Birmingham Clean Air Zone Feasibility Study

Birmingham City Council

Full Business Case Air Quality Modelling Report

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Executive Summary

A Clean Air Zone (CAZ) is being considered as part of a wider package of measures by Birmingham City Council (BCC) in order to achieve compliance with the European Union (EU) annual legal Limit Values for nitrogen dioxide (NO_2) of 40µg/m^3 in the shortest possible time.

Air Quality Consultants (AQC) was commissioned on behalf of Birmingham City Council (BCC) to assist with developing a feasibility study for a CAZ within the City of Birmingham, focusing on measures associated with road vehicles.

This technical report provides an overview of the methodology, data sources and associated outcomes of the processes followed to calculate the vehicle emissions and resulting concentrations of NO_2 in the (2016) base year and (2020 & 2022) future year scenarios. This technical evidence base has been used to design and evaluate future CAZ options and any additional measures required to deliver compliance with EU Limit Values within the shortest possible timescale.

The report contains a full description of the factors driving implementation of the CAZ, the existing measures being undertaken by BCC to improve air quality, and an evaluation of the potential air quality benefits which could be delivered by the implementation of a suitable CAZ with appropriate supporting additional measures, exemptions and mitigations.

This report follows the technical report supporting the Outline Business Case, which tested a range of potential options, and identified a preferred option to be taken forward for further detailed assessment. This preferred option was a class D charging CAZ (where all non-compliant vehicle classes, including buses, taxis, heavy and light goods vehicles, cars and motorcycles are subject to charging).

The results of the traffic and air quality modelling undertaken to date have demonstrated that implementation of a charging 'class D' CAZ plus associated additional measures, exemptions and mitigations is the route to compliance with the EU Limit for NO_2 in the fastest possible time, predicted to be 2022.

A range of sensitivity tests have also been undertaken, to inform a greater understanding of the influence of a key assumptions used within core scenario modelling. Overall, it is concluded that whilst there is uncertainty associated with the modelled outcomes, as is inevitable in any predictive modelling analysis, the process applied is considered to be reasonable and appropriate, and the conclusions regarding the case for the scheme are robust.

1. Introduction

1.1 What is meant by 'air quality'?

Air quality is a term used to describe the air that we breathe, and the level of pollutant concentrations that are considered to be reasonably 'safe' from a health perspective[1]. The main pollutants of concern in the UK are nitrogen dioxide (NO_2) and fine particulate matter (PM). The majority of these pollutant emissions are typically associated with combustion emissions, including from vehicles and industry. Part IV of the Environment Act (1995) and resultant initial Air Quality Strategy, in the late 1990's, introduced the concept of local air quality management (LAQM) in the UK and it was expected at this time that the forthcoming vehicle emissions standards for road vehicles and industrial permitting would deliver, if not all, the majority of the air quality improvements needed to meet heath based objectives set under this legislation. However, the predicted reductions in pollution concentrations of NO_2 have not occurred as rapidly as expected and further action is now required.

1.2 Air Pollution and Public Health

The main driver for tackling pollution is the benefit to public health. It is also a social justice issue, with more vulnerable people disproportionately affected, particularly given the high number of schools, hospitals and care homes affected by poor air quality.

NO_2 and PM, are currently causing the greatest concern in Birmingham and other major cities across the UK. Specific health impacts[2] for these pollutants are summarised as follows:

- NO_2: At high concentrations, NO_2 causes inflammation of the airways. Long-term exposure is associated with an increase in symptoms of bronchitis in asthmatic children and reduced lung development and function;
- PM: Long-term exposure contributes to the risk of developing cardiovascular and respiratory diseases, including lung cancer. Research shows that PM_{10} (particles with a diameter of 10 microns and smaller) are likely to be inhaled deep into the respiratory tract. The health impacts of particles with a diameter of 2.5 microns or smaller ($PM_{2.5}$) are especially significant as smaller particles can penetrate even deeper into the respiratory tract.

The extent of the negative effects of air pollution on health depends on an individual's level of exposure and other conditions that they may be vulnerable to, or suffering from. Evidence in this area is continually increasing as research progresses. Preliminary work undertaken in 2015 as part of the West Midlands Low Emissions Towns and Cities (LETC) Programme[3] provided estimates of the current impacts of NO_2 pollution on Birmingham city centre and the wider West Midlands Conurbation[4]. Table 1-1 shows the estimated number of deaths per year that are attributable to NO_2 pollution, the reduction in the prevalence of chronic bronchitis in asthmatic children compared to the 2011 baseline, and the number of respiratory hospital admissions for each of the 7 West Midlands Metropolitan Boroughs for 'business as usual' cases in 2011, 2018 and 2026.

In 2011, it was estimated that 906 deaths in the West Midlands Metropolitan Districts were attributable to NO_2 pollution, including 371 in Birmingham. It can be seen that the number will decrease substantially in the future 'business as usual' cases, primarily as a result of predicted emissions reductions in motor vehicles.

It was also estimated that the reduction in emissions between 2011 and 2026 under the 'business as usual' cases will reduce the number of asthmatic children showing bronchitis symptoms each year by 873 in Birmingham and 1946 across the wider West Midlands conurbation.

Further evaluation indicated that there were 1896 hospital admissions for respiratory diseases in 2011 the West Midlands Metropolitan Districts attributable to NO_2 air pollution, including 774 in Birmingham. The estimated

[1] It can also relate to impacts on eco-systems, but this is beyond the scope of this report.
[2] Ambient (Outdoor) Air Quality and Health Fact Sheet. World Health Organisation (2016). Accessed February 2018.
[3] West Midlands Low Emissions Towns and Cities (LETC) Programme. Accessed February 2018.
[4] West Midlands Low Emission Zones: Technical Feasibility Study. Economic and Health Impacts of Air Pollution Reductions. Ricardo-AEA. February 2015. Accessed February 2018.

number of hospital admissions will decrease by 27% between 2011 and 2026 under the 'business as usual' case.

Table 1-1 : Numbers of Deaths, Asthmatic Children with Bronchitic Symptoms and Respiratory Hospital Admissions Attributable to NO_2 Pollution Under the Business as Usual Case

Local Authority	Deaths per year attributable to NO_2 pollution			Prevalence of Chronic Bronchitis in Asthmatic Children				Respiratory Hospital Admissions Per Year		
	2011	2018	2026	Base	Reduction			2011	2018	2026
					2011	2018	2026			
Birmingham	371	175	59	9,055	0	525	873	774	648	563
Coventry	70	21	4	2,209	0	101	164	200	171	152
Dudley	72	21	3	2,239	0	101	166	165	166	148
Sandwell	147	71	22	2,411	0	155	252	231	191	165
Solihull	62	24	7	1,516	0	80	130	138	116	102
Walsall	107	43	10	2,091	0	133	215	193	158	136
Wolverhampton	78	29	7	1,800	0	90	147	165	139	123
West Midlands Metropolitan Districts	**906**	**383**	**112**	**21,322**	**-**	**1,184**	**1,946**	**1,896**	**1,589**	**1,388**

Table 1-2 shows the estimated burden on local mortality attributable to man-made particulate air pollution. It shows the calculated population weighted man-made $PM_{2.5}$ concentrations for each district and the calculated numbers of attributable deaths. It also shows the estimated number of attributable life-years lost. It is estimated that there were 1359 deaths attributable to particulate air pollution in 2011 in the West Midlands Metropolitan Authorities, including 486 in Birmingham. This is expected to decrease to 426 in 2026, and 1188 across the region, under the 'business as usual' scenario. The number of deaths attributable to NO_2 in Birmingham (371 in 2011) is slightly smaller than that calculated for particulate matter. (Note that particulate matter may contribute to the estimated number of deaths attributable to NO_2 so that the effects may not be additive).

Table 1-2: Local Mortality Burden Associated with Particulate Air Pollution in West Midlands Local Authorities

Local Authority	Average $PM_{2.5}$ concentration, μgm^{-3}			Deaths 2008-2012	Annual Deaths Per Year Attributable to $PM_{2.5}$ Particulate Air Pollution			Life Years Lost per Year Attributable to $PM_{2.5}$ Particulate Air Pollution		
	2011	2018	2026		2011	2018	2026	2011	2018	2026
Birmingham	10.5	9.5	9.1	41,242	486	441	426	5,838	5,296	5,112
Coventry	10.3	9.4	8.9	13,453	156	142	137	1,874	1,709	1,642
Dudley	9.4	8.5	8.1	14,771	158	142	137	1,896	1,710	1,650
Sandwell	11.0	9.9	9.5	14,411	178	161	156	2,134	1,927	1,873
Solihull	10.0	9.1	8.7	9,094	103	94	90	1,233	1,128	1,083
Walsall	10.6	9.6	9.2	12,304	147	133	128	1,756	1,593	1,542
Wolverhampton	9.5	8.6	8.3	12,094	131	118	114	1,569	1,421	1,369
West Midlands Metropolitan Districts	-	-	-	**117,369**	**1,359**	**1,231**	**1,188**	**16,300**	**14,784**	**14,271**

An understanding of the effects associated with sudden peaks in air pollutant concentrations is also improving. Air pollution is now believed to play a significant role in some cardiovascular episodes, for instance heart attacks, and in a range of health conditions from asthma to dementia.

Clearly, this emerging evidence demonstrates that air quality improvements can have a major impact in terms of delivering health benefits, and further practical interventions to improve air quality will accelerate the delivery of these positive outcomes. The evidence for health effects has changed with latest National Air Quality Plan and that these figures are based on the previous methodology summarised for the OBC.

1.3 EU/UK air quality legislation

The Air Quality (Standards) Regulations 2010 set legal limits (called 'limit values') for concentrations of pollutants in outdoor air. These are based on the EU Air Quality Limit Values[5].

The UK government is currently responsible to the EU for ensuring that it complies with the provisions of the EU Air Quality Directives[6], which are legally binding. However, under the Localism Act (2011), the UK government has discretionary powers to pass on any fines (or a proportion) to local authorities.

For NO_2, the European Commission has initiated infraction proceedings against the UK and 12 other Member States[7]. On the UK government's behalf, the Department for Transport (DfT) and Department for Environment Food and Rural Affairs (Defra) have Public Service Agreements relating to EU Air Quality Limit Values and it is their responsibility to ensure that the UK meets these. The legal limits for NO_2 and other pollutants of most concern for the West Midlands Urban Area (including Birmingham) are shown in Table 1-3.

Table 1-3 : Legal Limits for Pollutants of Most Concern in the West Midlands Urban Area, Including Birmingham

Pollutant	Conc-entration (limit value) $\mu g\ m^{-3}$	Averaging Period	Target and Limit Values	Number of permitted exceedances each year	Compliance assessment for 2016 in the West Midlands Urban Area (Including Birmingham)[8]
$PM_{2.5}$	25[9]	1 year	Target value came into force on 1 January 2010 Limit value came into force on 1 January 2015	n/a	Compliant
PM_{10}	50	24 hours	Limit value came into force on 1 January 2005 (time extension granted to June 2011)	35	Compliant[10]
	40	1 year	Limit value came into force on 1 January 2005	n/a	Compliant
NO_2	200	1 hour	Limit value came into force on 1 January 2010	18	Compliant
	40	1 year	Limit value came into force on 1 January 2010	n/a	Non-Compliant

Defra has reported PM compliance limits for 2016 across England and Wales, with most 'non-reportable' sites falling below the legal limits. However, there are no safe limits for PM, and it is accepted that $PM_{2.5}$ is more damaging to health than PM_{10}. Health evidence suggests that further emissions reductions, will bring about improvements in health for UK residents. Without further action there is the prospect of $PM_{2.5}$ emissions increasing if traffic levels rise.

[5] Taken from: ec.europa.eu/environment/air/quality/standards.htm. Accessed February 2018.
[6] Ambient Air Quality Directive 2008/50/EC and Directive 2004/107/EC relating to other pollutants. Accessed February 2018.
[7] Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions. A Europe That Protects: Clean Air For All (2018). Accessed June 2018.
[8] Air Pollution in the UK 2016. Defra (2016). Accessed February 2018.
[9] An obligation to reduce exposure to concentrations of fine particles also came into force from 2015.
[10] Following the subtraction of natural sources in accordance with the directive

1.4 Local Air Quality Management in Birmingham

The basic statutory framework for local air quality management (LAQM) exists under the national Air Quality Regulations and Part IV of the Environment Act 1995 ('the 1995 Act', as amended, and 'Part IV functions') and this framework remains in place, with relevant LAQM policy and technical guidance provided by Defra[11,12].

Under the LAQM regime, a city-wide Air Quality Management Area (AQMA) was declared in 2005 due to elevated concentrations of NO_2 resulting from road traffic emissions, particularly within the city centre area[13]. The AQMA boundary has been retained since this time to ensure that there is no risk of transferring exceedance areas during the implementation of wider compliance strategies (Figure 1).

The 2016 Annual Status Report for Birmingham City Council (BCC) concluded that currently, the Air Quality Objectives (AQO) were likely to be achieved in respect of all prescribed air pollutants except NO_2[14]. Results from the 2016 annual mean NO_2 monitoring programme, which incorporated both automatic (continuous) and diffusion tube (DT) monitoring, indicated that there were many locations within the city-wide AQMA where concentrations still exceeded the annual mean value of 40 $\mu g/m^3$ NO_2. However, it is noteworthy that none of the automatic monitors indicated a breach of the short-term AQO for NO_2 during 2016.

Crucially, several areas of Birmingham continue to exceed the annual mean limit for NO_2 and this is likely to continue beyond 2020, so more action needs to be taken.

A range of measures are being progressed by the City Council and to underpin these interventions air quality has been prioritised across all services and championed by relevant politicians. This updated and prioritised governance will be supported by underpinning policies, including a review of the current Air Quality Action Plan (AQAP).

1.5 National NO_2 Action Plan

In July 2017, the government published the UK Plan for Tackling Roadside Nitrogen Dioxide Concentrations setting out how it will achieve compliance in the shortest possible time[15] in response to a UK Supreme Court ruling[16]. The Government is requiring the initial five cities, including Birmingham, named in the 2015 UK Air Quality Plan to draw up full business cases for their local plans. In May 2017 the Government published a Clean Air Zone Framework setting out the principles local authorities should follow when setting up Clean Air Zones in England, with a view to achieving statutory NO_2 limit values within the shortest possible time.

The government use the Pollution & Climate Mapping (PCM) modelling to define whether the UK is complying with the EU Limit Values. The PCM model is the government's national air quality model which predicts air quality on the major road network across the UK, and reports on the compliance status to the European Commission. The National Action Plan reports the road links, which comprise relatively long sections of road based on the national traffic survey count sites or 'Census ID', where the PCM has predicted exceedances of the Limit Values. The government then requires the relevant local authority to undertake local modelling to confirm where exceedances are predicted, which must include all of the PCM road network along with any other roads excluded from the PCM modelling at risk of exceedance. The local authority must then develop plans based on the Clean Air Zone Framework[17] and other guidance, to reduce vehicle pollution in these locations and deliver compliance in the shortest possible time.

The government expects Birmingham to deliver their CAZ by the end of 2019, with a view to achieving statutory NO_2 Limit Values within the shortest possible time. The Birmingham CAZ consultation proposals are consistent with this National Action Plan.

11 Local Air Quality Management Technical Guidance (LAQM.TG (16)). Defra. April 2016. Accessed January 2018.
12 Local Air Quality Management Policy Guidance (LAQM.PG (16)). Defra. April 2016. Accessed January 2018.
13 Birmingham AQMA as amended (2005). Accessed February 2018.
14 2016 Air Quality Annual Status Report (ASR) for Birmingham City Council. BCC (2017). Accessed January 2018.
15 UK Plan for Tackling Roadside Nitrogen Dioxide Concentrations. Detailed plan. Defra/DfT, July 2017.
16 https://www.supremecourt.uk/cases/uksc-2012-0179.html
17 Clean Air Zone Framework. Principles for setting up Clean Air Zones in England. Defra. May 2017. Accessed June 2018.

2. Existing Initiatives

2.1 Air Quality Action Plan

Since the last update of BCC's AQAP in 2011[18], a number of actions have been completed, including:

- Increasing the number of park and ride schemes;
- Increasing the provision of charging infrastructure to encourage the take up of electric vehicles ;
- The delivery of improvements to the bus fleet under the Statutory Bus Quality Partnership (SBQP) ;
- Setting up an Air Quality Members Steering Group comprised of the Chair of the Public Protection Committee and the Cabinet members for Transportation, Health and Wellbeing, Clean Streets, and Recycling and Environment, to ensure that delivering improved air quality is a key priority integrated into all aspects of the Council's service delivery;
- Setting up an Air Quality Program Delivery Group, chaired by the Director of Public Health, and comprised of senior officers from departments involved in the delivery of programs to improve air quality; and
- Publication of Planning and Procurement Guidance to support Low Emissions Infrastructure via the West Midlands LETC programme.

It is proposed to review and update the AQAP once further details of the CAZ implementation are confirmed.

2.2 Taxis and Private Hire Vehicles

BCC's proposed policy on emission standards for taxis and private hire vehicles means that these vehicles will need to reach certain emission standards, which will gradually become stricter.

Under the Birmingham NO_x Reduction Champions' project, the emissions of 65 of Birmingham's Hackney carriages (black cabs) has been reduced by fitting LPG (liquefied petroleum gas) fuelled engines. These engines are Euro 6 (category N1, class III) compliant, meaning they would not be charged to enter a future CAZ.

Additional funding has been awarded by the Office for Low Emission Vehicles (OLEV) to introduce 197 electric taxi charging points, all of which will offer fast or rapid charging facilities for Hackney carriages and private hire vehicles. Electric vehicles would be exempt from charging as part of any future CAZ scheme.

2.3 Freight and Logistics

Birmingham's economy relies on the freight and logistics sector working efficiently. BCC wish to better understand the challenges facing local businesses seeking to improve their fleets, to appreciate the implications of a CAZ for freight operators, and to learn what other measures businesses may be required (e.g. seeking further Government funding to support a transition to cleaner fleets).

Addressing air quality presents an opportunity to not only reduce pollution levels in the city, but to open up new economic development and regeneration opportunities within the green economy for alternative fuels, new vehicle and product design, and manufacture supply chains in line with the Government's Industrial Strategy.

To this end, businesses were invited to complete a survey during 2017 and to work with the Council towards positive solutions leading to cost savings and more sustainable business operations. The final outcome of this initiative will be reported during 2018.

[18] Birmingham Air Quality Action Plan. BCC, 2011. Accessed February 2018.

2.4 Other Transport Projects

Birmingham Connected[19] covers all transport planning activity and is built on the Birmingham Connected White Paper[20], the city's 20-year transport strategy. Within this scheme, many of the Council's transport projects are focused on reducing pollution emissions and enabling more sustainable modes of transport.

Birmingham Cycle Revolution[21] aims to make cycling an everyday way to travel in Birmingham over the next 20 years. The scheme has set a target of 5% of all trips in the city to be made by bicycle by 2023, and to double this again to 10% by 2033. In 2017/18, two new, high quality cycle routes are being constructed, linking the city centre to Selly Oak and Perry Barr.

Birmingham is creating Green Travel Districts with less congestion, less pollution, fewer accidents, and healthier, safer, more productive communities. In densely populated residential areas, the aim is to create an environment where residents, workers and visitors can safely walk, cycle or take public transport as their preferred travelling option.

Alongside the CAZ, the Council is reviewing and extending parking controls in and around the city centre.

2.5 Smoke Control Areas

Birmingham was designated as a Smoke Control Area in 1995 to improve air quality. As a result of this, residents are only allowed to burn authorised fuels in an open fireplace or an exempt appliance. Burning coal is not permitted in Birmingham.

2.6 Policies and Strategies

2.6.1 Birmingham Connected

As mentioned in Section 2.4, The Birmingham Connected White Paper sets out a 20-year vision for transport in the city, including a reduction in emissions from transport and a move to more sustainable transport.

2.6.2 Low Carbon Fuel Infrastructure

In 2015, BCC launched its City Blueprint for Low Carbon Fuel Infrastructure [22].

Building on the Birmingham Connected Transport Strategy, the Council has developed a blueprint for low carbon fuel infrastructure. This blueprint identifies the key priorities and opportunities for the refuelling and recharging infrastructure that will be needed to support growing fleets of low and ultra-low carbon vehicles.

The blueprint covers electric, hydrogen, gas, methane/ bio-methane and LPG vehicles, and has been developed in close consultation with fleet operators active in the Birmingham area to deliver wide ranging air quality and CO_2 benefits offered by cleaner vehicles.

2.6.3 West Midlands Low Emission Bus Delivery Plan

Birmingham is part of the West Midlands Combined Authority Delivery Plan for Low Emission Buses.

The Low Emission Bus Delivery Plan [23] was developed by Transport for West Midlands (TfWM) to facilitate the delivery of low emission buses to help address the region's significant air quality problems.

[19] Birmingham Connected. Accessed February 2018.
[20] Birmingham Connected- Moving Our City Forward: Birmingham Mobility Action Plan White Paper. BCC, 2014. Accessed February 2018.
[21] Birmingham Cycle Revolution. Accessed February 2018.
[22] A City Blue Print for Low Carbon Fuel Refuelling Infrastructure. Birmingham City Council (2015). Accessed February 2018.
[23] West Midlands Low Emission Bus Delivery Plan- A Study Commissioned by Centro. Element Energy & Network West Midlands. 2016. Accessed February 2018.

It highlights areas where use of low emission buses should be prioritised, by identifying air quality hot-spots, and sets out a timeline for reducing NOx emissions by over 90% by 2035.

The West Midlands Bus Alliance is a collaboration of local councils and local bus operators, co-ordinated by TfWM, and committed to ensuring that all buses in the region reach a minimum Euro V standard by 2020.

3. The Case for Further Intervention

3.1 Update on Birmingham's Air Quality

3.1.1 Current Position

Birmingham is currently compliant with legal limits for PM. However, further reductions are needed (especially to $PM_{2.5}$ levels) to protect human health. Annual average PM_{10} and $PM_{2.5}$ concentrations are well within the legal limit values of 40 and 25µg/m^3 respectively. Although compliance has officially been achieved, by reducing PM concentrations even more, the health benefits will be even greater.

In contrast, annual average NO_2 concentrations still exceed the legal limit on several road links in and around Birmingham City Centre. Meeting the NO_2 legal limit poses a huge challenge for many cities in the UK and across Europe. One of the key reasons why ambient levels of NO_2 remain higher than had been previously expected is the driving conditions in urban areas and concerns over the performance of the more recent Euro emissions standards for some diesel vehicles (see Appendix A for more information on Euro standards). In general, Euro standards have failed to reduce oxides of nitrogen (NO_x)[24] emissions from light-duty diesel vehicles (e.g. cars and vans) to the extent that was predicted. However, Euro VI (for heavy vehicles) is performing well and the standard for light vehicles is still bringing about a significant reduction, albeit still not as much as predicted.

This report only includes discussion of the impacts of any potential measures on NO_2 emissions and concentrations, as this is the pollutant that defines compliance and the design of the potential CAZ scheme. However, the assessment process has included modelling of PM_{10} and $PM_{2.5}$, alongside carbon dioxide (CO_2). These data have been used in the overall assessment of the benefits of the scheme and are included in the health impact assessment and distributional analysis.

3.1.2 Future Year Estimates of Birmingham's Air Quality

Birmingham's air quality is expected to improve, although further and more urgent action is required. Emissions from all sources are projected to decrease due to technological advances in vehicle design, as well as policies and legislation already in place to reduce emissions across the UK and Europe. This includes the roll-out of a new emissions standard for Euro 6 diesel cars and vans which is anticipated to be more successful at reducing pollutants in urban driving conditions than previous standards, and a forthcoming requirement for all vehicles to meet real world driving emissions tests[25]. However, although it is expected that PM emissions will remain within legal limits, concentrations of NO_2 will continue to exceed the legal limits in some areas of Birmingham.

Further PM_{10} and $PM_{2.5}$ reductions by 2021 will mean that annual average concentrations should remain below the legal limits. However, there is a strong case to continue cutting PM concentrations to ensure health benefits, and a compelling need to accelerate the pace of change to achieve this even sooner in order to move towards meeting the WHO recommended guidelines, which are lower than current Limit Values.

The proportion of Birmingham City Centre where annual average NO_2 concentrations exceed the legal limit is also expected to decrease by 2020, due to anticipated reductions in background concentrations, ongoing upgrade of the local vehicle fleet and other local interventions. However, modelling indicates that, if nothing further is done, concentrations will continue to exceed the limit on some major roads in and around the City Centre, including the A38, A38M, A4400, A452 and A4540.

[24] Vehicle emissions are measured in terms of total NO_x. NO_x is made up of nitrogen oxide (NO) and NO_2, although the NO is subsequently converted into additional NO_2 by interaction with ozone in the atmosphere – this reaction being dependent on the availability of ozone.

[25] Please see appendix A for more details.

3.2 Areas of Exceedance

Whilst air quality remains a problem across Birmingham and the wider West Midlands conurbation, there are areas of the city centre where the problem is more pronounced than others. The modelled 2016 baseline concentrations are presented in Figure 2, showing wide spread exceedances across Birmingham.

Table 3-1 shows the estimated percentage of the length of major roads exceeding legal limits in Birmingham, derived from Defra's NO_2 projections data[26] based on the PCM model. In 2020, approximately 0.3 percent of roads in the city centre are forecast to still exceed the limit value for NO_2 with no CAZ in place.

Table 3-1 : Defra's Estimated Percentage of Modelled Road Length Exceeding Limits with No Further Action

Area	% of Road Length Exceeding Limit Values 2015	% of Road Length Exceeding Limit Values 2020
Birmingham City Council	1.13	0.34

[26] https://uk-air.defra.gov.uk/library/no2ten/2017-no2-projections-from-2015-data.

4. CAZ Options

4.1 Background to the Proposals

In order to meet the EU Limit Value for annual average NO_2 concentrations, Defra have set out an approach to introduce targeted local measures to tackle the most polluting vehicles in a number of air quality hotspots in a number of cities and primarily urban areas, including Birmingham[27]. These measures are intended to reduce air pollution, particularly in city and urban centres, and to encourage the replacement of the older and most polluting vehicles with more modern, cleaner vehicles.

BCC has been directed by the Government to draw up a full business case for its local plan because locations in the city exceed legal Limit Values for NO_2. BCC needs to demonstrate that it is implementing policies to meet compliance in the shortest possible time.

The implementation of a CAZ is more than just putting into place an access restriction for vehicles; this would simply constitute a Low Emission Zone (LEZ). In principle, a CAZ should deliver wider benefits, supporting economic growth and accelerating the transition to a low emission economy by raising public awareness and providing financial incentives to accelerate transition.

In addition to any access restrictions, a CAZ should promote short-term improvements, such as anti-idling measures and allow for an open dialogue with local businesses about fleet turnover plans, travel plans and healthier travel. Longer term, a CAZ should help support local growth and low-emission ambitions – this could include awareness raising, an improved business environment due to the reduced levels of air pollution, and "low emission" new developments. A key part of a CAZ ambition will be to promote modal shift to cleaner and healthier forms of travel, with the CAZ providing a guide for new investment, and where necessary infrastructure may be required.

4.2 Full Business Case Preferred Option for Birmingham

BCC has commissioned AQC to assist in developing the CAZ feasibility study in order to consider what type of CAZ would help Birmingham to meet the EU Limit Values for NO_2 in the shortest possible time.

This report follows the technical report supporting the Outline Business Case (OBC), which tested a range of potential options, and identified a preferred option to be taken forward for further detailed assessment for the Full Business Case (FBC). This preferred option was a class D charging CAZ (where all non-compliant vehicle classes, including buses, taxis, heavy and light goods vehicles, cars and motorcycles are subject to charging). The charging 'class D' CAZ is supported by a range of additional measures which further improve air quality, with exemptions and mitigations that reduce the impacts of the scheme on residents, visitors and businesses in Birmingham.

The package of additional measures tested include upgrade to buses and taxis, removal of free parking, and changes to the road network.

The CAZ uses a low emission zone, among other actions, to reduce emissions of nitrogen oxides (NOx – oxides of nitrogen which are a pre-cursor to NO_2), as well as emissions of NO_2 and other pollutants. In the longer term, it is envisaged that a CAZ will help to improve human health and create a more pleasant environment – by introducing quieter vehicles (e.g. electric/hybrid) and potentially reducing driver stress and accidents, due to reduced traffic in some areas. The proposals for Birmingham's CAZ are focused on the City Centre, in the area within and including the Inner Ring Road (A4540).

The implementation of a CAZ scheme in Birmingham fits with the Movement for Growth 2026 Transport Delivery Plan produced by Transport for West Midlands (TfWM)[28]; this in turn supports the West Midland's Combined Authority's Strategic Economic Plan. Measures within these documents are designed to unlock economic growth opportunities and support wider initiatives to improve social well-being and lives of residents. A larger,

[27] UK Plan for Tackling Roadside NO_2 Concentrations. Detailed Plan. Defra/DfT (July 2017). Accessed January 2018.
[28] TfWM, Movement for Growth: 2026 Delivery Plan for Transport.

more economically active population will have diverse transport needs and shifting attitudes to travel and travel behaviour. The implementation of a CAZ will capitalise on those shifts, as well as play a part in the need to transform Birmingham into a sustainable, low-emission city region. Implementation of a CAZ would also contribute towards Birmingham's committed 60% reduction in carbon emissions by 2027 (based on a 1990 baseline) as road vehicle transport currently accounts for ~20% of carbon emissions in Birmingham[29].

This report contains an overview of the methodology, data sources and associated outcomes of the processes followed to calculate the vehicle emissions and resulting concentrations of NO_2 in the (2016) base year and (2020 & 2022) future year scenarios. This technical evidence base has been used to design and evaluate a number of future CAZ options during the OBC optioneering and FBC preferred option phases, and predict what improvements could potentially be delivered by implementation. It also provides a summary of the outputs from the traffic and air quality modelling undertaken, which will inform the development of a wider air quality strategy for Birmingham. The charging CAZ introduces a policy targeting older vehicles with higher emissions, charging non-complaint vehicles from entering the CAZ. Compliance standards have been based on the Euro-classification of vehicle engines similar to those adopted for London's Ultra Low Emission Zone (ULEZ) and the government's Clean Air Zone Framework[30]. Proposed compliance standards for different vehicle types are shown in Table 4-1.

Table 4-1 : Proposed Classification Standards for Compliant Vehicles

Vehicle	Petrol	Diesel
Motorcycle	Euro Class 3 and above	Euro Class 3 and above
Car	Euro Class 4 and above	Euro Class 6 and above
Taxi	Euro Class 4 and above	Euro Class 6 and above
Light Goods Vehicle (LGV)	Euro Class 4 and above	Euro Class 6 and above
Heavy Goods Vehicle (HGV)	-	Euro Class VI and above
Bus/ Coach	-	Euro Class VI and above

Defra has identified four classes for the implementation of CAZ's across the UK as per Table 4-2.

Table 4-2 : Defra CAZ classes

CAZ class	Vehicles included
A	Buses, coaches, taxis (Euro 6/VI)
B	Buses, coaches, taxis and HGVs (Euro 6/VI)
C	Buses, coaches, taxis, HGVs and LGVs (Euro 6/VI diesel and Euro 4 petrol)
D	Buses, coaches, taxis, HGVs, LGVs, cars (Euro 6/VI diesel and Euro 4 petrol) and motorcycles (Euro 3)

The government has stated that local authorities should determine appropriate level of charges to be used for the scheme. In the absence of any specific guidance on proposed charge rates, this analysis of the impact of a Category D CAZ in Birmingham City Centre has tested a range of charges to determine the optimum charge level. The proposed charges are summarised in Table 4-3.

[29] BCC, Birmingham's Green Commission-Building a Green City, 2013
[30] Clean Air Zone Framework. Principles for setting up Clean Air Zones in England. Defra. May 2017. Accessed June 2018.

Table 4-3 Proposed CAZ Charging Rates

Vehicle Type	Proposed CAZ D (medium) Charge Rates
Car	£8.00
Taxi	£8.00
LGV	£8.00
HGV	£50.00
Bus/ Coach	£50.00

5. Traffic Modelling Methodology

5.1 Introduction

The air quality modelling process followed a number of sequential steps to calculate the emissions from traffic into NO_2 concentrations. In addition to covering the area in and around the Inner Ring Road (A4540), the model also covered areas beyond the city centre, where it could reasonably be expected that the CAZ would have an impact on the Road network as a result of diversion or reduction in traffic volume.

In order to provide input traffic data for the air quality model, traffic modelling was undertaken using a variety data sources, research and existing modelling platforms to fully comply with Defra's Joint Air Quality Unit (JAQU) guidance; these included the following timeframes:

- 2016 Base Year Model
- 2020 CAZ Opening Year Model
- 2022 CAZ Exemptions End
- Average Weekday morning (AM) / Inter-Peak (IP) / Afternoon (PM) periods

The AM period covered 7:30 to 09:30, the IP period covered 09:30 to 15:30 and the PM period covered 15:30 to 19:00. Using these data, annual average daily traffic, and the off-peak (OP) period from 19:00 to 07:30 was also calculated.

The traffic model was developed and used to provide traffic for the air quality model, as well as supporting other assessments required for the CAZ evaluation. The model has been developed to forecast 2020 conditions without a CAZ, and also to evaluate the impact of CAZ measures on traffic levels. Outputs from the model were used in several ways:

- To forecast compliant/ non-compliant link flows, thereby enabling the AQ model to demonstrate levels of compliance with air quality limit values
- To generate inputs for the impact assessment (IA), cost benefit analysis (CBA) and the distributional impacts.

The main tools used in forecasting traffic flows in 2020 are summarised in Table 5-1.

Table 5-1 : Traffic Modelling Tools

Source	Description
BCC Simulation and Assignment of Traffic to Urban Road Networks (SATURN) Model	SATURN assignment model: • 2016 base year and 2020 & 2022 CAZ scenarios • AM, IP and PM peak weekday periods • Car (taxis included in 2020 scenarios), LGV, HGV and Bus User Classes, split into compliant and non-compliant categories • Covers CAZ zone in detail, with network covering the "motorway box". Much of the network outside the CAZ is fixed speed (approx. 2km from the Ring Road) • Feeds traffic link flow data into the air quality models
Policy Responsive Integrated Strategy (PRISM) Demand Model	Regional demand model covering the West Midlands, maintained by Mott MacDonald on behalf of TfWM, BCC and other stakeholders. Inputs from PRISM are:

Source	Description
	• Base year prior matrices • Traffic Growth from PRISM, having been updated with Trip End Model Presentation Program (TEMPRO) V7.0 demographic data (with post model adjustments to account for v7.2 changes). TEMPRO is software provided by DfT that provides data from their National Trip End Model (NTEM). • To calculate non-route choice responsiveness to charging
Automatic number plate recognition (ANPR) Surveys	A large programme of ANPR surveys carried out in the CAZ area. This has been used to: • Validate base year through trip proportions • Calculate Euro Class fleet mix
Behavioural Research	TfL carried out a stated preference survey on car drivers in the extended ULEZ area covering an area not in the current congestion charging zone. Used to forecast vehicle upgrade rates from CAZ charging.
Internet transport analysis guidance (WebTAG)	Modelling follows WebTAG guidance and uses various data sources
Defra's Joint Air Quality Unit (JAQU) Guidance	JAQU guidance and data sources used as appropriate

5.2 2016 Base Year Model

Forecasting utilised the 2016 base year BCC SATURN model, which was calibrated against 2016 traffic data. The base year fleet mix data was derived from ANPR surveys conducted in and around Birmingham City Centre. The survey was undertaken specialist data collection company, Intelligent Data Collection (ID) during a seven-day period in November 2016[31]. Cameras were installed at 29 unique locations, supplemented with a further 7 sites which are managed by an independent company, Amey, on behalf of BCC. Figure 3 illustrates the location of each site, with red sites representing cameras positioned around the city centre and blue sites representing a cordon of entry/exit points to the city centre.

The collection of vehicle registration plate data was then matched to the Driver and Vehicle Licensing Agency (DVLA) database, which provides further information about the vehicle, including a breakdown of different Euro Class emission standards by vehicle class.

The 2016 model results were audited by JAQU in August 2017 and approved for use within subsequent calculations.

5.3 2020 Do Minimum (DM) Scenario

The analysis of the 2020 do-minimum scenario involved an evaluation of how base year traffic flows would change by 2020 in the absence of a CAZ or any other currently unapproved schemes. This included a consideration of approved changes to the local road network, regional traffic growth and changes to the traffic fleet.

5.3.1 Road Network

A number of approved changes to the highway network are due to be implemented between 2016 and 2020. These changes, which are focused around the proposed City Centre CAZ area were agreed with BCC Transport Studies team and incorporated into the highway model. Discussions with Highways England (HE)

[31] City Centre Data Collection Report (QU043), Reference: ID02908, 11/04/2017, Issue 2.0

showed that there would not be any significant changes to the strategic road network that would affect the proposed CAZ, so no changes were made to these roads within the model.

5.3.2 Traffic Growth to 2020

An evaluation of background traffic growth was undertaken using the PRISM model. This has been recently updated with TEMPRO V7.0 demographics, development locations and network assumptions, with further changes applied to account for changes between TEMPRO V7.0 and V7.2.

The sites of specific major developments within Birmingham were agreed with BCC development planners. Traffic impacts resulting from the demand at these developments was incorporated at the appropriate location within the model, whilst also ensuring that there is no double counting of developments already included in PRISM. The overall growth rates that resulted from this process are provided in Table 5-2.

Table 5-2 BCC Traffic Growth 2016 to 2020

Sector	AM Peak			Inter Peak			PM Peak		
	Car/ Taxi	LGV	HGV	Car/ Taxi	LGV	HGV	Car/ Taxi	LGV	HGV
City Centre	7.9%	10.8%	3.5%	8.0%	10.8%	3.6%	7.4%	10.8%	3.6%
Rest of Birmingham	3.7%	10.7%	3.2%	3.7%	10.7%	3.1%	3.7%	10.7%	3.1%
Birmingham (Total)	**4.2%**	**10.7%**	**3.2%**	**4.2%**	**10.7%**	**3.2%**	**4.1%**	**10.7%**	**3.2%**
Rest of West Midlands	4.4%	10.6%	2.9%	5.3%	10.7%	2.9%	4.6%	10.8%	3.0%
Total	**4.3%**	**10.7%**	**3.0%**	**4.7%**	**10.7%**	**3.0%**	**4.4%**	**10.7%**	**3.0%**

5.3.3 Traffic Fleet

Future year traffic fleet forecasts were based on guidance provided by JAQU. This enabled typical compositions of future CAZ compliant and non-compliant traffic fleets to be derived for further evaluation. The following assumptions were applied:

- National forecasts of how fleet proportions of petrol and diesel cars might change in future years were used to correct the local fleet proportions observed in the ANPR surveys. Conventional hybrid vehicles were included within the petrol and diesel car proportions when deriving these estimates.

- For other vehicle classes, the proportions of petrol and diesel vehicles were retained at the same levels as those observed in the ANPR surveys.

- It was assumed that the age distribution of vehicles will remain the same, but will increase in line with each additional year. This causes a natural increase in the proportion of compliant vehicles (i.e. a five-year-old car in 2020 will be of a higher Euro standard than a five-year-old car in 2016).

- It was assumed there will be no change to the contribution from the electric vehicle fleet beyond assumptions in Defra's Emission Factor Toolkit[32] , including plug in hybrids, battery electric or hydrogen vehicles,

Based on this evaluation, it was possible to estimate the number of compliant vehicles within the future 2020 & 2022 do-minimum scenarios. This forecast is summarised in Table 5-3.

[32] Emission Factor Toolkit V7.04. Defra (2017).

Table 5-3 Projected Proportion of Non-Compliant Vehicles Without a CAZ Scheme

Vehicle	% Non-Compliance Status (See Table 4-1)	
	2020	2022
Car	23%	16%
LGV	41%	30%
HGV	35%	22%
Bus	40%	37%
Taxi	73%	58%

5.4 Representing Driver Response to a CAZ

It is assumed that there would be various potential responses to the introduction of charging for trips entering the city centre. This has been modelled hierarchically in the order shown in Table 5-4.

Table 5-4 Demand Response Hierarchy

Hierarchy	Response	Method
1	Upgrade to compliant/ switch to already owned compliant vehicles (for households with more than one car)	Choice Modelling based on TfL Stated Preference Research for Cars and LGVs
		Taxis and buses are assumed to upgrade through licencing agreements
		HGVs users assess value for money over 5-year period as part of decision on whether to upgrade
2 (Car only)	Cancel – do not make a journey	Elasticity to charge derived from PRISM run to apply to Do Minimum trips to/ from the City Centre.
	Change Mode to non-highway PT/ Walk/ Cycle option	
	Avoid (Change destination from City Centre to non-City Centre trips)	
	Pay (with a city centre origin/ destination)	
3	Avoid (through trips change route to non-City Centre route).	BCC CAZ assignment model to forecast diversion due to toll for through trips.
	Pay (through trips use City Centre)	

Traffic model development was conducted at the journey level to retain compatibility with the vehicle kilometre tables provided within the JAQU technical reports.

Vehicle owners that choose to upgrade to a compliant vehicle have been represented in the model by using TfL's behavioural research for the extended London ULEZ. This research is relevant to Birmingham as it covers an area that is currently free to drive in (rather than the congestion charging area), and therefore captures people that do not currently pay a charge. To ensure that the forecasts reflect local conditions, factors from the TfL research were re-weighted using Birmingham data in the following way:

- Usage frequency from the ANPR City Centre survey was grouped into low, medium and high frequency in accordance with the following classifications: high (4-7 days a week); medium (2-3 days a week); low (1 day per week)

- End-user income grouping within the PRISM model was classified as low, medium and high as defined by the following classifications: low <-£35k, medium £35k-£50k, high >£50k

The cost to upgrade is a required input to the model, which was calculated based on assumptions published in JAQU's national data inputs for the economic models. The following assumptions were applied:

- Scrap: A proportion, 25%, of those people taking the upgrade response will scrap their old vehicle. This assumes that the cost to upgrade is equal to the purchase cost, neglecting any resale value. It is assumed that the replacement vehicle is brand new.

- Buy new: A proportion, 25%, of those people choosing to upgrade will buy a brand-new vehicle, selling their former car.

- Switch: A proportion, (75% of 75%), of those people who elect to upgrade will sell their old vehicle and buy the cheapest unaffected one. The purchase cost has been calculated in a similar fashion to the analysis above, plus £200 in transaction costs. It is assumed that all replacement vehicles are the eldest compliant Petrol Euro 4.

- Keep fuel: A proportion, (25% of 75%), of those people who decide to upgrade will sell their old vehicle and buy the cheapest unaffected one of the same fuel type. £200 in transaction costs plus depreciation are included in the estimation of the upgrade cost. This follows the same methodology used by Steer.

- The starting cost of a new car is brand-new compliant car by 2020 is £18,000[33]

- Standard depreciation rates were applied to derive the cost of compliant cars and non-compliant cars for the different Euro Classes.

- An average sell cost and buy cost for Birmingham users was derived by using the age profile of the fleet taken from the ANPR survey.

This enabled the derivation of appropriate factors which could be applied to non-compliant trips into the City Centre in the Do Minimum model.

For the remaining proportion of users that won't upgrade to a new vehicle, the PRISM model was used to estimate what proportion of users with an origin or destination in the city centre would respond by:

- Paying the charge;
- Shift to a new mode;
- Cancel their trip; or
- Avoid the zone by travelling somewhere else.

It is worth noting that this final option is not applicable to those trips with an origin in the city centre.

The West Midlands variable demand mode 'PRISM' model was run with the CAZ charges set applied. The PRISM model is not set up to be able to separate compliant and non-compliant vehicles, so could not be used directly to forecast the full responsiveness to the charge.

The PRISM demand model outputs provide a large set of demand responses in response to different model inputs, for example:

- Income segments

- Journey purposes

[33] National data inputs for Local Economic Models.xlsx, JAQU, 2018

- Origin/ destination pairs with different highways, public transport, and walking / cycling times

An average elasticity to charge was calculated by analysing the changes in demand between Do Minimum and CAZ scenarios against the change in generalised costs of each potential City Centre journey. The generalised costs were calculated as a sum of journey time costs, vehicle operating costs, charges and parking charges to ensure that costs other than the CAZ charge were considered in the choice.

As part of the FBC, a benchmarking exercise was carried out on the behavioural responses of the modelling (see appendix D of traffic forecasting report). This indicated that the elasticity to the toll at the £12.50 charge is reasonable. However, when comparing to the Bristol SP results the change in people willing to pay the charge between the £12.50 and £7.00 charge is steeper using the approach in the OBC.

The previous approach used in the OBC had been benchmarked against TfL's ULEZ research, however, however it is considered that the Bristol survey is more comparable to Birmingham conditions. Given this and the fact that the PRISM model had been run at £12.50 (with the lower levels derived from analysing the changes across different OD pairs generalised costs) an approach was adopted that adjusted the £12.50 willingness to pay based on the Bristol SP results.

To do this elasticity was derived of those willing to pay to the charge to apply to charges between £12.50 and £7.00, based on SP surveys in another CAZ city. The elasticity based on the numbers in the table below, is -1.09. In other words, every £1 increase from £7 up to £12.50 results in a 1.09% decrease in users willing to pay the charge.

In addition to the willingness to pay adjustment, changes to the mode shift response have been undertaken. PRISM forecasts low levels of mode shift in response to the charge. This is a reasonable long-term response and is calibrated against observed behaviour in the West Midlands. However, in the short term, users will have less choice to change destination and are more likely to cancel their trip or change mode.

This response has been adjusted using the 'short term' SP survey to redistribute the 'Mode Shift', 'Cancel Trip' and 'Change distribution', but keeping the total response across all the three responses at the same level as currently forecast.

The demand was also analysed within 3 different geographical segments depending on where the trip was generated. Trip generation refers to the home end of a trip, unless it is part of a trip chain, in which case it is modelled as an origin/ destination format. This approach is illustrated in Table 5-5.

Table 5-5 : Geographical Responses

<table>
<tr><th>Geography</th><th>Response</th></tr>
<tr><td>Trips Generated in the City Centre to outside the City Centre (CC to Non CC)</td><td>These trips can be cancelled, pay the charge or change mode. No change in destination assumed.</td></tr>
<tr><td rowspan="2">Trips Generated in the City Centre to inside the City Centre (CC to CC)</td><td>For home based trips, no change assumed as there would no way to charge them.</td></tr>
<tr><td>For non-home based trips, mode shift or cancelled trip assumed.</td></tr>
<tr><td>Trips Generated outside of the City Centre to inside the City Centre (Non CC to CC)</td><td>Pay the charge, mode choice, cancel trip, and change destination is modelled.</td></tr>
</table>

The analysis was conducted at two journey purpose levels to retain compatibility with the assignment mode:

- Non Work; and
- In Work

Overall, the model responded sensibly, demonstrating that more people were prepared to pay the charge at lower levels.

To apply these responses to the City Centre assignment model, adjustments were made as per Table 5-6.

Table 5-6 : Application of Responses to Assignment Model

Response	Modelled
Upgrade Vehicle	The compliant user class is uplifted and the non-compliant reduced
Mode Shift	The non-compliant car trips to/ from the City Centre are reduced
Cancel Journey	The non-compliant car trips to/ from the City Centre are reduced
Change Destination	The non-compliant trips to/ from the city centre are redistributed to outside so that neither trip end is in the City Centre, using the existing demand distribution from the appropriate origin/destination zone outside the city centre

For through trips, non-compliant through trips were modelled using route choice in the assignment model. Charges were coded onto links forming a cordon into and out of the City Centre. As the charge is only used for route choice it was only applied in the inbound direction to avoid double charging. Values of time were addressed by converting charges into a generalised journey time, with the model forecasting whether users were prepared to pay for the time savings of making a through trip.

Assumptions used in the transport modelling of other vehicle classes are summarised in Table 5-7.

Table 5-7 : Assumptions Used in Modelling Various Vehicle Types

Vehicle Type	Assumptions Made
Taxi/ Private Hire Vehicles (PHVs)	It was assumed that all Birmingham registered taxis and PHVs will upgrade to compliant vehicles, based on policy being developed by BCC.
LGV	LGVs were assumed to respond by: • upgrading their vehicle; • pay the charge and continuing to drive into the CAZ; or • through the route choice for through trips. TfL's ULEZ behavioural model was used to forecast the response to upgrading the vehicle. It was assumed that LGV users' behaviour will more closely reflect car users than HGV users, due to the following: • The charges and upgrade costs are similar. • The costs used are based on JAQU costings published in their technical report supporting the UK Plan for Tackling Roadside Nitrogen Dioxide Concentrations[34].
HGV	The approach compared the cost to upgrade over a 5-year period against the cost of paying a charge throughout this period. The costs involved both in upgrading, the charge paid, and the value of the business being carried out, is considerably higher than for the lighter vehicle classes. Users are therefore likely to take a longer-term outlook on whether to upgrade their vehicle. • Compliance rates were calculated by applying the following assumptions: • Depreciation Rates from JAQU • Users will upgrade to cheapest available option

[34] UK Plan for tackling roadside nitrogen dioxide concentrations - Technical report, DEFRA/ DfT July 2017

Vehicle Type	Assumptions Made
	• Frequency taken from the ANPR survey data, with assumptions of how the vehicle counted once in the week are distributed across the year. • The costs were calculated for rigid and artic separately with proportions in the ANPR surveys used to derive the fleet proportions to apply these assumptions to.
Bus	The effect of CAZ charges on buses was not explicitly modelled as it was assumed that all buses in the CAZ will be compliant, with an out of model adjustment made when applying the results in the AQ model.
BCC Fleet	It was assumed that the full Birmingham fleet will be made compliant. However, using number plate data provided by BCC and matching against the ANPR surveys showed that the proportion of the fleet within the traffic model was too small to include specifically within the modelling. Measures for staff owned vehicles would be an additional measure, and would be considered at a later stage in the study.

Traffic data were provided for CAZ D options for the following scenarios:

- 2016 Base Year for model verification
- 2020 & 2022 Do Minimum (baseline)
- 2020 & 2022 CAZ D plus additional measures, with exemptions and mitigations (referred to as “CAZ D+ w/ M&E”)
- 2020 & 2022 CAZ D plus additional measures with exemptions (excluding mitigations)
- 2020 & 2022 CAZ D plus additional measures with mitigations (excluding exemptions)

- A summary of the timeframes evaluated is provided below:
    - AM Peak Weekday Average Hour (07:30-09:30)
    - Inter Peak Weekday Average Hour (09:30-16:30)
    - PM Peak Weekday Average Hour (16:30-19:00)

The key metrics used to assess the impacts of the CAZ on transport movements are summarised as follows:

- Annual Average Daily Flows (AADT) entering the CAZ for compliant and non-compliant flows. This shows the numbers of vehicles driving across the CAZ boundary each day by vehicle type in the different scenarios.

- Network Plots – Showing change in flows graphically across the modelled links to see where flows are increasing and decreasing. Also includes analysis of change in link delay.

- Key Link Analysis – Tables showing changes in flows at key network links at the all-day level

- Network Statistics – Change in vehicle kilometres and average network speed. This provides an aggregate measure of change in network conditions and has been provided by different modelled areas.

Outputs from the traffic modelling process were used to produce inputs for a range of air quality model scenarios. Additionally, testing of the impact of altering key assumptions within the modelling process termed “sensitivity testing” was undertaken, to provide assurance of the modelling predictions and inherent uncertainty.

6. Outline of The Air Quality Modelling Process

6.1 Traffic Data, Fleet Mix and Emissions

Modelled traffic data outputs produced using BCC's Saturn model covered the road network area as shown in Figure 4. The traffic model contains differing level of density of road network coding, with detailed junctions in the centre and speed flow curves used further out, and beyond this the fixed speed 'buffer' area. The buffer area is not validated as part of the Saturn model development process (although the demand flows in PRISM regional transport model are, which is the source for the traffic demand in the BCC model) and therefore traffic data in these locations are considered less reliable.

The approach to the transport modelling, and Saturn spatial coverage was initially developed to address the government requirements based on the 2015 Pollution & Climate Mapping (PCM) modelling, which identified exceedance in Birmingham city centre only.

Following the issue of updated PCM model data in July 2017, JAQU identified potential link exceedances in the 2020 forecasts beyond the city centre. Some of these links were located within the Saturn model buffer zone. The transport modelling approach was subsequently approved by DfT/JAQU, recognising that certainty in the model outputs would be reduced. The air quality modelling in this location is compared with monitoring data, and a verification process applied. However, it is not considered to contain the same level of confidence in results. BCC intends to update and improve the transport modelling to cover these areas of exceedance risk as the project progresses.

Additional analysis of the PCM exceedance links in the Saturn model buffer zone has been undertaken comparing all day traffic flows provided from the BCC model for input into the AQ model against DfT traffic counts. This was undertaken at locations close to the PCM exceedance links on Tyburn and Chester Roads and are shown in Table 6-1. Given that the model has not been calibrated in the buffer area, the modelled flows are relatively close to the observed values, this provides some reassurance that traffic conditions are reasonably accurate on these external exceedance links.

Table 6-1 : Annual Average Daily Traffic Flows 2016

Road	Modelled Vehicles	Counted Observed Vehicles	Difference	% Difference
Tyburn Rd (A38 East of M6 junction)	30,688	33,699	- 3,011	-9%
Chester Rd (North of M6)	53,041	49,661	3,380	7%

Traffic modelling was based on ANPR data collected in September 2016, with additional data attribute fields added by JAQU, from sites inside the Inner Ring Road of Birmingham. These data were combined with licensing data for Hackney Carriages and Private Hire Vehicles (although limited to BCC licensing) and buses.

These data were then processed to develop the Euro Standards by class for each vehicle logged, and then using the data captured the overall fleet mix for Birmingham, by vehicle type, could be calculated. The analysis indicates that the fleet was older than the national fleet defaults used by Defra's Emission Factor Toolkit (EFT v7.4a) for all vehicle categories, except for diesel LGVs where there was a greater spread in the vehicles ages. However, once projected to 2020 the overall effect was that all vehicle categories were older (fewer vehicles of the latest Euro standard) in the local fleet compared to the forecast national average. There was an update to the fleet projection methodology from the OBC phase, with the date of Euro 6c vehicles entering the fleet amended to be consistent with the approach taken in Copert, based on guidance provided by JAQU[35]. The fleet mix profiles as input to EFT are presented in Appendix B.

Traffic data from Saturn were provided for the following categories:

- Buses (includes coaches)
- HGVs
- LGVs
- Hackney Carriages
- Private Hire Vehicles (PHV)
- Cars

All have been disaggregated into compliant and non-compliant vehicles defined by the CAZ Framework, and cars/Hackney carriages/PHV have been further disaggregated to petrol and diesel fuel types.

ANPR data has been used to develop age and Euro class profiles for each vehicle type/fuel, along with rigid/articulated splits for HGVs.

The emissions of NO_x, PM_{10} and $PM_{2.5}$ were calculated for each traffic model period, so that speeds in congested periods were represented. EFT v7.4a (Detailed Option 3) was used to calculate emissions by vehicle type. Hackney carriages and PHVs were included in the car flows, although the age profiles were recorded separately to enable CAZ interventions on these vehicles to be modelled specifically in the CAZ scenarios. The Advanced Options for Euro Compositions outputs was used to determine the proportion of emissions from every link by vehicle type and Euro class based local fleet mixes for the relevant year. These Output % Contributions from Euro Classes were combined with National Atmospheric Emissions Inventory (NAEI) f-NO_2 vehicle types[36] to develop link specific f-NO_2 for every road link, and the total NO_x and f-NO_2 (as NO_2) emissions were input to the dispersion model. The outputs of the dispersion model for NO_x and NO_2 at every monitoring site and receptor could be used to calculate the f-NO_2 for every output location.

6.2 Air Quality Modelling Set-Up

To model air quality, BCC use the Airviro modelling software produced by the Swedish Meteorological and Hydrological Institute (SMHI) and Apertum. The Airviro model was set up to model dispersion of pollutants across a 10m x 10m grid at 2m elevation. The specified locations for receptors and monitoring were then produced by Airviro based on ‘kriging’ (mathematical interpolation) of the exact grid reference within the 10m grid square. Locations where the EU Limit Values apply are defined in Annex III of the Air Quality Directive. These are defined by sites where the public could be reasonably present, and should be at least 25m from major junctions and be representative of at least 100m road length. The receptor is set 4m back from the road edge, and all PCM roads links are included. Additional receptors were then added where worst-case exposure might occur based on LAQM.TG (16)[37] guidance for relevant annual mean exposure, including at roads not included in the PCM model.

Meteorological data for 2016 from Birmingham Airport was used for the assessment, which was converted to a statistical meteorological dataset to reduce runtimes by SMHI. The wind rose for the meteorological data is shown in Figure 5.

6.3 Air Quality Monitoring Data

A total of 99 monitoring sites were reviewed for the model verification process, which compares the model predictions with the measurements of air quality in Birmingham.

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[35] This update does not affect 2016 model scenarios because Euro 6c was not available at this time, but slightly lowers the 2020 Do Minimum concentrations from those reported in the OBC and also reduces the relative effectiveness of a CAZ, however the analysis undertaken for the OBC is considered robust and is presented in the Baseline section for consistency.

[36] http://naei.beis.gov.uk/resources/PrimaryNO2_factors_NAEIBase_2016_v1.xlsx

[37] Local Air Quality Management Technical Guidance (LAQM.TG (16)). Defra. April 2016. Accessed January 2018.

There are 7 continuous analyser sites located in Birmingham, with 3 sited at background locations and 4 located at roadside locations. However, only one continuous analyser site is located in the city centre at Moor St Queensway, which recorded 52 µg/m^3 NO_2 as an annual mean in 2016.

The positions and measured concentrations of the sites are summarised in Figure 6, and clearly indicate a wide range of exceedances of the 40 µg/m^3 EU Limit values, with measured values at some diffusion tube sites exceeding 70 µg/m^3 NO_2 as an annual mean. This evidence supports the mandate for taking urgent and effective action across the City Centre at the earliest opportunity.

Diffusion tubes were supplied and analysed by Gradko International. Monitoring data for 2016 was collated by BCC and a local bias adjustment factor of 0.818 was calculated at Stratford Road, and 0.799 at Tyburn Road background site. These factors show good agreement with the Gradko national diffusion tube survey results. These factors were applied to the 2016 annual mean diffusion tube data for roadside and background sites respectively, which was consistent with the approach used for LAQM reporting in previous years. Measured concentrations at roadside sites with good data capture in 2016 ranged from 29 to 67 µg/m^3.

The diffusion tube data was used for verification, and Road NO_x back calculated using the Defra NO_x to NO_2 calculator v5.3, with calculated f-NO_2 from the dispersion modelling input for each site.

Monitoring at sites BMH66 to BMH93 was initiated in September 2016, with data available up to July 2017 at the time of verification. The use of four months of data from 2016 would normally be considered inappropriate for use in verification, however, because these sites have been deployed in the vicinity of the road links used in the PCM, they could provide additional information to input to the assessment process. The monitoring data from these sites were therefore annualised using the relationships of other Roadside tubes in the BCC survey for locations running from January 2016 to July 2017.

6.4 Background Air Quality Data

Defra 2013 based background maps have been adjusted in accordance with JAQU guidance, and then the total NO_x and NO_2 concentrations were compared with values recorded at background monitoring sites during 2016. Overall, good agreement was found, and no further adjustment considered necessary.

The NO_x maps were then processed in order to remove contributions from all roads in each sector, apart from the minor road component, and the NO_2 concentrations were recalculated using the Defra NO_2-Adjustment-for-NO_x-Sector-Removal-Tool.

6.5 NOx Chemistry

The conversion of modelled Road NO_x to NO_2 was undertaken using the Defra NO_x to NO_2 calculator v5.3. The dispersion model used link specific f-NO_2 emissions, modelled as NO_2. The modelled annual mean Road NO_x and f-NO_2 for each output point were put into the calculator so that a location specific f-NO_2 was applied.

6.6 Model Verification

Model verification is the process for comparing the modelled pollutant concentrations with the monitored concentrations for the same pollutant, and where necessary, adjusting the modelled results so they better align with the monitoring data. Given the complexities inherent throughout the model verification process, JAQU and Defra have provided specific guidance to inform this process and assist in the generation of robust data sets.

The AQ modelling outputs were converted to NO_2 and then compared to the monitoring data. Only road traffic sites with data capture greater than 75% were used in the verification process, with calendar year data for 2016. A total of 44 sites were selected for the verification process.

Full details of the verification process are provided in Appendix C.

Model verification was undertaken in accordance with Defra's technical guidance document LAQM.TG (16); this involved initial adjustment of Road NO_x, with a secondary adjustment factor being applied to the calculated Road NO_2 concentration. The adjusted results were then compared with the monitoring data, which demonstrated improved model performance consistent with the guidance in LAQM.TG (16).

7. Air Quality Modelling Results

7.1 Baseline Evaluation and Comparison with the National PCM Model

Local baseline air quality modelling has shown that the air quality issues identified are broadly in line with the national PCM information issued in the National Air Quality Plan with regard to the locations of exceedance of the NO_2 annual mean limit value of 40 µg/m^3. It should be noted that the PCM model does not include minor roads, notably those within the city centre.

The results of the BCC (local) modelling are displayed in Figure 7, and PCM data for 2020 is provided in Figure 8.

Comparison of the local modelling results for 2020 with the full PCM results shows reasonable agreement between the numbers of locations exceeding the NO_2 annual mean limit value of 40 µg/m^3, and the predicted concentrations. The PCM model is a coarser national scale model, using national scale assumptions (e.g. fleet mix, growth, meteorology) and less network refinement, when compared to the local model. It is therefore reasonable to expect disagreement between the two approaches.

Further evaluation of a number of selected points was carried out during the comparison of modelling results (Figure 9).

The A38/A4400 Queensway link (PCM_153, Census ID: 81493) yields the highest concentration of 50.5 µg/m^3 in the full PCM model, compared with a predicted concentration of 44.0 µg/m^3 in the local model.

The maximum recorded concentration at a PCM receptor point in the local Airviro modelling is further south on the A4400 (PCM_0, Census ID: 81490). A value of 44.1 µg/m^3 was predicted by the Full PCM model, however the local modelling generated a concentration of 46.1 µg/m^3. The local road network in the vicinity of this PCM link is complex so direct comparison is difficult.

The maximum modelled concentration generated by the local model at a non-PCM site (42.0 µg/m^3) was located at a receptor point in Digbeth, however this receptor point is not included in the PCM model.

Other locations with similar levels of predicted concentrations occur on the A4540 Watery Lane Middleway (PCM_6, Census ID: 27736) on the east side of the Inner Ring Road. A value of 41.6 µg/m^3 generated by the local model corresponded with a PCM value of 43.0 µg/m^3.

Outside of the city centre, the local modelling does not identify exceedances at the PCM link on the A38 Tyburn Road (Non_PCM_8, Census ID: 16365). The PCM modelling predicts an exceedance (43.2 µg/m^3), but the local modelling reports a value of 37.7 µg/m^3. Similarly, the PCM exceedance in northeast Birmingham on the A452 Chester Road (PCM_159, Census ID: 99234) of 45.8 µg/m^3 corresponds with a value of 36.5 µg/m^3 predicted by the local model. The links outside the city centre are located in the traffic model Buffer zone, so should be treated with additional caution.

7.2 2020 DM Baseline

Local baseline air quality modelling has shown that the air quality issues identified are broadly in line with the national PCM information issued in the National Air Quality Plan with regard to the locations of exceedance of the NO_2 annual mean limit value of 40 µg/m^3. It should be noted that the PCM model does not include minor roads, notably those within the city centre (Figure 7). The results of the BCC (local) modelling are displayed in Figure 8, and PCM data for 2020 is provided in Figure 9

Evaluation of the 2020 DM baseline (as described in Section 7.1) for the OBC analysis indicated the full extent of predicted exceedances in and around the city centre in the absence of any additional interventions. A breakdown of vehicle emissions or 'source apportionment' was undertaken at a number of specific receptor points inside and outside the CAZ boundary to provide specific information on the emission sources contributing to each exceedance which need to be targeted by the respective CAZ scenarios (Figure 10).

The respective source apportionments indicate significant contributions from a number of vehicle classes as summarised in Table 7-1 below:

Table 7-1 : Summary of 2020 DM Source Apportionment Results

Site Location	% Contributions From Respective Vehicle Classes					
	Diesel Cars	Petrol Cars	Diesel LGVs	Rigid HGVs	Artic HGVs	Buses & Coaches
A4400 Suffolk St. Queensway	53	6	25	14	2	0
A38 Corporation St	54	6	22	13	2	3
A4540 Lawley Middleway- Garrison Circus	42	5	21	28	4	0
A4100 Moat Lane, Digbeth	25	3	8	13	2	49

Evaluation of two specific CAZ scenarios during the OBC provided an opportunity to evaluate the impacts of targeting specific vehicle classes as part of a wider strategy, with specific focus on reducing emissions from diesel vehicles. These are clearly indicated as the predominant source of emissions in each of the areas evaluated above, apart from the A4100 (Moat Lane, Digbeth), which is populated with predominantly buses and coaches.

7.3 Preferred Option: CAZ D plus Additional Measures, with Exemptions and Mitigations

7.3.1 Overview

The OBC modelling showed that a charging CAZ D scheme alone would not bring compliance by 2020, and therefore supplementary interventions alongside the charging CAZ were developed and refined for the preferred option. Additional Measures are a series of supplementary interventions identified to support a potential charging CAZ scheme in delivering compliance in the shortest time possible.

The measures have been chosen and informed by the source apportionment analysis and the potential type of CAZ that will be implemented. The Additional Measures are aimed at reducing emissions from vehicles and encouraging modal shift from car to bus with CAZ scheme in place. The package of measures evaluated is summarised in Table 7-5.

Table 7-2 : Package of Additional Measures

Type	Summary	Comments
Parking	Remove all free parking from BCC controlled areas. Replace with paid parking spaces. Assume cost of parking in line with BCC off-street parking.	Around 15% of traffic parking in the City Centre currently parks on free on street parking. Transport modelling indicates that this will reduce car demand with free parking by around 30%. This leads to around a 2.5% reduction in overall vehicles kilometres, resulting in a reasonably significant reduction in emissions, although this is limited in the key locations (failing the legal limits) as the impacts are focused on the outer areas of the City Centre. An additional benefit is that it raises revenues of the City Centre which will be re-invested in mitigating the effects of the CAZ.
Network Changes	**Network 1:** Ban traffic entering (southbound) or leaving (northbound) Suffolk Street Queensway (A38) from Paradise Circus, other than local access.	Provides a reduction in overall traffic levels and reduces delays on the A38 at a key exceedance location. Reduces traffic through Paradise Circus an area with high pedestrian flows linking one of Birmingham's main cultural quarters, to the shopping/ business district and New Street Station. Paradise is the focus of one the city centre's main masterplan areas, so removing traffic will support this regeneration.

Type	Summary	Comments
	Network 2: Close Lister Street and Great Lister Street at the junction with Dartmouth Middleway.	Reduction in delay on the A4540 ring road, including less traffic needing to stop (and accelerate away from the junction) due to the removal of the signal stage for traffic crossing the road. This also provides a mitigation for increases in traffic caused by the CAZ charge for through trips on the A38.

The mitigations include a range of financial support measures to most significantly affected drivers, including packages for car, van and taxi owners who live or work within the CAZ. There is also a proposed HGV and coach compliance fund, and a residents parking scheme.

Further details on the additional measures, mitigations and exemptions can be found in the FBC Strategic and Economic Cases.

7.3.2 Other Air Quality Measures Included in the Preferred Option Modelling

There are two supporting measures that are being implemented by BCC in support of the CAZ option, that are not part of the Do Minimum scenario, but not funded as part of the CAZ project. These have been included in the with CAZ scenario models.

Fleet Upgrades to Taxi and PHV

Birmingham Council have undertaken taxi/ PHV studies, investigating the numbers of vehicles expected to upgrade to cleaner vehicles due to the cities' clean air policies. We have directly adopted these forecasts of the number of vehicles that will upgrade to Electric or LPG retrofitting.

These assumptions do not affect the flow of taxi/ PHV vehicles in the CAZ scenarios, but assumes they will be less polluting vehicles. Therefore, the adjustments were made to the link level Air Quality inputs traffic data rather than adjusting the traffic model demand and running the full modelling process. The adjustments were made to the traffic model outputs for air quality/emissions:

- For electric vehicles, vehicles are removed from the AQ inputs as they are assumed to have zero NOx emissions.
- For taxis retrofitting to LPG, they were removed from diesel and added into petrol, assuming to be the equivalent to a petrol Euro Class 4.

To adjust the flows input to the AQ model, we analysed the numbers of individual vehicles entering the CAZ zone during the week that the ANPR surveys were undertaken. The numbers of vehicles upgrading, was used to calculate a factor to apply to the AQ inputs.

Fleet Upgrades to Hydrogen Buses

Twenty two hydrogen buses are included as part of clean air policy to support the development of the CAZ. These new buses have been assigned to routes that that run along the A38 between Paradise Circus and Holloway Circus (which is the area with the highest concentration levels). This is implemented in the modelling post traffic assignment by removing bus flows from links along the selected routes in the modelling data provided to the Air Quality team. This is done post model run so that the traffic impacts are considered within the modelling, but the emission impacts are removed for the AQ modelling.

The no. 82, 87, 22 and 23 routes were assumed to be Hydrogen Buses, with the assumption that each Hydrogen bus can make a two-way journey within the city centre during the modelled hour, i.e. one inbound and one outbound journey. The bus frequencies range from 4 to 6 peak hour frequency.

7.3.3 Summary of Transport Modelling Impacts

Under CAZ Scenario D, non-compliant vehicles (excluding exemptions) are subjected to charges as summarised in Table 4-3.

The change in compliance for car, LGV and HGV traffic entering the CAZ is shown in the table below. Overall compliance rates increase from 72% to 97% of all vehicles entering the CAZ as a result of the scheme.

Table 7-3 : Summary of Vehicle Compliance Rates Crossing the CAZ Cordon

	Compliant?	Car	Taxi	LGV	HGV	Bus	Total
Do Min	Compliant	77%	30%	59%	65%	60%	72%
	Non-compliant	23%	70%	41%	35%	40%	28%
FBC CAZ	Compliant	93%	100%	70%	87%	100%	91%
	Non-compliant	7%	0%	30%	13%	0%	9%

The overall traffic impacts are shown in the model results are:

- a reduction of over 40,000 non-compliant vehicles entering the CAZ
- a total reduction of around 22,000
- there are significant reductions on each of the roads identified, with flows on the A38/A4400 forecast to reduce by between 6% to 13% from the Do Minimum.
- on the ring road, the impacts of the scheme are predominantly neutral, with reduction in car traffic to Birmingham due to behaviour choices offsetting diversion around the CAZ of non-compliant vehicles aiming to travel through Birmingham. However, the west side of the ring road experiences 6% increase in part due to the Additional Measures network change 1.
- the scheme does not have a significant impact on link delays or speeds.

7.3.4 Preferred Option Modelling Results

A summary of the results of the initial dispersion modelling for 2020 and 2022 are provided in Table 7-6, and the descriptive locations can be referenced against Figure 10. These are the only sections of road in exceedance managed by BCC. The full modelling results are presented in Appendix E. A 2021 transport model was not available, and therefore the concentrations in 2021 have been interpolated linearly using the 2020 and 2022 results.

Table 7-4 : Summary of Dispersion Modelling Results for the CAZ D+ w/M&E scheme at Worst Case Receptor Locations

Receptor	Position	Easting	Northing	Census ID	Road	Modelled NO_2 Concentration µg/m^3			
						2020 DM	2020 CAZ	2021 CAZ	2022 CAZ
PCM_0	Inside Ring Road	406752	286515	81490	A4400 Suffolk St. Queensway	**46.0**	**42.1**	**40.6**	39.0
PCM_2	Inside Ring Road	407477	287785	56394	A38 Corporation St.	**43.2**	**40.3**	38.7	37.1
PCM_6	Outside Ring Road	408473	286918	27736	A4540 Lawley Middleway - Garrison Circus	**41.1**	**40.6**	38.8	37.0
ObjectID_15_@4m	Inside Ring Road	407386	286548	N/A	A4100 Moat Lane, Digbeth	**42.0**	**40.6**	39.2	37.8

The outputs from this Preferred Option are summarised in Table 7-6 and Figure 17 and show significant improvements in air quality compared with the Do Minimum. The table summarises the worst-case locations in the study area, where compliance with the EU Limit Values is determined. The results show a significant reduction in predicted concentrations of up to -3.9 µg/m^3 due to scheme. However, whilst there is a reduction in the total number of exceedances from 15 to 7 (See Appendix E) in 2020, compliance is not achieved. By 2021 only one site (PCM_0, Census ID 81490) is estimated to remain non-compliant, and 2022 is predicted to be the first full year of compliance.

The maximum modelled concentration is at A4400 Suffolk St Queensway (PCM_0, Census ID 81490). Here, it is considered that the local road network in the vicinity of this PCM link is complex, so direct comparison with the PCM network remains difficult. The more detailed local model could be expected to be more reliable in this location.

Beyond the A38, the other location demonstrating an exceedance inside the CAZ is at Digbeth. Here, LAQM (non-PCM) exposure is at the first floor level, so the modelled outputs at ground level are likely to be an overestimate.

NO_2 concentrations along the Ring Road at A4540 Lawley Middleway - Garrison Circus (PCM_6, Census ID 17998) decrease by -0.5 µg/m^3 to 40.6 µg/m^3. This road is not located inside the CAZ, and despite an increase in traffic caused by re-routing of non-compliant vehicles which would be subject to a charge around the ring road, the effect of cleaner vehicles around Birmingham due to the CAZ improves air quality beyond the CAZ itself.

7.3.5 Sensitivity Testing Analysis

The modelling process for the CAZ analysis comprises various phases of modelling using best practice techniques, along with appropriate datasets and assumptions. All modelling inherently contains an element of uncertainty, and the sensitivity testing process is designed to provide an understanding of the level of uncertainty that key data inputs or assumptions might have on the overall conclusions. The datasets and assumptions used in the 'core' modelling are selected as they are believed to be the most appropriate, and lead to the most likely predictions of scheme impacts. The variations in input assumptions selected are designed to inform the likely range of uncertainty the core results.

Analysis of the effect of altering the charge pricing was undertaken during the transport and behavioural modelling process. This identified that there was very limited behavioural response to charging beyond 'medium' £8 level which was used for the scheme. At higher charge levels, further air quality improvements were no longer brought forward despite increased economics impacts. Modelling was undertaken which showed that the higher charge did not alter the date of compliance.

A range of other sensitivity tests have also been undertaken. Some of these focussed on the behavioural response, testing different assumptions on upgrading costs of vehicles, and testing of the impacts of using alternative proportions of responses, based on national guidance.

A range of other tests were also undertaken analysing the sensitivity of the emissions and air quality modelling processes, including emissions for different ages of vehicles, the effects of slow speeds and approaches to model verification.

The full range of sensitivity tests and analysis are described in Appendix E. These indicate that the modelled concentrations could be over or underestimated, however this is unavoidable and part of any predictive analysis. Overall, it is concluded that there are a variety of assumptions, which could act in combination, but the process applied is considered to be reasonable and appropriate, and the conclusions regarding the case for the scheme are robust.

7.3.6 Testing the Influence of Mitigation and Exemptions Packages

The Preferred CAZ D option can only be implemented with the necessary exemptions and mitigations required to ensure the scheme can be operationally functional and minimise adverse impacts to residents, visitors and business.

The impact of the exemptions and mitigation package have been separately tested, to gain an understanding of their possible effect on the performance of the CAZ D scheme in relation to NO_2 improvements.

The mitigation measures were found to have no significant effect on modelled NO_2 concentrations in 2020 or 2022, and therefore their implementation does not affect compliance.

The proposed CAZ scheme has a range of exemptions applied to residents and workers impacted by the scheme. The exemptions are in place for two years, and expire at the beginning of 2022. These exemptions have the effect of reducing the number of drivers who have to take action to comply with the scheme in 2020, but it is expected that they would take actions to obtain compliant vehicles through the two year exemption period in preparation for 2022.

Economic analysis has been undertaken to try to understand the possible effect these necessary exemptions may have on the overall improvements in air quality produced by the CAZ scheme. It should be noted that it is not considered feasible to open a charging CAZ scheme in these timescales without any exemptions in place, and doing so could affect the deliverability and opening date. This test scenario is therefore hypothetical, and the economic analysis which underpins it is also subject to its own uncertainty.

The modelling indicates that there is the potential that the exemptions will reduce the effectiveness of the CAZ, but a CAZ D scheme with no exemptions at all would still not be compliant in 2020. The preferred scheme is predicted to achieve full compliance in 2022, and the testing of the exemptions does not conclude that this would be altered.

The further information regarding the tests on the influence of mitigations and exemptions are described in Annex F.

8. Conclusions

This report contains a description of the factors driving implementation of the CAZ, the existing measures being undertaken by BCC to improve air quality, and an evaluation of the air quality benefits which could be delivered by the implementation of a potential charging CAZ with appropriate supporting Additional Measures plus necessary exemptions and mitigations required to ensure the scheme can be operational when opened rapidly for 2020, and minimise adverse impacts to residents, visitors and business.

The results of the traffic and air quality modelling undertaken for the OBC phase have demonstrated that implementation of a charging ‘class C’ or ‘class D’ Clean Air Zone (CAZ), in the absence of supporting additional measures, would be insufficient to deliver full compliance with EU Limit Values for annual mean NO_2 by 2020. The assessment of the preferred scheme updates the assessment for the OBC following the consultation process, to incorporate revised assumptions and charge levels where appropriate.

A number of Additional Measures which could be applied to support the various CAZ options have been evaluated as part of the business case. The package of measures tested include upgrade to buses and taxis, removal of free parking and changes to the road network. Testing of a higher charge has been demonstrated to be no more effective than that of the preferred scheme.

The CAZ D+ plus Additional Measures scheme with mitigations and exemptions is predicted deliver significant improvements by 2020 and full compliance is expected in 2022.

A range of sensitivity tests and analysis has been undertaken. These indicate that the modelled concentrations could be over or underestimated, however this is unavoidable and part of any predictive analysis. Overall, it is concluded that there are a variety of assumptions, which could act in combination, but the process applied is considered to be reasonable and appropriate, and the conclusions regarding the case for the scheme are robust.

Appendix A. Explanation of Vehicle Emissions Standards

Background

The Euro standards are a range of successively tightening emissions controls founded in European directives that set limits for air quality pollutants from petrol, gas and diesel engines. Compliance with these limits must be demonstrated as part of the European type approval process for new vehicles and Road vehicle engines. There are also 'durability' requirements to demonstrate continued compliance in service.

Light duty vehicles (cars and vans) are subject to whole vehicle emissions testing, whereas engines for heavy duty vehicles (HGVs and buses) are emissions tested on a test bench, prior to installation in any vehicle. They may subsequently be fitted to a variety of different vehicle types.

The emissions limit values are different for each vehicle type, and to indicate which is being referred to, there is a convention that, for instance, Euro 6 refers to cars and vans (whole vehicle emissions testing), while Euro VI refers to goods vehicles and buses (engine only emissions testing). In each case, the Euro standards set out emissions limits for type approval testing that control four 'legislated' emissions – carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) and particulate matter (PM).

Standards

Euro 1 appeared in 1992 and the standards have progressed to the current Euro 6/VI. This became mandatory for all new heavy duty engines for goods vehicles and buses from January 2014, September 2015 for cars and light vans, and September 2016 for larger vans up to 3,500kg gross vehicle weight.

Euro standards for motorcycles, mopeds, tricycles and quadricycles (collectively known as L-Category vehicles) were introduced later than for larger vehicles, with the current standard being Euro 3. In 2017, Euro 4 for L-Category vehicles will come into force.

Detailed information about emissions standards for light duty vehicles can be found by following these selected links:

https://www.dieselnet.com/standards/eu/ld.php and for heavy vehicles at:

https://www.dieselnet.com/standards/eu/hd.php

The tables below set out the approximate implementation dates for each Euro standard, which differ according to vehicle type, between 1990 and 2020.

Table A1-1: Heavy vehicle Euro standards over time

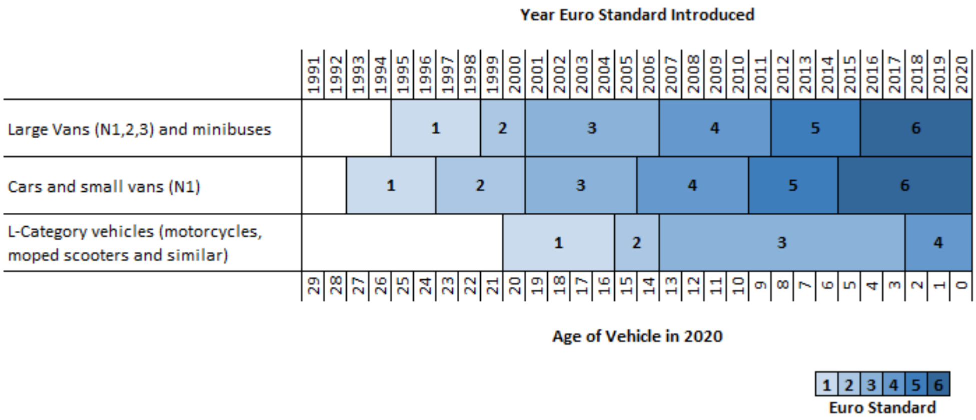
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Heavy vehicles (lorries, buses, coaches and other specialist vehicles		I					II				III					IV			V					VI						
	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Age of Vehicle in 2020

I	II	III	IV	V	VI

Euro Standard

Table A1-2: Light Duty Vehicle Euro Standards Over Time



Emissions

For NO_x emissions, light duty vehicles (e.g. cars and vans) use grams per kilometre (g/km) and heavy duty vehicles use grams per kilowatt hour (g/kwh) because of the different ways these vehicles are tested. In addition, heavy duty vehicles have both a 'steady state limit' and a 'transient limit'. These vehicles would need to comply with both limits to achieve CAZ compliance.

For certain vehicle types, some early Euro standards did not set limits for all pollutants. In this case 'n/a' is entered in the table below. This would mean that a vehicle is effectively compliant in terms of the CAZ for that pollutant. For example, Euro 4 petrol vehicles do not have PM limits, therefore vehicle owners only need to check that NOx emissions meet the CAZ standard to know whether the vehicle is compliant.

The NO_x and PM limits for Euro 4 and Euro 6/VI vehicles are summarised in the tables below. The vehicle weights provided are the reference mass of the unladen vehicle at the time of type approval testing. In the tables, an LGV category N1 is a light goods vehicle not exceeding 3,500kg maximum mass. An N2 LGV is a light goods vehicle not exceeding 12,000kg maximum mass. A heavy duty vehicle is a goods vehicle, bus or coach with a maximum mass greater than 3,500kg.

Table A1-3: Euro 4 and 6 Emission Limits for Light Duty Vehicles (g/km)

Engine Class	Fuel	Vehicle Description & Weights	Emission Limits g/km	
			NO_x	PM
Euro 4	Petrol	Cars and LGVs Category n1 Class 1 ≤ 1,305kg	0.08	n/a
Euro 4	Petrol	LGV category N1 Class II 1,305-1,760 kg	0.10	n/a
Euro 4	Petrol	LGV category N1 Class III > 1,760kg	0.11	n/a
Euro 4	Petrol	LGV category N2	n/a	n/a
Euro 6	Diesel	cars and LGV category N1 Class 1 ≤ 1,305kg	0.08	0.005
Euro 6	Diesel	LGV category N1 Class II 1,305-1,760 kg	0.105	0.005
Euro 6	Diesel	LGV category N1 Class III > 1,760kg	0.125	0.005
Euro 6	Diesel	LGV category N2	0.125	0.005

Table A1-4: Euro VI Emission Limits for Heavy Duty Vehicles (g/kwh)

Engine Class	Steady State Emission Limits g/km		Transient Emission Limits g/km	
	NO_x	PM	NO_x	PM
Euro VI	0.4	0.01	0.46	0.01

On-highway verification

It has been identified that emissions from vehicles, especially diesel cars and LGVs can be much greater under actual driving conditions than the emissions standards based on laboratory testing,

For the latest Euro 6/VI emissions standards, the laboratory-based type approval tests, using the limit values set out above, are verified by on-highway emissions testing of a completed vehicle. This has been the case since 2013 for heavy duty engines where the not-to-exceed limits in the on-highway test have ensured that vehicle exhaust emissions of NO_x and PM are greatly reduced compared to earlier standards. In many cases the emissions from a heavy truck or bus are comparable with those of passenger cars.

For light duty cars and vans, the Euro 6 on-highway verification is in the form of a test protocol known as Real Driving Emissions (RDE). These verification measures are being introduced in a number of stages, which have been loosely termed `Euro 6a to Euro 6d'as follows:

- 2014 Euro 6a new reduced emissions limits
- 2017 Euro 6b new Worldwide Harmonised Light Vehicle Test Cycle (WLTC) implemented
- 2019 Euro 6c (also referred to as Euro 6d-temp) conformity factor of 2.1 to be applied to on-highway RDE test results
- 2021 Euro 6d on-highway RDE conformity factor to be reduced to 1.5

For cars and LGVs, Euro 6a essentially consisted of a reduction in the allowable NO_x emissions from diesel engines of 55 per cent. Emissions of PM and all emissions limits from petrol engines are unchanged from Euro 5.

Euro 6b was the replacement of the New European Driving Cycle (NEDC), widely acknowledged as being unrepresentative, with the WLTC, which is far more transient and representative of real driving conditions.

Euro 6c will introduce RDE testing as a verification of laboratory emissions tests. A test route conforming to detailed criteria is driven with portable emissions measurement equipment on the vehicle. The average measured emissions must not be more than 110 per cent over the laboratory test limits (conformity factor of 2.1).

Euro 6d will see the conformity factor reduced to 1.5 (50 per cent over the laboratory test limits). This factor allows for variance between portable and laboratory emissions analysers.

Appendix B. Local Fleet Mix Profiles

2016

This sheet is only used if you wish to provide:

Section 1	User Defined Euro Fleet Composition Information		**POPULATE WITH DEFAULTS for chosen Year and Area**
Section 2	User Defined Vehicle Size Distributions	Click to go to Section 2	
Year	2016	*Defined in the Input Data Sheet*	**Traffic Flow Data must be entered in the Input Data sheet.**
Area	England (not London)	*Defined in the Input Data Sheet*	

Please Use Check Boxes next to each orange box to ensure your totals all equal 1. Information for All pollutants must be entered.

Section 1: Euro Proportions

	Default (veh-km based) Fleet Euro Proportions for Year and Area are provided below	Enter your (veh-km based) Euro Proportions below	Check Euro Proportions = 1 or 0
NOx			
			PM>>>>>>>

Petrol Car	Default Euro Proportions 2016 - England (not London)	User Euro Proportions 2013 - England (not London)	
1Pre-Euro 1	-	0.00	
2Euro 1	0.00	0.00	
3Euro 2	0.02	0.02	
4Euro 3	0.15	0.22	
5Euro 4	0.26	0.32	
6Euro 5	0.36	0.27	
7Euro 6	0.20	0.18	OK
7Euro 6c	-	-	

Diesel Car	Default Euro Proportions 2016 - England (not London)	User Euro Proportions 2013 - England (not London)	
1Pre-Euro 1	-	0.00	
2Euro 1	0.00	0.00	
3Euro 2	0.00	0.01	
4Euro 3	0.08	0.11	
5Euro 4	0.23	0.30	
6Euro 5	0.45	0.33	
7Euro 6	0.24	0.24	OK
7Euro 6c	-	-	
7Euro 6d	0.00	-	

Petrol LGV	Default Euro Proportions 2016 - England (not London)	User Euro Proportions 2013 - England (not London)	
1Pre-Euro 1	-	0.01	
2Euro 1	0.01	0.04	
3Euro 2	0.04	0.08	
4Euro 3	0.16	0.32	
5Euro 4	0.24	0.35	
6Euro 5	0.43	0.15	
7Euro 6	0.13	0.04	OK
7Euro 6c	-	-	

Diesel LGV	Default Euro Proportions 2016 - England (not London)	User Euro Proportions 2013 - England (not London)	
1Pre-Euro 1	-	0.00	
2Euro 1	0.00	0.00	
3Euro 2	0.01	0.01	
4Euro 3	0.08	0.13	
5Euro 4	0.24	0.22	
6Euro 5	0.53	0.42	
7Euro 6	0.15	0.21	OK
7Euro 6c	-	-	
7Euro 6d	-	-	

Rigid HGV	Default Euro Proportions 2016 - England (not London)	User Euro Proportions 2013 - England (not London)	
1Pre-Euro I	-	-	
2Euro I	0.00	0.00	
3Euro II	0.02	0.01	
4Euro III	0.12	0.12	
5Euro IV	0.10	0.18	
6Euro V_EGR	0.08	0.08	
7Euro V_SCR	0.23	0.25	
8Euro VI	0.45	0.35	
9Euro II SCRRF	-	-	
10Euro III SCRRF	-	-	
11Euro IV SCRRF	-	-	
12Euro V EGR + SCRRF	-	-	OK

Note: No emissions factors available for HGV SCRRF (Refrofits) therefore standard Euro class emissions factors will be assumed even if fleet information is input

Note: If London Motorway outside LEZ therefore separate default provided

Artic HGV	Default Euro Proportions 2016 - England (not London)	User Euro Proportions 2013 - England (not London)	
1Pre-Euro I	-	-	
2Euro I	0.00	0.00	
3Euro II	0.00	0.00	
4Euro III	0.03	0.03	
5Euro IV	0.05	0.09	
6Euro V_EGR	0.08	0.10	
7Euro V_SCR	0.23	0.29	
8Euro VI	0.62	0.49	
9Euro II SCRRF	-	-	
10Euro III SCRRF	-	-	
11Euro IV SCRRF	-	-	
12Euro V EGR + SCRRF	-	-	OK

Note: No emissions factors available for HGV SCRRF (Refrofits) therefore standard Euro class emissions factors will be assumed even if fleet information is input

Note: London Motorway outside LEZ therefore separate default provided

Buses (Not London Buses)	Default Euro Proportions 2016- Not London	User Euro Proportions 2013 - England (not London)	
1Pre-Euro I	-	-	
2Euro I	0.00	0.00	
3Euro II	0.04	0.01	
4Euro III	0.17	0.26	
5Euro IV	0.13	0.13	
6Euro V_EGR	0.09	0.08	
7Euro V_SCR	0.26	0.23	
8Euro VI	0.31	0.31	
9Euro II SCRRF	-	-	
10Euro III SCRRF	-	-	
11Euro IV SCRRF	-	-	
12Euro V EGR + SCRRF	-	-	OK

Note: Emissions factors (scaled) are available for Bus SCRRF (Refrofits) therefore user defined fleet may be used

Coaches	Default Euro Proportions 2016 - England (not London)	User Euro Proportions 2013 - England (not London)	
1Pre-Euro I	-	-	
2Euro I	0.00	0.00	
3Euro II	0.04	0.01	
4Euro III	0.17	0.26	
5Euro IV	0.13	0.13	
6Euro V_EGR	0.09	0.08	
7Euro V_SCR	0.26	0.23	
8Euro VI	0.31	0.31	
9Euro II SCRRF	-	-	
10Euro III SCRRF	-	-	
11Euro IV SCRRF	-	-	
12Euro V EGR + SCRRF	-	-	OK

Note: Emissions factors (scaled) are available for Bus SCRRF (Refrofits) therefore user defined fleet may be used

Note: If London Motorway outside LEZ therefore separate default provided

These fleet compositions were rolled forward to 2020 and 2022, incorporating revised guidance from JAQU to accommodate predicted trends in diesel and petrol fleet to the fleet mix below.

2020

This sheet is only used if you wish to provide:			POPULATE WITH DEFAULTS for chosen Year and Area	
Section 1	User Defined Euro Fleet Composition Information			
Section 2	User Defined Vehicle Size Distributions	Click to go to Section 2		
Year	2020	*Defined in the Input Data Sheet*	Traffic Flow Data must be entered in the Input Data sheet.	
Area	England (not London)	*Defined in the Input Data Sheet*		
			Please Use Check Boxes next to each orange box to ensure your totals all equal 1. Information for All pollutants must be entered.	

Section 1: Euro Proportions

	Default (veh-km based) Fleet Euro Proportions for Year and Area are provided below		Enter your (veh-km based) Euro Proportions below	Check Euro Proportions = 1 or 0
NOx				
				PM>>>>>>>
Petrol Car	**Default Euro Proportions 2020 - England (not London)**		**User Euro Proportions 2013 - England (not London)**	
1Pre-Euro 1	-		0.00	
2Euro 1	-		0.00	
3Euro 2	0.00		0.00	
4Euro 3	0.03		0.04	
5Euro 4	0.12		0.23	
6Euro 5	0.25		0.33	
7Euro 6	0.15		0.11	OK
7Euro 6c	0.45		0.28	
Diesel Car	**Default Euro Proportions 2020 - England (not London)**		**User Euro Proportions 2013 - England (not London)**	
1Pre-Euro 1	-		0.00	
2Euro 1	-		0.00	
3Euro 2	0.00		0.00	
4Euro 3	0.01		0.02	
5Euro 4	0.10		0.13	
6Euro 5	0.29		0.32	
7Euro 6	0.16		0.15	OK
7Euro 6c	0.33		0.25	
7Euro 6d	0.11		0.13	
Petrol LGV	**Default Euro Proportions 2020 - England (not London)**		**User Euro Proportions 2013 - England (not London)**	
1Pre-Euro 1	-		0.01	
2Euro 1	-		-	
3Euro 2	0.01		0.03	
4Euro 3	0.04		0.10	
5Euro 4	0.12		0.30	
6Euro 5	0.26		0.42	
7Euro 6	0.20		0.03	OK
7Euro 6c	0.38		0.11	
Diesel LGV	**Default Euro Proportions 2020 - England (not London)**		**User Euro Proportions 2013 - England (not London)**	
1Pre-Euro 1	-		0.00	
2Euro 1	-		0.00	
3Euro 2	0.00		0.00	
4Euro 3	0.02		0.02	
5Euro 4	0.09		0.14	
6Euro 5	0.25		0.25	
7Euro 6	0.16		0.14	OK
7Euro 6c	0.47		0.44	
7Euro 6d	-		-	
Rigid HGV	**Default Euro Proportions 2020 - England (not London)**		**User Euro Proportions 2013 - England (not London)**	
1Pre-Euro I	-		-	
2Euro I	-		-	
3Euro II	0.00		0.00	
4Euro III	0.03		0.02	
5Euro IV	0.03		0.08	
6Euro V_EGR	0.04		0.07	
7Euro V_SCR	0.12		0.22	
8Euro VI	0.77		0.61	
9Euro II SCRRF	-		-	
10Euro III SCRRF	-		-	
11Euro IV SCRRF	-		-	
12Euro V EGR + SCRRF	-		-	OK
	Note: No emissions factors available for HGV SCRRF (Refrofits) therefore standard Euro class emissions factors will be assumed even if fleet information is input			
	Note: If London Motorway outside LEZ therefore separate default provided			
Artic HGV	**Default Euro Proportions 2020 - England (not London)**		**User Euro Proportions 2013 - England (not London)**	
1Pre-Euro I	-		-	
2Euro I	-		-	
3Euro II	0.00		-	
4Euro III	0.00		0.01	
5Euro IV	0.01		0.01	
6Euro V_EGR	0.02		0.04	
7Euro V_SCR	0.06		0.11	
8Euro VI	0.90		0.83	
9Euro II SCRRF	-		-	
10Euro III SCRRF	-		-	
11Euro IV SCRRF	-		-	
12Euro V EGR + SCRRF	-		-	OK
	Note: No emissions factors available for HGV SCRRF (Refrofits) therefore standard Euro class emissions factors will be assumed even if fleet information is input			
	Note: London Motorway outside LEZ therefore separate default provided			
Buses (Not London Buses)	**Default Euro Proportions 2020- Not London**		**User Euro Proportions 2013 - England (not London)**	
1Pre-Euro I	-		-	
2Euro I	-		-	
3Euro II	0.01		0.00	
4Euro III	0.06		0.15	
5Euro IV	0.05		0.11	
6Euro V_EGR	0.05		0.04	
7Euro V_SCR	0.16		0.12	
8Euro VI	0.66		0.58	
9Euro II SCRRF	-		-	
10Euro III SCRRF	-		-	
11Euro IV SCRRF	-		-	
12Euro V EGR + SCRRF	-		-	OK
	Note: Emissions factors (scaled) are available for Bus SCRRF (Refrofits) therefore user defined fleet may be used			
Coaches	**Default Euro Proportions 2020 - England (not London)**		**User Euro Proportions 2013 - England (not London)**	
1Pre-Euro I	-		-	
2Euro I	-		-	
3Euro II	0.01		0.00	
4Euro III	0.06		0.15	
5Euro IV	0.05		0.11	
6Euro V_EGR	0.05		0.04	
7Euro V_SCR	0.16		0.12	
8Euro VI	0.66		0.58	
9Euro II SCRRF	-		-	
10Euro III SCRRF	-		-	
11Euro IV SCRRF	-		-	
12Euro V EGR + SCRRF	-		-	OK
	Note: Emissions factors (scaled) are available for Bus SCRRF (Refrofits) therefore user defined fleet may be used			
	Note: If London Motorway outside LEZ therefore separate default provided			

2022

This sheet is only used if you wish to provide:			
Section 1	User Defined Euro Fleet Composition Information		**POPULATE WITH DEFAULTS for chosen Year and Area**
Section 2	User Defined Vehicle Size Distributions	Click to go to Section 2	
Year	2022	*Defined in the Input Data Sheet*	**Traffic Flow Data must be entered in the Input Data sheet.**
Area	England (not London)	*Defined in the Input Data Sheet*	

Please Use Check Boxes next to each orange box to ensure your totals all equal 1. Information for All pollutants must be entered.

Section 1: Euro Proportions

	Default (veh-km based) Fleet Euro Proportions for Year and Area are provided below	Enter your (veh-km based) Euro Proportions below	Check Euro Proportions = 1 or 0

NOx

PM>>>>>>>

Petrol Car	Default Euro Proportions 2022 - England (not London)	User Euro Proportions 2013 - England (not London)	
1Pre-Euro 1	-	0.00	
2Euro 1	-	0.00	
3Euro 2	-	0.00	
4Euro 3	0.01	0.01	
5Euro 4	0.06	0.13	
6Euro 5	0.19	0.34	
7Euro 6	0.12	0.14	OK
7Euro 6c	0.62	0.38	

Diesel Car	Default Euro Proportions 2022 - England (not London)	User Euro Proportions 2013 - England (not London)	
1Pre-Euro 1	-	0.00	
2Euro 1	-	0.00	
3Euro 2	-	0.00	
4Euro 3	0.01	0.00	
5Euro 4	0.05	0.06	
6Euro 5	0.23	0.28	
7Euro 6	0.14	0.14	OK
7Euro 6c	0.27	0.20	
7Euro 6d	0.31	0.31	

Petrol LGV	Default Euro Proportions 2022 - England (not London)	User Euro Proportions 2013 - England (not London)	
1Pre-Euro 1	-	-	
2Euro 1	-	0.01	
3Euro 2	-	-	
4Euro 3	0.02	0.08	
5Euro 4	0.05	0.20	
6Euro 5	0.17	0.45	
7Euro 6	0.13	0.12	OK
7Euro 6c	0.63	0.14	

Diesel LGV	Default Euro Proportions 2022 - England (not London)	User Euro Proportions 2013 - England (not London)	
1Pre-Euro 1	-	-	
2Euro 1	-	0.00	
3Euro 2	-	0.00	
4Euro 3	0.01	0.01	
5Euro 4	0.05	0.07	
6Euro 5	0.18	0.22	
7Euro 6	0.12	0.13	OK
7Euro 6c	0.29	0.26	
7Euro 6d	0.35	0.30	

Rigid HGV	Default Euro Proportions 2022 - England (not London)	User Euro Proportions 2013 - England (not London)	
1Pre-Euro I	-	-	
2Euro I	-	-	
3Euro II	-	-	
4Euro III	0.01	0.01	
5Euro IV	0.02	0.03	
6Euro V_EGR	0.02	0.05	
7Euro V_SCR	0.07	0.16	
8Euro VI	0.87	0.74	
9Euro II SCRRF	-	-	
10Euro III SCRRF	-	-	
11Euro IV SCRRF	-	-	
12Euro V EGR + SCRRF	-	-	OK

Note: No emissions factors available for HGV SCRRF (Refrofits) therefore standard Euro class emissions factors will be assumed even if fleet information is input

Note: If London Motorway outside LEZ therefore separate default provided

Artic HGV	Default Euro Proportions 2022 - England (not London)	User Euro Proportions 2013 - England (not London)	
1Pre-Euro I	-	-	
2Euro I	-	-	
3Euro II	-	-	
4Euro III	0.00	0.00	
5Euro IV	0.00	0.01	
6Euro V_EGR	0.01	0.02	
7Euro V_SCR	0.03	0.06	
8Euro VI	0.96	0.91	
9Euro II SCRRF	-	-	
10Euro III SCRRF	-	-	
11Euro IV SCRRF	-	-	
12Euro V EGR + SCRRF	-	-	OK

Note: No emissions factors available for HGV SCRRF (Refrofits) therefore standard Euro class emissions factors will be assumed even if fleet information is input

Note: London Motorway outside LEZ therefore separate default provided

Buses (Not London Buses)	Default Euro Proportions 2022- Not London	User Euro Proportions 2013 - England (not London)	
1Pre-Euro I	-	-	
2Euro I	-	-	
3Euro II	-	-	
4Euro III	0.04	0.01	
5Euro IV	0.03	0.16	
6Euro V_EGR	0.03	0.06	
7Euro V_SCR	0.10	0.17	
8Euro VI	0.79	0.61	
9Euro II SCRRF	-	-	
10Euro III SCRRF	-	-	
11Euro IV SCRRF	-	-	
12Euro V EGR + SCRRF	-	-	OK

Note: Emissions factors (scaled) are available for Bus SCRRF (Refrofits) therefore user defined fleet may be used

Coaches	Default Euro Proportions 2022 - England (not London)	User Euro Proportions 2013 - England (not London)	
1Pre-Euro I	-	-	
2Euro I	-	-	
3Euro II	-	-	
4Euro III	0.04	0.01	
5Euro IV	0.03	0.16	
6Euro V_EGR	0.03	0.06	
7Euro V_SCR	0.10	0.17	
8Euro VI	0.79	0.61	
9Euro II SCRRF	-	-	
10Euro III SCRRF	-	-	
11Euro IV SCRRF	-	-	
12Euro V EGR + SCRRF	-	-	OK

Note: Emissions factors (scaled) are available for Bus SCRRF (Refrofits) therefore user defined fleet may be used

Note: If London Motorway outside LEZ therefore separate default provided

Appendix C. Model Verification

Model verification is the process for comparing the modelled pollutant concentrations with the monitored concentrations for the same pollutant, and where necessary, adjusting the modelled results so they better align with the monitoring data. Given the complexities inherent throughout the model verification process, JAQU and Defra have provided specific guidance to inform this process and assist in the generation of robust data sets.

The model performance at each monitoring site is provided in Table C1-1 along with details of the zone and whether the site was used in the verification process.

Table C1-1: Summary of Verification Exercise

Receptor	Easting	Nothing	Site Type	Concentration µg/m^3		Data Capture %	Concentration µg/m^3				Mon/Mod Total NO_2	Concentration µg/m^3		Mon/Mod Rd NO_x	Concentration µg/m^3		Mon/Mod Road NO_2	Zone	Used In Verification
				NO_x	NO^2		Mod f-NO_2	BG_NO_x_16	BG_NO_2_16	Mod Total		Mod Road NO_x	Mon Road NO_x		Mod Rd NO_2	Mon Rd NO_2			
BHM1	411211	282756	DT	21.79	15.43	67%	0.27	28.96	19.55	28.28	0.83	17.60	-7.17	-0.41	8.73	-4.13	-0.47	0	Excluded
BHM2	404082	282128	DT	24.33	17.14	83%	0.27	32.82	21.60	30.62	0.79	18.30	-8.49	-0.46	9.02	-4.47	-0.50	0	Excluded
BHM3	407386	282131	DT	70.46	38.87	92%	0.28	28.98	19.53	33.95	-0.13	30.00	41.48	1.38	14.42	19.34	1.34	3	Used
BHM4	407404	282031	DT	75.21	40.87	83%	0.27	28.98	19.53	34.32	-0.16	30.90	46.23	1.50	14.79	21.33	1.44	3	Used
BHM5	409108	284158	DT	74.25	40.87	83%	0.27	38.01	24.35	42.29	0.03	39.70	36.24	0.91	17.94	16.52	0.92	1	Used
BHM6	409141	284054	DT	113.47	55.87	50%	0.26	38.01	24.35	40.14	-0.28	34.40	75.46	2.19	15.79	31.51	2.00	0	Excluded
BHM7	406114	286635	DT	94.87	49.35	83%	0.26	50.54	30.48	44.82	-0.09	32.70	44.33	1.36	14.34	18.87	1.32	2	Used
BHM8	406036	286489	DT	92.29	48.43	92%	0.25	50.54	30.48	46.02	-0.05	35.60	41.75	1.17	15.54	17.95	1.16	2	Used
BHM9	408618	291350	DT	74.81	40.32	92%	0.25	29.74	19.93	47.41	0.18	63.60	45.07	0.71	27.48	20.38	0.74	3	Used
BHM10	408818	284591	DT	66.23	37.27	83%	0.25	34.86	22.76	37.11	0.00	31.00	31.37	1.01	14.35	14.51	1.01	0	Excluded
BHM11	408818	284591	DT	63.90	36.27	83%	0.25	34.86	22.76	37.11	0.02	31.00	29.04	0.94	14.35	13.52	0.94	0	Excluded
BHM12	408818	284591	DT	66.40	37.34	83%	0.25	34.86	22.76	37.11	-0.01	31.00	31.54	1.02	14.35	14.58	1.02	0	Excluded
BHM13	411592	290438	DT	47.88	28.91	92%	0.25	32.69	21.51	39.97	0.38	40.40	15.19	0.38	18.46	7.41	0.40	0	Excluded
BHM14	411592	290438	DT	49.60	29.71	92%	0.26	32.69	21.51	39.97	0.35	40.40	16.91	0.42	18.46	8.20	0.44	0	Excluded
BHM15	411592	290438	DT	47.50	28.73	83%	0.26	32.69	21.51	39.97	0.39	40.40	14.81	0.37	18.46	7.23	0.39	0	Excluded
BHM16	407313	287534	DT	106.34	53.53	75%	0.26	47.36	29.11	51.62	-0.04	53.70	58.98	1.10	22.51	24.42	1.08	1	Used
BHM17	410004	289998	DT	93.70	48.10	83%	0.25	36.70	23.53	51.27	0.07	65.70	57.00	0.87	27.74	24.57	0.89	3	Used
BHM18	410073	290002	DT	90.36	46.58	92%	0.25	32.37	21.39	49.71	0.07	66.50	57.99	0.87	28.32	25.20	0.89	3	Used
BHM19	404739	279701	DT	90.50	48.00	50%	0.25	36.42	23.39	35.77	-0.25	25.70	54.08	2.10	12.38	24.61	1.99	0	Excluded
BHM20	404444	282884	DT	69.23	38.78	83%	0.28	32.82	21.60	36.05	-0.07	30.20	36.41	1.21	14.45	17.18	1.19	3	Used
BHM21	408195	287393	DT	134.23	62.26	83%	0.28	44.60	27.51	48.87	-0.21	50.40	89.63	1.78	21.36	34.74	1.63	2	Used
BHM22	405793	286648	DT	55.80	32.90	92%	0.24	38.32	24.60	38.28	0.16	29.80	17.48	0.59	13.68	8.30	0.61	0	Excluded
BHM23	406743	286539	DT	100.97	52.02	67%	0.25	50.54	30.48	53.05	0.02	53.10	50.43	0.95	22.57	21.54	0.95	0	Excluded
BHM24	406621	287108	DT	92.97	48.63	75%	0.26	48.29	29.55	46.41	-0.05	38.90	44.68	1.15	16.86	19.08	1.13	2	Used
BHM25	408586	286455	DT	95.30	49.19	67%	0.25	44.04	27.35	48.38	-0.02	49.10	51.26	1.04	21.03	21.84	1.04	0	Excluded

Table C1-1: Summary of Verification Exercise

Receptor	Easting	Nothing	Site Type	Concentration µg/m³		Data Capture %	Concentration µg/m³				Mon/Mod Total NO_2	Concentration µg/m³		Mon/Mod Rd NO_x	Concentration µg/m³		Mon/Mod Road NO_2	Zone	Used In Verification
				NO_x	NO^2		Mod f-NO_2	BG_NO_x_16	BG_NO_2_16	Mod Total		Mod Road NO_x	Mon Road NO_x		Mod Rd NO_2	Mon Rd NO_2			
BHM26	405648	287041	DT	37.09	23.93	92%	0.25	38.77	24.77	35.97	0.50	24.00	-1.68	-0.07	11.20	-0.84	-0.08	0	Excluded
BHM27	407836	288037	DT	92.52	47.77	92%	0.25	41.45	26.09	53.07	0.11	66.00	51.07	0.77	26.98	21.68	0.80	1	Used
BHM28	406762	287329	DT	123.11	59.58	83%	0.24	48.29	29.55	50.06	-0.16	48.10	74.82	1.56	20.51	30.03	1.46	1	Used
BHM29	406582	286728	DT	109.94	55.36	83%	0.25	50.54	30.48	52.17	-0.06	50.80	59.40	1.17	21.69	24.87	1.15	1	Used
BHM30	407967	287151	DT	87.06	46.14	58%	0.26	47.36	29.11	45.28	-0.02	37.50	39.70	1.06	16.17	17.03	1.05	0	Excluded
BHM31	406564	286685	DT	102.33	52.44	75%	0.24	50.54	30.48	49.64	-0.05	44.40	51.79	1.17	19.16	21.96	1.15	1	Used
BHM33	406702	286513	DT	101.20	51.99	83%	0.26	50.54	30.48	49.07	-0.06	42.90	50.66	1.18	18.59	21.51	1.16	1	Used
BHM34	407114	286906	DT	54.00	32.09	92%	0.26	50.21	30.29	44.71	0.39	33.00	3.79	0.11	14.42	1.80	0.12	0	Excluded
BHM35	407177	286996	DT	62.57	35.99	92%	0.24	50.21	30.29	45.28	0.26	34.70	12.36	0.36	14.99	5.70	0.38	0	Excluded
BHM36	407208	287064	DT	89.95	47.03	83%	0.24	47.36	29.11	45.37	-0.04	38.10	42.59	1.12	16.26	17.93	1.10	2	Used
BHM37	405380	285318	DT	58.83	34.21	50%	0.23	37.57	24.14	35.24	0.03	23.60	21.26	0.90	11.10	10.06	0.91	0	Excluded
BHM38	407217	287132	DT	110.03	54.15	75%	0.26	47.36	29.11	45.58	-0.16	38.70	62.67	1.62	16.47	25.04	1.52	2	Used
BHM39	407259	287112	DT	90.41	47.06	75%	0.23	47.36	29.11	46.58	-0.01	41.70	43.05	1.03	17.47	17.95	1.03	2	Used
BHM40	407407	287092	DT	112.77	54.63	92%	0.23	47.36	29.11	49.02	-0.10	48.90	65.41	1.34	19.91	25.52	1.28	2	Used
BHM41	407403	287079	DT	121.67	57.65	92%	0.22	47.36	29.11	48.68	-0.16	47.60	74.31	1.56	19.57	28.55	1.46	2	Used
BHM42	407548	287107	DT	87.11	45.75	92%	0.22	47.36	29.11	50.93	0.11	54.50	39.75	0.73	21.82	16.64	0.76	2	Used
BHM43	407617	287108	DT	90.54	47.15	92%	0.22	47.36	29.11	49.40	0.05	49.50	43.18	0.87	20.29	18.04	0.89	2	Used
BHM44	407638	287108	DT	92.54	47.90	92%	0.23	47.36	29.11	49.68	0.04	50.20	45.18	0.90	20.57	18.80	0.91	2	Used
BHM45	407581	287014	DT	91.55	47.43	92%	0.23	47.36	29.11	49.40	0.04	49.80	44.19	0.89	20.29	18.33	0.90	2	Used
BHM46	407567	287044	DT	154.95	66.95	92%	0.22	47.36	29.11	49.82	-0.26	51.50	107.59	2.09	20.71	37.84	1.83	2	Used
BHM47	407488	287023	DT	116.23	55.42	58%	0.22	47.36	29.11	51.71	-0.07	57.50	68.87	1.20	22.60	26.31	1.16	0	Excluded
BHM48	407503	286964	DT	98.85	50.08	83%	0.21	50.21	30.29	49.82	-0.01	47.90	48.64	1.02	19.53	19.79	1.01	2	Used
BHM49	407455	286989	DT	91.01	47.14	83%	0.22	50.21	30.29	51.94	0.10	54.70	40.80	0.75	21.65	16.85	0.78	2	Used
BHM50	407435	286926	DT	129.07	59.81	92%	0.22	50.21	30.29	52.29	-0.13	55.50	78.86	1.42	22.00	29.52	1.34	2	Used
BHM51	406921	285937	DT	104.82	52.45	33%	0.22	34.31	22.45	44.81	-0.15	50.20	70.51	1.40	22.36	30.00	1.34	0	Excluded

Table C1-1: Summary of Verification Exercise

Receptor	Easting	Nothing	Site Type	Concentration µg/m³		Data Capture %	Concentration µg/m³				Mon/Mod Total NO_2	Concentration µg/m³		Mon/Mod Rd NO_x	Concentration µg/m³		Mon/Mod Road NO_2	Zone	Used In Verification
				NO_x	NO^2		Mod f-NO_2	BG_NO_x_16	BG_NO_2_16	Mod Total		Mod Road NO_x	Mon Road NO_x		Mod Rd NO_2	Mon Rd NO_2			
BHM52	407372	286844	DT	137.20	62.31	92%	0.26	50.21	30.29	50.70	-0.19	50.70	86.99	1.72	20.41	32.02	1.57	2	Used
BHM53	407365	286791	DT	114.55	55.34	92%	0.22	50.21	30.29	50.66	-0.08	50.50	64.34	1.27	20.37	25.05	1.23	2	Used
BHM54	407324	286773	DT	126.20	59.39	92%	0.22	50.21	30.29	47.85	-0.19	42.00	75.99	1.81	17.56	29.10	1.66	2	Used
BHM55	407356	286719	DT	145.10	64.87	83%	0.23	50.21	30.29	49.58	-0.24	47.20	94.89	2.01	19.29	34.58	1.79	2	Used
BHM56	407377	286896	DT	91.64	47.53	92%	0.22	50.21	30.29	49.44	0.04	46.70	41.43	0.89	19.15	17.24	0.90	2	Used
BHM57	407692	283369	DT	49.91	29.85	50%	0.22	30.95	20.67	32.00	0.07	23.60	18.96	0.80	11.33	9.18	0.81	0	Excluded
BHM58	407255	286862	DT	85.07	45.25	50%	0.26	50.21	30.29	46.06	0.02	37.00	34.86	0.94	15.77	14.96	0.95	0	Excluded
BHM59	407273	286926	DT	86.39	45.60	58%	0.23	50.21	30.29	47.30	0.04	40.80	36.18	0.89	17.01	15.31	0.90	0	Excluded
BHM60	407234	286985	DT	86.32	45.67	83%	0.23	50.21	30.29	46.44	0.02	38.20	36.11	0.95	16.15	15.38	0.95	2	Used
BHM61	406919	287037	DT	67.68	38.38	92%	0.23	48.29	29.55	45.08	0.17	35.80	19.39	0.54	15.53	8.83	0.57	2	Used
BHM62	407032	287195	DT	78.85	42.92	92%	0.24	47.36	29.11	45.78	0.07	38.80	31.49	0.81	16.67	13.81	0.83	2	Used
BHM63	407509	287225	DT	61.86	35.73	92%	0.24	47.36	29.11	49.78	0.39	50.40	14.50	0.29	20.67	6.62	0.32	2	Used
BHM64	406973	286751	DT	100.29	51.34	92%	0.23	50.54	30.48	45.24	-0.12	33.80	49.75	1.47	14.76	20.86	1.41	2	Used
BHM65	407448	286479	DT	116.43	56.31	75%	0.25	50.21	30.29	50.74	-0.10	50.00	66.22	1.32	20.45	26.02	1.27	2	Used
BHM66	407421	288294	DT	97.25	49.68	82%	0.23	41.45	26.09	46.28	-0.07	46.70	55.80	1.19	20.19	23.59	1.17	0	Excluded
BHM67	407044	288318	DT	74.60	40.98	100%	0.25	41.45	26.09	45.44	0.11	44.40	33.15	0.75	19.35	14.89	0.77	0	Excluded
BHM68	405781	288131	DT	94.77	48.82	100%	0.25	34.72	22.69	37.84	-0.22	32.60	60.05	1.84	15.15	26.13	1.72	0	Excluded
BHM69	405806	288115	DT	77.86	42.24	100%	0.26	34.72	22.69	38.75	-0.08	34.60	43.14	1.25	16.06	19.55	1.22	0	Excluded
BHM70	405225	287000	DT	53.11	31.67	73%	0.26	38.77	24.77	36.73	0.16	25.50	14.34	0.56	11.96	6.90	0.58	0	Excluded
BHM71	405300	286430	DT	58.22	34.03	100%	0.26	38.32	24.60	37.69	0.11	28.20	19.90	0.71	13.09	9.44	0.72	0	Excluded
BHM72	405285	286395	DT	42.66	26.74	82%	0.26	38.32	24.60	36.50	0.36	25.50	4.34	0.17	11.90	2.15	0.18	0	Excluded
BHM73	406038	285961	DT	97.36	49.35	100%	0.26	34.31	22.45	38.75	-0.21	35.70	63.05	1.77	16.30	26.90	1.65	0	Excluded
BHM74	406018	285933	DT	173.05	73.54	100%	0.25	34.31	22.45	38.11	-0.48	34.20	138.74	4.06	15.66	51.09	3.26	0	Excluded
BHM75	406355	285729	DT	87.87	46.00	100%	0.25	34.31	22.45	38.73	-0.16	35.30	53.56	1.52	16.28	23.54	1.45	0	Excluded
BHM76	406367	285665	DT	53.15	31.50	100%	0.26	34.31	22.45	36.29	0.15	29.70	18.84	0.63	13.84	9.04	0.65	0	Excluded

Table C1-1: Summary of Verification Exercise

Receptor	Easting	Nothing	Site Type	Concentration µg/m³		Data Capture %	Concentration µg/m³				Mon/Mod Total NO_2	Concentration µg/m³		Mon/Mod Rd NO_x	Concentration µg/m³		Mon/Mod Road NO_2	Zone	Used In Verification
				NO_x	NO^2		Mod f-NO_2	BG_NO_x_16	BG_NO_2_16	Mod Total		Mod Road NO_x	Mon Road NO_x		Mod Rd NO_2	Mon Rd NO_2			
BHM77	406936	285461	DT	73.40	40.27	91%	0.26	34.31	22.45	44.67	0.11	50.10	39.09	0.78	22.22	17.82	0.80	0	Excluded
BHM78	406912	285418	DT	81.78	43.69	73%	0.26	34.31	22.45	41.37	-0.05	41.70	47.47	1.14	18.92	21.23	1.12	0	Excluded
BHM79	407373	285211	DT	58.60	34.09	100%	0.26	38.16	24.44	40.83	0.20	36.20	20.44	0.56	16.39	9.65	0.59	0	Excluded
BHM80	407386	285241	DT	86.80	45.80	100%	0.25	38.16	24.44	42.71	-0.07	40.80	48.64	1.19	18.27	21.36	1.17	0	Excluded
BHM81	408015	285303	DT	91.00	47.43	82%	0.25	40.84	25.71	42.79	-0.10	38.30	50.16	1.31	17.08	21.72	1.27	0	Excluded
BHM82	407979	285315	DT	86.97	45.74	82%	0.25	38.16	24.44	41.28	-0.10	37.50	48.81	1.30	16.84	21.30	1.26	0	Excluded
BHM83	408558	286447	DT	210.17	84.79	91%	0.25	44.04	27.35	47.82	-0.44	47.70	166.13	3.48	20.47	57.44	2.81	0	Excluded
BHM84	408168	287377	DT	159.98	70.16	82%	0.25	44.60	27.51	46.70	-0.33	44.60	115.38	2.59	19.19	42.65	2.22	0	Excluded
BHM85	407807	288037	DT	176.15	74.35	100%	0.24	41.45	26.09	50.55	-0.32	58.70	134.70	2.29	24.46	48.25	1.97	0	Excluded
BHM86	407171	287561	DT	87.48	46.54	100%	0.24	47.36	29.11	51.26	0.10	52.50	40.12	0.76	22.15	17.43	0.79	0	Excluded
BHM87	407163	287599	DT	204.33	84.35	91%	0.25	47.36	29.11	52.85	-0.37	56.50	156.97	2.78	23.74	55.25	2.33	0	Excluded
BHM88	406797	287315	DT	160.85	71.49	73%	0.25	48.29	29.55	51.02	-0.29	50.80	112.56	2.22	21.47	41.94	1.95	0	Excluded
BHM89	406581	287097	DT	120.35	58.45	91%	0.25	48.29	29.55	46.51	-0.20	39.00	72.06	1.85	16.96	28.91	1.70	0	Excluded
BHM90	406716	287411	DT	63.15	36.42	82%	0.25	48.29	29.55	45.92	0.26	37.70	14.86	0.39	16.37	6.88	0.42	0	Excluded
BHM91	409496	287938	DT	82.97	44.23	100%	0.25	42.21	26.38	40.56	-0.08	31.60	40.76	1.29	14.18	17.85	1.26	0	Excluded
BHM92	406882	285924	DT	116.33	56.50	73%	0.24	34.31	22.45	43.46	-0.23	46.80	82.02	1.75	21.01	34.05	1.62	0	Excluded
BHM93	407052	288283	DT	98.93	50.36	91%	0.26	41.45	26.09	44.48	-0.12	41.90	57.48	1.37	18.39	24.27	1.32	0	Excluded
B'ham Tyburn Roadside	411577	290491	CM	100.04	42.64	68%	0.25	32.69	21.51	41.77	-0.02	44.80	67.36	1.50	20.26	21.13	1.04	0	Excluded
Birmingham Tyburn	411592	290440	CM	54.16	28.96	99%	0.26	32.69	21.51	39.97	0.38	40.40	21.47	0.53	18.46	7.46	0.40	0	Excluded
New Hall	414574	296724	CM	25.14	17.09	83%	0.26	23.64	16.48	19.72	0.15	6.08	1.50	0.25	3.24	0.62	0.19	0	Excluded
Stratford Road	408820	284591	CM	79.22	35.09	96%	0.27	34.86	22.76	37.32	0.06	31.50	44.36	1.41	14.56	12.33	0.85	1	Used
Bristol Road	404545	283020	CM	67.03	29.05	83%	0.25	47.46	28.62	42.46	0.46	29.90	19.57	0.65	13.84	0.43	0.03	3	Used
Moor Street Q'way	407435	286891	CM	138.90	51.82	94%	0.28	50.21	30.29	50.94	-0.02	51.50	88.69	1.72	20.65	21.53	1.04	2	Used
Acocks Green	411649	282207	CM	32.65	21.31	99%	0.22	28.96	19.55	26.84	0.26	14.60	3.70	0.25	7.29	1.76	0.24	0	Excluded

A number of sites were excluded from the model verification process, including those summarised in Table C1-2, together with any sites with a data capture rate of <75%.

Additionally, a verification scenario run including the sites BMH66 to BMH93 with the Sept 2016 to July 2017 monitoring result (annualised) to 2016 was undertaken. However, the additional dataset increased overall model uncertainty in Zone 1 with a root mean square error (RMSE) of >10 µg/m³. Therefore, only the 2016 calendar year dataset has been selected.

Table C1-2: Summary of Sites Excluded from Verification

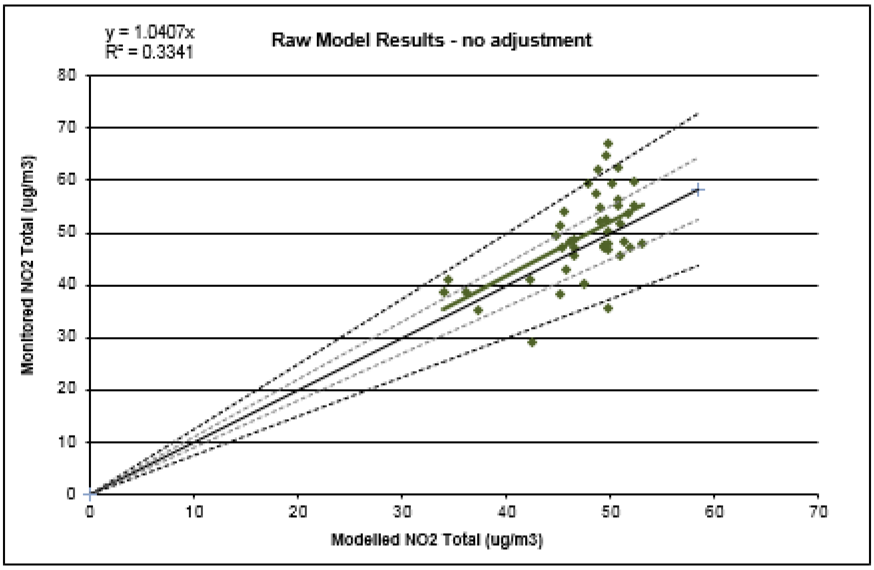
Ref	Reason To Exclude
Birmingham Tyburn	Background Site
New Hall	Background Site
Acocks Green	Background Site
BHM10	Co-located with Stratford Road Continuous Monitor
BHM11	Co-located with Stratford Road Continuous Monitor
BHM12	Co-located with Stratford Road Continuous Monitor
BHM13	Co-located with Tyburn Background Continuous Monitor
BHM14	Co-located with Tyburn Background Continuous Monitor
BHM15	Co-located with Tyburn Background Continuous Monitor
BHM1	Background Site
BHM2	Background Site
BHM22	Background Site
BHM26	Background Site
BHM34	Background Site

The results of the model verification process are summarised below. The raw model outputs for the 44 sites used in the verification have been compared to the monitoring data, before any zoning was considered. This showed a systematic under prediction, as shown in the fraction bias value of 0.04, most prevalent at the monitored concentrations greater than 50 µg/m³. Analysis was undertaken to address the overall under prediction, and refine the model performance.

Table C1-3: Model Performance Statistics (Unadjusted)

	No Adjustment
Number of Sites	**44**
Modelled NOx Rd v Monitored NOx Rd Factor	n/a
Modelled NO2 Rd v Monitored NO2 Rd Factor	n/a
RMSE	7.0
Fractional Bias	0.04
Correlation Coefficient	0.57
No. sites within ±25%	41

Table C1-4: Modelled vs Monitored Total NO_2 for all sites (Unadjusted)



A verification process was applied following guidance in LAQM.TG (16) to adjust road NO_x, with a further adjustment applied to road NO_2. Spatial analysis of the model performance was reviewed, and the model delineated into 3 zones:

Table C1-5: Summary of Delineated Zones

Zone No.	Description	No. Monitoring Sites
1	Sites beside the primary road network (PCM links), within the Detailed and Speed Flow region of the Saturn model	8
2	Sites within central Birmingham, notable locations with roads that might be considered canyons	29
3	Sites in the Buffer region	7

The verification process was applied, and the resulting model performance of the zones is presented in Table C1-6.

Table C1-6: Model Performance Within Delineated Zones

	No Adjustment	Zone 1	Zone 2	Zone 3
No. Sites	**44**	**8**	**29**	**7**
Mod NOx Rd v Mon NOx Rd Factor	n/a	1.105	1.233	0.902
Mod NO_2 Rd v Mon NO_2 Rd Factor	n/a	0.975	0.967	0.973
RMSE	**7.0**	**4.2**	**7.0**	**6.4**
Fractional Bias	0.04	0.00	0.00	0.01
Correlation Coefficient	0.57	0.84	0.34	0.44
No. sites within ±25%	41	8	28	6

The results show that the RMSE for each zone is improved compared to the overall dataset, and the fractional bias reduced. Overall the number of sites within ± 25% of monitored concentrations is reduced from 3 to 2 locations.

There was one roadside continuous analyser in each zone. In zones 1 and 2 (Stratford Rd and Moor St Queensway, respectively), the continuous analyser results were both within ± 10% of monitored concentrations following model adjustment, indicating their performance was consistent with the diffusion tubes within that zone. In zone 3, the roadside continuous analyser (Bristol Road) recorded atypically low concentrations compared with the roadside diffusion tubes, and as a result the modelled concentrations based on the verification process are an over-prediction at this site. Removal of the Bristol Road analyser from the zone would increase the road NOx adjustment factor from 0.902 to 0.916.

These verification factors were applied to the model results on the zonal basis described.

The model road NOx and total NO_2 (pre- and post- adjustment) are provided for each zone in the following graphs.

Zone 1:

Table C1-7: Modelled vs Monitored Total NO_2 for Zone 1 (Unadjusted)

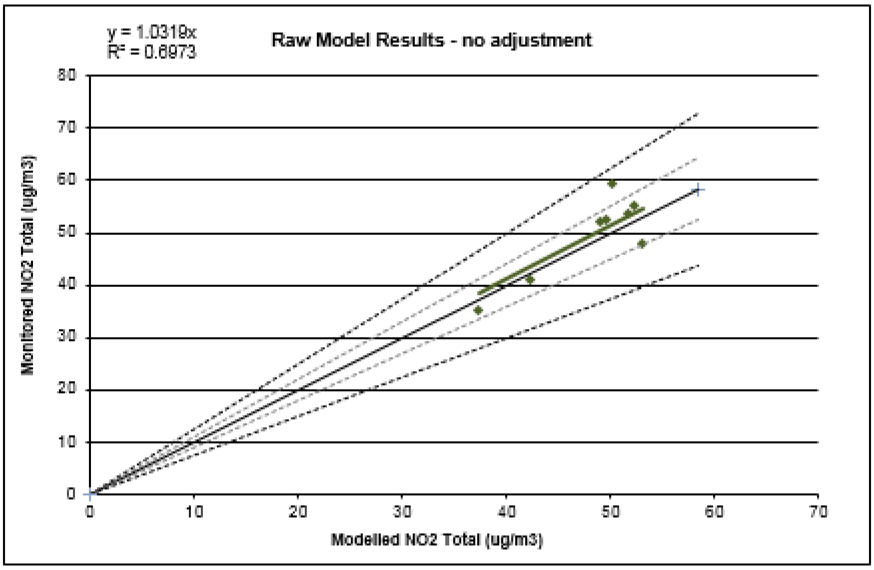


Table C1-8: Modelled vs Monitored Road NO_x for Zone 1 (Unadjusted)

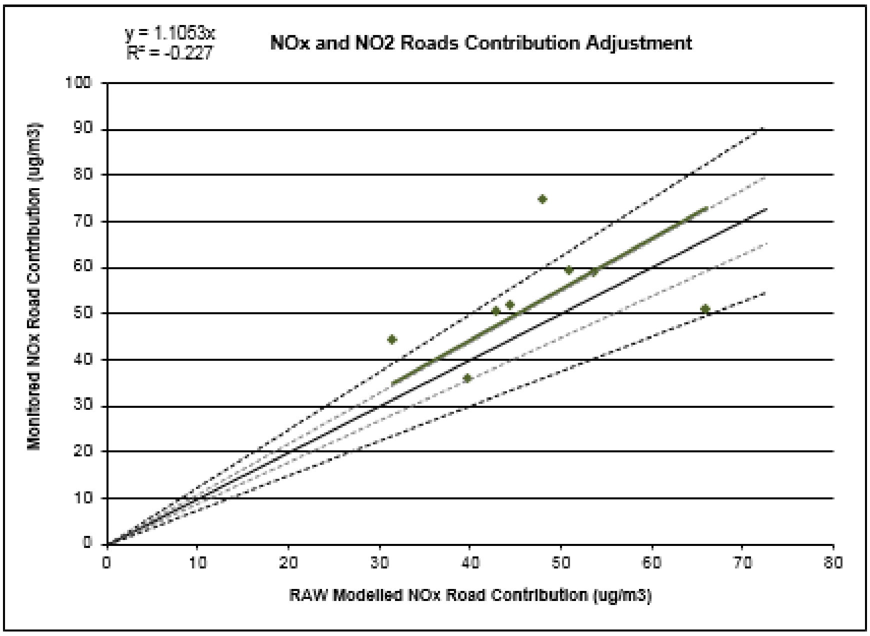
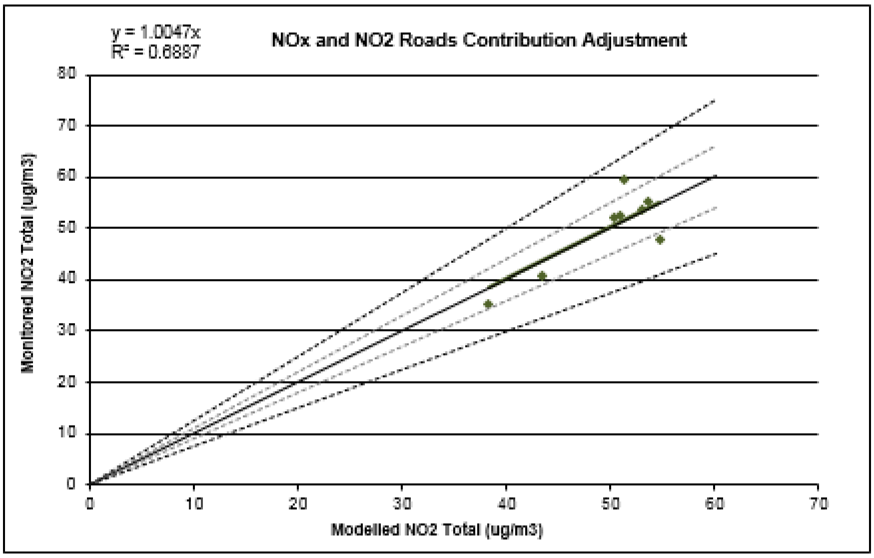


Table C1-9: Modelled vs Monitored Total NO_2 for Zone 1 (Adjusted)



Zone 2:

Table C1-10: Modelled vs Monitored Total NO_2 for Zone 2 (Unadjusted)

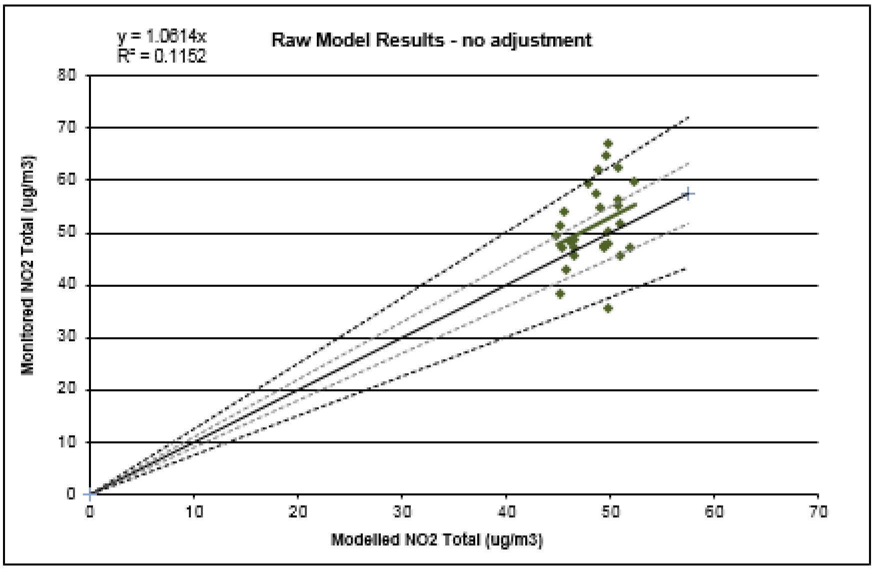


Table C1-11: Modelled vs Monitored Road NO_x for Zone 2 (Unadjusted)

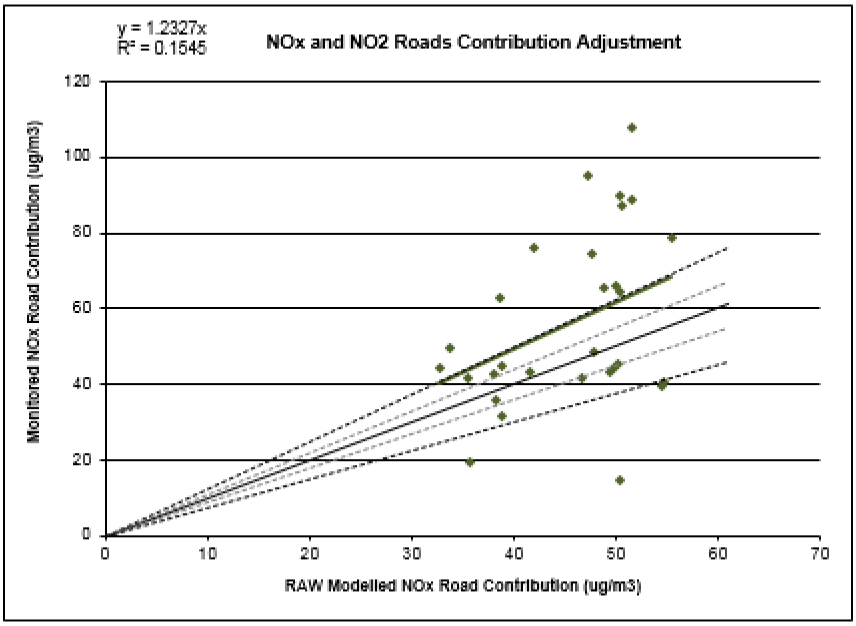
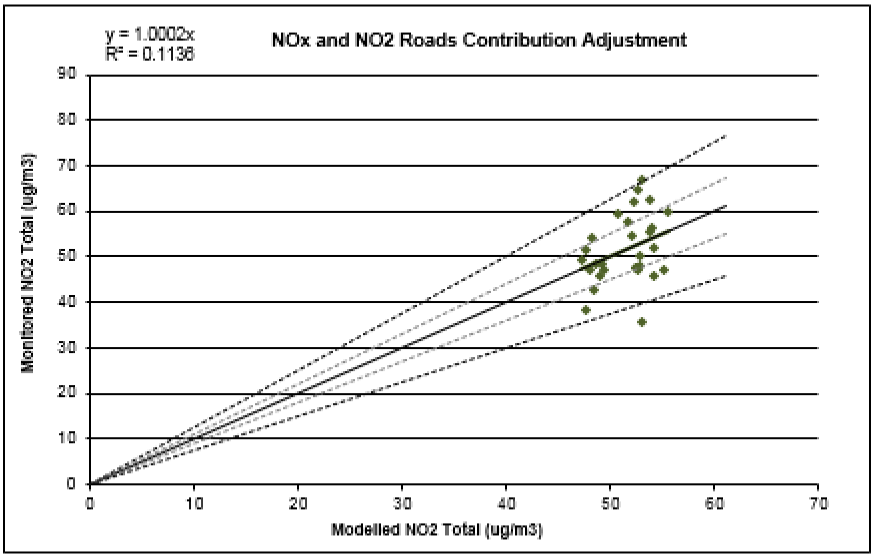


Table C1-12: Modelled vs Monitored Total NO_2 for Zone 2 (Adjusted)



Zone 3:

Table C1-13: Modelled vs Monitored Total NO_2 for Zone 3 (Unadjusted)

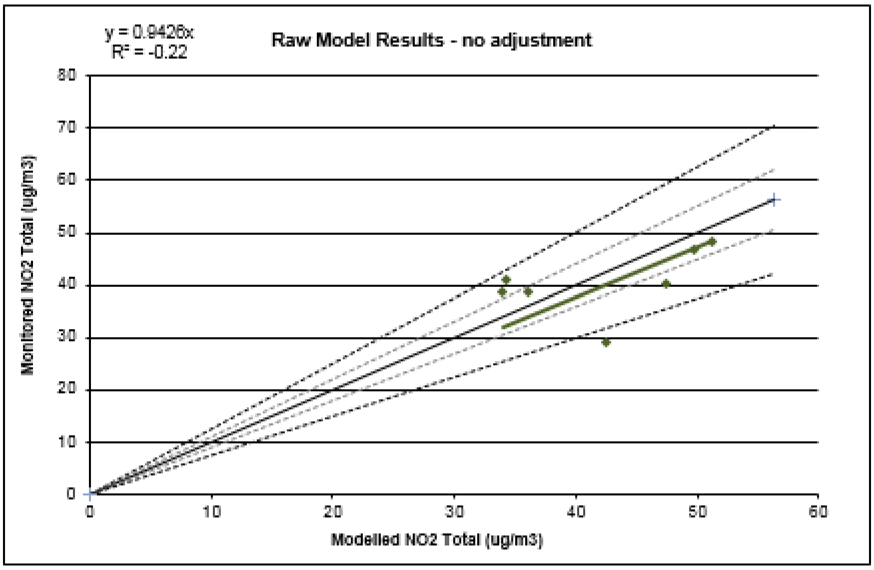


Table C1-14: Modelled vs Monitored Road NO_x for Zone 3 (Unadjusted)

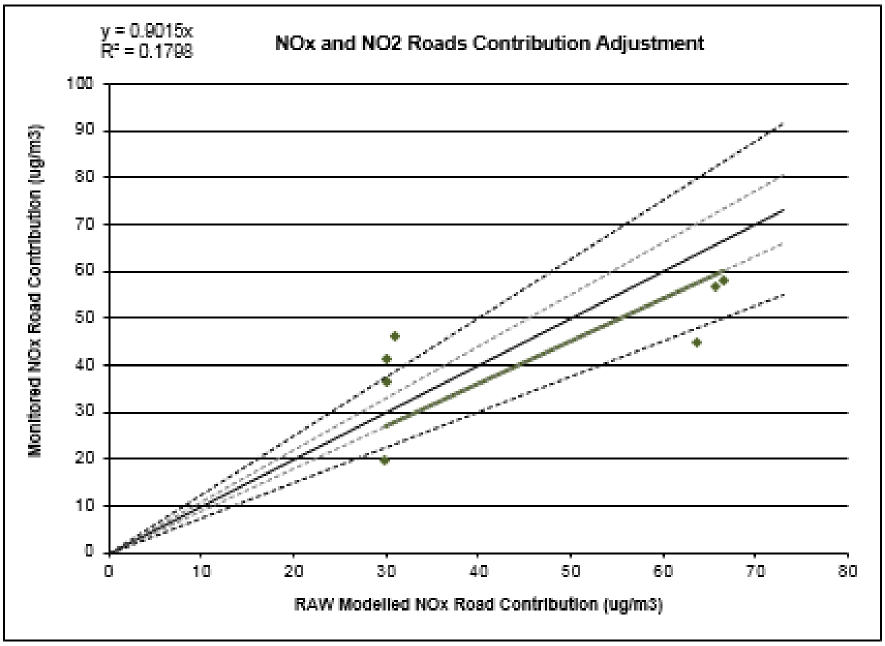
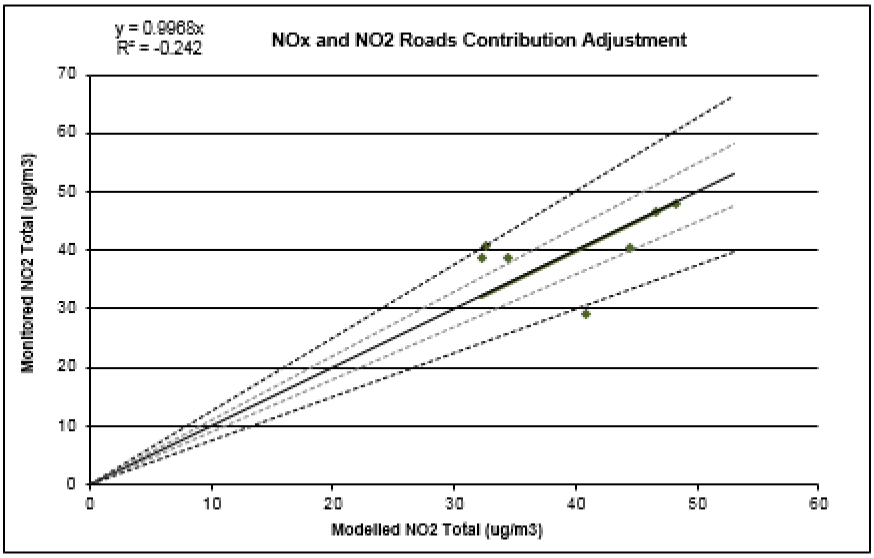


Table C1-15: Modelled vs Monitored Total NO_2 for Zone 3 (Adjusted)



Appendix D. Dispersion Modelling Results

Table D1-1: Summary of Dispersion Modelling Results (Preferred Option: CAZ D medium charge with Additional Measures, plus Mitigations & Exemptions)

Ref	Receptor	Easting	Northing	Asset Owner	Census ID	Road	Modelled NO_2 Concentration µg/m^3				Change in NO_2 Conc. (CAZ D – DM) in 2020	
							Do Minimum	CAZ 2020	CAZ 2021 (interpolated)	CAZ 2022	Actual Change (µg/m^3)	Relative Change (%)
1	PCM_0	406752	286515	BCC	81490	A4400 Suffolk St. Queensway	**46.0**	**42.1**	**40.6**	39.0	-3.9	-8%
2	PCM_2	407477	287785	BCC	56394	A38 Corporation St.	**43.2**	40.3	38.7	37.1	-2.9	-7%
3	PCM_3	406861	285777	BCC	81489	A38 Bristol St.	35.3	32.0	30.8	29.5	-3.3	-9%
4	PCM_4	407844	288028	BCC	7676	A4540 Dartmouth Circus	**41.6**	39.7	38.0	36.2	-1.9	-5%
5	PCM_6	408473	286918	BCC	27736	A4540 Watery Lane Middleway	**41.1**	**40.6**	38.8	37.0	-0.5	-1%
6	PCM_8	406860	285495	BCC	17998	A4540 Belgrave Middleway	38.2	34.6	33.2	31.7	-3.6	-9%
7	PCM_10	410204	290048	BCC	N/A	A38 Tyburn Road	36.1	35.5	34.0	32.5	-0.6	-2%
8	PCM_11	407836	289062	BCC	57233	A38(M) Aston Expressway	37.5	35.7	34.2	32.6	-1.8	-5%
9	PCM_12	407257	285308	BCC	57194	A4540 Belgrave Middleway	35.9	34.8	33.4	31.9	-1.1	-3%
10	PCM_13	408578	290003	BCC	36070	A38(M) Aston Expressway (Elevated Rd.)	37.0	35.6	34.2	32.7	-1.4	-4%
11	PCM_14	407594	288084	BCC	70227	A38(M) Aston Expressway	**41.7**	38.8	37.3	35.7	-2.9	-7%
12	PCM_15	413727	291047	BCC	47202	A452 Chester Rd.	32.3	32.3	31.1	29.8	0.0	0%
13	PCM_16	408461	285861	BCC	28042	A4540 Bordesley Middleway	36.5	36.2	34.7	33.2	-0.3	-1%
14	PCM_17	407312	288273	BCC	37779	A4540 Newtown Middleway	38.3	37.5	35.9	34.3	-0.8	-2%
15	PCM_18	408027	287667	BCC	57193	A4540 Lawley Middleway	39.5	39.3	37.8	36.2	-0.2	-1%
16	PCM_20	404909	286003	BCC	7179	A456 Hagley Rd.	29.4	28.9	27.6	26.3	-0.5	-2%
17	PCM_21	409968	289903	HE	48185	M6	**41.4**	**41.0**	39.4	37.7	-0.4	-1%
18	PCM_24	410214	290721	BCC	27773	A38(M) Aston Expressway	31.0	30.5	29.3	28.1	-0.5	-2%
19	PCM_26	406858	288359	BCC	17644	A4540 New John St. West	33.4	32.9	31.6	30.2	-0.5	-1%
20	PCM_27	407083	291647	BCC	17132	A453 Aldridge Rd.	29.1	28.7	27.6	26.5	-0.4	-1%
21	PCM_28	408950	285641	BCC	28465	A45(T) Coventry Rd.	35.0	34.4	33.1	31.8	-0.6	-2%
22	PCM_29	411671	290578	BCC	56399	A38 Tyburn Rd.	32.2	31.9	30.7	29.4	-0.3	-1%
23	PCM_30	408837	291121	HE	70230	M6	39.6	39.3	37.6	35.9	-0.3	-1%
24	PCM_32	415263	284344	BCC	56416	A45(T) Coventry Rd.	27.3	27.2	26.2	25.1	-0.1	0%
25	PCM_34	412665	290982	BCC	6390	A38 Kingsbury Rd.	30.4	30.2	29.2	28.2	-0.2	-1%
26	PCM_35	408084	285451	BCC	47166	A4540 Highgate Middleway	35.1	34.8	33.4	32.0	-0.3	-1%

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							Do Minimum	CAZ 2020	CAZ 2021 (interpolated)	CAZ 2022	Actual Change (µg/m^3)	Relative Change (%)
27	PCM_38	406168	285875	BCC	37780	A4540 Lee Bank Middleway	32.2	31.3	30.0	28.6	-0.9	-3%
28	PCM_39	406762	287329	BCC	81492	A4400 Lancaster Circus Q'way	**42.6**	39.6	38.1	36.6	-3.0	-7%
29	PCM_41	407381	292440	BCC	47206	A453 College Rd.	31.6	31.3	30.0	28.6	-0.3	-1%
30	PCM_43	405799	288186	BCC	47731	A4540 Icknield St.	30.9	31.1	29.8	28.4	0.2	1%
31	PCM_44	405626	287598	BCC	47731	A4540 Icknield St.	33.5	33.5	32.2	30.8	0.0	0%
32	PCM_45	403507	286035	BCC	38552	A456 Hagley Rd.	25.7	25.1	24.1	23.0	-0.6	-2%
33	PCM_48	412138	288809	BCC	27690	A4040 Bromford Lane	32.7	32.7	31.3	29.8	0.0	0%
34	PCM_50	407025	291233	BCC	75005	A453 Aldridge Rd.	31.4	31.0	29.7	28.4	-0.4	-1%
35	PCM_51	404129	282515	BCC	81576	A4040 Chapel Lane	27.4	27.3	26.3	25.2	-0.1	0%
36	PCM_54	406776	285419	BCC	26395	A38 Bristol Rd.	34.5	31.7	30.5	29.2	-2.8	-8%
37	PCM_55	406670	290330	BCC	56330	A34 New Town Row	29.0	28.5	27.3	26.0	-0.5	-2%
38	PCM_56	406697	284702	BCC	47176	A441 Pershore Rd.	28.6	27.6	26.4	25.2	-1.0	-3%
39	PCM_60	407906	288814	BCC	46398	A5127 Lichfield Rd.	37.9	36.6	35.2	33.8	-1.3	-3%
40	PCM_61	405450	287362	BCC	27737	A4540 Icknield St.	32.5	32.7	31.4	30.0	0.2	1%
41	PCM_63	404776	283163	BCC	81577	A38 Bristol Rd.	33.8	33.3	31.9	30.5	-0.5	-1%
42	PCM_65	403488	283605	BCC	81575	A4040 Harborne Park Rd.	21.9	21.9	21.1	20.2	0.0	0%
43	PCM_66	402119	285954	BCC	37233	A456 Hagley Rd. West	24.0	23.8	22.8	21.8	-0.2	-1%
44	PCM_67	414424	292023	BCC	26393	A38 Kingsbury Rd.	26.8	26.7	25.7	24.7	-0.1	0%
45	PCM_69	413022	291939	BCC	17128	A452 Chester Rd.	31.4	31.5	30.4	29.2	0.1	0%
46	PCM_70	405427	286269	BCC	7677	A4540 Ladywood Middleway	32.3	32.1	30.8	29.5	-0.2	-1%
47	PCM_73	411162	283879	BCC	28476	A41 Warwick Rd.	28.4	28.3	27.3	26.3	-0.1	0%
48	PCM_74	404984	279846	BCC	7142	A441 Pershore Rd.	31.4	31.2	30.2	29.2	-0.2	-1%
49	PCM_76	410198	283914	BCC	26454	A41 Warwick Rd.	26.4	26.1	25.2	24.3	-0.3	-1%
50	PCM_78	405669	283632	BCC	6392	A38 Bristol Rd.	27.9	26.8	25.7	24.5	-1.1	-4%
51	PCM_79	409221	284326	BCC	48068	A41 Warwick Rd.	32.4	32.0	30.8	29.5	-0.4	-1%
52	PCM_83	408525	285031	BCC	56331	A41 Stratford Rd.	33.0	32.5	31.3	30.1	-0.5	-2%
53	PCM_85	412309	284572	BCC	17593	A4040 Stockfield Rd.	30.3	30.5	29.3	28.0	0.2	1%
54	PCM_86	407715	288583	BCC	74479	A38(M) Aston Expressway	**41.7**	39.7	38.1	36.4	-2.0	-5%

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							Do Minimum	CAZ 2020	CAZ 2021 (interpolated)	CAZ 2022	Actual Change (µg/m³)	Relative Change (%)
55	PCM_87	404974	287651	BCC	37238	A457 Spring Hill	27.8	27.3	26.3	25.2	-0.5	-2%
56	PCM_88	408277	284783	BCC	7927	A4540 Highgate Rd.	30.2	29.7	28.5	27.2	-0.5	-2%
57	PCM_89	403255	290217	BCC	6448	A41 Holyhead Rd.	22.2	22.1	21.4	20.6	-0.1	0%
58	PCM_90	409831	290070	BCC	70236	A38(M) Tyburn Rd.	35.3	34.8	33.3	31.8	-0.5	-1%
59	PCM_91	412949	290234	BCC	99233	A47 Fort Parkway	32.3	32.2	31.1	29.9	-0.1	0%
60	PCM_92	401772	278975	BCC	46400	A38 Bristol Rd. South	22.2	22.0	21.1	20.2	-0.2	-1%
61	PCM_93	404420	289540	BCC	28039	A41 Soho Rd.	29.4	28.8	27.7	26.5	-0.6	-2%
62	PCM_94	405828	282547	BCC	27167	A441 Pershore Rd.	23.4	22.8	22.0	21.2	-0.6	-3%
63	PCM_95	411355	280336	BCC	73055	A34 Stratford Rd.	23.8	23.9	22.9	21.9	0.1	0%
64	PCM_96	406055	288388	BCC	70221	A4540	33.2	32.9	31.6	30.2	-0.3	-1%
65	PCM_97	403782	290765	BCC	57689	A4040 Oxhill Rd.	22.2	22.1	21.4	20.6	-0.1	0%
66	PCM_98	409796	289307	BCC	75461	A47 Nechells Parkway	32.9	32.7	31.5	30.2	-0.2	-1%
67	PCM_99	404282	287636	BCC	58153	A457 Dudley Rd.	27.9	27.7	26.6	25.5	-0.2	-1%
68	PCM_100	411812	292780	BCC	37222	A452 Chester Rd.	30.3	30.3	29.0	27.7	0.0	0%
69	PCM_101	405948	288561	BCC	70223	A4540 New John St. West	31.3	30.7	29.4	28.1	-0.6	-2%
70	PCM_102	411244	292289	BCC	47777	A5127 Birmingham Rd.	28.1	27.8	26.7	25.6	-0.3	-1%
71	PCM_103	411333	290157	BCC	75001	A4040 Wheelwright Rd.	34.1	33.8	32.5	31.1	-0.3	-1%
72	PCM_104	403755	289766	BCC	36456	A41 Holyhead Rd.	28.9	28.6	27.6	26.6	-0.3	-1%
73	PCM_105	411537	283251	BCC	47688	A4040 Fox Hollies Rd.	30.6	30.7	29.6	28.5	0.1	0%
74	PCM_107	404935	279189	BCC	37198	A441 Pershore Rd. South	31.0	31.0	30.1	29.1	0.0	0%
75	PCM_109	409456	290312	HE	70234	M6	38.8	38.4	36.7	35.0	-0.4	-1%
76	PCM_110	405765	288416	BCC	70222	A4540 Heaton St.	29.4	29.1	28.0	26.8	-0.3	-1%
77	PCM_111	405402	293241	BCC	46365	A34 Walsall Rd.	22.7	22.5	21.7	20.8	-0.2	-1%
78	PCM_113	405229	289267	BCC	16423	A41 Soho Hill	28.5	27.8	26.7	25.5	-0.7	-2%
79	PCM_114	401966	279754	BCC	16367	A38 Bristol Rd. South	23.6	23.4	22.4	21.3	-0.2	-1%
80	PCM_115	409949	282822	BCC	26361	A34 Stratford Rd.	24.2	24.1	23.1	22.1	-0.1	0%
81	PCM_116	409195	290614	HE	70233	M6	39.3	38.8	37.1	35.4	-0.5	-1%
82	PCM_117	411658	297851	BCC	27203	A5127 Lichfield Rd.	21.7	21.8	20.9	20.0	0.1	0%

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83	PCM_118	410496	293811	BCC	7167	A452 Chester Rd.	30.8	30.8	29.6	28.3	0.0	0%
84	PCM_119	407512	280005	BCC	37188	A435 Alcester Rd. South	21.2	21.1	20.4	19.6	-0.1	0%
85	PCM_120	410877	281437	BCC	27691	A4040 Fox Hollies Rd.	25.9	26.0	25.0	23.9	0.1	0%
86	PCM_121	411945	283283	BCC	6449	A41 Warwick Rd.	27.2	27.2	26.3	25.4	0.0	0%
87	PCM_122	412630	285198	BCC	57729	A4040 Church Rd.	31.1	31.2	30.0	28.7	0.1	0%
88	PCM_123	409583	294591	BCC	27191	A452 Chester Rd. North	28.2	28.2	27.1	25.9	0.0	0%
89	PCM_124	411426	290122	BCC	75000	A4040 Bromford Lane	36.8	36.7	35.1	33.5	-0.1	0%
90	PCM_125	411834	295634	BCC	37227	A5127 Birmingham Rd.	28.1	28.1	26.9	25.6	0.0	0%
91	PCM_126	412976	287572	BCC	7628	A4040 Station Rd.	33.8	34.0	32.5	31.0	0.2	1%
92	PCM_127	404475	281012	BCC	47706	A4040 Watford Rd.	21.1	21.1	20.4	19.6	0.0	0%
93	PCM_128	404075	287619	BCC	57238	A457 Dudley Rd.	26.2	26.0	25.1	24.1	-0.2	-1%
94	PCM_129	411912	293746	BCC	17682	A5127 Birmingham Rd.	28.1	27.9	26.7	25.5	-0.2	-1%
95	PCM_130	407849	284574	BCC	27159	A435 Alcester Rd.	29.3	28.8	27.6	26.4	-0.5	-2%
96	PCM_131	408910	295560	BCC	18539	A452 Chester Rd. North	22.4	22.4	21.5	20.6	0.0	0%
97	PCM_132	405279	290550	BCC	7627	A4040 Wellington Rd.	25.6	25.5	24.5	23.4	-0.1	0%
98	PCM_133	407403	282510	BCC	7132	A435 Alcester Rd. South	25.2	25.1	24.2	23.2	-0.1	0%
99	PCM_134	415873	292384	BCC	57701	A4097 Kingsbury Rd.	24.8	24.8	23.9	22.9	0.0	0%
100	PCM_135	408005	292804	BCC	27196	A453 College Rd.	24.6	24.4	23.5	22.5	-0.2	-1%
101	PCM_136	412066	296569	BCC	70226	A5127 High St.	27.1	27.1	26.0	24.8	0.0	0%
102	PCM_137	411105	290977	BCC	47687	A4040 Reservoir Rd.	31.6	31.5	30.4	29.3	-0.1	0%
103	PCM_138	411085	280616	BCC	36366	A34 Stratford Rd.	26.9	26.9	25.7	24.4	0.0	0%
104	PCM_140	410169	282752	BCC	6359	A34 Stratford Rd.	28.0	27.8	26.7	25.6	-0.2	-1%
105	PCM_141	403115	286678	BCC	38010	A4040 City Rd.	22.4	22.2	21.4	20.6	-0.2	-1%
106	PCM_142	403930	277773	BCC	57103	A441 Redditch Rd.	19.1	19.0	18.5	17.9	-0.1	-1%
107	PCM_143	399340	277515	BCC	26396	A38 Bristol Rd. South	14.8	14.8	14.3	13.8	0.0	0%
108	PCM_144	402286	284658	BCC	17612	A4123 Court Oak Rd.	21.5	21.5	20.7	19.9	0.0	0%
109	PCM_145	410119	281126	BCC	8010	A4040 Brook Lane	24.0	24.1	23.2	22.2	0.1	0%
110	PCM_146	404309	289502	BCC	8347	A4040 Handsworth New Rd.	26.7	26.5	25.5	24.5	-0.2	-1%

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111	PCM_147	408612	295963	BCC	78684	A452 Chester Rd. North	21.2	21.2	20.4	19.6	0.0	0%
112	PCM_148	406764	290899	BCC	75003	A34	31.6	31.2	29.8	28.4	-0.4	-1%
113	PCM_149	411167	294824	BCC	7172	A453 Jockey Rd.	24.1	24.1	23.2	22.3	0.0	0%
114	PCM_150	405901	280705	BCC	37730	A4040 Fordhouse Lane	24.6	24.6	23.8	23.0	0.0	0%
115	PCM_151	407209	281162	BCC	37730	A4040 Fordhouse Lane	24.0	24.0	23.1	22.2	0.0	0%
116	PCM_152	403065	284398	BCC	7926	A4040 Lordswood Rd.	24.9	24.9	24.0	23.0	0.0	0%
117	PCM_153	411896	296028	BCC	70224	A5127 Brassington Avenue	24.9	24.8	23.8	22.7	-0.1	0%
118	PCM_154	412639	297353	BCC	17133	A453 Tamworth Rd.	21.8	21.8	21.0	20.1	0.0	0%
119	PCM_155	411617	298739	BCC	37818	A5127 Lichfield Rd.	22.2	22.2	21.3	20.4	0.0	0%
120	PCM_156	411423	298246	BCC	57213	A454 Walsall Rd.	22.2	22.2	21.3	20.4	0.0	0%
121	PCM_157	406048	283688	BCC	47998	A4029 Pebble Mill Rd.	23.9	23.4	22.5	21.5	-0.5	-2%
122	PCM_158	407186	287602	BCC	81493	A38 St Chads Queensway	**44.0**	**40.5**	38.9	37.3	-3.5	-8%
123	PCM_159	413856	290448	BCC	99234	A452 Chester Rd.	36.5	36.5	35.3	34.0	0.0	0%
124	PCM_161	406629	286681	BCC	81487	A38 Queensway (Tunnel)	**43.8**	**40.5**	39.1	37.7	-3.3	-8%
125	PCM_162	413845	289847	BCC	84077	A452 Newport Rd.	30.4	30.4	29.2	27.9	0.0	0%
126	Non_PCM_1	407628	287094	BCC	N/A	Park St.	39.1	37.7	36.4	35.1	-1.4	-4%
127	Non_PCM_2	407404	282031	BCC	N/A	High St.	25.6	25.6	24.6	23.5	0.0	0%
128	Non_PCM_3	407386	282131	BCC	N/A	High St.	25.1	25.0	24.0	23.0	-0.1	0%
129	Non_PCM_4	409143	284055	BCC	N/A	Stratford Rd.	33.4	32.9	31.6	30.3	-0.5	-1%
130	Non_PCM_5	409106	284157	BCC	N/A	Stratford Rd.	34.6	34.1	32.7	31.2	-0.5	-1%
131	Non_PCM_7	410004	290000	BCC	N/A	Tyburn Rd.	37.3	36.8	35.2	33.6	-0.5	-1%
132	Non_PCM_8	410072	290002	BCC	16365	A38 Tyburn Rd.	37.7	37.1	35.6	34.0	-0.6	-2%
133	Non_PCM_9	404739	279699	BCC	N/A	Middleton Hall Rd.	28.7	28.6	27.8	27.0	-0.1	0%
134	Non_PCM_10	407458	286475	BCC	N/A	Moat Lane	39.8	38.4	37.1	35.7	-1.4	-4%
135	Non_PCM_11	408101	287215	BCC	N/A	Curzon St.	36.2	35.4	34.2	32.9	-0.8	-2%
136	ObjectID_18_@2m	407176	285684	BCC	N/A	Sherlock St.	35.9	33.7	32.4	31.0	-2.2	-6%
137	ObjectID_22_@2m	408826	288686	BCC	N/A	Thimble Mill Lane	35.0	34.5	33.3	32.0	-0.5	-1%
138	ObjectID_23_@2m	408710	289186	BCC	N/A	Thimble Mill Lane	33.5	33.0	31.7	30.3	-0.5	-1%

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139	ObjectID_25_@2m	408612	289453	BCC	N/A	Lichfield Rd.	33.8	33.2	31.9	30.5	-0.6	-2%
140	ObjectID_26_@2m	409511	290050	BCC	N/A	Lichfield Rd.	39.4	38.9	37.2	35.5	-0.5	-1%
141	ObjectID_28_@2m	406336	284156	BCC	N/A	Priory Rd.	29.7	28.9	27.6	26.3	-0.8	-3%
142	ObjectID_29_@2m	406034	283376	BCC	N/A	Pershore Rd.	25.7	24.8	23.8	22.8	-0.9	-4%
143	ObjectID_32_@2m	408222	285948	BCC	N/A	Bradford St.	35.1	34.0	32.7	31.4	-1.1	-3%
144	ObjectID_33_@2m	408306	285871	BCC	N/A	Bradford St.	35.7	34.7	33.4	32.0	-1.0	-3%
145	ObjectID_39_@2m	406448	288225	BCC	N/A	Unett St.	31.8	31.0	29.8	28.6	-0.8	-3%
146	ObjectID_40_@2m	406697	289032	BCC	N/A	Clifford St.	31.9	31.5	30.1	28.7	-0.4	-1%
147	ObjectID_41_@2m	407063	288865	BCC	N/A	Alma St.	35.1	34.2	33.0	31.7	-0.9	-3%
148	ObjectID_42_@2m	410522	286704	BCC	N/A	Bordesley Green	32.0	31.7	30.4	29.1	-0.3	-1%
149	ObjectID_1_@4m	406661	287126	BCC	N/A	Newhall St.	39.2	37.3	36.0	34.6	-1.9	-5%
150	ObjectID_2_@4m	406750	287149	BCC	N/A	Cornwall St.	38.8	37.0	35.7	34.3	-1.8	-5%
151	ObjectID_3_@4m	406863	287108	BCC	N/A	Barwick St.	38.0	36.5	35.2	33.8	-1.5	-4%
152	ObjectID_4_@4m	406869	287137	BCC	N/A	Church St.	38.2	36.6	35.3	33.9	-1.6	-4%
153	ObjectID_5_@4m	406938	287170	BCC	N/A	Barwick St.	38.2	36.6	35.3	34.0	-1.6	-4%
154	ObjectID_6_@4m	406910	287227	BCC	N/A	Edmund St.	38.8	37.1	35.8	34.4	-1.7	-4%
155	ObjectID_7_@4m	406926	286840	BCC	N/A	Temple St.	38.8	37.4	36.2	34.9	-1.4	-4%
156	ObjectID_8_@4m	406936	286839	BCC	N/A	Temple St.	38.8	37.4	36.1	34.8	-1.4	-4%
157	ObjectID_9_@4m	407251	286971	BCC	N/A	Bull St.	38.5	37.3	36.1	34.8	-1.2	-3%
158	ObjectID_10_@4m	407207	286991	BCC	N/A	Bull St.	38.3	37.1	35.9	34.6	-1.2	-3%
159	ObjectID_11_@4m	407210	287197	BCC	N/A	Corporation St.	37.8	36.4	35.1	33.7	-1.4	-4%
160	ObjectID_12_@4m	407223	287286	BCC	N/A	Steelhouse Lane	38.5	36.9	35.5	34.1	-1.6	-4%
161	ObjectID_13_@4m	407333	287214	BCC	N/A	Corporation St.	38.5	37.1	35.7	34.3	-1.4	-4%
162	ObjectID_14_@4m	407381	287180	BCC	N/A	Dalton St.	39.2	37.7	36.3	34.8	-1.5	-4%
163	ObjectID_15_@4m	407386	286548	BCC	N/A	Digbeth	**42.0**	**40.6**	39.2	37.8	-1.4	-3%
164	ObjectID_16_@4m	408318	287349	BCC	N/A	Vauxhall Rd.	39.2	38.8	37.2	35.6	-0.4	-1%
165	ObjectID_17_@4m	408482	287482	BCC	N/A	Vauxhall Rd.	36.8	36.3	35.0	33.6	-0.5	-1%
166	ObjectID_19_@4m	406263	288037	BCC	N/A	Great Hampton St.	33.3	31.9	30.7	29.4	-1.4	-4%

Ref	Receptor	Easting	Northing	Asset Owner	Census ID	Road	Modelled NO_2 Concentration µg/m^3				Change in NO_2 Conc. (CAZ D – DM) in 2020	
							Do Minimum	CAZ 2020	CAZ 2021 (interpolated)	CAZ 2022	Actual Change (µg/m^3)	Relative Change (%)
167	ObjectID_20_@4m	408331	288081	BCC	N/A	Nechells Parkway	36.1	35.2	33.9	32.6	-0.9	-2%
168	ObjectID_21_@4m	408813	288266	BCC	N/A	Nechells Parkway	35.5	34.7	33.5	32.2	-0.8	-2%
169	ObjectID_24_@4m	408754	289503	BCC	N/A	Lichfield Rd.	34.2	33.6	32.3	30.9	-0.6	-2%
170	ObjectID_27_@4m	408057	286304	BCC	N/A	High St. Deritend	**40.5**	38.4	36.8	35.2	-2.1	-5%
171	ObjectID_31_@4m	407818	286195	BCC	N/A	Bradford St.	38.6	37.5	36.2	34.9	-1.1	-3%
172	ObjectID_34_@4m	407307	285959	BCC	N/A	Sherlock St.	35.0	33.1	31.8	30.5	-1.9	-5%
173	ObjectID_35_@4m	406593	287207	BCC	N/A	Newhall St.	38.5	36.9	35.6	34.2	-1.6	-4%
174	ObjectID_36_@4m	406236	287395	BCC	N/A	Graham St.	36.5	35.3	34.1	32.8	-1.2	-3%
175	ObjectID_37_@4m	406156	287527	BCC	N/A	Vittoria St.	36.1	35.1	33.9	32.6	-1.0	-3%
176	ObjectID_38_@4m	406335	287953	BCC	N/A	Great Hampton St.	38.0	36.7	35.4	34.0	-1.3	-3%
177	Children's Hospital	407313	287534	BCC	N/A	A38 / A4400	**42.7**	39.7	38.2	36.6	-3.0	-7%
178	Childrens_Hospital_1	407314	287534	BCC	N/A	A38 / A4400	**42.8**	39.7	38.2	36.7	-3.1	-7%
179	Childrens_Hospital_2	407400	287492	BCC	N/A	A38 / A4400	**41.2**	38.9	37.4	35.9	-2.3	-6%
Number of Exceedances (Interpreted by JAQU as >40 g/m^3 as a rounded integer i.e. 41 µg/m^3)							**15**	**6**	**1**	**0**		

Appendix E. Sensitivity Testing

This appendix provides a summary of sensitivity tests undertaken for the FBC appraisal. This has been performed according to the guidance provided by JAQU in their 'supplementary note on sensitivity testing' issued in July 2018, and analyses the uncertainty associated with assumptions used in the traffic, emissions, air quality and economics modelling process. When appropriate, air quality testing has been performed to estimate the emissions, NO_2 concentrations, and compliance of the test scenarios and compare the results to the core scenario.

In order to meet the programme, the behavioural assumptions tests have been undertaken against the OBC Preferred Option scenario (CAZ D high charge, with no additional measures) for 2020. Further information on these tests can be found in Appendix D of the FBC Transport Modelling Report.

The tests associated with the emissions and air quality modelling aspects have been undertaken on the FBC CAZ D medium charge plus Additional Measures, with Exemptions and Mitigations for 2020. The CAZ D High charge test was also based on the FBC package.

A list of the sensitivity tests is provided in Table E1-1.

Table E1-1: Sensitivity Testing Address by the Air Quality Analysis Stage

Area of uncertainty (and JAQU ref)	JAQU Suggested sensitivity testing	Priority or Recommended?	Notes
Transport modelling and behavioural responses			
Behavioural response to charging (Section 5.1.2)	**1)** Apply published JAQU responses **2)** Apply TfL ULEZ responses directly	Priority	Uncertainty around behavioural response choice to charge tested by using other projects research looking at Clean Air Charging. Full transport re-run traffic data supplied.
Fleet age Section 5.2.3)	Dependent on methodology used. Scenarios to be discussed with JAQU.	Recommended	Not undertaken. Local fleet projection applied based on ANPR date of first registration, assuming a constant rate of renewal.
CAZ D high charge			Undertaken to confirm that the analysis on driver response to the charges post consultation feedback has not altered compliance.
Air quality			
Future emissions standards (Section 6.1.1)	**Low scenario**: Euro 6d-temp emissions equivalent to Euro 6d **High scenario**: Euro 6d-temp emissions halfway between Euro 6 & Euro 6d-temp and Euro 6d emissions halfway between Euro 6d-temp and Euro 6d	Priority	Addressed following JAQU guidance
Projecting f-NO2 (Section 6.1.2)	Lower f-NO2 values in projected year by 40%.	Priority	Addressed following JAQU guidance

Gradient based emission factors (Section 6.1.3)	Remove the effect of gradients (if modelled), add the effect of gradients (if not modelled).	Priority	Not undertaken. Gradient reviewed, and would have very limited effect on verification or key output sites. Topography of the road network is difficult to determine as the road network is not always at grade.
Emissions at low speeds (Section 6.2.1)	**Low scenario**: Emissions factors for HDVs used to speeds recommended in COPERT 4. **High scenario**: Emissions factors for HDVs used to 5kph.	Recommended	Applied by altering the low bound in the EFT NOx functions worksheet for all vehicle types to 12kph for the Low Emissions test, and 5 kph for the High Emissions test.
Zonal vs full model domain calibration (Section 6.2.2)	Full model domain calibration (if zonal applied), zonal calibration (if full model domain applied).	Recommended	A zonal approach has been applied. Sensitivity Testing on the Full Domain approach has been undertaken.
Background NO_2 calibration (Section 6.2.3)	Calibrate background NO_2 (if uncalibrated background maps used), remove background NO_2 calibration (if calibrated background maps used).	Recommended	Not required. Background maps were compared with local BG monitoring as part of the assessment process. The maps were found to show reasonable agreement, and therefore no adjustment was required. Therefore, this approach sensitivity test is not applicable.
f-NO, and calibration (Section 6.2.4)	Calibrate NOx using chemiluminescence monitors only	Recommended	Qualitative assessment. There is only 1 CM in each of the verification zones, therefore local f-NO_2 approach cannot reasonably be applied.
Surface roughness length (Section 6.2.5)	High and low surface roughness values (to be discussed with JAQU on a case by case basis).	Recommended	Not undertaken. Airviro uses a spatially variable surface roughness layer derived from OS topo information.
Meteorology (Section 6.2.6)	Model in projected year using alternative years of meteorological data	Recommended	Qualitative assessment. Not undertaken.

Canyon effects (Section 6.2.7)	Use canyon module (if not used in 'central' modelling), use separate calibration for canyon road links (if not done in 'central' modelling).	Recommended	The Airviro model canyon module cannot be readily applied on a study area of this scale. However, the zonal approach to model verification has applied a canyon approach in the city centre as specified in the guidance.

Behavioural response to charging

The actual response to a charging CAZ is dependent on many factors. To test the sensitivity of this, two alternative set of assumptions have been used, following JAQU guidance.

1) JAQU published a technical report as part of their National Air Quality Plan which included the assumptions on how users would respond to a charging CAZ. These responses have been compared to the BCC responses as developed in the OBC. The route choice response is still forecast within the assignment model rather than being taken directly from JAQU.

2) TfL's ULEZ stated preference survey results were used directly to test the car user's responsiveness rates. As with the JAQU the route choice for non-city centre traffic was taken from the assignment model.

Table E-1 and Figure E-1 provide the summary statistics requested in JAQU's 'Supplementary Note on Sensitivity Testing' and the compliance status for each of these scenarios. These sensitivity tests demonstrate that the potential effect of the behavioural responses is an important aspect of the scheme. The methodology used in this scheme has been derived from the ULEZ work, and shows a slightly lower response than would have been predicted by direct application of the ULEZ responses. Application of the JAQU guidance behavioural responses would show significantly lower air quality benefits of a CAZ D scheme. This is because more cars upgrade rather than change mode or cancel, so there more car trips, and there is lower HGV upgrading so an older fleet.

The BCC method sits between the two sensitivity tests, with the maximum predicted concentrations for the OBC CAZ D ranging from 42.0 µg/m^3 to 44.8 µg/m^3. The range of maximum results could likely alter the predicted first year of compliance either forwards or backwards, but does confirm that a charging CAZ D scenario is necessary because compliance is not delivered in 2020 by any of the methods.

Table E-1: Simple Summary Statistics for Sensitivity Testing of Behavioural Responses to Charging (µg/m^3)

Statistic	Test Results (µg/m^3)		
	OBC CAZD High AM 2020	JAQU	ULEZ S.P.
Mean	31.3	33.3	31.7
Median	31.7	34.0	32.0
Maximum	42.7	44.8	42.0
Minimum	14.8	15.4	14.9
Upper Quartile	42.7	44.8	42
Lower Quartile	27.2	29.0	27.6
Standard Deviation	5.7	5.9	5.7
Range	27.9	29.4	27.1
No. of Non-Compliance Receptors	6	21	4

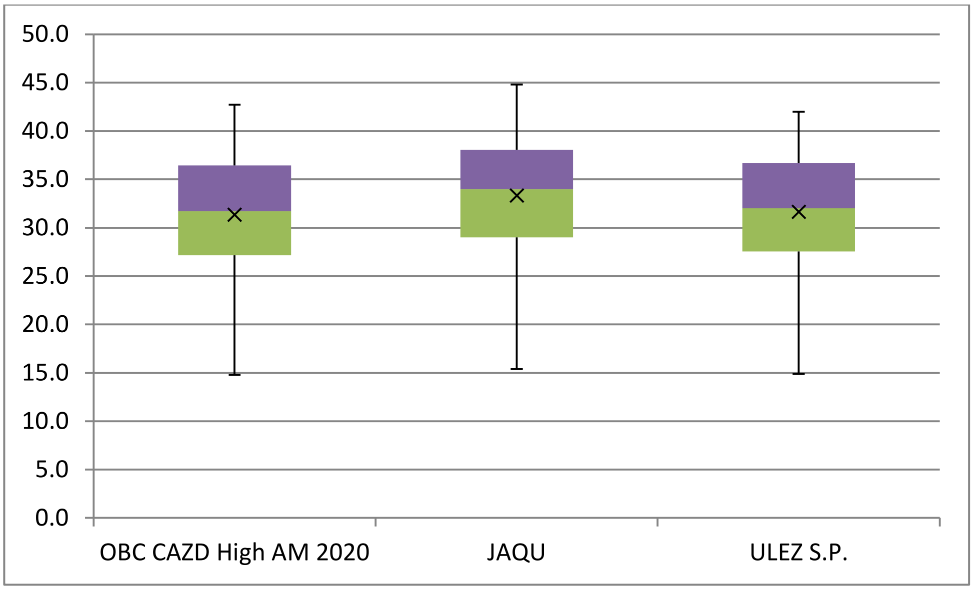

Figure E-1: Distribution of NO_2 Concentrations for Sensitivity Testing of Behavioural Responses to Charging (µg/m^3)

CAZ D High charge

In order to check that the reduced charge levels from the OBC high charge scenarios of £12.50 to £8 for cars, taxis and was not delaying compliance, the FBC scenario was re-run with the high charge levels. The results show that 3 of the marginal exceedances in 2020 may no longer exceed, but that the maximum location (PCM_0 on Sufflolk St Queensway) is only reduced by <1%, and this will not realistically alter the first year of predicted compliance from 2022.

Table E-2: Simple Summary Statistics for Sensitivity Testing of f-NO_2 Emissions (µg/m^3)

Statistic	Test Results (µg/m^3)	
	FBC 2020 CAZ	FBC 2020 CAZ High Charge
Mean	31.3	31.2
Median	31.7	31.7
Maximum	42.1	41.9
Minimum	14.8	14.8
Upper Quartile	42.1	41.9
Lower Quartile	27.2	27.1
Standard Deviation	5.7	5.6
Range	27.3	27.1
No. of Non-Compliance Receptors	6	3

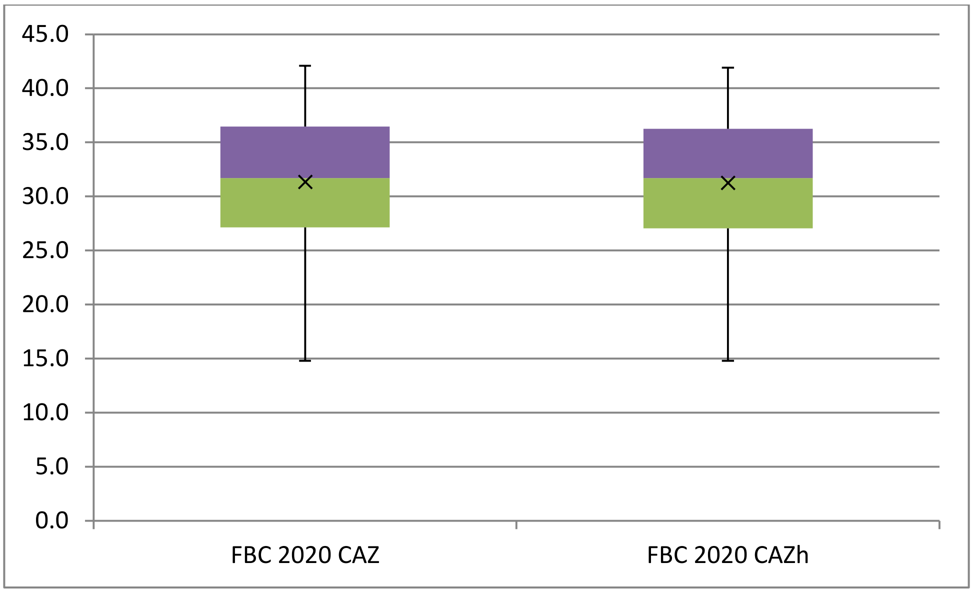

Figure E-2: Distribution of NO_2 Concentrations for Sensitivity Testing of Behavioural Responses to Charging (µg/m³)

Future emissions standards

The EFT includes NOx and PM speed-emission coefficients taken from the European Environment Agency COPERT 5 emission calculation tool[38] and fleet and fuel compositions in line with Department for Transport (DfT) projections. COPERT 5 predicts different NOx emissions from Euro 6 diesel vehicles registered in different years. This is based on a general expectation that emissions from these vehicles will reduce over time. Between 2015 and 2021, new aspects of the Euro 6 standards and real driving emissions (RDE) will come into force, but it is important to recognise that the Euro 6 emissions reductions assumed within COPERT 5 do not, and were not intended to, coincide precisely with specific iterations of the Euro 6 emissions standards themselves. Thus, for example, COPERT 5 does not contain emissions factors specific to Euro 6c (also known as Euro 6d-temp) vehicles.

JAQU suggest that LAs run a 'low emissions' scenario for future emissions standards. JAQU suggest that an appropriate 'low emissions' scenario would be to assume that Euro 6d-temp diesel cars and LGVs achieve the same emissions level as Euro 6d vehicles. This can be achieved by moving the % of cars and LGVs in the Euro 6d-temp category of the EFT into the Euro 6d category.

Although RDE testing results suggest that existing Euro 6d-temp cars are meeting the type approval NOx emissions limit, this does not mean that the real-world NOx emissions of these vehicles will be below that assumed in COPERT 5. There are a number of reasons for this. First, the small number of vehicles tested could represent the 'best in class' and therefore not reflect the average of the fleet. Second, there is uncertainty in the behaviour of vehicles under urban driving conditions where there is a greater degree of stop-start behaviour. Under such conditions, selective catalytic reduction (SCR) technology is not as effective and consequently NOx emissions may be higher.

Consequently, JAQU suggest that LAs run a 'high emissions' scenario for future emissions standards. JAQU suggest that an appropriate 'high emissions' scenario would be to assume that Euro 6dtemp cars and LGVs achieve emissions halfway between Euro 6 (non-RDE) and Euro 6dtemp and that Euro 6d cars and LGVs achieve emissions halfway between Euro 6d-temp and Euro 6d. This can be achieved by moving 50% of the cars and LGVs in the Euro 6dtemp category of the EFT (or similar COPERT 5 emissions toolkit) into the Euro 6 (nonRDE) category and moving 50% of the cars and LGVs in the Euro 6d category of the EFT into the Euro 6d-temp category.

These two sensitivity tests have been considered.

[38] http://copert.emisia.com

Table E-3 and Figure E-3 provide the summary statistics requested in JAQU's 'Supplementary Note on Sensitivity Testing' and the compliance status for each of these scenarios. These sensitivity tests demonstrate that the potential effect of the assumed uncertainty in future Euro 6 diesel vehicles is relatively high, with the maximum predicted concentrations for CAZ D ranging from 40.6 µg/m^3 to 42.4 µg/m^3. This significantly reduces the number of non-compliant sites in 2020 in the CAZ D preferred option, from 6 sites to 1. The range of maximum results could likely alter the predicted first year of compliance either forwards or backwards.

Table E-3: Simple Summary Statistics for Sensitivity Testing of Future Euro 6 Diesel Vehicle Emissions (µg/m^3)

Statistic	Test Results (µg/m^3)		
	Low	FBC 2020 CAZ	High
Mean	30.4	31.3	31.5
Median	30.7	31.7	31.9
Maximum	40.6	42.1	42.4
Minimum	14.5	14.8	14.8
Upper Quartile	40.6	42.1	42.4
Lower Quartile	26.2	27.2	27.3
Standard Deviation	5.5	5.7	5.7
Range	26.1	27.3	27.6
No. of Non-Compliance Receptors	1	6	7

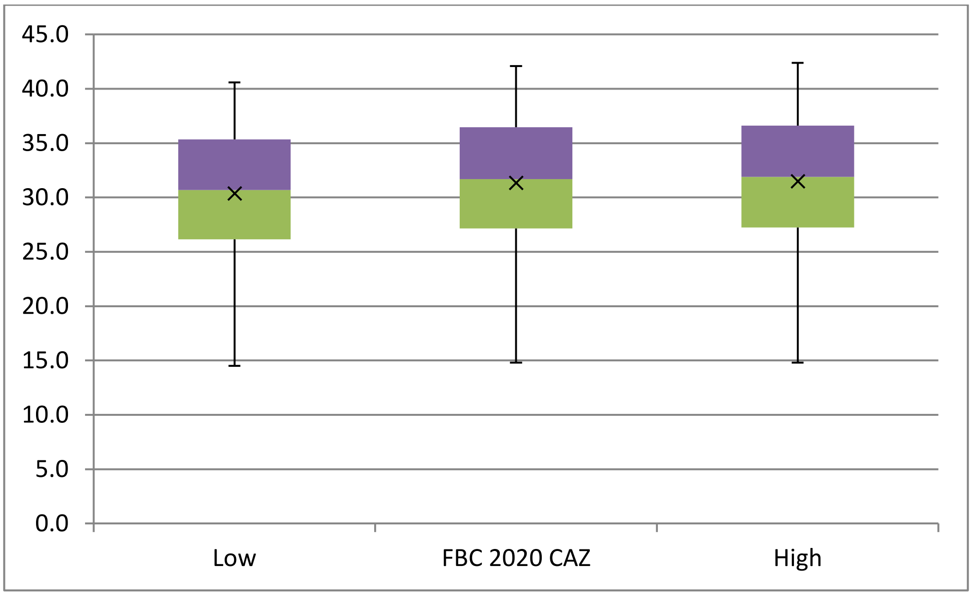

Figure E-3: Distribution of NO_2 Concentrations for Sensitivity Testing of Future Euro 6 Diesel Vehicle Emissions (µg/m^3)

Projecting f-NO2

There is emerging evidence that the average primary NO_2 fraction (f-NO_2) in exhaust emissions from road vehicles has begun to decrease in recent years[39]. This is not taken into account within the EFT, as used for the air quality modelling. To account for this, JAQU suggest that a sensitivity test be carried out whereby the f-NO_2 values are reduced by 40% in the future projected year. Following the JAQU guidance, the f-NO_2 values have been reduced by this percentage and the NO_2 concentrations re-calculated (in Defra's NOx to NO_2 Calculator) using these reduced f-NO_2 values. The results from this 'Low' scenario have then been compared to the NO_2 concentrations without applying this reduction (FBC 2020 scenario).

Table E-4 provides a summary of statistics and the compliance status for each of these scenarios as well as the FBC CAZ modelling. Figure E-4 shows the distribution of the resulting NO_2 concentrations. If the f-NO_2 values

[39] Grange S. et al., (2017) Lower vehicular primary emissions of NO_2 in Europe than assumed in policy projections, Nature Geoscience, pp 914-920, ISSN 1752-0908, https://doi.org/10.1038/s41561-017-0009-0

are reduced by 40% then the predicted concentrations are substantially lower, by 1.8 µg/m^3 compared to the preferred option modelling. In this Low f-NO_2 test, the CAZ D, plus mitigations and exemptions would be compliant in 2020.

Table E-4: Simple Summary Statistics for Sensitivity Testing of f-NO_2 Emissions (µg/m^3)

Statistic	Test Results (µg/m^3)	
	Low	FBC 2020 CAZ
Mean	30.1	31.3
Median	30.5	31.7
Maximum	40.3	42.1
Minimum	14.6	14.8
Upper Quartile	40.3	42.1
Lower Quartile	26.1	27.2
Standard Deviation	5.3	5.7
Range	25.7	27.3
No. of Non-Compliance Receptors	0	6

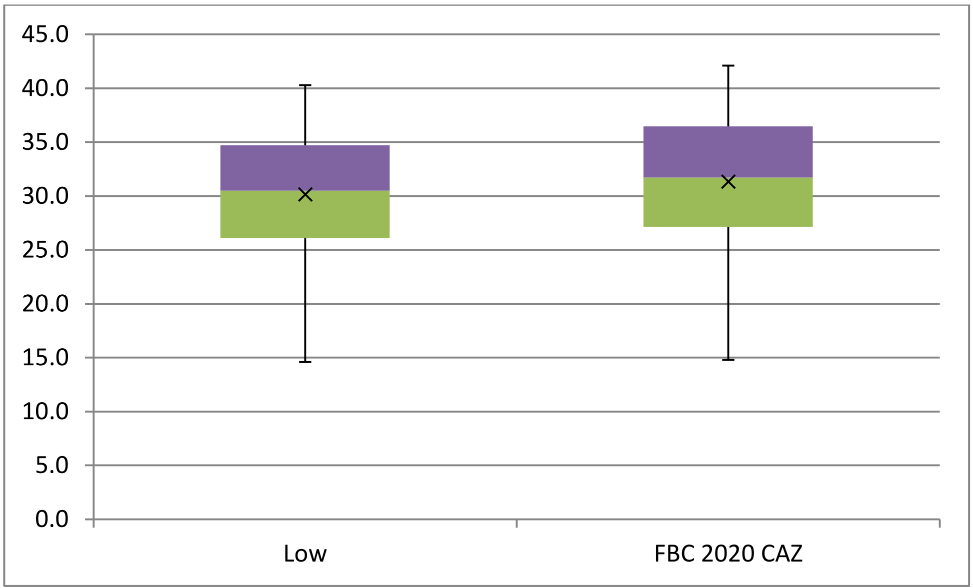

Figure E-4: Distribution of NO_2 Concentrations for Sensitivity Testing of f-NO_2 Emissions (µg/m^3)

Emissions at low speeds

Roads with queuing traffic or frequent congested behaviour will in general have lower average vehicle speeds than other roads and so stop/start driving is accounted for by way of reduced average speeds in the EFT. Traffic speeds have been estimated from the SATURN model and validated against journey time information by the traffic team. The speeds are based on the average speed along a road. In reality, the speed will can be slower at the start and end of a road and faster in the middle. The reduced speeds will lead to higher vehicle emissions and thus increased predicted concentrations. In addition, the average vehicle speed along a road will be lower than that which occurs along the middle section of the road in reality, and the model therefore assumes higher emissions along the entire road than may occur in reality. The exception to this is where significant idling occurs, so as to reduce the link-average speed (as an annual average) below the minimum of the speed range in the EFT emissions functions.

Emissions functions from HGVs particularly are very sensitive at low speeds, as these vehicles show a steep rise in NOx emissions as speeds decrease from low speed.

JAQU has set out a methodology to assess the uncertainty of emissions from vehicles travelling at low speeds. This approach has been applied by altering the lower bound in the EFT 'NOx functions' worksheet for all vehicle types to 12kph for the Low Emissions test, and 5 kph for the High Emissions test. This approach is intended to simply test the impact of different approaches to emissions at low speeds: the outputs derived from following such an approach should are not presented as a meaningful estimate of the 'true' uncertainty in emission factors at low speeds.

Table E-5 and Figure E-5 provides a summary of statistics and the compliance status for each of these scenarios as well as the FBC CAZ modelling. The model results indicate that there is little difference between the tests at the maximum receptor location, which defines compliance. This is because of those links close to the A4400, none are predicted by the transport model of have average speeds below 12kph, and the road immediately adjacent to the highest receprtor has very low flows of HGVs.

Table E-5: Simple Summary Statistics for Sensitivity Testing of Emissions at Low Speeds (µg/m³)

Statistic	Test Results (µg/m³)		
	Lowest Speeds @ 5pkh	FBC 2020 CAZ	Lowest Speeds @ 12pkh
Mean	31.3	31.3	31.2
Median	31.7	31.7	31.7
Maximum	42.2	42.1	41.9
Minimum	14.8	14.8	14.8
Upper Quartile	42.2	42.1	41.9
Lower Quartile	27.2	27.2	27.1
Standard Deviation	5.7	5.7	5.6
Range	27.4	27.3	27.1
No. of Non-Compliance Receptors	6	6	3

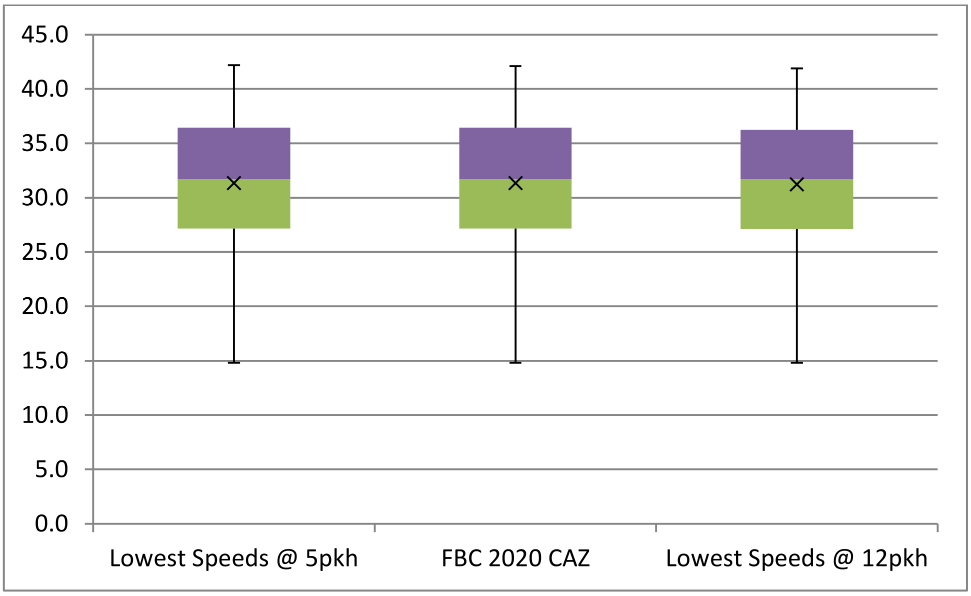

Figure E-5: Distribution of NO_2 Concentrations for Sensitivity Testing of Emissions at Low Speeds (µg/m³)

<u>Zonal vs full model domain calibration</u>

Local authorities are expected to verify their models in the base year with respect to measured NOx and NO_2 concentrations in their local area. However, different methodologies can be followed to achieve this verification. In particular, authorities can use either a full model domain verification (i.e. applying an average verification factor across the model domain) or a zonal calibration (i.e. applying different verification factors in different areas of the model domain). There are advantages and disadvantages to both methodologies. A zonal verification may account more effectively for effects specific to certain road links in the model domain (e.g. canyon effects) but could lead to a small number of monitoring sites being used to verify particular zones, decreasing the reliability of the verification factors derived with respect to a full model domain verification.

JAQU suggest that authorities run a sensitivity test around this by verifying the base year across the full model domain if a zonal verification was used in the 'central' modelling or verifying in an appropriate zonal fashion if a full model domain calibration was used in the 'central' modelling. This approach was applied in the model testing and development phase. The model verification is explained in detail in Appendix C, where a comparison of the model performance using the selected zonal approach versus the full domain is discussed, showing improved model performance for the zonal approach.

Table E-6 provides a summary of statistics and the compliance status for each of these scenarios as well as the FBC CAZ modelling. Figure E-6 shows the distribution of the resulting NO_2 concentrations. The test results indicate that the predictions are highly sensitive to the verification method, with the Full Domain approach significantly increasing maximum predicted concentration for the FBC CAZ D central modelling from 42.1 µg/m^3 to 45.4 µg/m^3, and the number of non-compliant sites doubling from 6 to 12. This is to be expected as the model domain includes areas of wide roads with multiple lanes, and narrow canyons. Whilst the model adjustment factors do not appear to be very different between Zones, their influence in determining compliance is important, and the approach applied is considered the more robust.

Table E-6: Simple Summary Statistics for Sensitivity Testing of Full Domain Verification (µg/m^3)

Statistic	Test Results (µg/m^3)	
	FBC 2020 CAZ	Full Domain
Mean	31.3	32.5
Median	31.7	33.3
Maximum	42.1	45.4
Minimum	14.8	15.5
Upper Quartile	42.1	45.4
Lower Quartile	27.2	28.3
Standard Deviation	5.7	5.4
Range	27.3	29.9
No. of Non-Compliance Receptors	6	12

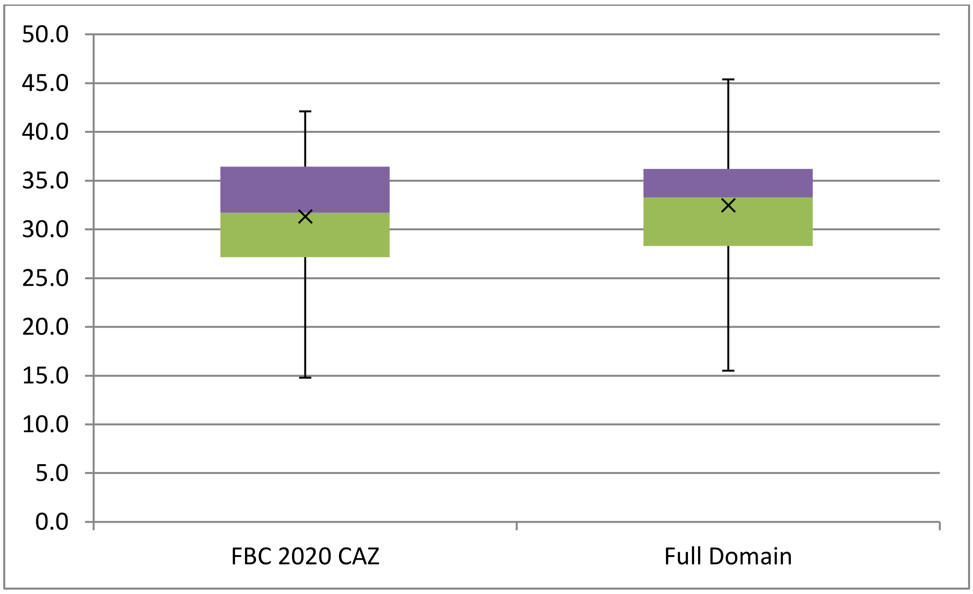

Figure E-6: Distribution of NO_2 Concentrations for Sensitivity Testing of Full Domain Verification (µg/m^3)

f-NO, and verification

The fraction of primary NO_2 (f-NO_2) is a significant source of uncertainty in roadside air quality modelling (see the comments of the uncertainty panel convened to support the 2017 NO2 Plan[40]). It is used in two stages in the modelling process:

1. To 'back-calculate' NOx concentrations from NO_2 concentrations measured using diffusion tubes. These NOx concentrations are used to calibrate the NOx concentrations outputted from the dispersion model.

2. To calculate NO_2 concentrations from calibrated NOx concentrations.

As f-NO_2 is applied twice in the process, once to 'back-calculate' NOx and once to 'forwardcalculate' NO_2, the final NO_2 concentration outputs are relatively independent of f-NO_2. JAQU has confirmed this through a study looking into the impact of varying f-NO_2 on calibrated roadside NO_2 concentrations. The distribution of NO_2 concentrations is relatively unaffected by changing f-NO_2 (even to extreme levels, as reflected in the negligible variation in the mean) although the maximum NO_2 shows a fairly strong positive correlation with f-NO_2.

This effect is a limitation in the modelling process, although unavoidable given that limited data is available from roadside chemiluminescence monitors. The effect will not drive a systematic error in NO_2 concentrations in the base year but could lead to errors on particular road links. This is because, for example, two road links with identical NOx emissions rates and background concentrations but different f-NO_2 values could produce the same NO_2 concentration (although in reality the concentrations should be different).

There are only three roadside CMs available for use in the modelling, one in each verification zone. It is therefore not considered that a specific test using f-NO_2 from the CMs directly can be undertaken.

Meteorology

Meteorological data is a key input in any dispersion modelling process which has the potential to impact on the 'compliance gap' and the choice of measures. The fact that the same meteorology has been assumed in the projected year as in the base year may be causing an over or under estimation of NO_2 concentrations in the projected year. It is a well-established fact that inter-annual variability in meteorology can have a significant impact on NO_2 concentrations (though potentially less significant at the roadside where variations in vehicle emissions is likely to be the key driver of inter-annual differences in NO_2 concentration).

JAQU has attempted to quantify the potential for meteorologically driven inter-annual variability in NO_2 concentrations by investigating the impact of applying 3 different years of meteorological data from the same site (with all other inputs remaining constant) on NO_2 concentrations for a 'mock' LA. The study suggests (though results are not statistically meaningful given that only one 'mock' area has been considered with 3 years of meteorological data) that inter-annual changes in meteorology may not have a large impact on the overall distribution of roadside NO_2 concentrations in a local area but can have a significant impact for particular road links.

Canyon effects

The presence of street canyons can have a significant impact on roadside NO_2 concentrations. There is a well-established body of literature examining the effect of street canyons on NO_2 concentrations (see for example, Degraeuwe *et al*.[41], Vardoulakis *et al*[42] and Fu *et al.* [43]). Fu et al concluded that deep canyons can lead to significantly higher concentrations (on the order of 10s of μg/m^3 of NOx depending on circumstance) on the leeward (downwind) side of street canyons. Furthermore, they concluded that average NOx concentrations

[40] Section 4, 'Uncertainties and Sensitivities': https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/632916/ai r-quality-plan-technical-report.pdf
[41] Degraeuwe B. et al, 'Impact of passenger car NOx emissions on urban NO_2 pollution – Scenario analysis for 8 European cities', Atmospheric Environment (2017)
[42] Vardoulakis S, et al, 'Operational air pollution modelling in the UK—Street canyon applications and challenges', Atmospheric Environment (2007)
[43] Fu X. et al, 'Effects of canyon geometry on the distribution of traffic-related air pollution in a large urban area: Implications of a multi-canyon air pollution dispersion model', Atmospheric Environment (2017)

across a domain can increase by approximately 2-3 μg/m^3 when buildings are higher than 40m (relative to a domain with all buildings lower than 40m).

Additionally, because of the complexity of the flow within street canyons, the uncertainty in dispersion modelling at these locations is greater than that for open roads. Canyon modules within dispersion models can be used or canyon effects can be accounted for through model calibration, by deriving separate calibration factors for road links with canyons and those without (opinions vary within the modelling community). The latter approach was used in this assessment, and is described in Appendix C. Given the time constraints of the CAZ programme and Airviro interface limitations for modelling canyons, it is not considered feasible to undertake explicit canyon modelling.

Overall, it is considered likely that there is considerable variation of modelled concentrations in central Birmingham due to the presence of canyons. The assessment has applied the most robust approach to representing model predictions in the vicinity of canyons that it can in the time available, using the tools available.

Conclusions

A wide range of sensitivity tests and analysis has been undertaken, based on guidance issued by JAQU. These indicate that the modelled concentrations could be over or underestimated, however this is unavoidable and a reasonable aspect of any predictive analysis.

The testing of the behavioural responses demonstrates that the Birmingham methodology produces results between the two alternative methods, but that these assumptions could alter the predicted date of compliance. However, all of the methodologies indicate that a CAZ D type scheme is necessary because compliance is not predicted in 2020 based on any methodology.

There are recognised limitations around the number of CMs within the study mean that understanding local variability in f-NO_2 cannot be easily addressed, but is typical of almost all air quality assessments. Meteorology has been assumed to be consistent in the projected year and in the base year and that this may be causing an over or under estimation of NO_2 concentrations in the projected year, and again this cannot be predicted in the future, but it is expected to be within typical recent historic ranges. Additionally, the statistical adjustments made to the plume by the meteorological data supplier to enable acceptable dispersion model run times mean that hourly sequential data and profiling could not be applied and cross-examined. However, this approach has been applied systematically in the Base verification and future years.

Overall, it is concluded that there are a variety of assumptions that could act in combination either synergistically or antagonistically, to mean that future concentrations are higher or lower, and that the impacts of the scheme could be greater or lesser than predicted. However, the process applied is considered to be reasonable and appropriate, and the conclusions regarding the case for the scheme are robust.

Appendix F. Testing the Influence of Mitigation and Exemptions Packages

The Preferred CAZ D option can only be implemented with the necessary exemptions and mitigations required to ensure the scheme can be operationally functional and minimise adverse impacts to residents, visitors and business. The impact of the exemptions and mitigation packages have been separately tested, to gain an understanding their possible effect on the performance of the CAZ D scheme on NO_2 improvements.

A summary of the results of the dispersion modelling testing the influence of the mitigations and exemptions are presented in Table F-1. A 2021 transport model was not available, and therefore the concentrations in 2021 have been interpolated linearly using the 2020 test scenarios, and 2022 core FBC scenario results when the exemptions no longer apply.

Table F-1 : Summary of Dispersion Modelling Results at Worst Case Receptor Locations for the Preferred Scheme Testing the Influence of Mitigations and Exemptions

Receptor	Position	Easting	Northing	Census ID	Road	Do Min.	CAZ D+ w/ M&E			CAZ D+ w/ E (no M)			CAZ D+ only (no M&E)		
						2020 DM	2020 CAZ	2021 CAZ	2022 CAZ	2020 CAZ	2021 CAZ	2022 CAZ	2020 CAZ	2021 CAZ	2022 CAZ
PCM_0	Inside Ring Road	406752	286515	81490	A4400 Suffolk St. Queensway	**46.0**	**42.1**	**40.6**	39.0	**42.1**	**40.6**	39.0	**41.0**	40.0	39.0
PCM_2	Inside Ring Road	407477	287785	56394	A38 Corporation St.	**43.2**	**40.3**	38.7	37.1	**40.3**	38.7	37.1	39.0	38.1	37.1
PCM_6	Outside Ring Road	408473	286918	27736	A4540 Lawley Middleway - Garrison Circus	**41.1**	**40.6**	38.8	37.0	**40.6**	38.8	37.0	39.1	38.1	37.0
ObjectID_15_@4m	Inside Ring Road	407386	286548	N/A	Moat Lane	**42.0**	**40.6**	39.2	37.8	**40.5**	39.2	37.8	39.5	38.7	37.8

The difference between the full FBC scheme ‘CAZ D+ w/ M&E’ and the comparative test scenario with the mitigation measures excluded ‘CAZ D+ w/ E (no M)’ is negligible at the worst-case receptors. This demonstrates that the mitigation measures are not expected to have a significant effect on the FBC CAZ scheme NO_2 concentrations in 2020 or 2022.

The proposed CAZ scheme has a range of exemptions applied to residents and workers impacted by the scheme. The exemptions are in place for two years, and expire at the beginning of 2022. These exemptions have the effect of reducing the number of drivers who have to take action to comply with the scheme in 2020, but it is expected that they would take actions to obtain compliant vehicles through the two-year exemption period in preparation for 2022.

Economic analysis has been undertaken to try to understand the possible effect these necessary exemptions may have on the overall improvements in air quality produced by the CAZ scheme. It should be noted that it is not considered feasible to open a charging CAZ scheme in these timescales without any exemptions in place, and doing so could affect the deliverability and opening date. This test scenario is therefore hypothetical, and the economic analysis which underpins it is also subject to its own uncertainty.

The worst-case receptor, which defines the compliance date is PCM_0 on the A4400 Suffolk St Queensway. The modelling indicates that there is the potential that the exemptions will reduce the effectiveness of the CAZ, but a CAZ D with no exemptions at all would still not be compliant in 2020. The preferred scheme is predicted to achieve full compliance in 2022, and the testing of the exemptions does not conclude that this would be altered. However, there is uncertainty in when the date of compliance would occur as there is not a 2021 model available. Linear interpolation has had to been used as in indicative approach, which indicates the exemptions could be slowing compliance, with the NO_2 concentrations in 2021 approximately 1% greater than with the exemptions in place. However, this interpolation approach is not considered sufficiently robust to be definitive and the influence of the exemptions are relatively minor when compared to the uncertainty described within the model verification and sensitivity testing.