using a baseline 2018 fleet and the other assuming all buses were upgraded to Euro VI standard.

Along St Clement's Street / The Plain emissions were dominated by buses when the baseline 2018 fleet was used. In particular, 69.9% of NOx emissions were attributed to buses. Cars were the next largest contributor, followed by LGVs. In terms of contribution to the total concentrations of each pollutant, buses made up more than half the total concentration of NOx/NO_2, with the background only contributing approximately 20% of total NOx. Looking at the breakdown of total measured NO_2 (46.0 $\mu g\ m^{-3}$), the background accounted for 10.5 $\mu g\ m^{-3}$ and buses accounted for 24.8 $\mu g\ m^{-3}$. With the bus upgrades to Euro VI taken into account, bus emissions were estimated to decrease to around 30% of NOx emissions and just under 50% of PM emissions, making cars the largest contributor. Under this scenario, buses contributed less than 20% of the total modelled concentration of NOx/NO_2, and the background contributed approximately 40% of total NOx.

On Worcester Street, approximately half the emissions came from cars using the baseline fleet; this increased when taking bus upgrades into account. LGVs were the next largest contributor to emissions in both scenarios. In contrast to St Clement's / The Plain, 18% of NOx/NO_2 emissions and 9% of PM_{10}/$PM_{2.5}$ emissions were attributed to buses using the standard fleet; with the upgrades applied, this decreased from 18.4% to 2.7% for NOx and for PM this decreased by about one third. Worcester Street was the only study location with reliable taxi information; taxis and Hackney cabs together attributed to approximately 5% of emissions of all pollutants. Examining the breakdown of total measured NO_2 (37.0 $\mu g\ m^{-3}$), the background concentration was higher than for St Clement's, at 15.8 $\mu g\ m^{-3}$ and buses accounted for just 3.9 $\mu g\ m^{-3}$ at this location.

For Botley Road the percentage emissions from cars increased from around 35 – 45% with the baseline fleet, to approximately 50% with the bus upgrade. Buses contributed around 30% of NOx emissions and just under 20% for PM_{10} and $PM_{2.5}$ using the baseline fleet – taking the bus upgrades into account they contributed only 5% of NOx emissions and 10% of PM emissions. Looking at the breakdown of total measured NO_2 (32.0 $\mu g\ m^{-3}$) under the baseline scenario, the background concentration was almost the same as Worcester street: 15.8 $\mu g\ m^{-3}$. Buses accounted for 5.1 $\mu g\ m^{-3}$ of total NO_2, as did diesel cars.

Throughout all three locations and pollutants, diesel cars contributed almost all NOx emissions from cars and rigid HGVs contributed significantly more emissions than artic HGVs for all three pollutants. Background PM_{10} and $PM_{2.5}$ made up nearly all the total modelled concentration of those pollutants.

Of the three locations identified for source apportionment, only one had a measured NO_2 annual mean exceeding the AQO (St Clement’s / The Plain, DT55). However, there were three additional monitoring locations within The City of Oxford AQMA that measured NO_2 annual exceedances in 2018.

The required reduction in emissions to achieve compliance with the NO_2 annual mean AQO was calculated for the four locations of exceedance within The City of Oxford AQMA. For St Clement’s Street / The Plain, to achieve compliance with the NO_2 annual mean AQO a reduction of road NOx of 14.9 µg/m^3, or 22.4% is required. The source apportionment identified buses as by far the largest contributor to emissions, so reduction in emissions should be focused on buses. Source apportionment was not carried out for George Street or the High Street, however local knowledge and the total modelled NO_2 results under the Euro VI bus scenario suggest that the reductions in road NOx required to achieve NO_2 compliance should also focus on buses.

A comparison of the source apportionment study results using a standard fleet, and one assuming all Euro VI buses, demonstrated significant reductions in modelled NO_2 concentrations as a result of the bus upgrades. In particular, there was a predicted decrease in modelled NO_2 concentration from 48.0 µg/m^3 to 30.8 µg/m^3 (a reduction of 17.2 µg/m^3 or 36%) at St Clement’s which brings the location well into compliance with the annual mean AQO. At Worcester Street and Botley Road, reductions of 2.3 µg/m^3 (6%) and 2.0 µg/m^3 (8%) NO_2 respectively were predicted. Although these locations were already below the annual mean AQO, any reduction is beneficial to human health.

Appendices

Appendix 1: Air dispersion model verification and adjustment for identification of hotspots
Appendix 2: Air dispersion model verification and adjustment for 2018 baseline
Appendix 3: Background maps source apportionment
Appendix 4: NAEI source apportionment

Appendix 1 – Air dispersion model verification and adjustment for identification of hotspots

Verification of the model involves comparison of the modelled results with any local monitoring data at relevant locations; this helps to identify how the model is performing and if any adjustments should be applied. The verification process involves checking and refining the model input data to try and reduce uncertainties and produce model outputs that are in better agreement with the monitoring results. This can be followed by adjustment of the modelled results if required. The LAQM.TG(16) guidance recommends making the adjustment to the road contribution of the pollutant only and not the background concentration these are combined with.

The approach outlined in LAQM.TG(16) section 7.508 – 7.534 (also in Box 7.14 and 7.15) has been used in this case. To verify the model, the predicted annual mean Road NOx concentrations were compared with concentrations measured at the various monitoring sites during 2018.

The model output of Road NOx (the total NOx originating from road traffic) was compared with measured Road NOx, where the measured Road NOx contribution is calculated as the difference between the total measured NOx and the background NOx value. Total measured NOx for each monitoring site was calculated from the measured NO_2 concentration using Version 7.1 of the Defra NOx/NO_2 calculator available from the LAQM website[14]. Background NOx values for 2018 were obtained from the 2017 reference year background maps available on the LAQM website.

The gradient of the best fit line for the modelled Road NOx contribution vs. measured Road NOx contribution was then determined using linear regression and used as a global/domain wide Road NOx adjustment factor. This factor was then applied to the modelled Road NOx concentration at each discretely modelled receptor point to provide adjusted modelled Road NOx concentrations. A linear regression plot comparing modelled and monitored Road NOx concentrations before and after adjustment was produced. A primary NOx adjustment factor (PAdj) of **0.9989** based on model verification using all of the included 2018 NO_2 measurements was applied to all modelled Road NOx data prior to calculating an NO_2 annual mean.

The total annual mean NO_2 concentrations were then determined at points within the model domain using the NOx/NO_2 calculator to combine background and adjusted road contribution concentrations. For this step of the process, regional concentrations of ozone, oxides of nitrogen and nitrogen dioxide were set to those of the local authority where the calibration point was located. The following relationship was determined for conversion of total NOx concentrations to total NO_2 concentrations:

$$(NO_2 \text{ in } \mu g/m^3) = -\ 0.001221\ (NOx \text{ in } \mu g/m^3)^2 + 0.5813\ (NOx \text{ in } \mu g/m^3) + 3.919$$

To evaluate the model performance and uncertainty, the Root Mean Square Error (RMSE) for the observed vs predicted NO_2 annual mean concentrations was calculated, as detailed in Technical Guidance LAQM.TG(16). The calculated RMSE is presented in Table A1-1. In this case the RMSE was calculated at **6.526 µg/m³**.

[14] https://laqm.defra.gov.uk/review-and-assessment/tools/background-maps.html

Table A-1 Modelled and measured NO_2 concentrations for 2018 (national fleet) and calculated RMSE value

Site ID	Easting	Northing	NO_2 annual mean ($\mu g/m^3$) in 2018	
			Measured	Modelled
CM1	451359	206157	39	33.0
CM2	451677	206272	38	36.6
DT2	451904	204215	27	22.8
DT3	451914	204154	29	26.2
DT4	452961	204662	27	22.0
DT7	454472	204246	28	23.1
DT8	454355	204296	27	25.8
DT9	453151	205536	24	21.7
DT72	452761	205745	29	26.6
DT14	454554	207102	32	23.1
DT15	454433	207058	25	29.1
DT16	453982	206817	25	29.4
DT17	454138	206903	25	30.9
DT18	455596	207367	26	22.8
DT20	454999	207759	27	19.0
DT21	455116	207796	24	22.9
DT76	451226	206504	33	23.5
DT77	452451	205999	36	30.6
DT25	450419	210256	35	22.2
DT26	450389	210189	41	25.0
DT27	449824	210198	29	31.1
DT28	449856	210162	27	24.7
DT71	449617	210216	38	26.6
DT29	449530	210734	25	21.7
DT30	450668	206053	28	21.7
DT31	450566	206227	31	24.2
DT32	450674	206273	31	32.3
DT33	450409	206224	26	22.9
DT34	450356	206255	22	24.4
DT35	450029	206207	32	25.7
DT36	449657	206245	27	26.5
DT37	449655	206227	23	22.8
DT39	451359	206157	39	33.0
DT42	451073	206191	29	34.4
DT43	450885	206275	32	37.3
DT44	450795	206343	29	30.5
DT45	450942	206424	37	36.7
DT46	451167	206519	31	30.6
DT47	451222	206387	37	26.0
DT73	450960	206590	26	22.9
DT48	450981	206344	42	34.0
DT49	451320	206241	24	23.6
DT50	451467	206222	28	37.6
DT51	451900	206250	33	40.8
DT52	451972	206283	38	22.9

Site ID	Easting	Northing	NO_2 annual mean (µg/m^3) in 2018	
			Measured	Modelled
DT53	452099	206117	23	23.3
DT54	452325	206015	23	32.8
DT55	452326	205992	46	52.2
DT56	451576	206232	44	31.3
DT57	451407	205807	35	35.7
DT58	451437	205529	33	25.8
DT59	451353	205643	27	20.3
DT60	451248	205710	30	20.7
DT61	451219	205707	19	20.6
DT62	451072	205750	20	21.0
DT63	450926	205797	20	20.7
DT64	450887	205825	23	22.6
DT65	451206	205780	30	37.8
DT66	451149	205859	23	27.4
DT67	451149	205947	20	32.9
DT68	451030	205962	24	28.6
DT69	450982	205973	24	23.2
DT70	451062	206066	29	37.5
RMSE (all sites in this table)				**6.526**

Appendix 2 – Air dispersion model verification and adjustment for 2018 baseline

Verification of the model was completed following the update with the Oxford-specific bus information, using the same methodology as outlined in Appendix 1.

The gradient of the best fit line for the modelled Road NOx contribution vs. measured Road NOx contribution was determined using linear regression and used as a global/domain wide Road NOx adjustment factor. This factor was then applied to the modelled Road NOx concentration at each discretely modelled receptor point to provide adjusted modelled Road NOx concentrations. A linear regression plot comparing modelled and monitored Road NOx concentrations before and after adjustment was produced. A primary NOx adjustment factor (PAdj) of **0.9258** based on model verification using all of the included 2018 NO_2 measurements was applied to all modelled Road NOx data prior to calculating an NO_2 annual mean.

To evaluate the model performance and uncertainty, the Root Mean Square Error (RMSE) for the observed vs predicted NO_2 annual mean concentrations was calculated, as detailed in Technical Guidance LAQM.TG(16). The calculated RMSE is presented in Table A1-1. In this case the RMSE was calculated at **6.701 µg/m^3**.

Table A- 2 Modelled and measured NO_2 concentrations for 2018 (fleet with Oxford-specific bus information) and calculated RMSE value

Site ID	Easting	Northing	NO_2 annual mean (µg/m^3) in 2018	
			Measured	Modelled
CM1	451359	206157	39	33.4
CM2	451677	206272	38	36.8
DT2	451904	204215	27	22.7
DT3	451914	204154	29	25.9
DT4	452961	204662	27	21.8
DT7	454472	204246	28	22.7
DT8	454355	204296	27	25.1
DT9	453151	205536	24	21.6
DT72	452761	205745	29	26.4
DT14	454554	207102	32	23.3
DT15	454433	207058	25	29.4
DT16	453982	206817	25	29.6
DT17	454138	206903	25	31.2
DT18	455596	207367	26	22.4
DT20	454999	207759	27	18.7
DT21	455116	207796	24	22.3
DT76	451226	206504	33	23.5
DT77	452451	205999	36	28.5
DT25	450419	210256	35	21.7
DT26	450389	210189	41	24.5
DT27	449824	210198	29	30.1
DT28	449856	210162	27	24.1
DT71	449617	210216	38	25.7
DT29	449530	210734	25	21.2

Site ID	Easting	Northing	NO_2 annual mean (μg/m^3) in 2018	
			Measured	Modelled
DT30	450668	206053	28	21.6
DT31	450566	206227	31	24.1
DT32	450674	206273	31	32.2
DT33	450409	206224	26	22.8
DT34	450356	206255	22	24.1
DT35	450029	206207	32	25.3
DT36	449657	206245	27	26.1
DT37	449655	206227	23	22.4
DT39	451359	206157	39	33.4
DT42	451073	206191	29	34.7
DT43	450885	206275	32	37.3
DT44	450795	206343	29	30.0
DT45	450942	206424	37	36.0
DT46	451167	206519	31	30.0
DT47	451222	206387	37	25.9
DT73	450960	206590	26	22.8
DT48	450981	206344	42	34.1
DT49	451320	206241	24	23.6
DT50	451467	206222	28	38.6
DT51	451900	206250	33	41.4
DT52	451972	206283	38	23.0
DT53	452099	206117	23	23.1
DT54	452325	206015	23	31.7
DT55	452326	205992	46	48.0
DT56	451576	206232	44	31.6
DT57	451407	205807	35	36.7
DT58	451437	205529	33	25.6
DT59	451353	205643	27	20.4
DT60	451248	205710	30	20.9
DT61	451219	205707	19	20.7
DT62	451072	205750	20	21.2
DT63	450926	205797	20	20.7
DT64	450887	205825	23	22.5
DT65	451206	205780	30	39.1
DT66	451149	205859	23	27.9
DT67	451149	205947	20	33.8
DT68	451030	205962	24	29.3
DT69	450982	205973	24	23.4
DT70	451062	206066	29	38.5
RMSE (all sites in this table)				**6.701**

Appendix 3 – Background maps source apportionment

The point sampled background concentrations at each of the study locations have been apportioned into the contributions from each source.

The Defra background maps are downloaded at 1 km x 1 km resolution. RapidAIR interpolates these concentrations to a 1 m x 1 m grid to match the resolution of the modelled road contribution output. The background concentrations at the exact location of each diffusion tube has then been extracted, to provide the most accurate estimate of the background concentration at that site.

The ‘Sources In’ column therefore accounts for all pollution sources within the 1 km x 1 km grid square (as well as a number of other sources, see the note beneath each table) and the remaining background pollution comes from outside the 1 km x 1 km grid square the diffusion tube is located in. Note that DT35 and DT45 are located in the same grid square, hence their percentage background contributions are the same.

Some sources are not included in the background concentrations; at the time of download their relative contributions were removed because they are already included in our road source modelling.

- For NOx, these are: Motorway, Trunk, and Primary roads.
- For PM_{10} and $PM_{2.5}$ these are: Motorway, Trunk, and Primary roads, brake and abrasion.

The remaining background sources / sectors not included in our road modelling have been apportioned in terms of percentage of the background concentration as well as the associated pollutant concentration in µg/m^3.

The definitions of each source / sector are provided in Table A- 9.

Table A- 3 Source apportionment of background NOx concentrations (%) at hotspots in 2018

NOx (%)	Minor Road & Cold Start		Industry		Domestic		Aircraft		Rail		Other		Point Sources	Rural	Total In*	Total
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out				
DT55	9.4%	6.0%	0.0%	2.6%	8.4%	7.7%	0.0%	0.0%	0.0%	14.0%	0.9%	8.1%	2.3%	40.5%	61.5%	100.0%
DT45	7.9%	3.0%	0.0%	2.1%	5.4%	4.7%	0.0%	0.0%	15.1%	6.7%	19.0%	4.6%	1.4%	30.1%	79.0%	100.0%
DT35	7.9%	3.0%	0.0%	2.1%	5.4%	4.7%	0.0%	0.0%	15.1%	6.7%	19.0%	4.6%	1.4%	30.1%	79.0%	100.0%

*Total In includes all In sources as well as Point Sources and Rural

Table A- 4 Source apportionment of background NOx concentrations (μg m^{-3}) at hotspots in 2018

NOx (μg/m³)	Minor Road & Cold Start		Industry		Domestic		Aircraft		Rail		Other		Point Sources	Rural	Total In*	Total BG NOx
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out				
DT55	2.0	1.3	0.0	0.5	1.8	1.6	0.0	0.0	0.0	3.0	0.2	1.7	0.5	8.6	13.0	21.1
DT45	2.1	0.8	0.0	0.6	1.4	1.3	0.0	0.0	4.1	1.8	5.1	1.2	0.4	8.1	21.2	26.9
DT35	1.6	0.6	0.0	0.4	1.1	0.9	0.0	0.0	3.0	1.3	3.7	0.9	0.3	5.9	15.5	19.7

*Total In includes all In sources as well as Point Sources and Rural

Table A- 5 Source apportionment of background PM_{10} concentrations (%) at hotspots in 2018

PM_{10} (%)	Minor Road & Cold Start		Industry		Domestic		Rail		Other		Secondary PM	Residual & Salt	Point Sources	Total In*	Total
	In	Out	In	Out	In	Out	In	Out	In	Out					
DT55	0.1%	0.1%	1.3%	2.4%	5.2%	4.3%	0.0%	0.3%	0.2%	0.7%	46.9%	37.9%	0.7%	92.2%	100.0%
DT45	0.3%	0.1%	1.5%	2.1%	3.8%	3.1%	0.3%	0.2%	2.0%	0.5%	46.5%	39.1%	0.5%	94.0%	100.0%
DT35	0.3%	0.1%	1.5%	2.1%	3.8%	3.1%	0.3%	0.2%	2.0%	0.5%	46.5%	39.1%	0.5%	94.0%	100.0%

*Total In includes all In sources as well as Secondary PM, Residual & Salt, and Point Sources

Table A- 6 Source apportionment of background PM_{10} concentrations (µg m^{-3}) at hotspots in 2018

PM_{10} (µg/m³)	Minor Road & Cold Start		Industry		Domestic		Rail		Other		Secondary PM	Residual & Salt	Point Sources	Total In*	Total BG PM_{10}
	In	Out	In	Out	In	Out	In	Out	In	Out					
DT55	0.0	0.0	0.2	0.4	0.8	0.6	0.0	0.0	0.0	0.1	7.1	5.7	0.1	13.9	15.1
DT45	0.0	0.0	0.2	0.3	0.6	0.5	0.0	0.0	0.3	0.1	7.0	5.9	0.1	14.2	15.1
DT35	0.0	0.0	0.2	0.3	0.6	0.5	0.0	0.0	0.3	0.1	7.0	5.9	0.1	14.2	15.1

*Total In includes all In sources as well as Secondary PM, Residual & Salt, and Point Sources

Table A- 7 Source apportionment of background $PM_{2.5}$ concentrations (%) at hotspots in 2018

$PM_{2.5}$ (%)	Minor Road & Cold Start		Industry		Domestic		Rail		Other		Secondary PM	Residual & Salt	Point Sources	Total In*	Total
	In	Out	In	Out	In	Out	In	Out	In	Out					
DT55	0.2%	0.1%	0.5%	1.7%	7.3%	6.1%	0.0%	0.4%	0.3%	1.0%	58.0%	23.5%	1.0%	90.7%	100.0%
DT45	0.4%	0.1%	0.6%	1.8%	5.5%	4.4%	0.5%	0.2%	3.0%	0.7%	58.1%	24.0%	0.6%	92.7%	100.0%
DT35	0.4%	0.1%	0.6%	1.8%	5.5%	4.4%	0.5%	0.2%	3.0%	0.7%	58.1%	24.0%	0.6%	92.7%	100.0%

*Total In includes all In sources as well as Secondary PM, Residual & Salt, and Point Sources

Table A- 8 Source apportionment of background $PM_{2.5}$ concentrations (µg m^{-3}) at hotspots in 2018

$PM_{2.5}$ (µg/m³)	Minor Road & Cold Start		Industry		Domestic		Rail		Other		Secondary PM	Residual & Salt	Point Sources	Total In*	Total BG $PM_{2.5}$
	In	Out	In	Out	In	Out	In	Out	In	Out					
DT55	0.0	0.0	0.0	0.2	0.8	0.6	0.0	0.0	0.0	0.1	6.0	2.4	0.1	9.4	10.4
DT45	0.0	0.0	0.1	0.2	0.6	0.5	0.1	0.0	0.3	0.1	6.0	2.5	0.1	9.6	10.4
DT35	0.0	0.0	0.1	0.2	0.6	0.4	0.1	0.0	0.3	0.1	5.9	2.4	0.1	9.4	10.2

*Total In includes all In sources as well as Secondary PM, Residual & Salt, and Point Sources

Figure A. 1 Pie chart representation of source apportionment for sources of NOx (background and road, %) for 2018

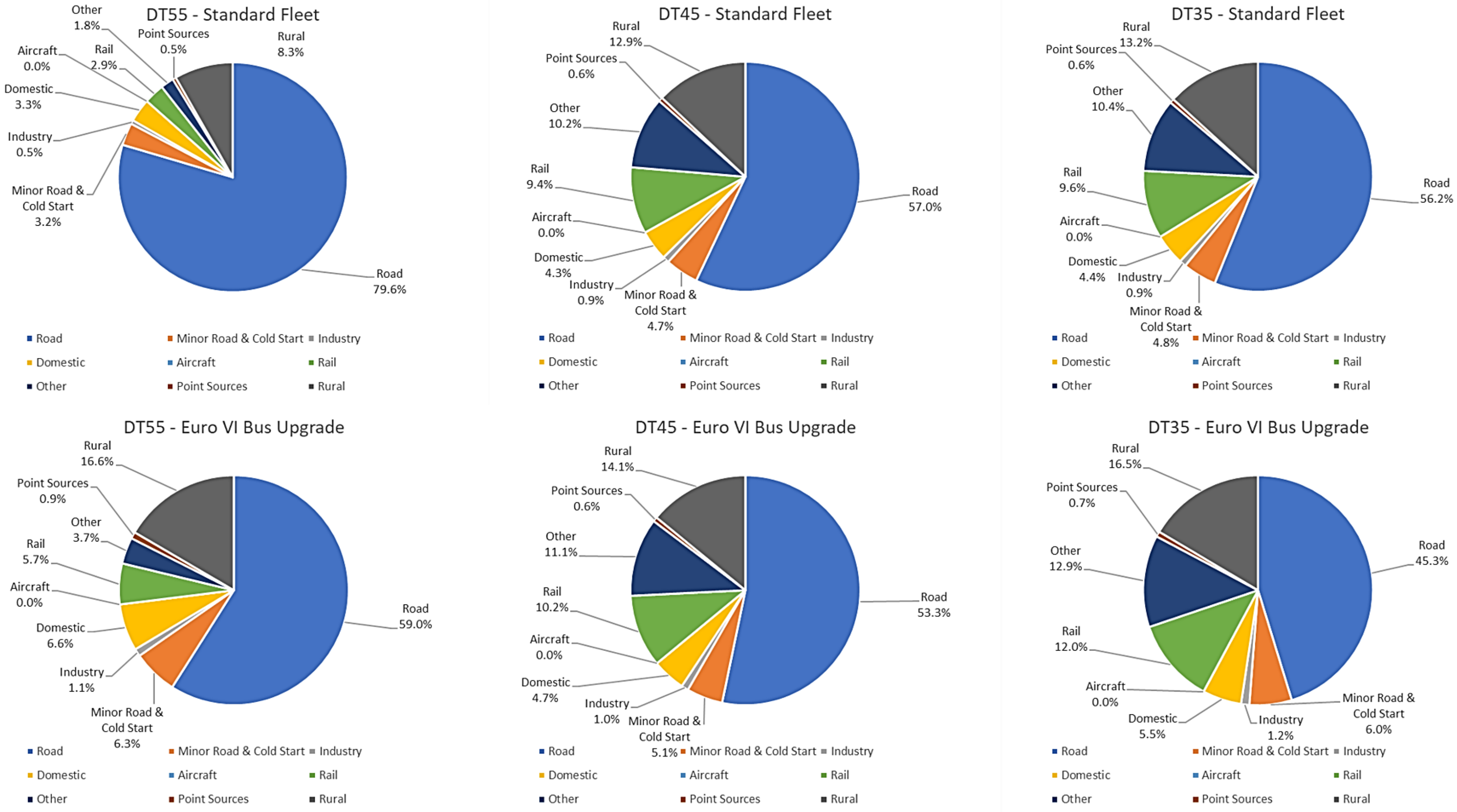


Figure A. 2 Pie chart representation of source apportionment for sources of PM_{10} (background and road, %) for 2018

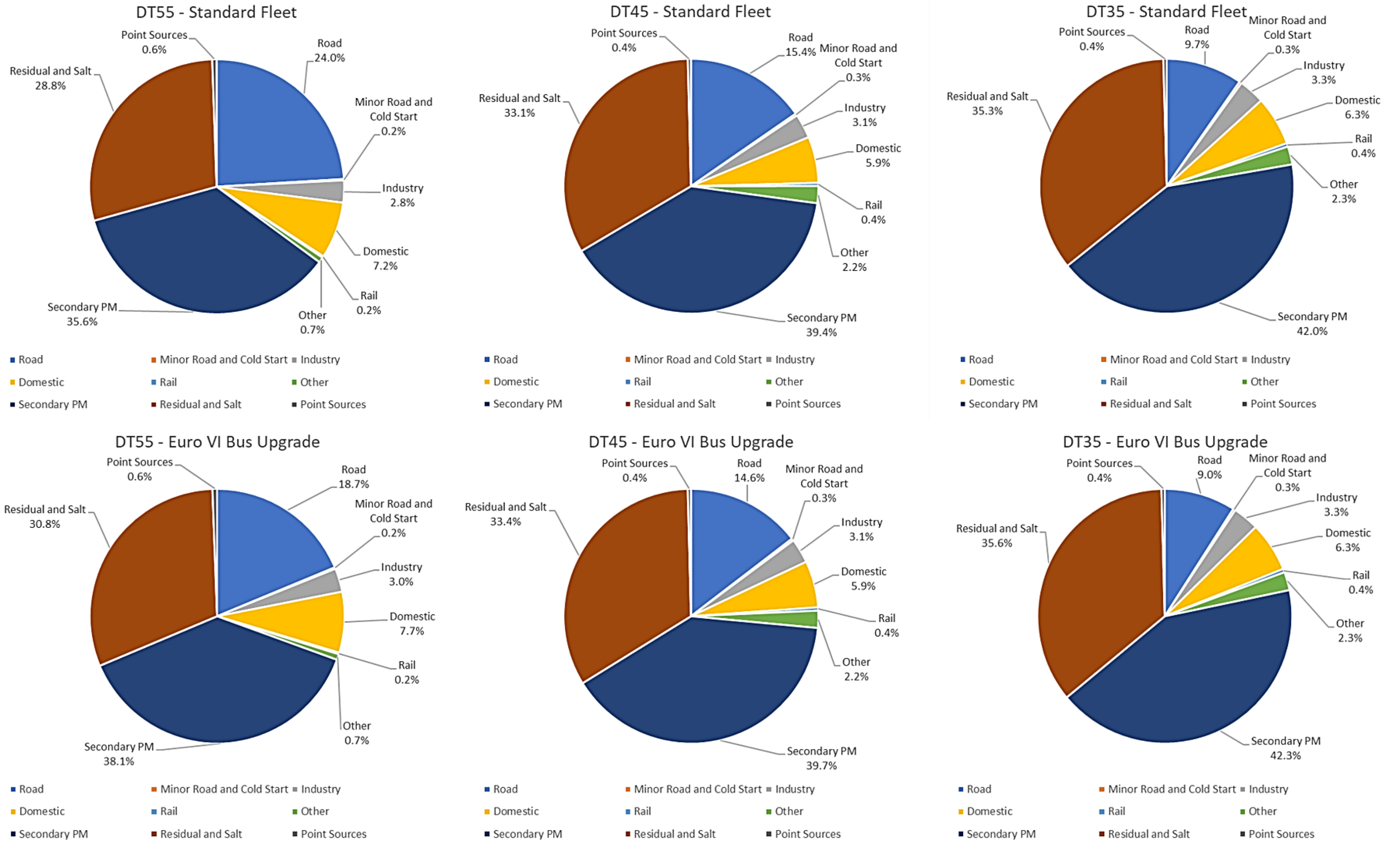


Figure A. 3 Pie chart representation of source apportionment for sources of $PM_{2.5}$ (background and road, %) for 2018

Table A- 9 describes the sources and sectors included in the above source apportionment. These definitions were taken from the Defra Background Maps User Guide (v1.0, 2019).[15]

Table A- 9 Sources of background map concentrations for NOx, PM_{10} and $PM_{2.5}$

Header	Description
In	Source is from within the 1 km x 1 km grid square
Out	Source is from outside the 1 km x 1 km grid square
Minor Road & Cold Start	Minor roads and cold starts
Industry	Industry area including: agriculture, combustion in industry, construction, energy production, extraction of fossil fuel, processes in industry, quarries, solvents and waste
Domestic	Domestic, institutional and commercial space heating
Aircraft	Aircraft
Rail	Rail
Other	Other including: ships, off-road and other emissions
Point Sources	Point sources
Rural	Regional rural concentration
Secondary PM	Secondary particulate matter (organic and inorganic)
Residual & Salt	Sea salt, calcium and iron rich dusts, regional primary particulate matter, and residual non-characterised sources (residual is defined as 1.0 $\mu g/m^3$)

[15] Background Concentration Maps User Guide, DEFRA, May 2019 available online at: https://laqm.defra.gov.uk/documents/2017-based-background-maps-user-guide-v1.0.pdf

Appendix 4 – NAEI source apportionment

The emissions across Oxford City have been apportioned into the contributions from each source. The National Atmospheric Emissions Inventory (NAEI) emissions maps[16,17,18] are downloaded at 1 km x 1 km resolution. All 1 km x 1 km squares located within the City of Oxford local authority boundary have been included in the source apportionment. The most up-to-date information available is for the year 2017, whereas all road transport emissions modelling has been completed for 2018.

The total emissions for each NAEI sector were summed across the whole of the local authority. These emissions were converted to a percentage of all emissions across the City of Oxford. The sectors are described in Table A- 10.

Table A- 10 NAEI emissions source sectors for NOx/NO_2, PM_{10} and $PM_{2.5}$

Sector	Description
Energy production	Combustion in Energy Production and Transformation
Domestic combustion	Combustion in Commercial, Institutional, Residential and Agriculture
Industry combustion	Combustion in Industry
Production processes	Production processes
Offshore	Extraction and Distribution of Fossil Fuels
Solvents	Solvent Use
Road transport	Road Transport
Other transport	Other Transport and Mobile Machinery
Waste	Point sources
Agriculture	Agriculture, Forestry and Landuse Change
Nature	Nature
Point sources	Point sources*

*Total area sources is provided by the NAEI as the sum of all the sectors in the above table, excluding point sources. Total emissions including point sources are also provided. We have assumed the difference between these two totals equal the point source emissions.

The road transport sector has been broken down further using Defra pollutant background maps and our emissions modelling:

- As mentioned previously in Appendix 3, some sources are not included in the background maps downloaded from Defra; at the time of download their relative contributions were removed because they were already included in our road source modelling. Motorway, primary and trunk roads were represented in our emissions modelling, however, minor roads were not modelled. The Defra background map concentrations at a 1 km x 1 km scale were used to generate a proportion of emissions for the motorway, primary and trunk roads compared to emissions from minor roads. This was then applied to the road transport NAEI sector in order to split it into those two categories.

- The motorway, primary and trunk roads sector has been further broken down into emissions from different vehicle types. The same source apportionment methodology that was applied in the main report was used to complete source apportionment for all modelled road links within

[16] Emission map data for Nitrogen oxides (NOx expressed as NO2) in 2017, NAEI, 2019, available online at https://naei.beis.gov.uk/data/map-uk-das?pollutant_id=6&emiss_maps_submit=naei-20191209121804 (accessed 06/12/2019).
[17] Emission map data for PM10 (Particulate Matter < 10µm) in 2017, NAEI, 2019, available online at https://naei.beis.gov.uk/data/map-uk-das?pollutant_id=24&emiss_maps_submit=naei-20191209121814 (accessed 06/12/2019).
[18] Emission map data for PM2.5 (Particulate Matter < 2.5µm) in 2017, NAEI, 2019, available online at https://naei.beis.gov.uk/data/map-uk-das?pollutant_id=122&emiss_maps_submit=naei-20191206140351 (accessed 06/12/2019).

the study area, using the 2018 baseline fleet. The total emissions across all modelled road links, for each vehicle type available, were calculated and then the proportion of emissions for each vehicle type were expressed as a percentage of total emissions from vehicles. These percentages were multiplied by the proportion of emissions from motorway, primary and trunk roads to give an estimate of the percentage of total emissions across the City of Oxford for each vehicle type.

In the following pie charts, the NAEI sectors in Table A- 10 are represented in the larger pie charts on the left, as well as minor roads. The smaller pie charts on the right show source apportionment of the motorway, primary and trunk road emissions in terms of vehicle type.

Road transport comprises approximately 40% of NOx emissions in comparison to around 10% of PM_{10} and $PM_{2.5}$ emissions. Domestic combustion, on the other hand, makes up just 19% of NOx emissions compared to 48% of PM_{10} emissions and 66% of $PM_{2.5}$ emissions. Sources of particulate matter generally had similar percentages, except for production processes. For PM_{10}, production processes accounted for 26% of emissions, however, for $PM_{2.5}$ the sector only accounted for 4% of emissions.

Figure A. 4 Source apportionment of NAEI sources of NOx, and road transport, in Oxford

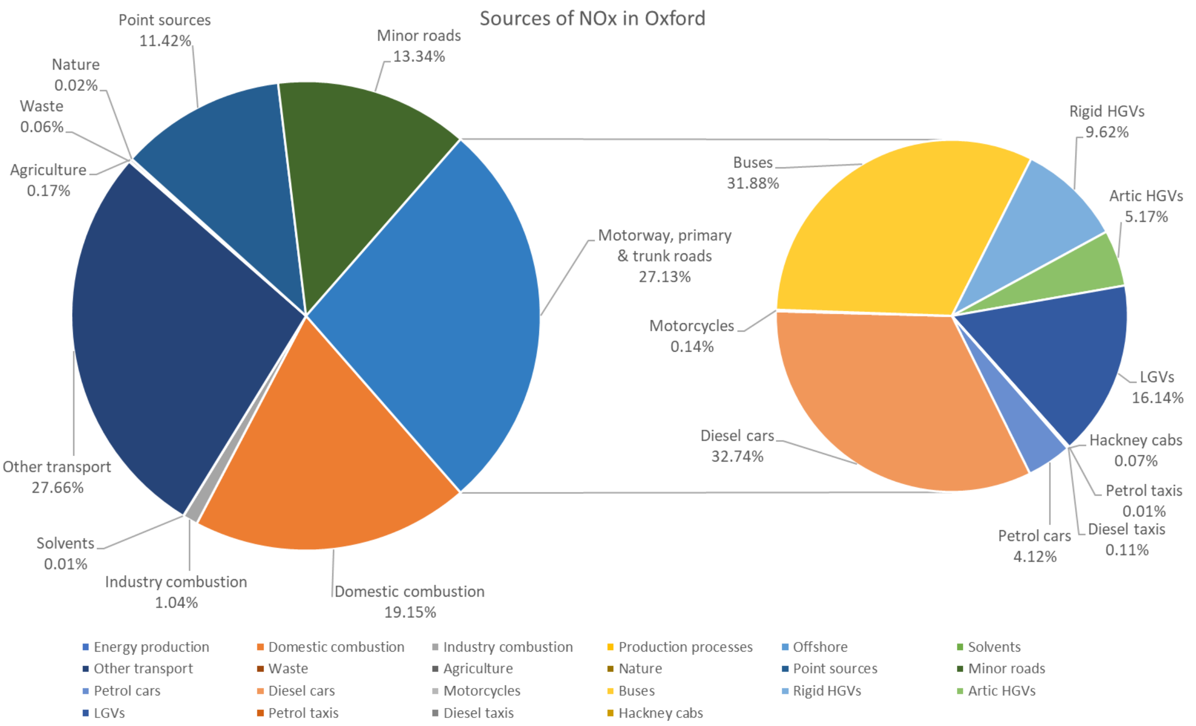


Figure A. 5 Source apportionment of NAEI sources of PM_{10} and road transport, in Oxford

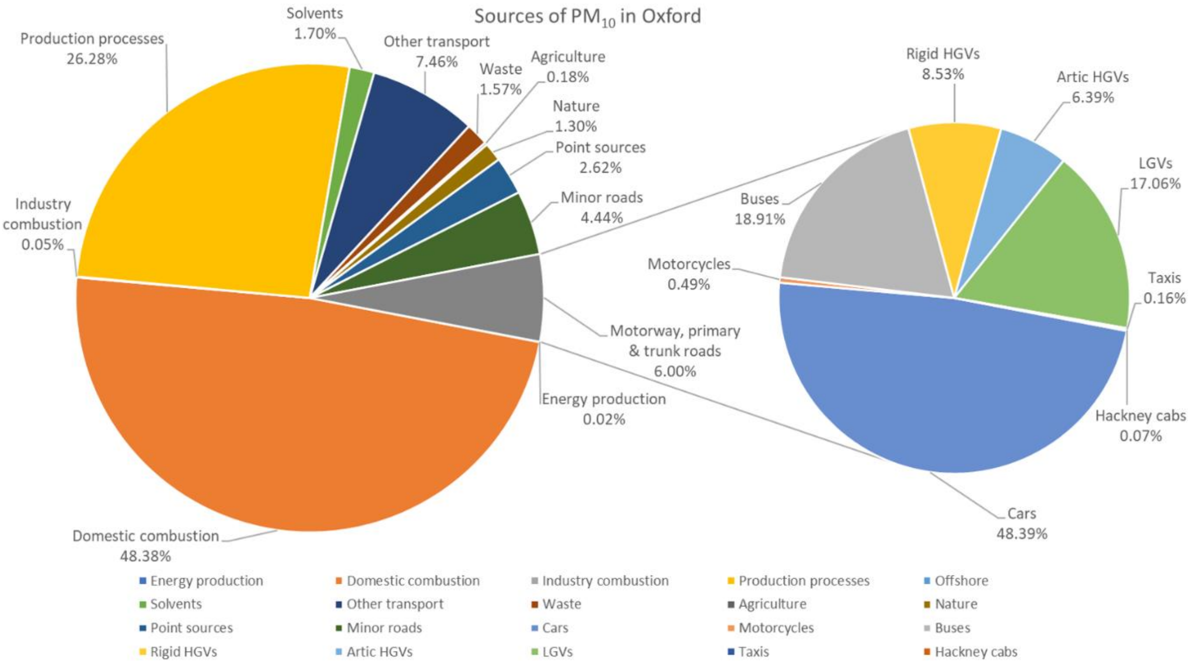
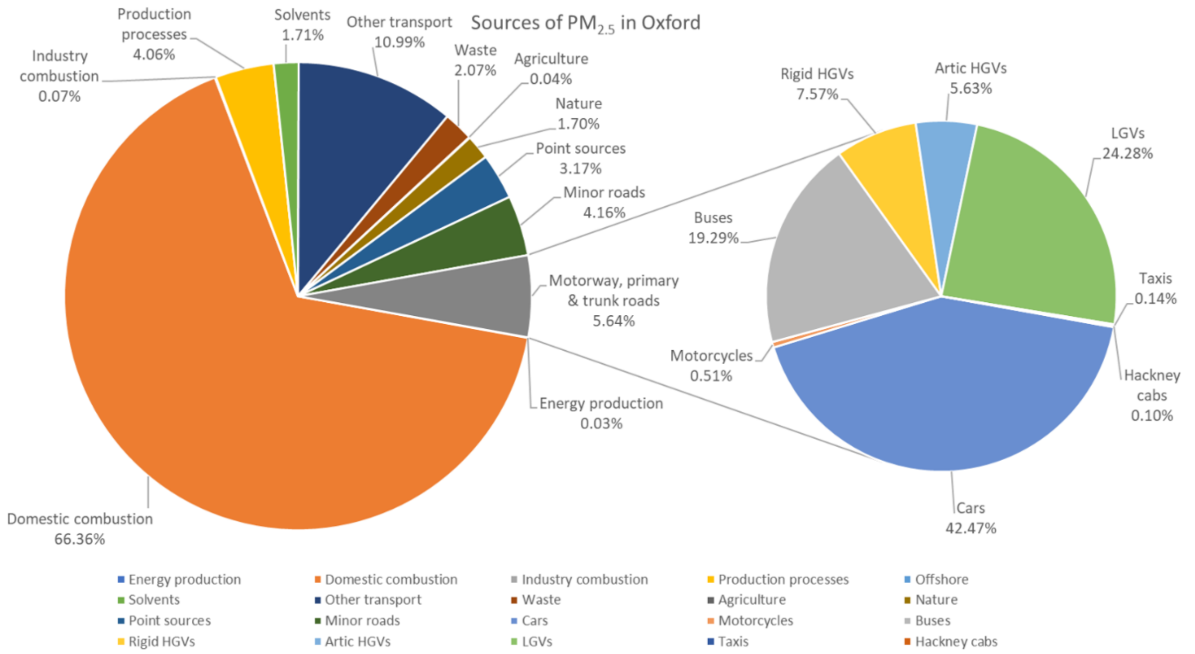


Figure A. 6 Source apportionment of NAEI sources of $PM_{2.5}$ and road transport, in Oxford



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