Bath Clean Air Plan

Bath and North East Somerset Council

Sensitivity Testing Technical Note

674726.BR.042.FBC-31 | 3

January 2020

JACOBS

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Project No: 674726.BR.042
Document Title: Sensitivity Testing Technical Note
Document No.: 674726.BR.042.FBC-31
Revision: 3
Date: January 2020
Client Name: Bath and North East Somerset Council
Project Manager: RR
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Document history and status

Revision	Date	Description	By	Review	Approved
1	04.11.19	FBC draft	LK (J) CB (AQC)	CB (J) BM (AQC)	RR
2	13.12.19	Updated FBC Draft	LK (J) CB (AQC)	CB (J) BM (AQC)	RR
3	17.01.2020	Final FBC	LK (J) CB (AQC)	CB (J) BM (AQC)	RR

Contents

Acronyms and Abbreviations

ANPR	Automatic Number Plate Recognition
B&NES	Bath and North East Somerset
BCC	Bristol City Council
CAZ(s)	Clean Air Zone(s)
CAP	Clean Air Plan
CO_2	Carbon Dioxide
Defra	Department for Environment Food & Rural Affairs
DfT	Department for Transport
EFT	Emissions Factors Toolkit
Euro	European
GBATH	Greater Bath Area Transport Model
HGV	Heavy Goods Vehicle
JAQU	Joint Air Quality Unit
LAQM	Local Air Quality Management
LGV	Light Goods Vehicle
HGV	Heavy Goods Vehicle
MSOA(s)	Middle Layer Super Output Area(s)
NRMM	Non-Road Mobile Machinery
NOx	Nitrous Oxides
NO_2	Nitrogen Dioxide
OGV	Other Goods Vehicle
OS	Ordnance Survey
PM	Particulate Matter
PSV	Public Service Vehicle
RSI	Roadside Interview
SP	Stated Preference
ULEV	Ultra Low Emissions Vehicle
(Web)TAG	Transport Analysis Guidance

1. Introduction

Poor air quality is the largest known environmental risk to public health in the UK[1]. Investing in cleaner air and doing more to tackle air pollution are priorities for the EU and UK governments, as well as for Bath and North East Somerset Council (B&NES). B&NES has monitored and endeavoured to address air quality in Bath, and within the wider B&NES area since 2002. Despite this, Bath has ongoing exceedances of the legal limits for Nitrogen Dioxide (NO_2) and these are predicted to continue until 2025 without intervention.

In 2017 the government published a UK Air Quality Plan for Nitrogen Dioxide[2] setting out how compliance with the EU Limit Value for annual mean NO_2 will be reached across the UK in the shortest possible time. Due to forecast air quality exceedances, B&NES, along with 27 other Local Authorities, was directed by Minister Therese Coffey (Defra) and Minister Jesse Norman (DfT) in 2017 to produce a Clean Air Plan (CAP). The Plan must set out how B&NES will achieve sufficient air quality improvements in the shortest possible time. In line with Government guidance B&NES are considering implementation of a Clean Air Zone (CAZ), including both charging and non-charging measures, in order to achieve sufficient improvement in air quality and public health.

Jacobs has been commissioned by B&NES to produce an Outline Business Case (OBC) and Full Business Case (FBC) for the delivery of the CAP; a package of measures which will bring about compliance with the Limit Value for annual mean NO_2 in the shortest time possible in Bath. The OBC assessed the shortlist of options set out in the Strategic Outline Case[3] and proposes a preferred option including details of delivery. The FBC develops the preferred option set out in the Outline Business Case, detailing the commercial, financial and management requirements to implement and operate the scheme. The OBC and FBC form a bid to central government for funding to implement the CAP.

1.1 Purpose of this report

This document is written to support the FBC and provides a summary of sensitivity tests undertaken for the transport and air quality analysis. This has been performed according to the guidance provided by JAQU in their 'supplementary note on sensitivity testing' issued in July 2018.

The sensitivity tests relate their findings to the final model results from the CAZ C plus TM Revised Boundary scenario in 2021. This is referred to throughout this document as the 'core' or 'central' scenario.

Detailed reports on the development of the air quality and traffic core/central scenario can be found in Appendices D and E of the FBC respectively. Some tests have additionally related their findings to the 'baseline' scenario, which is a forecasted 2021 model without the CAP. A list of all sensitivity tests undertaken in this report is provided in Table 1-1.

[1] Public Health England (2014) Estimating local mortality burdens associated with particular air pollution. https://www.gov.uk/government/publications/estimating-local-mortality-burdens-associated-with-particulate-air-pollution
[2] https://www.gov.uk/government/publications/air-quality-plan-for-nitrogen-dioxide-no2-in-uk-2017
[3] Bath and North East Somerset Council Clean Air Plan: Strategic Outline Case, March 2018 (http://www.bathnes.gov.uk/sites/default/files/siteimages/Environment/Pollution/strategic_outline_case_bath_28.03.2018_with_annexes.pdf)

Table 1-1: List of Sensitivity Tests Performed for Transport and Air Quality

Traffic Modelling (Section 2)	Air Quality Modelling (Section 3)
• Uncertainties in the Transport Model at the National Level • Fleet splits by fuel type: ANPR vs. WebTAG • Fleet splits by European emissions standards: EFT option 1 vs option 2 • Fleet splits by Euro Standards: high and low fleet renewal • Behavioural response to charging	• Differential bias • Euro 6 vehicles • LGV Emissions • Lower Uptake of Compliant LGVs • Inappropriate Emissions Groupings • Engine Size and Vehicle Weight • Average speed emissions factors • Emissions at low speeds • Background concentrations • Model verification • Receptor locations • Road widths and geometries • Gradients • Meteorological Data • Meteorological Parameters • Primary NO_2 Fraction • Regional Ozone • Non-Road Sources • Lower Uptake of Compliant LGVs (FBC)

In addition to these sensitivity tests, analysis was performed in section 4 to examine the effects of a second CAZ that may be implemented nearby in Bristol.

A summary of all sensitivity tests and key findings in this report is provided in section 5.

2. Traffic Modelling

2.1 Overview

In estimating the effects of the CAZ, the air quality predictions are dependent upon the traffic data used in the modelling. This data is a combination of national predictions, JAQU guidance, consultations with B&NES, and local studies. The data sources used in the traffic modelling have been selected to give the best possible representation of the effects of the CAZ. Like all predictions, this methodology has several uncertainties associated with it. A detailed account of the forecasting methodology and core scenario assumptions can be found in FBC-17 T4 Transport Model Forecasting Report in appendix E of the FBC. In this section, a series of sensitivity tests have been developed based on known uncertainties in these assumptions. Section 2-2 analyses uncertainties at the national level by developing alternative growth scenarios based on ''high' and 'low' forecasts. Section 2.3 considers uncertainties in the current and projected fleet composition with regards to fuel type and euro emissions standards. Section 2.4 considers uncertainties in the predicted behavioural response to charging by developing and analysing the most likely 'pessimistic' and 'optimistic' alternative scenarios. 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.

2.2 Uncertainties in the Transport Model at the National Level

Some of the uncertainties in the Core Scenario are inherent uncertainties associated with all traffic forecasting. According to the DfT, some of these are caused by uncertainties in national trends such as GDP, fuel price, and vehicle efficiency.[4] To account for these uncertainties, the DfT's Web-based Transport Analysis Guidance (WebTAG) provides a methodology based on defining high-growth and low-growth scenarios. These scenarios are developed by taking a proportion of the 2017 base-year model demand and adding or subtracting it from the 2021 core scenario demand. This proportion is based on a parameter 'p' which, for highway demand, is equal to 2.5% to "reflect uncertainty around the annual forecasts from the National Transport Model (NTM), based on the macro-economic variables that influence the main drivers of travel demand[5]." In accordance with the WebTAG guidance, this 2.5% was multiplied by the square root of the number of years between the base year and core scenario to come a final proportion of 5%. This proportion was then applied to the core scenario using a matrix-based procedure, as follows:

1) The total of interzonal flows were extracted from the base year and core scenario matrices for the AM Peak, Interpeak, and PM Peak hours. Intrazonal totals were ignored as they do not contribute to traffic flow on links in the model.
2) The AM, PM, and Interpeak totals were combined into a daily total traffic flows using the following formula:

$$Daily\ Total = 3 * (average\ AM\ peak\ hour) + 3 * (average\ PM\ peak\ hour) + 6 * (average\ Interpeak\ hour) + 12 * (average\ Off\ peak\ hour)$$

The off-peak hour was assumed to be equal to 20% of the average interpeak hour flow.

3) High-growth and low-growth totals were developed according to the WebTAG guidance by taking 5% of the 2017 base year total and adding or subtracting it from the core scenario total.
4) The percent change between the core scenario and the high and low growth models were found to be **+4.68%** and **-4.68%**, respectively. This is equivalent to the following:

$$\pm 4.68\% = \pm 5\% \times \left(\frac{2017\ Model\ Total}{2021\ Model\ Total}\right)$$

[4] TAG Unit M4: Forcasting and Uncertainty §4.1.3. Department for Transport, May 2018
[5] TAG Unit M4: Forcasting and Uncertainty §4.2.3. Department for Transport, May 2018

Therefore, factors of +4.68% and -4.68% were applied to the core scenario AADT traffic flows to develop the high and low alternative scenarios. These were then analysed to determine their emissions and subsequently NO_2 concentrations according to the air quality model. High and low scenarios were tested for both the core scenario model and the baseline model. In line with the guidance in JAQU's 'supplementary note on sensitivity testing', the results from each scenario are presented in the following tables: Table 2-1 provides a summary of air quality statistics in terms of micrograms per cubic meter, Figure 2-1 shows the distribution of NO_2 concentrations and Table 2-2 presents the compliance status for each scenario.

For the 2021 baseline, there are numerous non-compliant receptors in the 'Low', 'Central' and 'High' scenarios. The 2021 CAZ C + TM scenario is compliant in all scenarios.

Table 2-1: Simple Summary Statistics (μg/m^3)

Statistic	2021 Baseline			2021 CAZ C + TM		
	Low	Central	High	Low	Central	High
Mean	24	24	25	20	20	20
Median	23	23	24	19	19	20
Maximum	60	62	64	39	40	40
Minimum	11	11	11	10	10	10
Upper Quartile	29	30	30	23	24	24
Lower Quartile	17	17	18	15	16	16
Standard Deviation	8	8	9	5	5	6
Range	50	51	53	29	30	30

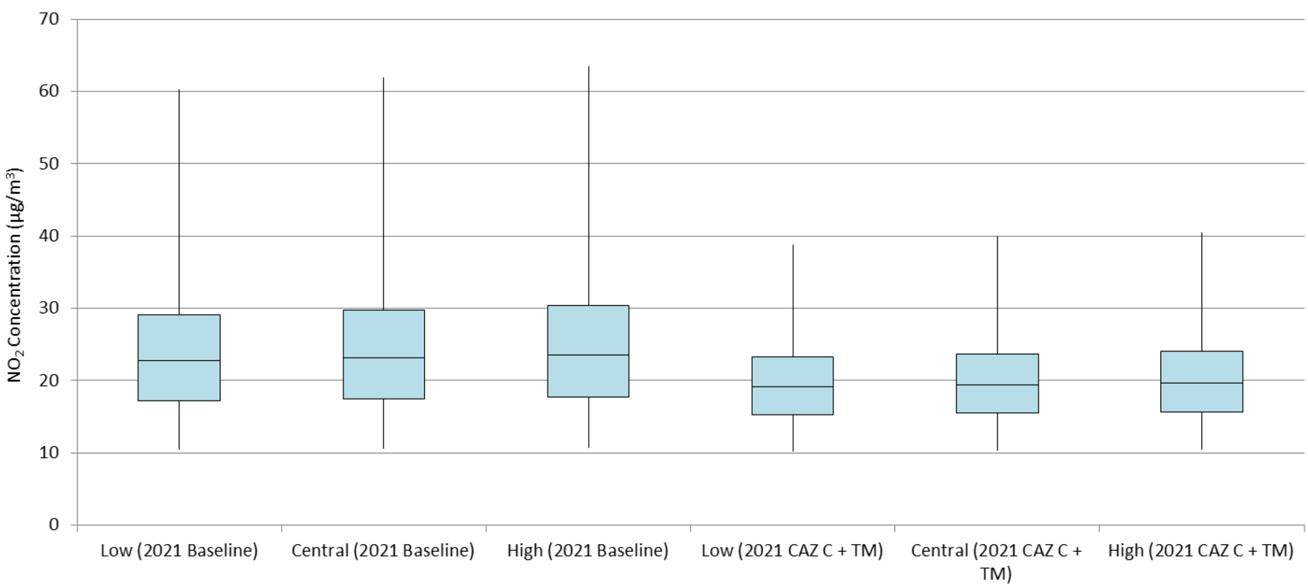

Figure 2-1: Distribution of NO_2 Concentrations

Table 2-2: Summary of Compliance Status

Statistic	2021 Baseline			2021 CAZ C + TM		
	Low	Central	High	Low	Central	High
No. of Non-Compliance LAQM Receptors	28	33	43	0	0	0
No. of Non-Compliance PCM Receptors	477	575	661	0	0	0
Compliance Status of Road Link with Highest NO_2 Value	Non-Compliant	Non-Compliant	Non-Compliant	Compliant	Compliant	Compliant
Maximum NO_2 Percentage Gap from Compliance	32.7	34.6	36.2	-4.3	-1.5	-0.2
Maximum Road-NO_2 Percentage Gap from Compliance	41.7	43.7	45.5	-6.5	-2.2	-0.3

2.3 Fleet Composition

A vehicle's emissions depend on a variety of factors, such as its age and the type of fuel it consumes. Therefore, to accurately model the NO_2 pollution in Bath, information was required regarding the composition of vehicles that enter Bath City Centre. To accomplish this, a 2-week survey was performed using Automatic Number Plate Recognition (ANPR) cameras placed at key locations around and within the city centre. The captured number-plates were cross-referenced with data purchased from Carweb to gain information on the corresponding vehicle types, fuel types, and euro emissions standards. Details of the ANPR study can be found in FBC-14 ANPR Data Analysis and Application in Appendix E of the FBC. This ANPR data was used to estimate the fleet composition for the base year. For the 2021 Core Scenario, the fleet composition was projected into the future using tools provided by the DfT and Defra. However, this methodology has several uncertainties associated with it. For example, number-plates are occasionally missed or misread using ANPR technology. Additionally, there is more than one method for predicting future fleet compositions. The following sensitivity tests examine several possible alternatives for estimating the core scenario fleet composition and evaluate how these alternatives would cause emissions and NO_2 concentrations to differ from the core scenario.

2.3.1 Splits by Fuel Type: Comparison of ANPR and WebTAG

A vehicle's emissions depend on the type of fuel it consumes. Petrol vehicles emit carbon dioxide (CO_2) and some nitrous oxides (NOx), while diesel vehicles emit significantly less CO_2 but significantly more NOx than petrol. In the air quality model, a diesel vehicle will cause higher NO_2 concentrations than its petrol equivalent. Therefore, the air quality model required the proportion of each vehicle type that was petrol, diesel, or electric. These splits can be obtained at a national level using the DfT's WebTAG Databook[6]. However, both the base year (2017) and core scenario (2021) models utilized ANPR data as is it assumed to provide a better representation of the vehicles that enter Bath City Centre. This sensitivity test will compare the air quality results from the core scenario to alternative results based on taking fuel splits directly from the WebTAG Databook.

A comparison of the base year compliance splits from each source is given in Figure 2-2.

In addition to providing current fuel type splits, the WebTAG Databook also predicts future fuel type splits based on UK government projections and policies. To develop the core scenario fuel type splits, the base year ANPR

[6] WebTAG Databook March 2017 Release 1.7, Department for Transport

splits were projected into 2021 using the WebTAG projections as a guide. This was accomplished using the following procedure:

1) For each vehicle class and fuel type, the percent change between 2017 and 2021 was calculated based on the WebTAG data. This was then applied to the 2017 ANPR data.
2) For each vehicle class, the projected ANPR splits were normalised so that the fuel types added up to 100%.

A comparison between the 2021 WebTAG splits and the projected splits based on ANPR data is provided in Figure 2-3.

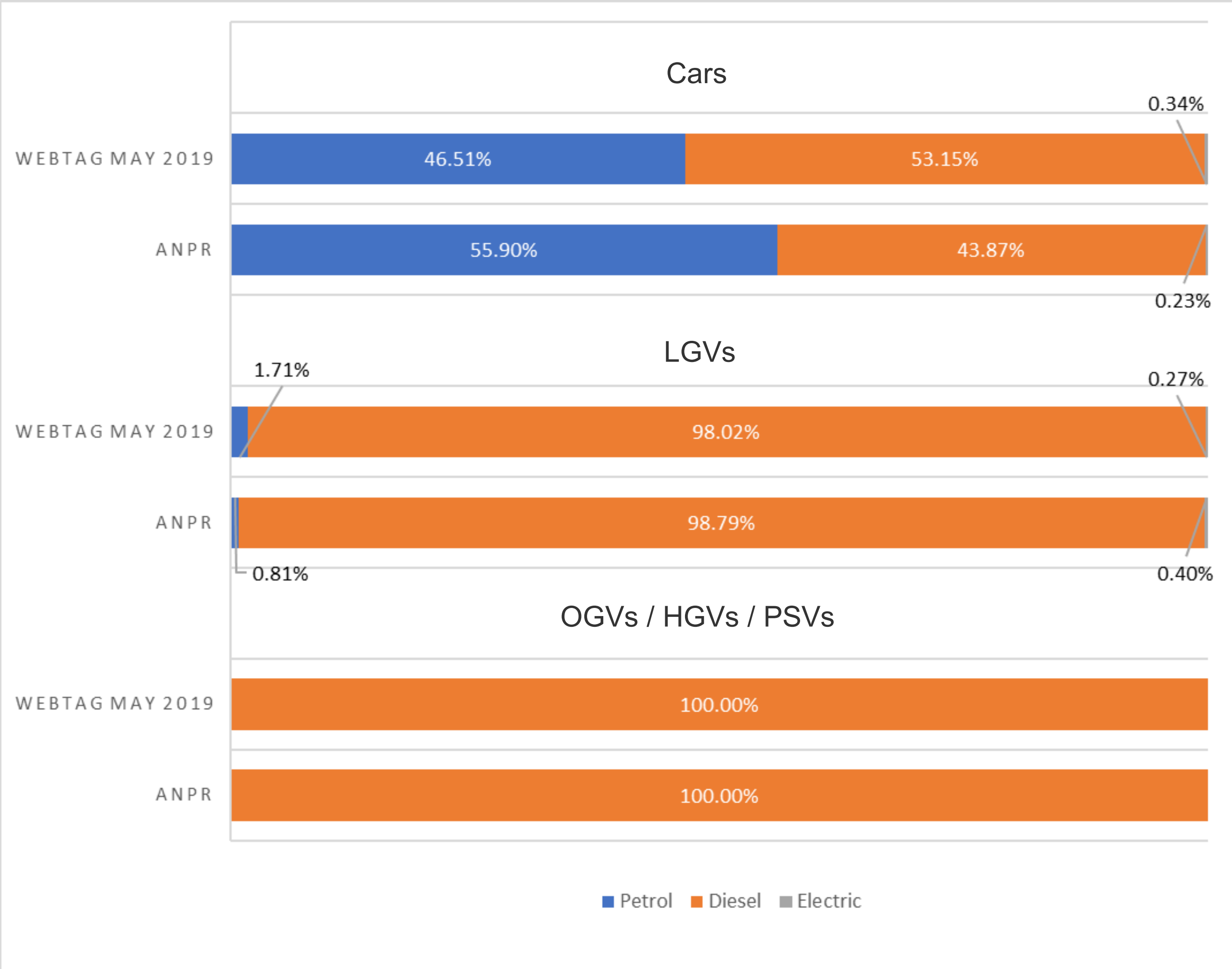

Figure 2-2: Comparison of 2017 fuel type splits from the WebTAG Databook and the Bath ANPR study (veh-km)

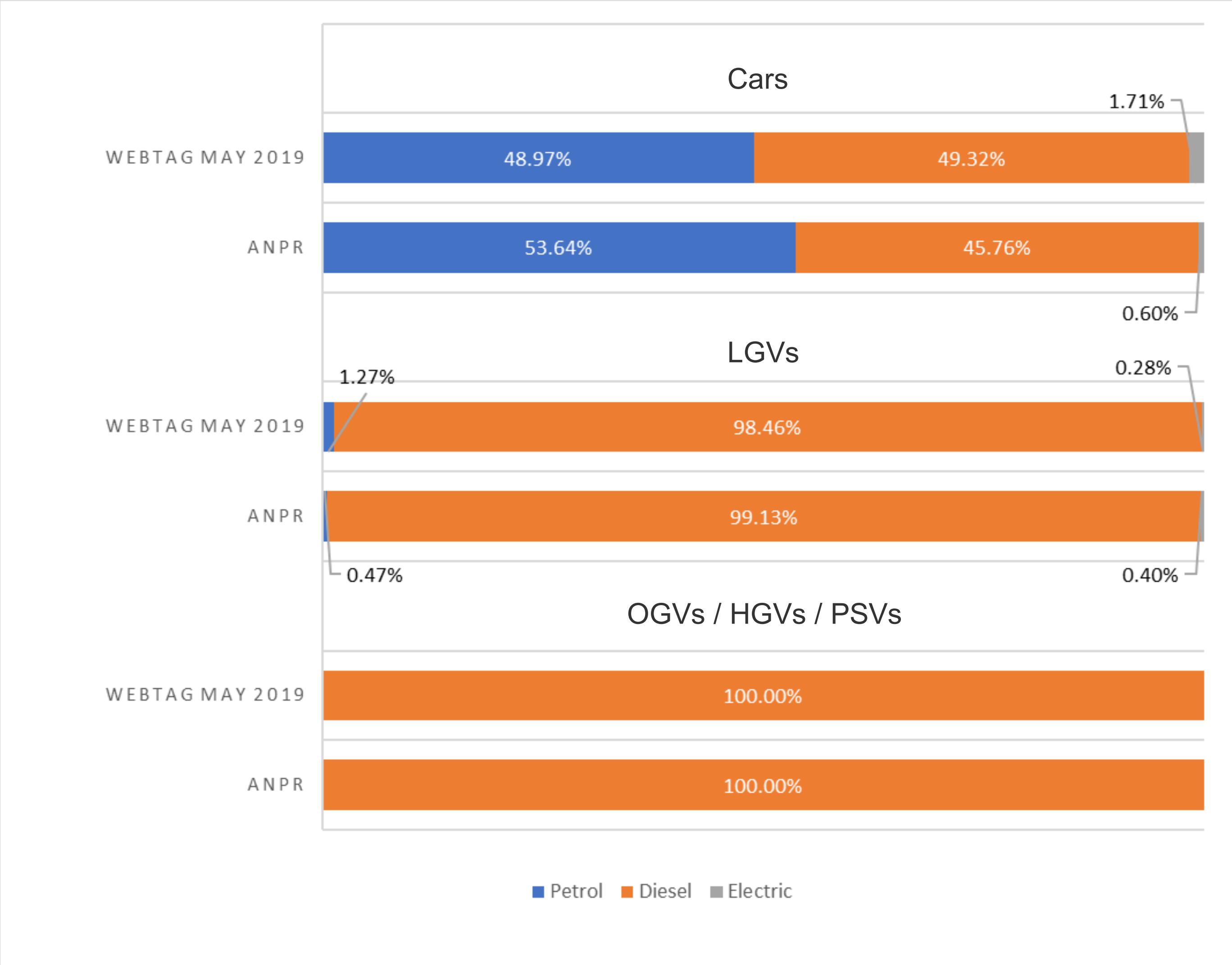

Figure 2-3: Comparison of 2021 fuel type splits from the WebTAG Databook and the projection based on ANPR data (veh-km)

Table 2-3 provides a summary of statistics (as requested in JAQU's 'Supplementary Note on Sensitivity Testing') and Table 2-4 presents the compliance status for this sensitivity test as well as the 'Central' (core scenario) modelling. Figure 4-4 shows the distribution of the resulting NO_2 concentrations. If the WebTAG fuel splits are used then the 2021 CAZ C + TM scheme would be non-compliant at one LAQM receptor and no PCM receptors; with a maximum exceedance of 0.2 µg/m^3. The 'Central' modelling is, however, considered to be more realistic, since it is based on ANPR surveys of traffic using multiple roads in Bath, and is therefore calibrated to local traffic, rather than national traffic.

Table 2-3: Simple Summary Statistics for Compliance Splits by Fuel Type (µg/m³)

Statistic	2021 CAZ C + TM	
	Central	WebTAG Fuel Splits
Mean	20	20
Median	19	20
Maximum	40	41
Minimum	10	10
Upper Quartile	24	24
Lower Quartile	16	16
Standard Deviation	5	6
Range	30	30

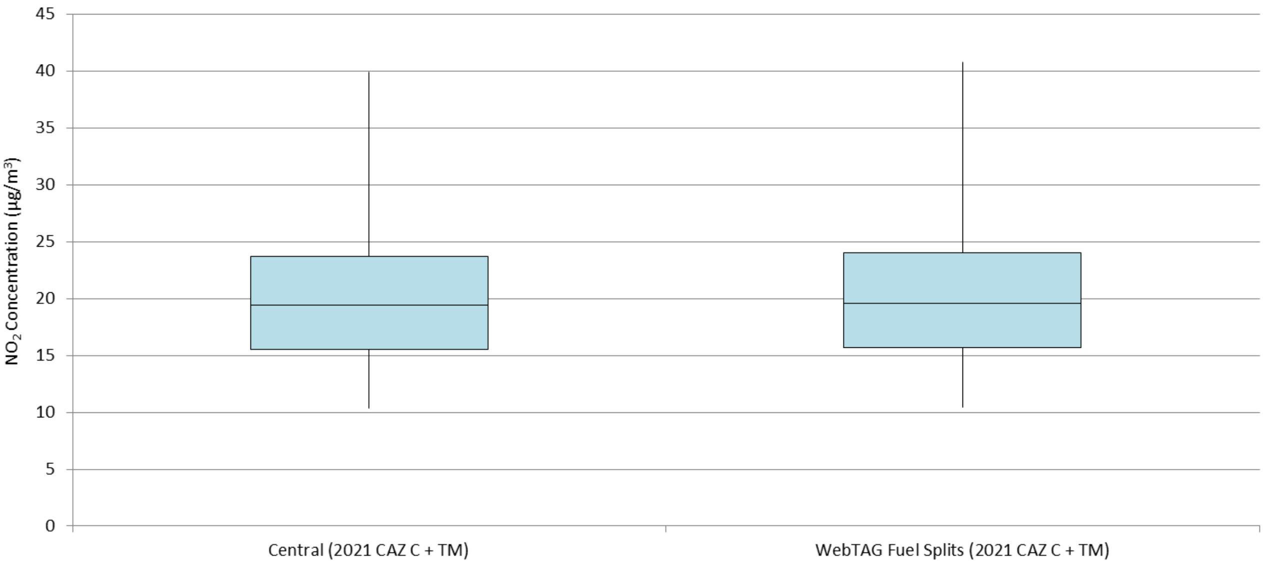

Figure 2-4: Distribution of NO_2 Concentrations for Compliance Splits by Fuel Type

Table 2-4: Summary of Compliance Status for Compliance Splits by Fuel Type

Statistic	2021 CAZ C + TM	
	Central	WebTAG Fuel Splits
No. of Non-Compliance LAQM Receptors	0	1
No. of Non-Compliance PCM Receptors	0	0
Compliance Status of Road Link with Highest NO_2 Value	Compliant	Non-Compliant
Maximum NO_2 Percentage Gap from Compliance	-1.5	0.6
Maximum Road-NO_2 Percentage Gap from Compliance	-2.2	0.8

2.3.2 Splits by Euro Emissions Standards: Comparison of EFT Option 1 and Option 2

Age is a critical factor in determining a vehicle's emissions. The European Union has been imposing standards on vehicle emissions since 1992, and their regulations have become stricter over time. A vehicle's compliance within the CAZ framework is ultimately determined by its European (euro) emissions standard: a petrol vehicle is compliant if it meets at least Euro 4 standards, and a diesel vehicle is compliant if it meets at least Euro 6 standards. Therefore, both the CAZ traffic and air quality models required data about how the fleet is split by Euro emissions standards. The ANPR study determined the base year splits, and these were projected into the future with a fleet projection tool in Defra's Emissions Factors Toolkit (EFT). The tool provided two projection options:

- *Option 1* assumes that the difference in Euro classes in the future year is the same as in the base year
- *Option 2* assumes that the difference in Euro classes will converge towards the default assumptions at a particular year, called the "convergence year"

The base year fleet composition was input into the EFT fleet projection tool and projected using both option 1 and option 2 assuming a convergence year of 2021. Option 1 was ultimately chosen for the core scenario traffic model as it gives a more conservative estimate of future compliance ratios and relies more heavily on local fleet data which is representative of Bath. However, it is useful to understand the difference between the two options, so both were analysed to determine future non-compliance ratios for each vehicle class. These results from this analysis is provided in Figures 2-5 and 2-6.

As evident in the figures, non-compliance ratios are higher in option 1 for all vehicle classes and years. Option 2 produced some results that were deemed unrealistic, such as negative projections which led to negative non-compliance ratios for some vehicle classes and years. Because of these irregularities, the results from option 2 were ultimately not considered in the modelling, and only the results from option 1 were used. Option 1 is also a more conservative projection, as its higher non-compliance ratios mean higher NO_2 emissions in the model. In the air quality model, there is no possibility that a scenario tested using option 2 would be non-compliant if the scenario was compliant using option 1. Therefore, no additional sensitivity testing was performed for option 2.

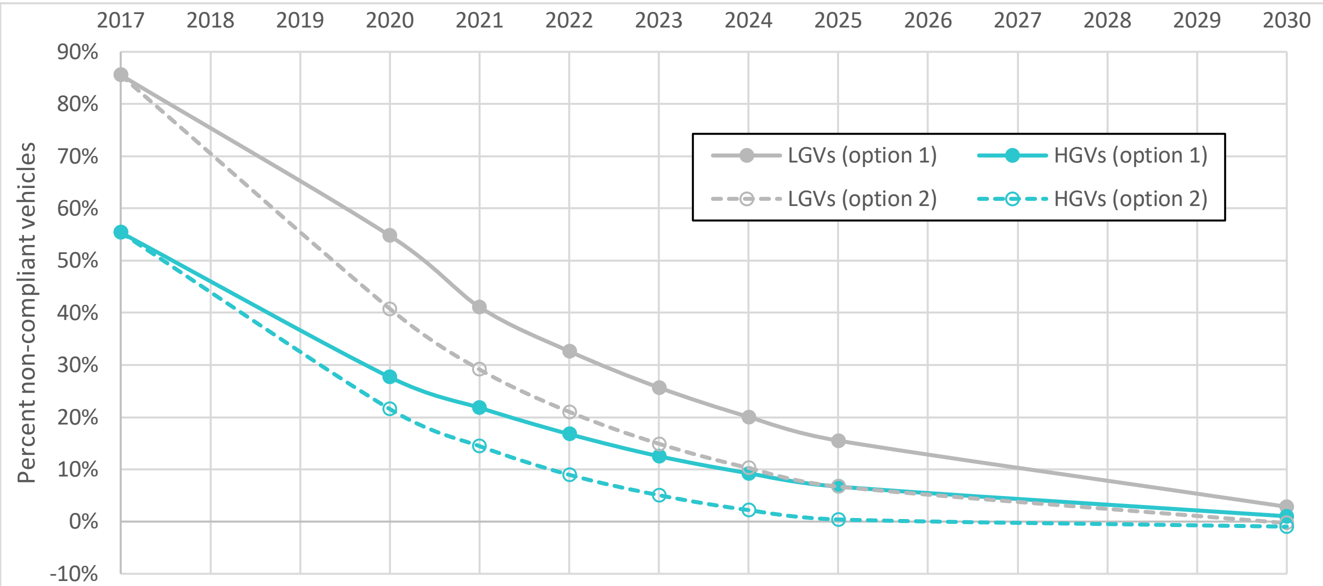

Figure 2-5: Comparison between EFT Option 1 and Option 2 for LGVs and HGVs

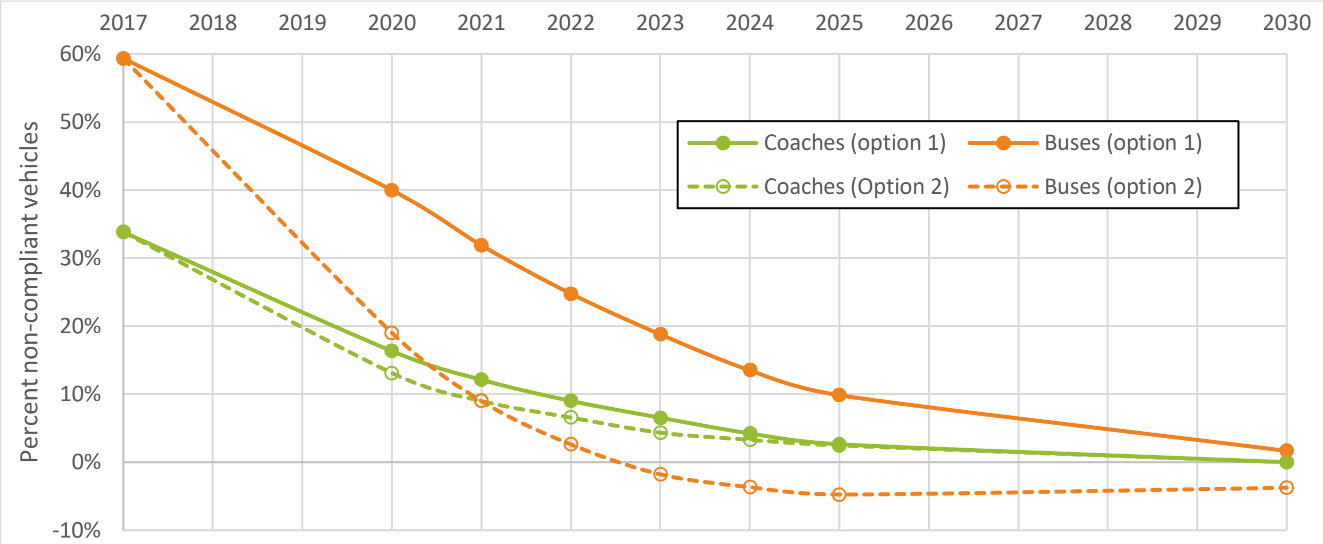

Figure 2-6: Comparison between EFT Option 1 and Option 2 for Coaches and Buses

2.3.3 Splits by Euro Emissions Standards: High and Low Fleet Renewal

The fleet composition in the future is unknown. Key uncertainties relate to the rate of uptake of alternative-fueled (e.g. electric) vehicles, the rate of uptake of new (lower-emission) conventionally-fueled vehicles, and fuel choice (petrol or diesel) of new vehicles. Of interest to emissions inventories is the distance-weighted vehicle fleet. This takes account of the fact that different vehicles travel different distances, e.g. new cars tend to travel greater distances in a year than old cars, and it is not, therefore, appropriate to base inventories solely on vehicle registrations. The EFT includes a fleet projection tool to predict fleet composition in future years and its use has been recommended by JAQU. This tool is considered to currently provide the best available approach for fleet projections and has thus been used in the assessment. It is, however, uncertain. In particular:

- New diesel car sales are currently falling, but the recent rate of reduction in sales is not reflected in the EFT distance-weighted projections. It seems quite likely that the proportion of diesel vehicles in the future fleet may have been over-estimated, which will mean that emissions in the future, both without and with the CAZ, will have been over-predicted (and that the effect of the CAZ may also have been over-predicted).
- While the number of electric vehicles sold in the UK is small (2% of new car sales, the majority of which are plug-in hybrids), the proportion of such vehicles is growing; with this growth being encouraged by national-level policies. Despite this, the EFT assumes a relatively slow uptake of such vehicles. There is thus a risk that the proportion of fully-electric vehicles in the future fleet may have been under-estimated, which will mean that NOx emissions in the future, both without and with the CAZ, will have been over-predicted (and that the effect of the CAZ on NOx emissions may also have been over-predicted).
- While there is no intended correlation between the EFT subcategories for different types of Euro 6 vehicle (a, b, and c) and the different phases of the Euro 6 type-approval standard, the number of Euro 6b diesel cars assumed in the EFT in recent years has been significantly greater than the number of Euro 6d-temp vehicles on UK roads. There is a concern that the rate of uptake of newer Euro 6 diesel vehicles may have been over-predicted by the EFT. This would mean that NOx emissions in the future, both without and with the CAZ, will have been under-predicted.

While it is not possible to take explicit account of these points, JAQU's guidance has been followed to allow a general sensitivity test of the effect of overall fleet renewal in Bath being quicker or slower than predicted. The model has been run for two additional scenarios. The 'High' scenario assumes that the vehicle fleet in 2021 will be that for 2020 and thus assumes more older vehicles will be on the road. The 'Low' scenario assumes that the fleet in 2021 will be that for 2022 and thus assumes fewer older vehicles on the road. These fleet projections, as well as that for the central (2021) scenario, are shown in Figure 2-7. This figure illustrates that the main difference is how many vehicles are projected to be Euro 6/VI, with more in 2022 than 2020.

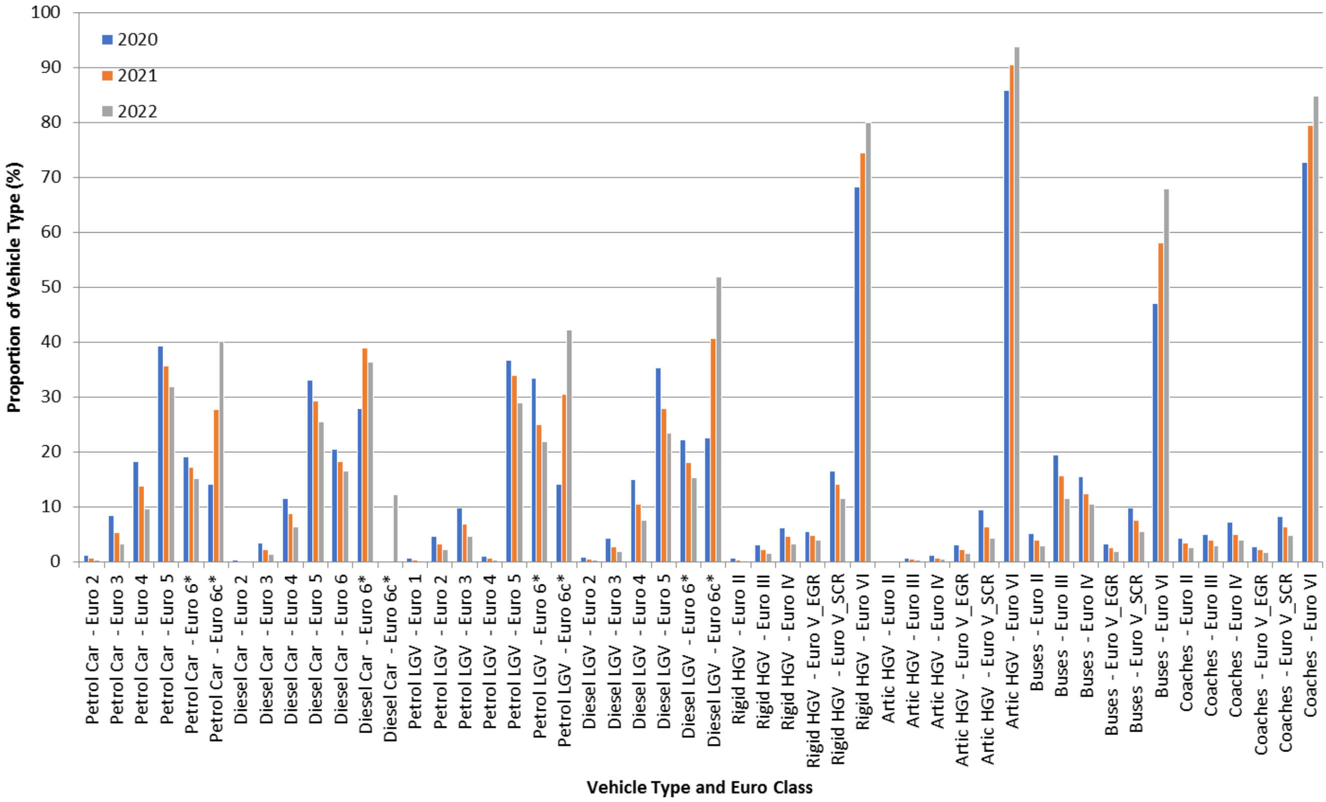

Figure 2-7: Projected Fleet Composition in 2020, 2021 and 2022, as Proportions of each Vehicle Type, for each Vehicle Type and Euro Class

Table 2-5 and Figure 2-8 provide a summary of and Table 2-6 presents the compliance status for each of the scenarios as well as the 'Central' modelling. If the vehicle fleet in Bath renews at a slightly slower rate than anticipated then the 2021 CAZ C + TM scheme will be non-compliant, with the maximum concentration exceeding the limit value by 0.2 µg/m^3 (0.5% gap from compliance) at only one LAQM receptor and no PCM receptors. Alternatively, if the fleet renews slightly quicker, then the scheme will be compliant with a percentage gap from compliance of -4.7%. Compliance will not be achieved without the CAZ in any scenario. Given the scheme is only marginally non-compliant with a slower fleet renewal, at one LAQM receptor, on balance it is considered likely the scheme will be compliant. The fleet projection used in the assessment follows JAQU's recommended approach.

Table 2-5: Simple Summary Statistics for Sensitivity Testing of Fleet Projections (µg/m^3)

Statistic	2021 Baseline			2021 CAZ C + TM		
	Low	Central	High	Low	Central	High
Mean	24	24	25	20	20	20
Median	23	23	23	19	19	20
Maximum	61	62	62	39	40	41
Minimum	11	11	11	10	10	10
Upper Quartile	29	30	30	23	24	24
Lower Quartile	17	17	18	15	16	16
Standard Deviation	8	8	8	5	5	6
Range	51	51	52	28	30	30

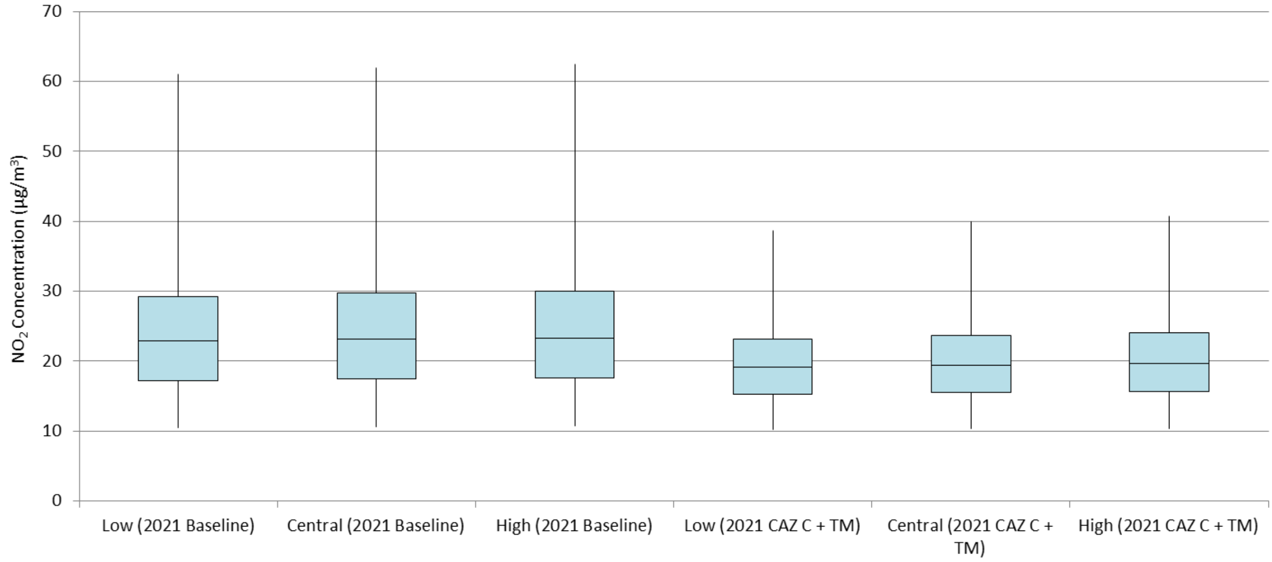

Figure 2-8: Distribution of NO_2 Concentrations for Fleet Projections

Table 2-6: Summary of Compliance Status for Sensitivity Testing of Fleet Projections

Statistic	2021 Baseline			2021 CAZ C + TM		
	Low	Central	High	Low	Central	High
No. of Non-Compliance LAQM Receptors	30	33	35	0	0	1
No. of Non-Compliance PCM Receptors	503	575	616	0	0	0
Compliance Status of Road Link with Highest NO_2 Value	Non-Compliant	Non-Compliant	Non-Compliant	Compliant	Compliant	Non-Compliant
Maximum NO_2 Percentage Gap from Compliance	33.7	34.6	35.1	-4.7	-1.5	0.5
Maximum Road-NO_2 Percentage Gap from Compliance	42.7	43.7	44.3	-7.3	-2.2	0.7

2.4 Behavioural Response to Charging

2.4.1 Overview and Core Scenario

The success of the clean air zone depends entirely on how it influences the behaviour of drivers in the region. Most LGV or HGV drivers are expected to respond to charging by either avoiding the city centre, changing their travel mode, or changing to a compliant vehicle, all of which will help to improve NO_2 pollution in Bath. However, some drivers will decide to pay the CAZ charge instead of changing their behaviour.

For the core scenario, the behavioural response to charging was predicted using a variety of sources. For LGVs, a stated preference (SP) survey was conducted on drivers in Bath and the surrounding areas to determine how they would respond, and how likely they would be to upgrade their vehicle based on various CAZ charges and upgrade costs. The final response rates were based on statistical models from the SP survey and predicted costs for upgrading to a compliant vehicle. A full report of the SP survey and statistical modelling is provided in FBC-30 Stated Preference Surveys Report in Appendix L of the FBC. For HGVs, operators were assumed to upgrade their vehicle if the cost to upgrade is less than the cost of paying the charge over a 5-year period. However, due to the simplicity of this calculation, HGV response rates were adjusted for error based on the SP survey data for LGVs. Response rates for Taxi's were calculated based on B&NES post-CAZ licensing agreements with taxi operators. Response rates for buses were determined through discussions between

B&NES and bus operators, which determined that half the bus fleet would be fully replaced by 2021 and the remaining buses would be retrofitted with financial assistance from this project. The response rates for coaches were taken directly from the JAQU evidence package, with a small adjustment made for school coaches that may receive a concession.

The final core scenario response rates are provided in Table 2-7 below. A detailed report on the methodology for calculating these response rates is available in FBC-16 Primary Behavioural Response Calculation Methodology in Appendix E of the FBC.

Table 2-7: Core Scenario Primary Behavioural Response Rates

Response	Cars	Taxis	LGVs	HGVs	Buses	Coaches
Pay Charge	N/A	4.1%	18.4%	13.8%	0.0%	20.1%
Avoid Zone	N/A	0.0%	11.7%	4.4%	0.0%	0.0%
Cancel Journey / Change Mode	N/A	0.0%	3.6%	1.4%	6.4%	11.5%
Replace Vehicle	N/A	95.9%	66.3%	80.4%	93.6%	68.4%

2.4.2 Development of Pessimistic and Optimistic Scenarios

To account for uncertainties in the core scenario response rates, alternative scenarios were developed assuming worst-case (pessimistic) and best-case (optimistic) conditions. The pessimistic scenario accounts for the most-likely uncertainties that would cause more drivers to pay the CAZ charge than in the core scenario. In this case, there would be a smaller behavioural response to charging and therefore a smaller improvement to the NO_2 pollution in Bath city centre. To develop a pessimistic scenario, the parameters of the SP survey statistical models were adjusted to the top or bottom end of their 95% confidence intervals so that more drivers would pay the CAZ charge instead of changing their behaviour. This adjustment affected the response rates for LGVs, and HGVs. For buses, the pessimistic scenario assumed that no retrofitting would take place and no bus routes would be cancelled. For coaches, the pessimistic scenario assumed that the proportion that pays the charge (excluding school coaches) increases by 10% and the other responses decrease proportionally. No pessimistic scenario was developed for Taxis. The pessimistic response rates and percent changes from core scenario are given in Table 2-8.

Table 2-8: Pessimistic Scenario Primary Response Rates and Percent Changes from Core Scenario

Response	Cars	Taxis	LGVs	HGVs	Buses	Coaches
Pay Charge	N/A	4.1% (same)	35.6% (+93.6%)	25.3% (+82.6%)	44.4% (+ n/a)*	29.7% (+47.8%)
Avoid Zone	N/A	0.0% (same)	8.8% (-25.1%)	4.4% (-0.4%)	0.0% (same)	0.0% (same)
Cancel Journey / Change Mode	N/A	0.0% (same)	2.5% (-30.4%)	1.2% (-13.2%)	0.0% (-100.0%)	10.1% (-12.4%)
Replace Vehicle	N/A	95.9% (same)	53.1% (-19.9%)	69.1% (-14.0%)	55.6% (-40.6%)	60.2% (-12.0%)

** This value was 0.0% in core scenario, so a percent change cannot be calculated.*

The optimistic scenario accounts for the most-likely uncertainties that would lead to a higher behavioural response to CAZ charging. In this case, less drivers would pay the CAZ charge and the NO_2 pollution in the city centre would improve beyond what was predicted in the core scenario. To develop an optimistic scenario, the parameters of the SP survey statistical models were adjusted based on 95% confidence intervals using the same method as for the pessimistic scenario, this time so that less drivers would pay the CAZ charge. For taxis, the optimistic scenario assumed that 100% of drivers would replace their vehicle. For coaches, the optimistic scenario assumed that the proportion that pays the charge (excluding school coaches) decreases by 10% and the other responses increase proportionally. No optimistic scenario was developed for Buses. The optimistic response rates and percent changes from core scenario are given in Table 2-9.

Table 2-9: Optimistic Scenario Primary Response Rates and Percent Changes from Core Scenario

Response	Cars	Taxis	LGVs	HGVs	Buses	Coaches
Pay Charge	N/A	0.0% (-100%)	6.3% (-65.6%)	3.8% (-72.6%)	0.0% (same)	10.5% (-47.8%)
Avoid Zone	N/A	0.0% (same)	9.2% (-21.4%)	4.3% (-2.7%)	0.0% (same)	0.0% (same)
Cancel Journey / Change Mode	N/A	0.0% (same)	4.7% (+31.8%)	0.8% (-43.7%)	6.4% (same)	12.9% (+12.4%)
Replace Vehicle	N/A	100.0% (+4.2%)	79.7% (+20.2%)	91.1% (+13.4%)	93.6% (same)	76.6% (+12.0%)

Figure 2-9 gives a comparison of the pessimistic, optimistic, and core scenarios for each vehicle type.

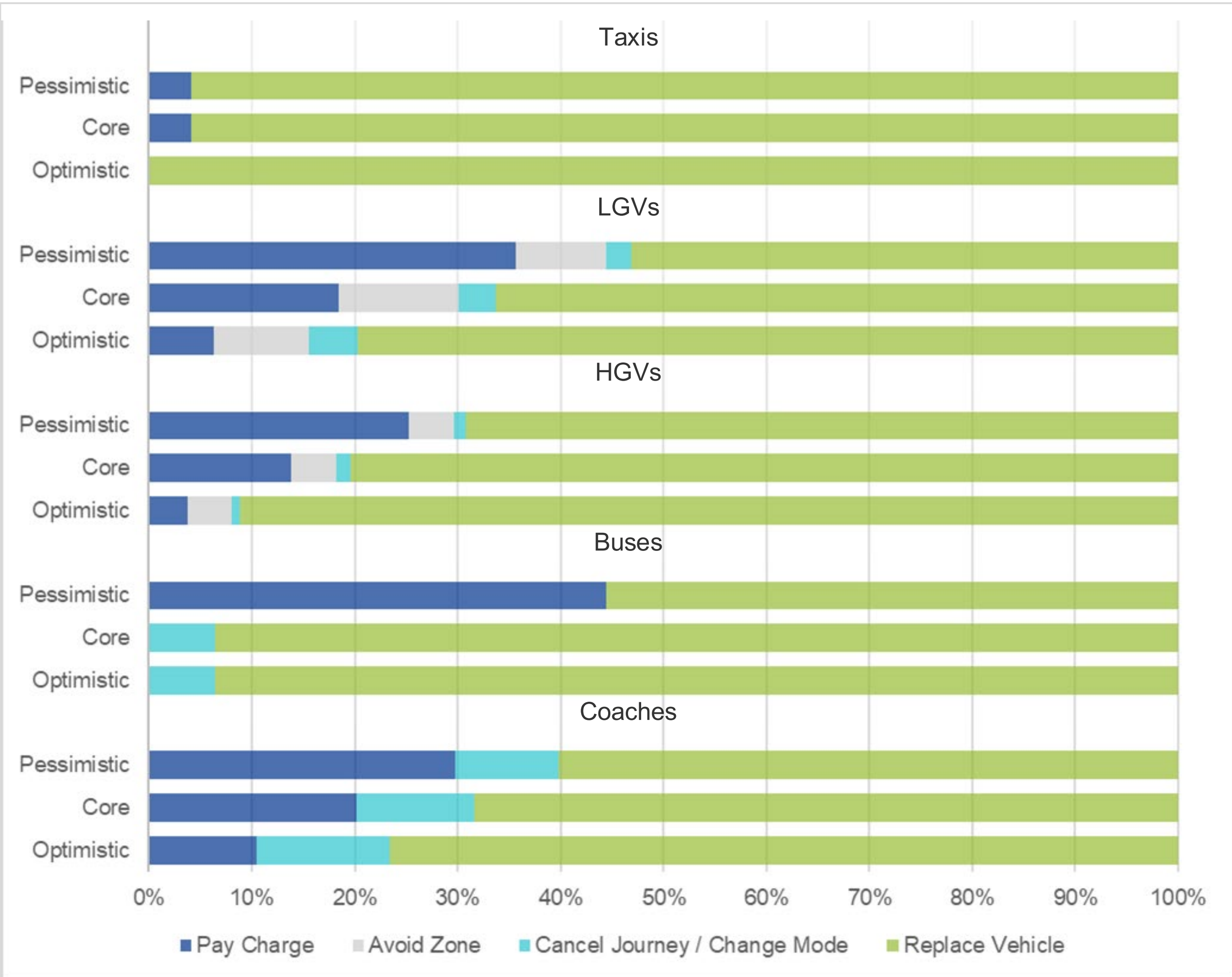

Figure 2-9: Comparison of Pessimistic, Optimistic, and Core Scenario Response Rates

2.4.3 Results from Air Quality Testing

Table 2-10 provides a summary of statistics and Table 2-11 presents the compliance status for each of these scenarios as well as the ‘Central’ model results. Figure 2-10 shows the distribution of the resulting NO_2 concentrations. The 2021 CAZ C + TM scenario is compliant in both the ‘Low’ (Optimistic) and ‘Central’ (Core) scenarios, but non-compliant at one LAQM receptor locations in the ‘High’ (Pessimistic) scenario, with a percentage gap of up to 1% (0.4 $\mu g/m^3$). The ‘Low’ scenario is compliant by at least 3.4%; overall, the ‘Central’ scenario is considered to be most representative and the conclusion of compliance is thus considered appropriate.

Table 2-10: Simple Summary Statistics for Response Rates (µg/m³)

Statistic	2021 CAZ C + TM		
	Low	Central	High
Mean	20	20	20
Median	19	19	20
Maximum	39	40	41
Minimum	10	10	10
Upper Quartile	23	24	24
Lower Quartile	15	16	16
Standard Deviation	5	5	6
Range	29	30	31

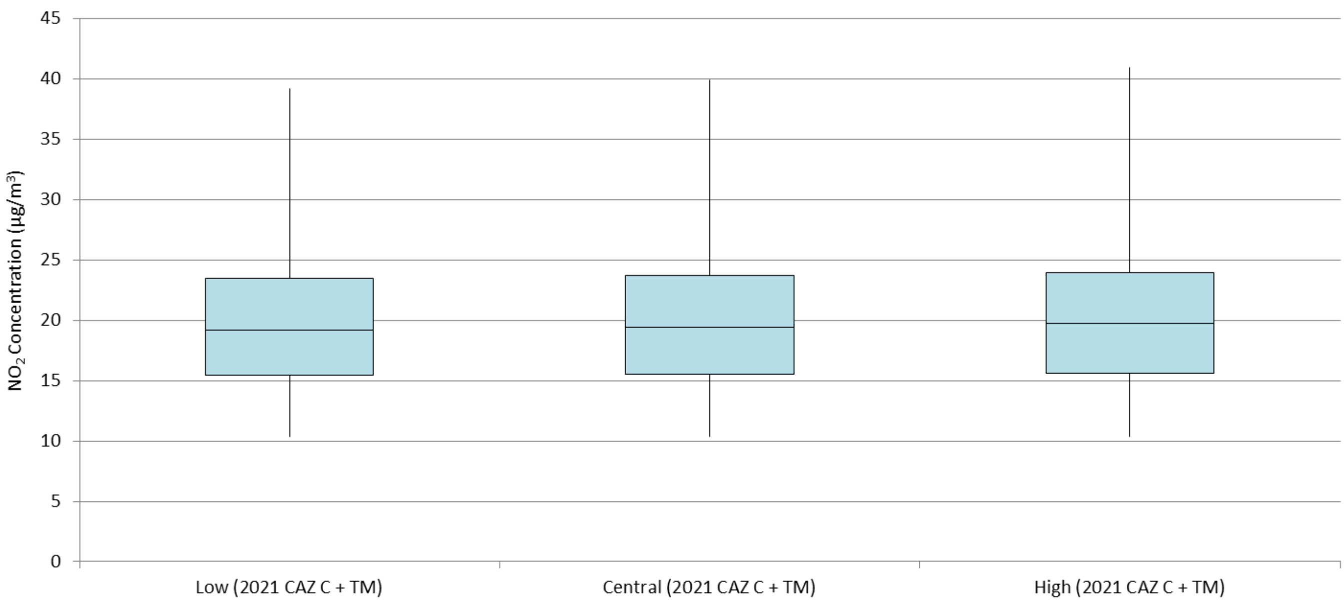

Figure 2-10: Distribution of NO_2 Concentrations for Response Rates

Table 2-11: Summary of Compliance Status for Response Rates

Statistic	2021 CAZ C + TM		
	Low	Central	High
No. of Non-Compliance LAQM Receptors	0	0	1
No. of Non-Compliance PCM Receptors	0	0	0
Compliance Status of Road Link with Highest NO_2 Value	Compliant	Compliant	Non-Compliant
Maximum NO_2 Percentage Gap from Compliance	-3.4	-1.5	1.0
Maximum Road-NO_2 Percentage Gap from Compliance	-5.1	-2.2	1.5

3. Air Quality Modelling

There are many components that contribute to the uncertainty of modelling air quality predictions. The road traffic emissions dispersion model used in this assessment is dependent upon the traffic data that have been input, which will have inherent uncertainties associated with them. There are then additional uncertainties, as models are required to simplify real-world conditions into a series of algorithms. The key uncertainties are explained below and where practical, sensitivity analyses have been carried out to determine the sensitivity of the model to each parameter.

3.1 Vehicle-Specific Emission Factors

3.1.1 Differential Bias

Emissions of NOx and PM_{10} from road traffic have been calculated using Defra's Emissions Factors Toolkit (EFT v8.0.1a). The model outputs have been verified and adjusted against local monitoring, assuming that any bias is assigned equally across all vehicle types and models (except for a crude split by vehicle class on roads with gradients – see paragraph 3.6.2 for details). In the future there will be a different suite of vehicles, but the model is adjusted assuming the same bias as in the base year. This assumption is unlikely to be correct. Overall, there is considered to be no practical alternative and there will thus be an uncertainty in future year model predictions as a result. This uncertainty cannot be quantified nor can the direction of any possible bias be ascertained.

Differential bias in the EFT emissions may have significant implications for the assessment, and delivery, of a CAZ. As an example, the EFT calculates NOx emissions from certain pre-Euro 5 diesel LGVs by simply multiplying the calculated emissions for pre-Euro vehicles by a simple scaling factor. These scaling factors were based on the expected performance of Euro 1 to Euro 4 vehicles and have not been updated for some time. The predicted emissions from Euro 5 and Euro 6 vehicles, on the other hand, calculated by the EFT using model-specific speed-emissions functions. There is thus a significant methodological difference when comparing the EFT predictions for a Euro 4 LGV with those from a Euro 6 LGV and no reason to expect the effect of moving from a Euro 4 LGV to a Euro 6 LGV to be predicted correctly. Given that the EFT predicts that exchanging certain Euro 4 LGVs for equivalent Euro 6 models would increase, rather than reduce, emissions, this is a potentially significant issue as a measure to replace Euro 4 LGVs with Euro 6 LGVs will be predicted to increase emissions when in fact the opposite might occur. It is not possible to quantify the model-specific bias in the EFT without referring to alternative emissions models or emissions test data, which themselves will have uncertainties associated with them. Subsequent sections of this note present sensitivity tests of specific, individual areas of uncertainty, but cannot fully address the range of potential uncertainty introduced by the implicit modelling assumption that the bias in emissions is spread equally across different vehicle types.

3.1.2 Euro 6 Diesel Vehicles

The EFT includes NOx and PM speed-emission coefficients taken from the European Environment Agency COPERT 5 emission calculation tool[7] and fleet and fuel compositions in line with Department for Transport 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. Over a similar timeframe, new aspects of the Euro 6 emissions standards will come into force, but it is important to recognize 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 6d-temp vehicles.

Because the EFT is based on COPERT 5, it differentiates between NOx emissions from Euro 6 diesel vehicles registered in different years. It does this according to three categories: 'a', 'b', and 'c'. Following the spirit of JAQU's 'Supplementary Note on Sensitivity Testing', two sensitivity tests have been considered. In the 'Low' scenario, all Euro 6 'b' diesel cars and LGVs (using the EFT nomenclature) are assumed to be Euro 6 'c'. In the

[7] http://copert.emisia.com. All references to COPERT 5 in this document refer to COPERT V5.0 as included in EFT V8. COPERT V5.3 has recently been released and this contains updated NOx emissions factors for LGVs. COPERT V5.3 has not been yet been included in any Defra tools or in any guidance issued by JAQU and so has not been included in these analyses.

‘High’ scenario, 50% of Euro 6 ‘b’ diesel cars and LGVs are assumed to be Euro 6 ‘a’, and 50% of Euro 6 ‘c’ diesel cars and LGVs are assumed to be Euro 6 ‘b’.

Table 3-1 and Figure 3-1 provide the summary statistics requested in JAQU’s ‘Supplementary Note on Sensitivity Testing’. Table 3-2 then presents the compliance status for each of these scenarios as well as the ‘Central’ modelling. 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 C + TM ranging from 36 μg/m^3 to 42 μg/m^3. The maximum percentage gap from compliance ranges from -12.6% to 2.7% for the ‘Low’ and ‘High’ scenarios respectively. It is noted that the ‘Central’ scenario lies closer to the ‘High’ scenario than the ‘Low’ scenario in terms of predicted concentrations.

Table 3-1: Simple Summary Statistics for Sensitivity Testing of Euro 6 Diesel Vehicle Emissions (μg/m^3)

Statistic	2021 Baseline			2021 CAZ C + TM		
	Low	Central	High	Low	Central	High
Mean	23	24	25	19	20	21
Median	22	23	23	19	19	20
Maximum	60	62	63	36	40	42
Minimum	10	11	11	10	10	10
Upper Quartile	28	30	30	22	24	24
Lower Quartile	17	17	18	15	16	16
Standard Deviation	8	8	9	5	5	6
Range	49	51	52	26	30	31

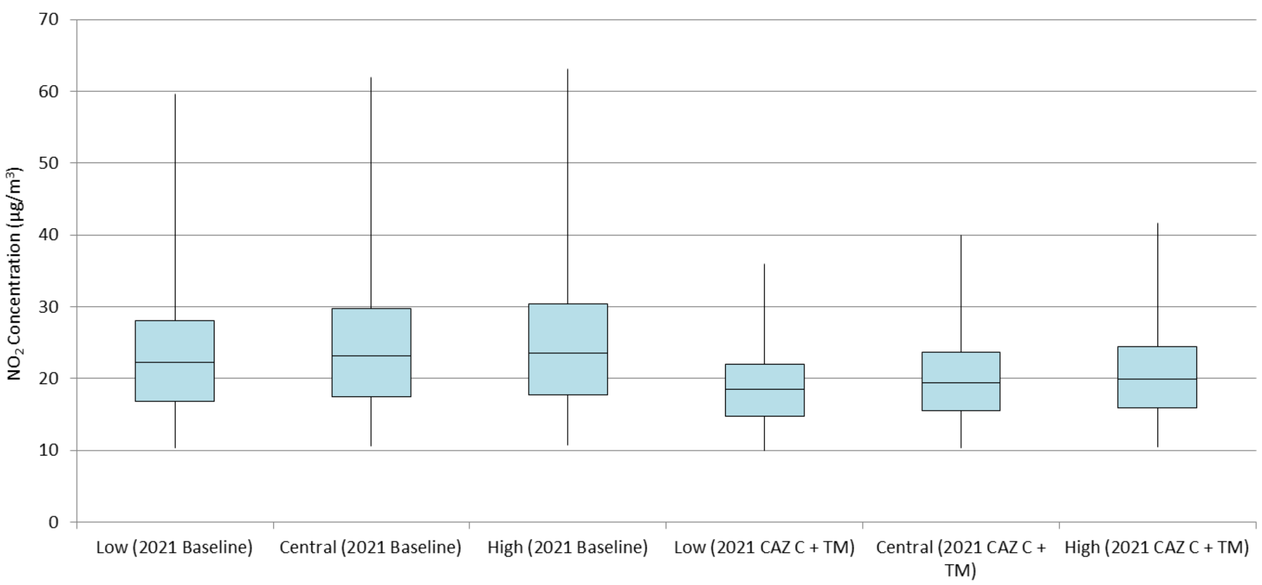

Figure 3-1: Distribution of NO_2 Concentrations for Sensitivity Testing of Euro 6 Diesel Vehicle Emissions

Table 3-2: Summary of Compliance Status for Sensitivity Testing of Euro 6 Diesel Vehicle Emissions

Statistic	2021 Baseline			2021 CAZ C + TM		
	Low	Central	High	Low	Central	High
No. of Non-Compliance LAQM Receptors	27	33	41	0	0	4
No. of Non-Compliance PCM Receptors	431	575	657	0	0	0
Compliance Status of Road Link with Highest NO_2 Value	Non-Compliant	Non-Compliant	Non-Compliant	Compliant	Compliant	Non-Compliant
Maximum NO_2 Percentage Gap from Compliance	32.1	34.6	35.8	-12.6	-1.5	2.7
Maximum Road-NO_2 Percentage Gap from Compliance	41.0	43.7	45.0	-19.7	-2.2	3.9

3.1.3 Diesel LGV Emissions

The EFT includes emission factors for diesel LGVs that have been based upon COPERT 5. However, COPERT 5 only updated diesel LGV emission factors for Euro 5 and 6 vehicles, not pre-Euro 5 vehicles. Whilst these Euro 5 and 6 emission factors are based on measured emissions[8], the pre-Euro 5 emissions factors are not. Consequently, pre-Euro 5 diesel LGV emission factors in the EFT are lower than Euro 5 and 6 emission factors, which are considered to be unrealistic since older vehicles are typically more polluting. There is thus some uncertainty in pre-Euro 5 diesel LGV emissions which have been used in the modelling. This uncertainty has been investigated and a test has been undertaken that takes account that older LGVs are likely to be more polluting than newer LGVs (within pre-Euro 5 standards). Thus, pre-Euro 5 emissions factors have been amended, which includes uplifting of pre-Euro 1 to Euro 4 LGV emissions. The EFT includes factors to derive incrementally higher emission factors for older pre-Euro 5 diesel LGVs. These factors have been applied to the Euro 5 LGV emissions to obtain emissions for pre-Euro 1 to Euro 4 emissions. For example, Euro 4 = Euro 5 emission, Euro 3 = Euro 4 emission*1.24 (where the factor is 24%), and so on. This sensitivity test takes account of changes to the model adjustment factor (since emissions from the existing fleet are assumed to change). Table 3-3 and Figure 3-2 provide the summary statistics requested in JAQU's 'Supplementary Note on Sensitivity Testing' for this test. Table 3-4 then presents the compliance status for these scenarios as well as the 'Central' modelling. With these adjusted emissions, the maximum predicted concentration with a CAZ C + TM scheme implemented is predicted to be 40 µg/m3; the CAZ C + TM scheme remains compliant.

Table 3-3: Simple Summary Statistics for Sensitivity Testing of Diesel LGV Emissions (µg/m3)

Statistic	2021 Baseline		2021 CAZ C + TM	
	Central	Pre-Euro 5 Diesel LGV Sensitivity	Central	Pre-Euro 5 Diesel LGV Sensitivity
Mean	24	24	20	20
Median	23	23	19	19
Maximum	62	62	40	40
Minimum	11	11	10	10
Upper Quartile	30	30	24	24
Lower Quartile	17	17	16	15
Standard Deviation	8	8	5	5
Range	51	51	30	29

[8] Albeit that the LGV emissions have since been updated in COPERT V5.3[9] LDV = LGVs + Cars + Motorcycles

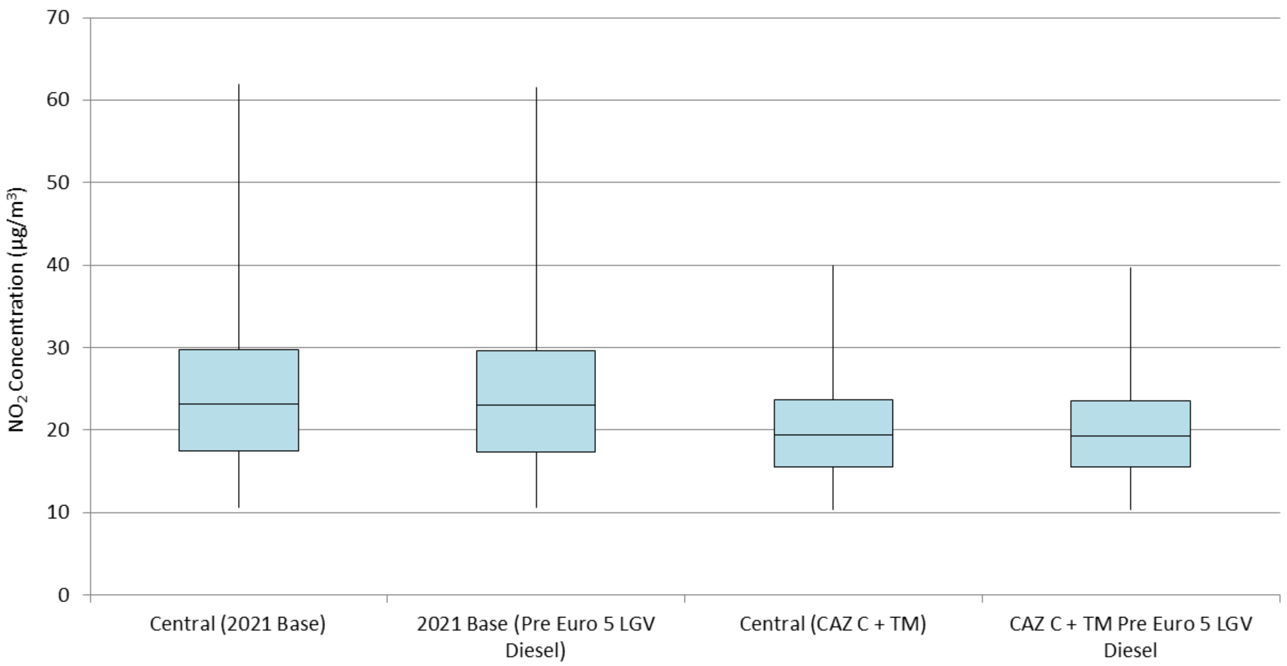

Figure 3-2: Distribution of NO_2 Concentrations for Sensitivity Testing of Diesel LGV Emissions

Table 3-4: Summary of Compliance Status for Sensitivity Testing Diesel LGV Emissions

Statistic	2021 Baseline		2021 CAZ C + TM	
	Central	Pre-Euro 5 Diesel LGV Sensitivity	Central	Pre-Euro 5 Diesel LGV Sensitivity
No. of Non-Compliance LAQM Receptors	33	33	0	0
No. of Non-Compliance PCM Receptors	575	562	0	0
Compliance Status of Road Link with Highest NO_2 Value	Non-Compliant	Non-Compliant	Compliant	Compliant
Maximum NO_2 Percentage Gap from Compliance	34.6	34.2	-1.5	-2.2
Maximum Road-NO_2 Percentage Gap from Compliance	43.7	43.2	-2.2	-3.3

3.1.4 Lower Uptake of Compliant LGVs

Following the OBC submission, discussions were held with JAQU about the robustness of the CAZ C + TM, resulting in one further sensitivity test being undertaken for the FBC in which a 20% lower uptake of compliant LGVs was tested (and run through the air quality model). Table 3-5 provides a summary of statistics (as requested in JAQU's 'Supplementary Note on Sensitivity Testing') and Table 3-6 presents the compliance status for this sensitivity test as well as the 'Central' (core scenario) modelling. Figure 3-3 shows the distribution of the resulting NO_2 concentrations. Even if the 20% lower uptake of compliant LGVs is assumed, the 2021 CAZ C + TM scheme would still be compliant.

Table 3-5: Simple Summary Statistics for Lower Uptake of Compliant LGVs (µg/m³)

Statistic	2021 CAZ C + TM	
	Central	Lower Uptake of Compliant LGVs
Mean	20	20
Median	19	19
Maximum	40	40
Minimum	10	10
Upper Quartile	24	24
Lower Quartile	16	16
Standard Deviation	5	5
Range	30	30

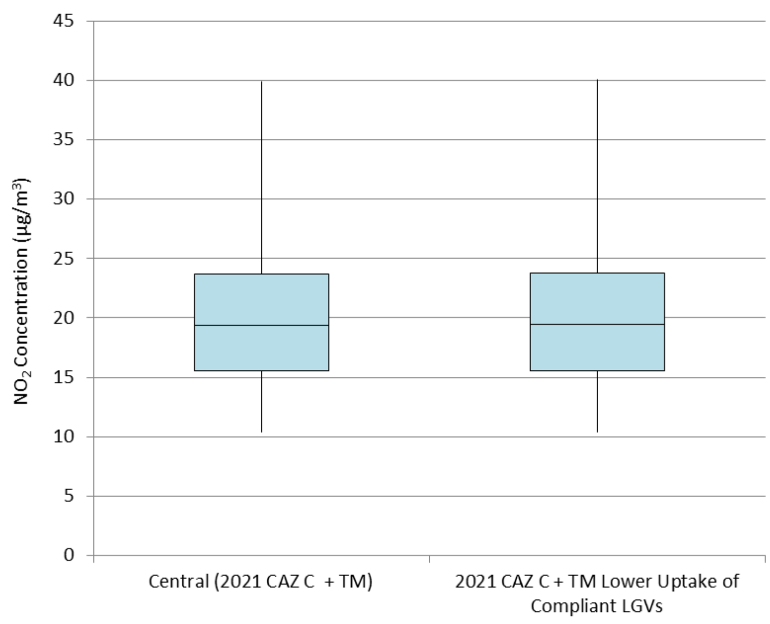

Figure 3-3: Distribution of NO_2 Concentrations for Lower Uptake of Compliant LGVs

Table 3-6: Summary of Compliance Status for Lower Uptake of Compliant LGVs

Statistic	2021 CAZ C + TM	
	Central	Lower Uptake of Compliant LGVs
No. of Non-Compliance LAQM Receptors	0	0
No. of Non-Compliance PCM Receptors	0	0
Compliance Status of Road Link with Highest NO_2 Value	Compliant	Compliant
Maximum NO_2 Percentage Gap from Compliance	-1.5	-1.0
Maximum Road-NO_2 Percentage Gap from Compliance	-2.2	-1.5

3.1.5 Inappropriate Emissions Groupings

The CAZ definition of compliant and non-compliant vehicles is based on the fundamental assumption that compliant vehicles will emit less NOx than non-compliant vehicles. As a fleet-weighted average, this is expected to be the case, but on an individual-vehicle basis, it often will not be. For example, there is considerable evidence that, when averaged across a typical urban drive-cycle, NOx emissions from some Euro 4 and/or Euro 5 diesel cars will be lower than those from some Euro 6 diesel cars. Similarly, emissions from some compliant petrol cars may be higher than those from some non-compliant diesel vehicles. Given that the precise make-up of the future vehicle fleet is not known, this creates uncertainty regarding the effect that the CAZ will have; as well as introducing potential enforcement risks.

An alternative approach would be to produce CAZ-representative drive-cycles and use these to map vehicle-specific on-board emissions measurements; thus creating model-specific CAZ-average emissions. Remote-sensing data could then be used to provide 'error bars' to these data. Not only would this involve a great deal of time-consuming work, it would require a fundamentally different approach to defining CAZs than is being promoted by JAQU. On this basis, it is not considered possible to carry out any sensitivity testing of this issue and is accepted to contribute to the uncertainty in the conclusions of the assessment.

3.1.6 Engine Size and Vehicle Weight

The EFT contains default vehicle size distributions, which specify the proportion of passenger cars with different engine sizes and the proportion of LGVs and HDVs with different kerb weights. Vehicle weights and engine sizes were not available from the traffic surveys and so the EFT-default values have been used in the modelling.

To provide an indication of the sensitivity of the model to these assumptions, ‘Low’ and ‘High’ vehicle size distribution scenarios have been modelled. In the ‘Low’ scenario, 50% of vehicles within each size group have been moved to the next smallest size group. For example, in the EFT the weights of buses are defined by three weight groups: lighter than 15 tonnes (group 1), between 15 and 18 tonnes (group 2), and heavier than 18 tonnes (group 3). The default distributions of weights within these groups are 31%, 69% and 0%, respectively. Applying the ‘Low’ scenario assumption, 34.5% of buses have been re-assigned from group 2 to group 1. The distribution of weights for the ‘Low’ scenario would thus be 65.5%, 34.5% and 0%, respectively. Similarly, a ‘High’ vehicle weight scenario has been modelled, whereby it has been assumed that 50% of the proportion of vehicles within each weight group are in the next heaviest weight group. Taking buses for example, 15.5% of buses are re-assigned from group 1 to group 2 and 34.5% of buses are re-assigned from group 2 to group 3. The distribution of weights for the ‘High’ scenario would thus be 15.5%, 50% and 34.5%, respectively.

It should be noted that vehicle *type* in the EFT has not been re-classified, so HGVs are not assumed to move from being rigid to articulated and vice-versa. Similarly, no migration between HGV and LGV is assumed. Finally, it should be noted that COPERT 5 does not differentiate between emissions from passenger cars with different sized engines for many vehicle categories. This means that moving to a different engine size category changes the assumed emissions from some passenger cars, but not all of them.

The predicted NO_2 concentrations resulting from the ‘Low’ and ‘High’ scenarios have then been compared to the concentrations predicted from using the default weight distributions in the EFT (‘Central’ scenario). Table 3-7 and Figure 3-4 provide a summary of statistics as requested in JAQU’s ‘Supplementary Note on Sensitivity Testing’. Table 3-8 then presents the compliance status for each of these scenarios as well as the ‘Central’ modelling. Although there is an uncertainty associated with vehicle weights, this has a minimal effect on concentrations, and in all three scenarios the 2021 CAZ C + TM scheme is compliant, with the maximum predicted concentrations all being 40 $\mu g/m^3$.

Table 3-7: Simple Summary Statistics for Sensitivity Testing of Vehicle Size (µg/m³)

Statistic	2021 Baseline			2021 CAZ C + TM		
	Low	Central	High	Low	Central	High
Mean	24	24	24	20	20	20
Median	23	23	23	19	19	19
Maximum	62	62	62	40	40	40
Minimum	11	11	11	10	10	10
Upper Quartile	30	30	30	24	24	24
Lower Quartile	17	17	18	15	16	16
Standard Deviation	8	8	8	5	5	5
Range	51	51	51	29	30	30

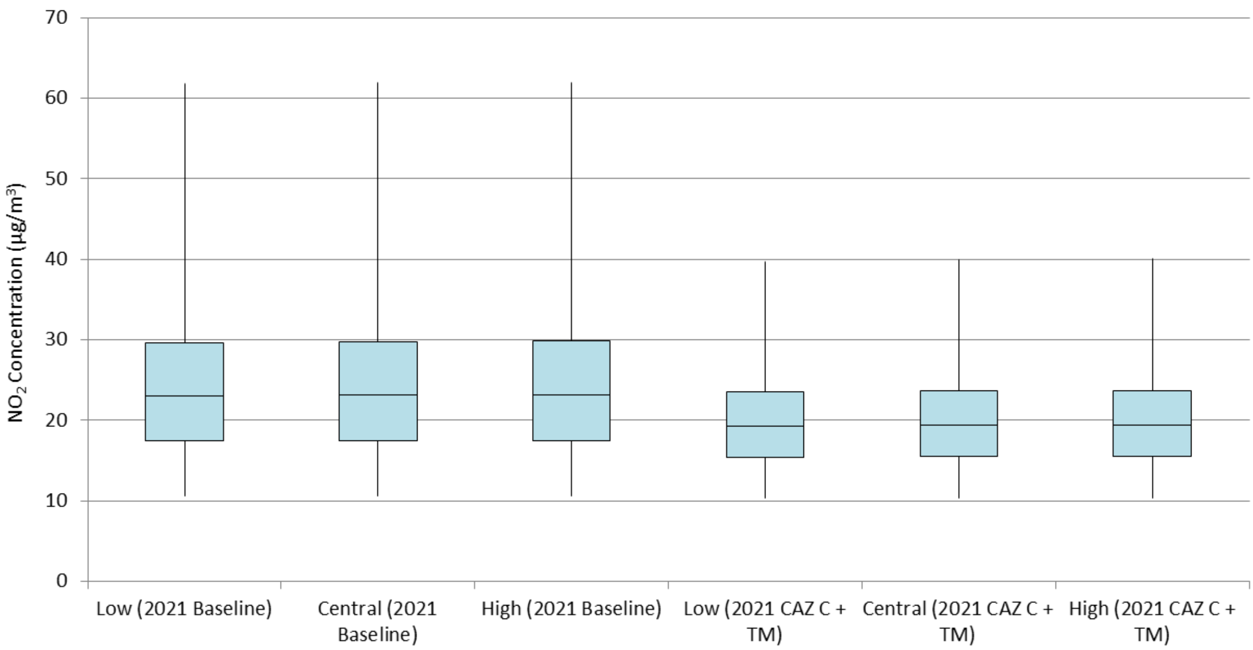

Figure 3-4: Distribution of NO_2 Concentrations for Sensitivity Testing of Vehicle Size

Table 3-8: Summary of Compliance Status for Sensitivity Testing of Vehicle Size

Statistic	2021 Baseline			2021 CAZ C + TM		
	Low	Central	High	Low	Central	High
No. of Non-Compliance LAQM Receptors	33	33	34	0	0	0
No. of Non-Compliance PCM Receptors	565	575	600	0	0	0
Compliance Status of Road Link with Highest NO_2 Value	Non-Compliant	Non-Compliant	Non-Compliant	Compliant	Compliant	Compliant
Maximum NO_2 Percentage Gap from Compliance	34.4	34.6	34.6	-1.9	-1.5	-1.1
Maximum Road-NO_2 Percentage Gap from Compliance	43.5	43.7	43.7	-2.9	-02.2	-1.6

The EFT also assumes that HGVs operate 50% laden at all times. In practice, vehicles are likely to be spend a great deal of their time both more and less than 50% laden. The relationship between assumed freight load and predicted NOx emissions in COPERT V5 is not straightforward and depends on the emissions-reduction technology that is used. Uncertainty regarding the freight load of vehicles in Bath, as well as the relationship between this parameter and emissions, will contribute to the uncertainty in the conclusions of the assessment.

3.2 Relationship between traffic speed and emissions

3.2.1 Average-speed Emissions Factors

The EFT provides emissions for different vehicle types which vary based on the average vehicle speed. In principle, these speeds relate to the average speed of a vehicle during an entire journey but the EFT is typically used with speeds averaged across multiple vehicles over a short-stretch of road. An important point is that a given average speed can potentially be achieved by many different patterns of driving. For example, for an average speed of 20 kph, the EFT assumes a reasonable amount of stop-start driving. In practice, the same average speed could be achieved by driving at a constant 20 kph, by braking from a faster speed, or accelerating up to a faster speed. Acceleration events are often associated with increased emissions. During deceleration, there will often be reduced NOx emissions, but potentially increased emissions of PM due to brake wear. There is also some evidence that primary nitrogen dioxide emissions are higher during heavy acceleration phases. It is also worth noting that the effect of acceleration and deceleration may be enhanced along roads with gradients. An alternative approach would be to use an instantaneous emissions model. However, this is not considered to be practical at the current time. On this basis, it is not considered possible to carry out any sensitivity testing of this issue and this will contribute to the uncertainty in the conclusions of the assessment.

In addition to the general patterns noted above, NOx emissions from internal combustion vehicles fitted with modern pollution control technology can be significantly weighted to occur during very brief events on the drive cycle. This means that a very large proportion of the total trip-average NOx can be emitted over quite a short period of time. It is not currently possible to predict where on the network these events might occur. On this basis, it is not considered possible to carry out any sensitivity testing of this issue and this will contribute to the uncertainty in the conclusions of the assessment.

3.2.2 Emissions at low speeds

Roads with queuing traffic or lots of start/stop 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 (GBATH) model and compared to Trafficmaster data. The speeds are based on the average speed along a road. In reality, the speed will very often be slower at the start and end of a road and faster in the middle. The air quality model includes an adjustment to reduce speeds at the starts and ends of roads and where congestion is most likely. The reduced speeds will lead to higher vehicle emissions and thus increased pollution. 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.

JAQU has set out a methodology to assess the uncertainty of emissions from vehicles travelling at low speeds in their ‘Supplementary Note on Sensitivity Testing’ and state that this methodology should be followed. This involves using a polynomial equation provided by JAQU which is based on using the COPERT emissions functions beyond their intended speed ranges. Details are provided in JAQU’s ‘Supplementary Note on Sensitivity Testing’. This methodology has been followed and extended to calculate both NOx and NO_2 emissions, and the resulting predicted NO_2 concentrations from the air quality model. This results in a ‘Low’ emissions scenario which uses the speed thresholds from COPERT V4 and a ‘High’ emissions scenario extends the speed thresholds down to 5 kph. The ‘Low’ and ‘High’ NO_2 concentrations have then been compared to the ‘Central’ NO_2 concentrations (i.e. without applying the polynomial equation).

Table 3-9 and Figure 3-5 provide a summary of statistics as requested in JAQU’s ‘Supplementary Note on Sensitivity Testing’. Table 3-10 then presents the compliance status for each of these scenarios as well as the

'Central' modelling. In all three scenarios, the 2021 CAZ C + TM scheme is compliant by a minimum percentage gap of 1.3%

Table 3-9: Simple Summary Statistics for Sensitivity Testing of Low Speeds (µg/m³)

Statistic	2021 Baseline			2021 CAZ C + TM		
	Low	Central	High	Low	Central	High
Mean	24	24	24	20	20	20
Median	23	23	23	19	19	19
Maximum	62	62	62	39	40	40
Minimum	11	11	11	10	10	10
Upper Quartile	29	30	30	24	24	24
Lower Quartile	17	17	17	16	16	16
Standard Deviation	8	8	8	5	5	5
Range	51	51	51	29	30	30

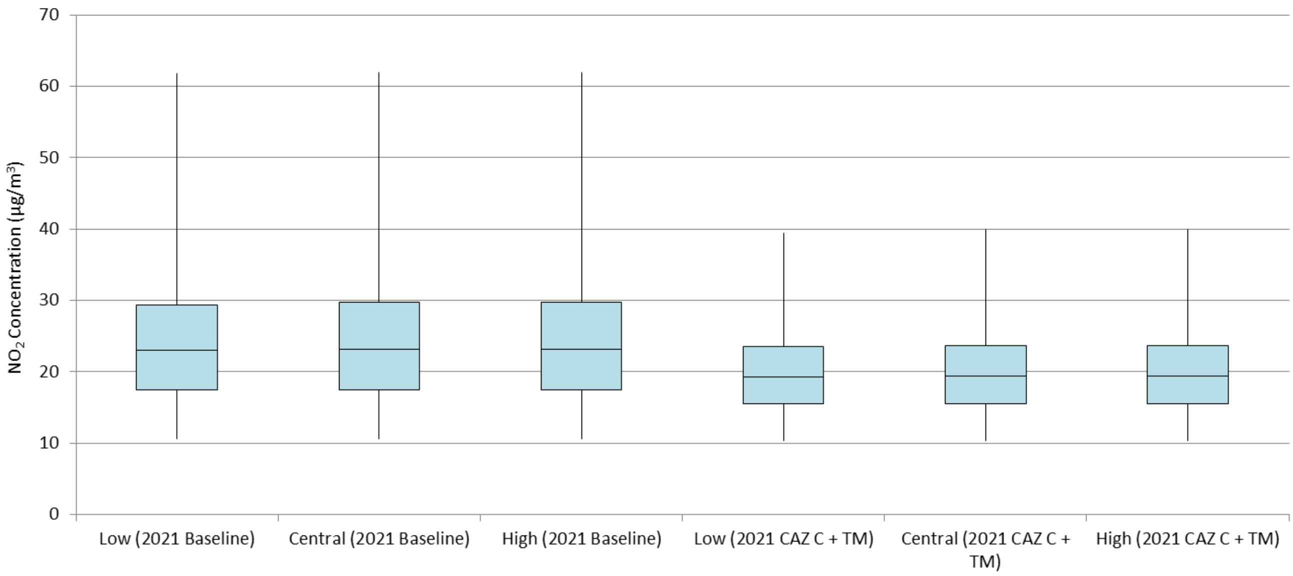

Figure 3-5: Distribution of NO_2 Concentrations for Sensitivity Testing of Low Speeds

Table 3-10: Summary of Compliance Status for Sensitivity Testing of Low Speeds

Statistic	2021 Baseline			2021 CAZ C + TM		
	Low	Central	High	Low	Central	High
No. of Non-Compliance LAQM Receptors	24	33	35	0	0	0
No. of Non-Compliance PCM Receptors	589	575	589	0	0	0
Compliance Status of Road Link with Highest NO_2 Value	Non-Compliant	Non-Compliant	Non-Compliant	Compliant	Compliant	Compliant
Maximum NO_2 Percentage Gap from Compliance	34.5	34.6	34.6	-2.8	-1.5	-1.3
Maximum Road-NO_2 Percentage Gap from Compliance	43.7	43.7	43.7	-4.2	-2.2	-1.9

3.3 Background Concentrations

The background pollutant concentrations across the study area have been defined using the national pollution maps published by Defra (2018d) and calibrated against local measurements made at a single background diffusion tube monitoring site in Bath in 2017. This local calibration has been used to help take account of any inaccuracies in the Defra maps (which are derived from a national calibration in 2015), and has been applied to all future-year background concentrations. It is possible, however, that there may be inaccuracies in the measurements, or that the site may be affected by some unidentified local emission source. To test the sensitivity of the results to this issue, NO_2 concentrations have been predicted for 2021 for both the baseline and CAZ C + TM scenarios, with and without the local calibration applied to the background concentrations. In order to accurately take account of different background concentrations, the model verification has been re-calculated with the uncalibrated backgrounds, using the methodology given in FBC-11 Air Quality Modelling Report (AQ3) in Appendix D of the FBC.

Table 3-11 and Figure 3-6 provide a summary of statistics as requested in JAQU's 'Supplementary Note on Sensitivity Testing'. Table 3-12 then presents the compliance status for each of these scenarios. Without a local calibration factor being applied to Defra's national pollution background maps, the predicted concentrations are generally lower than if backgrounds are calibrated, but the maximum concentration is higher. This is because the background concentrations affect the derived 'measured' local road contributions and hence the calibration factor for the modelled local road contributions. The maximum concentration marginally exceeds the limit value by 0.1 µg/m^3 (0.2% gap from compliance) at only one LAQM receptor.

Table 3-11: Simple Summary Statistics for Sensitivity Testing of Background Concentrations (µg/m^3)

Statistic	2021 Baseline		2021 CAZ C + TM	
	Without Calibration	With Calibration	Without Calibration	With Calibration
Mean	23	24	18	20
Median	21	23	17	19
Maximum	65	62	41	40
Minimum	9	11	8	10
Upper Quartile	29	30	22	24
Lower Quartile	16	17	13	16
Standard Deviation	9	8	6	5
Range	56	51	32	30

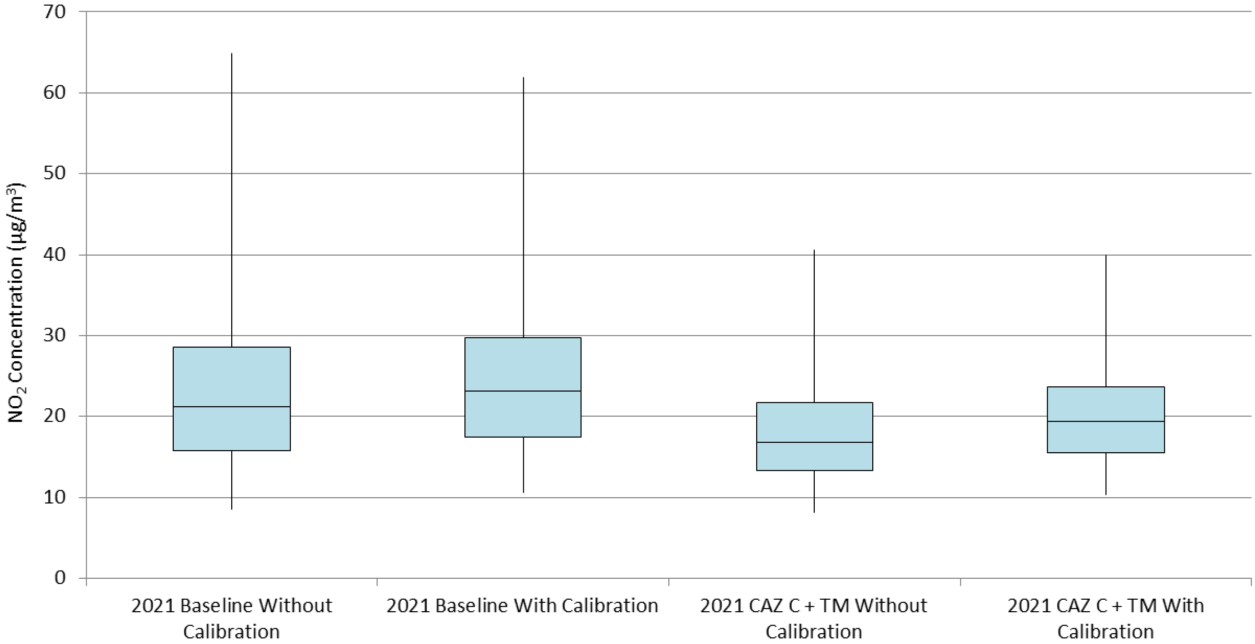

Figure 3-6: Distribution of NO_2 Concentrations for Sensitivity Testing of Background Concentrations

Table 3-12: Summary of Compliance Status for Sensitivity Testing of Background Concentrations

Statistic	2021 Baseline		2021 CAZ C + TM	
	Without Calibration	With Calibration	Without Calibration	With Calibration
No. of Non-Compliance LAQM Receptors	36	33	1	0
No. of Non-Compliance PCM Receptors	597	575	0	0
Compliance Status of Road Link with Highest NO_2 Value	Non-Compliant	Non-Compliant	Non-Compliant	Compliant
Maximum NO_2 Percentage Gap from Compliance	37.6	34.6	0.1	-1.5
Maximum Road-NO_2 Percentage Gap from Compliance	46.9	43.7	0.2	-2.2

3.4 Model Verification

The model verification for NOx and NO_2 concentrations has been investigated in detail. This involved looking at the verification in different ways and testing if any parameters had any significant effect on the verification. This included looking at monitor heights, monitor distances to kerbs, data capture of measured concentrations, whether monitoring sites are in street canyons, canyon porosities, whether monitoring sites are near junctions, fleet composition on roads adjacent to monitoring sites, vehicle speeds on roads adjacent to monitoring sites, gradients, the type roads adjacent to monitoring sites (i.e. A road, B road or minor road), and combinations of these. As set out in the Technical Note on Gradient Emissions in Appendix 1 of FBC-11 Air Quality Modelling Report (AQ3) in Appendix D of the FBC, the only parameter that was found to have a systematic effect on the verification was the combined percentage of light goods vehicles and heavy-duty vehicles on hilly roads adjacent to monitoring sites. Since no other correlations were found, there is no justification for sensitivity testing the verification for any other parameters. In addition, a detailed analysis has been carried out to determine which monitoring sites should be included or excluded from the model verification, as detailed in

FBC-10 Local Plan Air Quality Modelling Methodology Report (AQ2) in Appendix D of the FBC. There is thus no justification for removing any other monitoring sites from the model verification.

It is also important to consider the model verification for particulate matter. The verification of PM_{10} is based on a single monitoring site. The local-road component of PM_{10} as a proportion of the total concentration is also relatively small and this means that the assumed adjustment factor is very sensitive to any error in the assumed background concentration. There is thus significant uncertainty regarding how well this site represents the entire study area. In addition, the model adjustment factor derived for PM_{10} has also been applied to $PM_{2.5}$ concentrations, leading to additional uncertainties for $PM_{2.5}$. If the model had not been adjusted based on locally-measured PM_{10} concentrations, then there would be no predicted risk of non-compliance for PM_{10}. The professional experience of the consultants is that the latter is the most likely situation, as non-compliance for PM_{10} is not currently predicted elsewhere in the UK.

3.5 Receptor Locations

LAQM receptors have been modelled at the façades of relevant properties close to the modelled roads and at a height of 1.5 m, which is considered to be a typical breathing height. These locations have been based on OS Mastermap vector lines and placed to within an accuracy of about 0.2 m. Any inaccuracy in these locations is considered to be insignificant. There are, however, a number of remaining uncertainties in the receptor locations. Although LAQM receptors have been located at worst-case locations along each road, i.e. on the façades of sensitive properties closest to the road, it is possible that a worst-case property may have been missed or the receptor location at a façade hasn't been situated at the worst-case location on that façade. These inaccuracies may lead to some isolated concentrations being under-predicted. In addition, all LAQM receptors have been modelled at a height of 1.5 m, and there is thus an uncertainty in the realistic height that should be used for these receptors, as some buildings have multiple floors that are sensitive, some buildings have windows or vents at different heights and some buildings include exposure for shorter people (e.g. school children). Air quality conditions will vary with height and a sensitivity test has thus been carried out to assess this aspect.

NO_2 concentrations have been predicted at intervals of 0.5 m from a height of 0 m to 12 m at three LAQM receptor locations; a residential property at Gay Street, St Andrews C of E Primary School at Julian Road and a residential property at London Road (close to the junction with Cleveland Place). Figure 3-7 shows the concentrations for each height. The predicted concentrations fall off with height and thus if there is relevant exposure higher than 1.5 m then concentrations will be lower and thus compliant with a 2021 CAZ C + TM scheme. Below 1.5 m, concentrations remain very similar to those predicted at 1.5 m ($\leq$0.5 $\mu g/m^3$ different) and all concentrations remain compliant with a CAZ C + TM scheme.

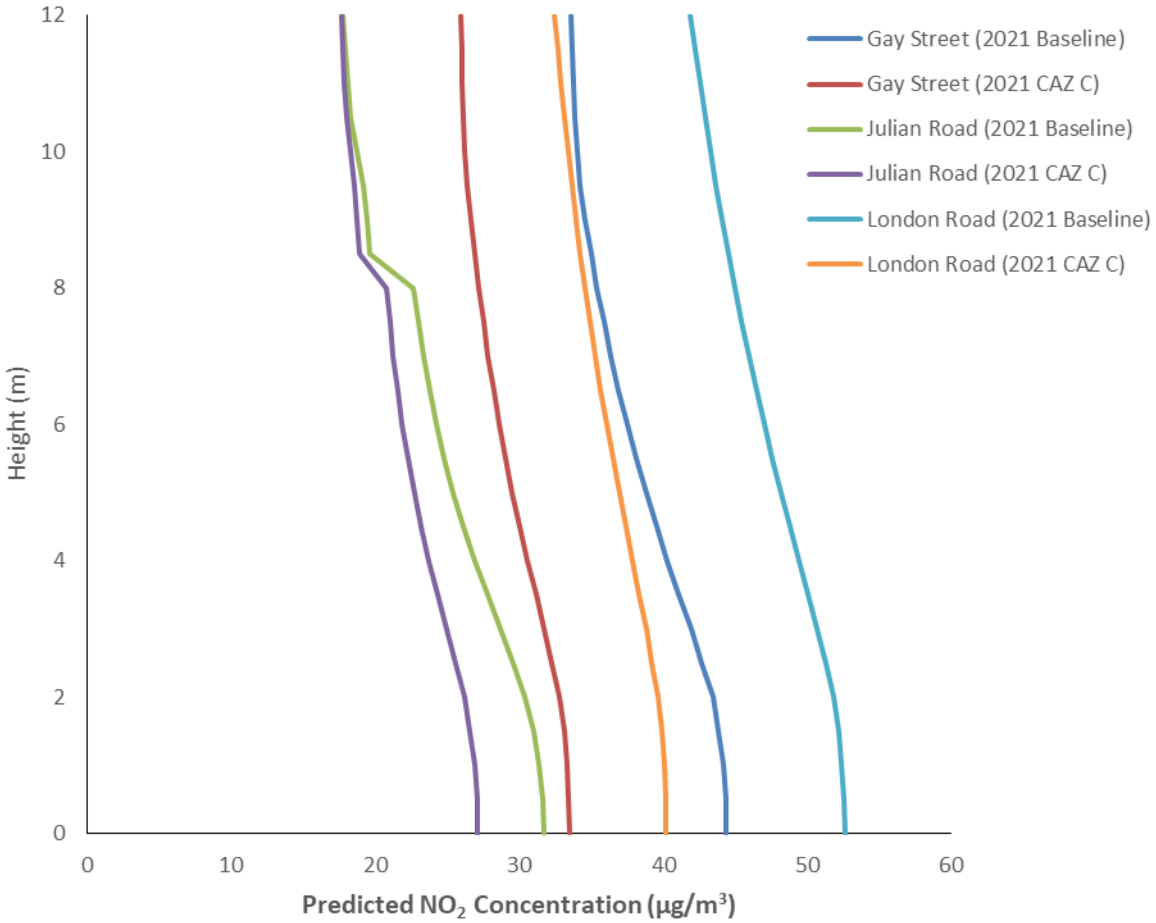

Figure 3-7: NO_2 Concentrations with Height

There is a kink in the concentrations at Julian Road where the height reaches the top of the modelled street canyon. Concentrations outside of the street canyon are lower due to increased dispersion.

3.6 Dispersion Uncertainties

3.6.1 Road Widths and Geometries (including street canyons)

Road widths and geometries have been included in the model manually using a combination of OS mapping and photographs (to check for elements such as permanently parked vehicles, heights of buildings, facades of properties etc). Although time consuming, this is judged to be the most accurate way of reflecting a complex local situation within the model. There is, however, an element of judgement which has been used. This is based on professional experience, but as with any judgement, there will be a risk of uncertainty in terms of the parameters used. Judgement has been used in defining elements of the geometries for the model, as well as the data used for the advanced canyon module (heights, widths and porosity of each side of the canyons). The model set up has been subject to extensive QA procedures. Because of the large numbers of roads, and street canyons, within the model, any disparity in interpretation is unlikely to be standard across the whole modelled network. There is no objective basis for testing the effect of this issue and this will contribute to the uncertainty in the conclusions of the assessment.

3.6.2 Gradients

Road Gradient

Vehicle emissions on roads with gradients have been uplifted (as explained in the Technical Note on Gradient Emissions in Appendix 1 of FBC-11 Air Quality Modelling Report (AQ3) in Appendix D of the FBC) and the decision of whether an individual road should have this adjustment applied is important. The approach taken has been to apply this uplift to all roads where the gradient is greater than 2.5%, which has been based on Environment Agency in England Lidar data. The roads have been broken into sections based on observations of gradient changes. There should, therefore, be no significant changes in gradient along any individual link; but this is based on subjective, and thus uncertain, observations. The Lidar data will also have inherent uncertainties associated with it. The data is provided at a 1 x 1 m resolution and it is possible that the camber of roads and the choice of road length may have affected the heights used to determine the gradient. It is thus possible that the gradient of some roads may have been underestimated slightly and others overestimated slightly. This would result in emissions potentially not uplifted enough or uplifted too much. A sensitivity test has thus been carried out to assess the sensitivity of the results to this uncertainty. A 'Low' scenario has been run where the change in height along each road has been reduced by 2 m to provide a shallower gradient. Similarly, a 'High' scenario has been run where the change in height along the road has been increased by 2 m to provide a steeper gradient. To correctly take account of the changes to the modelling, for both scenarios the model has been re-verified and re-adjusted following the approach set out in the Technical Note on Gradient Emissions. The results have then been compared to the 'Central' scenario, where the 2 m change has not been applied.

Table 3-13 and Figure 3-8 provide a summary of statistics as requested in JAQU's 'Supplementary Note on Sensitivity Testing'. Table 3-14 then presents the compliance status for each of these scenarios as well as the 'Central' modelling. The results of the sensitivity tests for a 2021 CAZ C + TM scenario show higher concentrations in the 'Low' scenario and lower concentrations in the 'High' scenario, with the scenarios being non-compliant and compliant, respectively. The 'Low' scenario is non-compliant at one LAQM receptor by 0.4 µg/m^3 (0.9% gap from compliance). The highest predicted concentrations occur in the 'Low' scenario because artificially reducing road gradients in the baseline has the effect of increasing the required model adjustment factor.

Table 3-13: Simple Summary Statistics for Sensitivity Testing of Gradients (µg/m^3)

Statistic	2021 Baseline			2021 CAZ C + TM		
	Low	Central	High	Low	Central	High
Mean	24	24	24	20	20	20
Median	23	23	23	20	19	19
Maximum	63	62	61	41	40	40
Minimum	11	11	11	10	10	10
Upper Quartile	29	30	30	24	24	24
Lower Quartile	17	17	17	16	16	16
Standard Deviation	8	8	8	5	5	5
Range	52	51	51	30	30	30

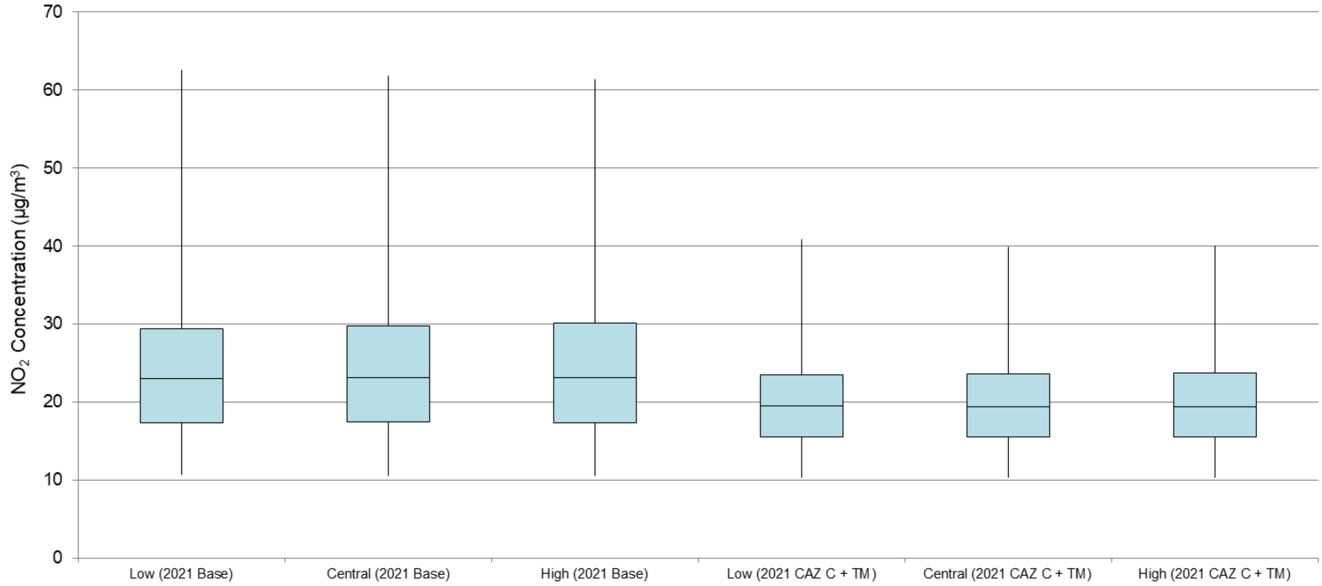

Figure 3-8: Distribution of NO_2 Concentrations for Sensitivity Testing of Gradients

Table 3-14: Summary of Compliance Status for Sensitivity Testing of Gradients

Statistic	2021 Baseline			2021 CAZ C + TM		
	Low	Central	High	Low	Central	High
No. of Non-Compliance LAQM Receptors	29	33	32	1	0	0
No. of Non-Compliance PCM Receptors	559	575	593	0	0	0
Compliance Status of Road Link with Highest NO_2 Value	Non-Compliant	Non-Compliant	Non-Compliant	Non-Compliant	Compliant	Compliant
Maximum NO_2 Percentage Gap from Compliance	35.3	34.6	33.9	0.9	-1.5	-1.3
Maximum Road-NO_2 Percentage Gap from Compliance	44.5	43.7	43.0	1.3	-2.2	-1.9

Gradient Adjustment Factor

Sensitivity test based on Caerphilly Study (Caerphilly Borough Council, 2018)

The Core modelling scenario has applied two adjustment factors; one for LGV and HDV emissions on uphill lanes of gradient roads and one for all other emissions (i.e. emissions on non-gradient roads, emissions on downhill lanes of gradient roads, and car/motorcycle emissions on uphill lanes of gradient roads).

Following a request by JAQU, a sensitivity test has been undertaken whereby non-LGV+HDV emissions on uphill links were uplifted by factors of both 2 (Test 1) and 3 (Test 2) (instead of the value of 1.575 used in the Core modelling) reflecting the outcomes of the Caerphilly study. This then reduces the required adjustment to the uphill LGV+HDV emissions. Table 3-15 and Figure 3-9 provide a summary of statistics as requested in JAQU's 'Supplementary Note on Sensitivity Testing'. Table 3-16 then presents the compliance status for each of these scenarios as well as the 'Central' modelling. The results demonstrate that if a higher non-LGV+HDV uplift factor is applied (thereby requiring a lower LGV+ HDV uplift factor) the scheme will still achieve compliance with Test 1. PCM receptors in both tests are compliant, but in Test 2 (using a factor of 3 for non-LGV+HDVs) the scheme is non-compliant at two LAQM receptors.

Table 3-15: Simple Summary Statistics for Sensitivity Testing of Gradient Adjustment Factor Caerphilly Study (µg/m³)

	Baseline 2021			2021 CAZ C + TM		
Statistic	Central	Test 1	Test 2	Central	Test 1	Test 2
Uphill LGV/HDV Adjustment	7.4	7.1	6.4	7.4	7.1	6.4
Non Gradient Adjustment	1.6	1.6	1.6	1.6	1.6	1.6
Uphill non-LGV/HDV Adjustment	1.6	2	3	1.6	2	3
Mean	24	24	24	20	20	20
Median	23	23	23	19	20	20
Maximum	62	62	61	40	40	43
Minimum	11	11	11	10	10	10
Upper Quartile	30	30	30	24	24	24
Lower Quartile	17	17	17	16	16	16
Standard Deviation	8	8	8	5	5	6
Range	51	51	51	30	30	33

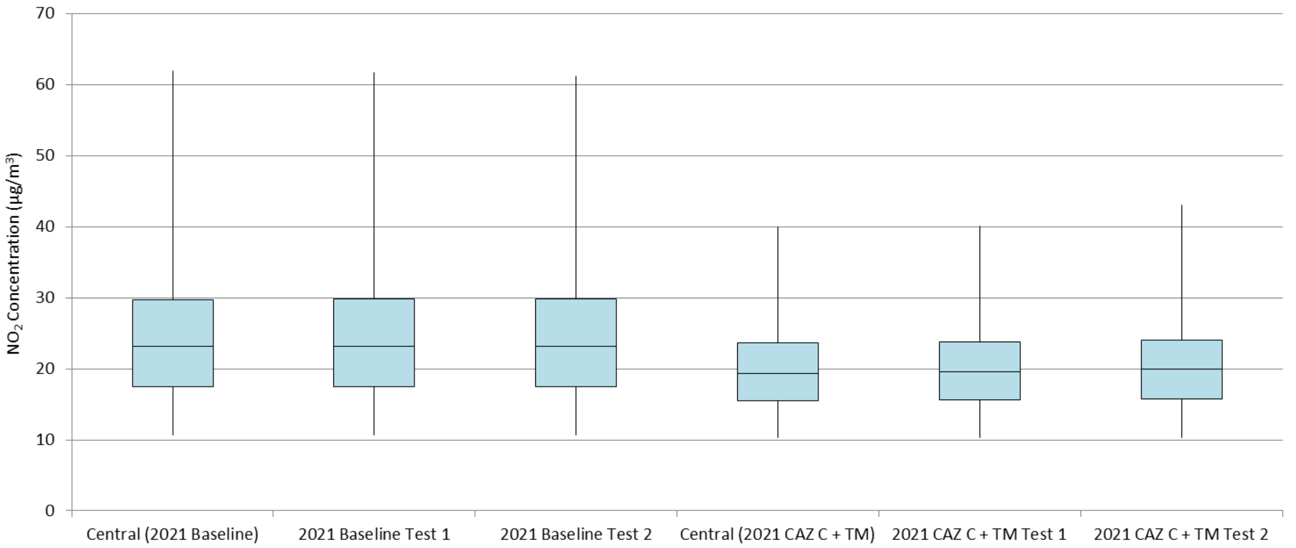

Figure 3-9: Distribution of NO_2 Concentrations for Sensitivity Testing of Gradient Adjustment Factor Caerphilly Study

Table 3-16: Summary of Compliance Status for Sensitivity Testing of Gradient Adjustment Factor Caerphilly Study

Statistic	2021 Baseline			2021 CAZ C + TM		
	Central	Test 1	Test 2	Central	Test 1	Test 2
No. of Non-Compliance LAQM Receptors	33	34	39	0	0	2
No. of Non-Compliance PCM Receptors	575	577	572	0	0	0
Compliance Status of Road Link with Highest NO_2 Value	Non-Compliant	Non-Compliant	Non-Compliant	Compliant	Compliant	Non-Compliant
Maximum NO_2 Percentage Gap from Compliance	34.6	34.4	33.9	-1.5	-1.2	5.8
Maximum Road-NO_2 Percentage Gap from Compliance	43.7	43.5	42.9	-2.2	-1.7	8.7

Sensitivity based on Grouping LGVs with Cars

A further sensitivity test has been carried out, at the request of JAQU, whereby LGVs are grouped with cars on gradient roads, rather than HDVs. This results in an uphill HDV adjustment factor of 8.48 and an LDV[9] + downhill HDV adjustment factor of 1.59. Table 3-17 and Figure 3-10 provide a summary of statistics as requested in JAQU's 'Supplementary Note on Sensitivity Testing'. Table 3-18 then presents the compliance status for this scenarios as well as the 'Central' modelling. The results demonstrate that if these factors are applied CAZ C + TM still achieves compliance and the compliance gap increases to -2.2%.

Table 3-17: Simple Summary Statistics for Sensitivity Testing on Grouping LDVs with Cars (μg/m³)

Statistic	2021 Baseline		2021 CAZ C + TM	
	Central	2021 CAZ C + TM LDV Grouping with Cars	Central	2021 CAZ C + TM LDV Grouping with Cars
Mean	24	24	20	20
Median	23	23	19	19
Maximum	62	61	39	40
Minimum	11	10	10	10
Upper Quartile	30	23	23	23
Lower Quartile	17	15	15	15
Standard Deviation	8	5	5	5
Range	51	51	29	29

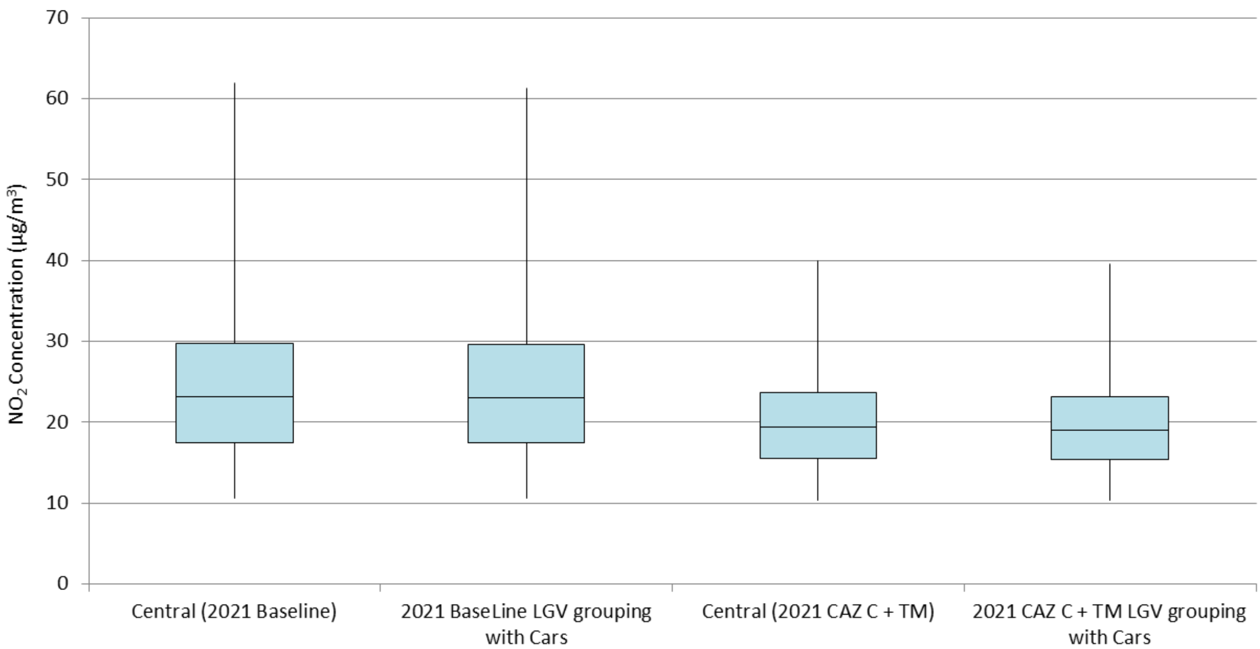

Figure 3-10: Distribution of NO_2 Concentrations for Sensitivity Testing on Grouping LDVs with Cars

[9] LDV = LGVs + Cars + Motorcycles

Table 3-18: Summary of Compliance Status for Sensitivity Testing on Grouping LDVs with Cars

Statistic	2021 Baseline		2021 CAZ C + TM	
	Central	2021 CAZ C + TM LDV Grouping with Cars	Central	2021 CAZ C + TM LDV Grouping with Cars
No. of Non-Compliance LAQM Receptors	33	32	0	0
No. of Non-Compliance PCM Receptors	575	567	0	0
Compliance Status of Road Link with Highest NO_2 Value	Non-Compliant	Non-Compliant	Compliant	Compliant
Maximum NO_2 Percentage Gap from Compliance	34.6	33.9	-1.5	-2.2
Maximum Road-NO_2 Percentage Gap from Compliance	43.7	43.0	-2.2	-3.4

3.6.3 Junctions

As with road widths and geometries, junctions have been included in the model manually using a combination of OS mapping and photographs. Paths of vehicles at junctions have been defined on the basis of experience. This has required subjective decisions and there is thus potential for additional uncertainty associated with the treatment of specific junctions. The model set up has been subject to extensive QA procedures by other members of the air quality team, which will reduce the impact of this issue. Any disparity in interpretation of a junction is likely to be junction-specific, and as such there is no basis for testing any different conditions. This issue will contribute to the uncertainty in the conclusions of the assessment.

3.7 Meteorological Conditions

3.7.1 Meteorological Data

Meteorological conditions, in particular wind speed and direction, play a key role in the dispersion of pollution in the atmosphere. The air quality modelling has been carried out using one year of meteorological data (2017) from a single meteorological station (Filton Airfield). Although this meteorological station and year of meteorology are considered to be representative of conditions in Bath, conditions will vary from year to year and locally over different topographies. Figure 3-11 shows wind roses covering five years of meteorology for Filton Airfield and the next nearest meteorological station: Bristol Lulsgate. These wind roses clearly demonstrate that the dominant wind direction is west southwesterly, between 245° and 265°, and is generally consistent for all of the wind roses. Overall, the wind direction data used in the model (Filton 2017) is considered to provide a good representation of conditions in the region and this meteorological site displays little variation from year to year.

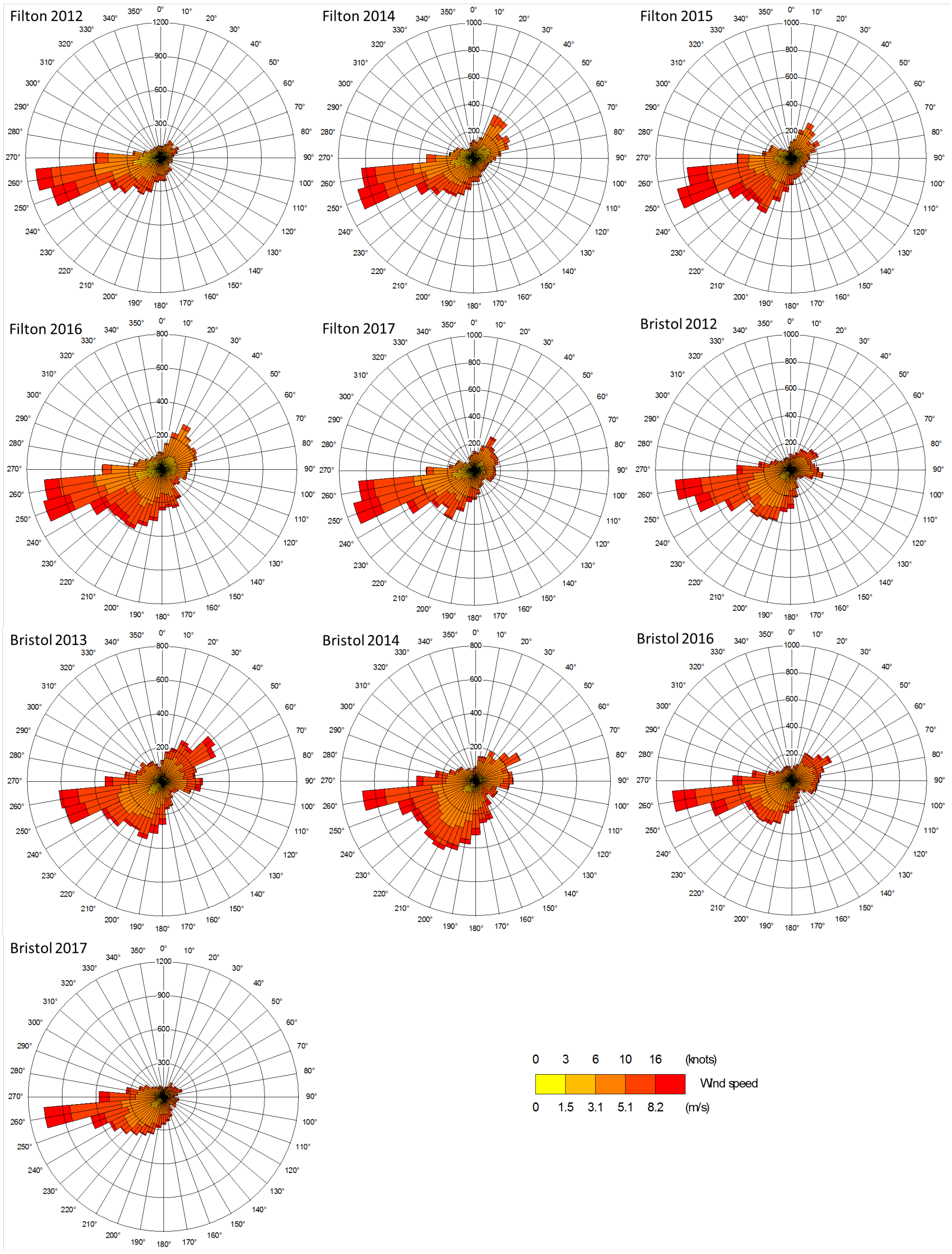

Figure 3-11: Five Years of Wind Roses for Bristol Lulsgate and Filton Airfield Meteorological Stations

3.7.2 Meteorological Parameters

The ADMS dispersion model requires a number of meteorological parameters to be set for both the meteorological station and the study area. These are: latitude, surface roughness, surface albedo, minimum Monin-Obukhov length and Priestley-Taylor parameter. The values used for these parameters have been set subjectively and there is thus scope to introduce uncertainty. The latitude has been set to the latitude of the centre of Bath and any variation from this will have an insignificant effect on predicted concentrations. The surface albedo has been set to the model default value for non-snow surfaces and the Priestley-Taylor parameter has been set to moist grassland; both of which are the default values set in the ADMS-Roads model and considered to be appropriate for this study. Model predictions can be sensitive to variations in surface roughness and minimum Monin-Obukhov length and it is thus important to use appropriate values for these parameters, as has been the case for this assessment. The minimum Monin-Obukhov length is considered to be similar for both the meteorological site and study area, so there is unlikely to be any significant uncertainty for this parameter. Surface roughness is, however, different for the two areas and the uncertainty in the values used will be increased by the difference between the values, since the difference defines how wind speed changes within the model. Although appropriate values have been used for surface roughness, it is possible though, that slightly different values could have been used and there is thus an uncertainty in the modelling associated with these. Despite this uncertainty, as the model has been verified against local monitoring in Bath, any inaccuracies in the values used for these parameters will essentially be accounted for in the model adjustment process. The remaining uncertainty will be minimal but will nevertheless contribute to the overall uncertainty in the conclusions of the assessment. To determine level of uncertainty, a sensitivity test has thus been carried out for the 2021 CAZ C + TM scenario to assess the sensitivity of the results to this uncertainty. This included modelling three scenarios with different surface roughness values.

Table 3-19 and Figure 3-11 provide details of the surface roughness values tested and a summary of statistics as requested in JAQU's 'Supplementary Note on Sensitivity Testing'. Table 3-20 then presents the compliance status for each of these scenarios as well as the 'Central' modelling. The results of the sensitivity tests for a 2021 CAZ C + TM scenario show all scenarios are compliant.

Table 3-19: Simple Summary Statistics for Sensitivity Testing of Surface Roughness (μg/m^3)

Statistic	Central	Test 1	Test 2	Test 3
Meteorological Site Surface Roughness (m)	0.1	0.2	0.1	0.2
Study Area Surface Roughness (m)	1	1	0.75	0.75
Mean	19	20	20	20
Median	19	19	19	20
Maximum	40	40	40	40
Minimum	10	10	10	10
Upper Quartile	23	24	24	24
Lower Quartile	15	16	16	16
Standard Deviation	5	5	5	5
Range	30	29	30	29

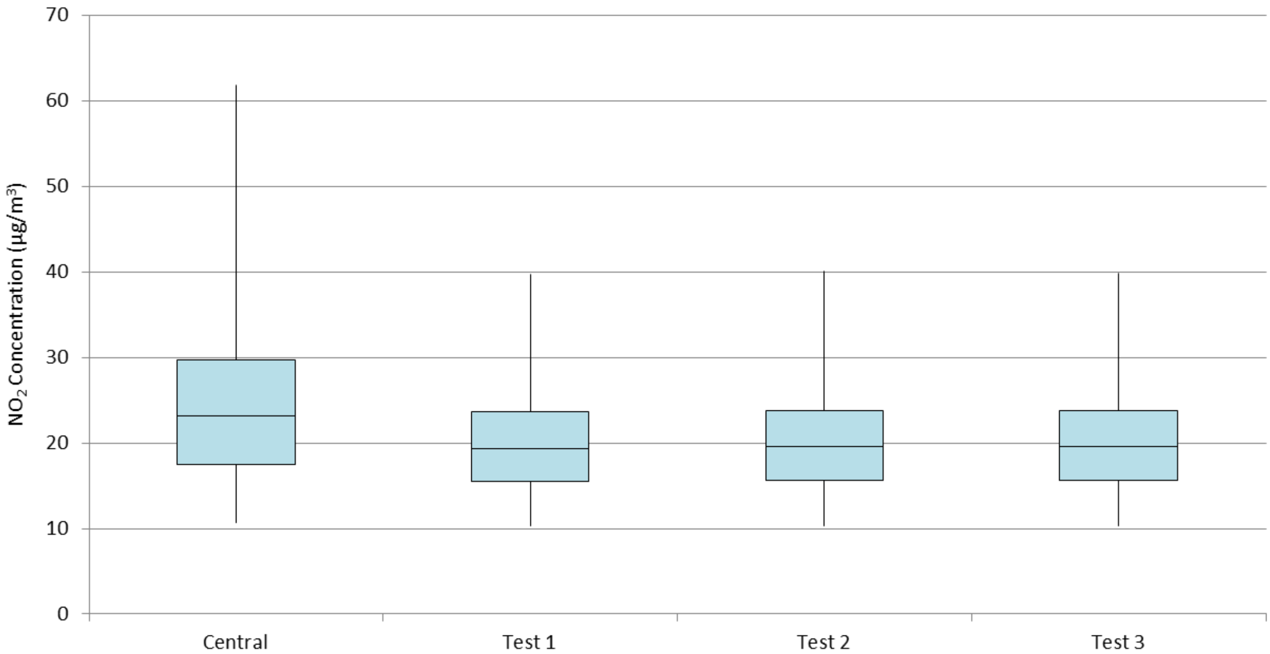

Figure 3-12: Distribution of NO_2 Concentrations for Sensitivity Testing of Surface Roughness

Table 3-20: Summary of Compliance Status for Sensitivity Testing of Surface Roughness

Statistic	Central	Test 1	Test 2	Test 3
Meteorological Site Surface Roughness (m)	0.1	0.2	0.1	0.2
Study Area Surface Roughness (m)	1	1	0.75	0.75
No. of Non-Compliance LAQM Receptors	0	0	0	0
No. of Non-Compliance PCM Receptors	0	0	0	0
Compliance Status of Road Link with Highest NO_2 Value	Compliant	Compliant	Compliant	Compliant
Maximum NO_2 Percentage Gap from Compliance (µg/m³)	-1.5	-2.2	-1.2	-1.8
Maximum Road-NO_2 Percentage Gap from Compliance (µg/m³)	-2.2	-3.3	-1.8	-2.7

3.8 Relationship of NOx and NO_2

3.8.1 Primary NO_2 Fraction

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[10]. 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 ('Central' scenario).

Table 3-21 provides a summary of statistics (as requested in JAQU's 'Supplementary Note on Sensitivity Testing') and Table 3-22 presents the compliance status for each of these scenarios as well as the 'Central' modelling. Figure 3-13 shows the distribution of the resulting NO_2 concentrations. If the f-NO_2 values are reduced by 40% then the predicted concentrations are slightly lower, with the maximum predicted concentration being 4 µg/m^3 lower than the 'Central' scenario. Although this suggests that an earlier year could be compliant if f-NO_2 values decrease, the earliest year B&NES may be able to implement a CAZ C + TM would be 2020 in any event and f-NO_2 values are unlikely to be as low as 40% of current values by 2020. On this basis, the 'Central' scenario with a 2021 compliant year is considered to be robust. It should be noted, that this is based on the assumption that current f-NO_2 values are correct. Using the f-NO_2 values from the EFT is JAQU's recommended approach.

Table 3-21: Simple Summary Statistics for Sensitivity Testing of f-NO_2 (µg/m^3)

Statistic	2021 Baseline		2021 CAZ C + TM	
	Low	Central	Low	Central
Mean	23	24	19	20
Median	22	23	19	19
Maximum	52	62	36	40
Minimum	10	11	10	10
Upper Quartile	28	30	23	24
Lower Quartile	17	17	15	16
Standard Deviation	7	8	5	5
Range	42	51	26	30

[10] Grange S. et al., (2017) Lower vehicular primary emissions of NO2 in Europe than assumed in policy projections, Nature Geoscience, pp 914-920, ISSN 1752-0908, https://doi.org/10.1038/s41561-017-0009-0

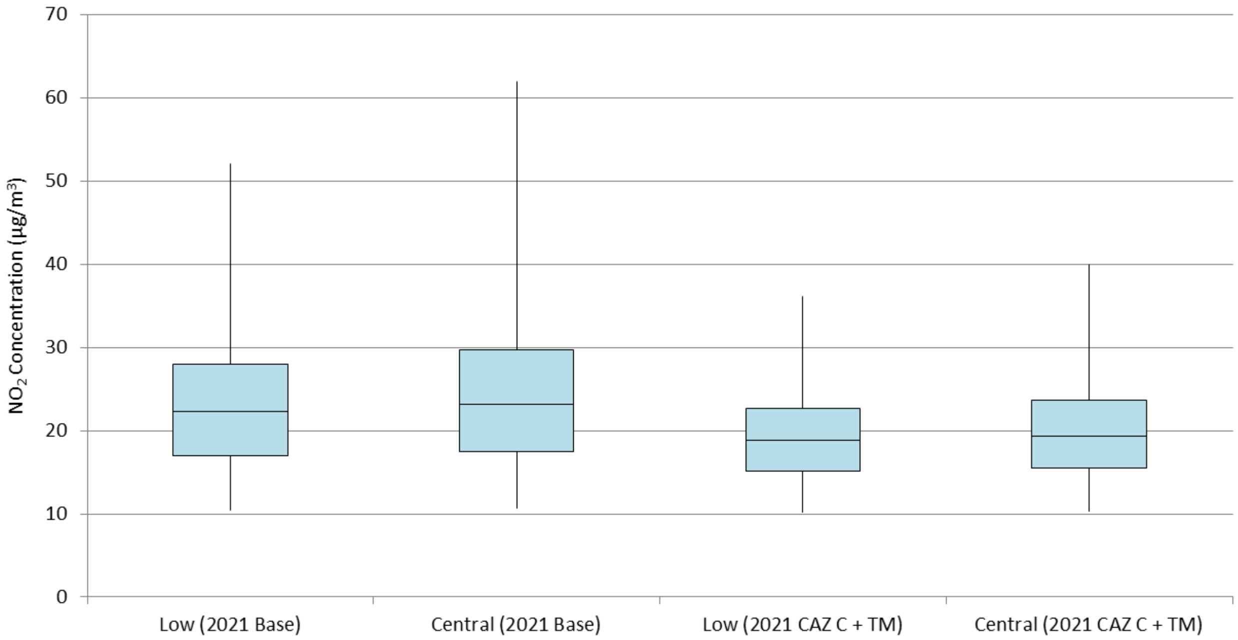

Figure 3-13: Distribution of NO_2 Concentrations for Sensitivity Testing of f-NO_2

Table 3-22: Summary of Compliance Status for Sensitivity Testing of f-NO_2

Statistic	2021 Baseline		2021 CAZ C + TM	
	Low	Central	Low	Central
No. of Non-Compliance LAQM Receptors	17	33	0	0
No. of Non-Compliance PCM Receptors	260	575	0	0
Compliance Status of Road Link with Highest NO_2 Value	Non-Compliant	Non-Compliant	Compliant	Compliant
Maximum NO_2 Percentage Gap from Compliance	22.2	34.6	-12.2	-1.5
Maximum Road-NO_2 Percentage Gap from Compliance	29.6	43.7	-19.4	-2.2

3.8.2 Regional Ozone

Defra's NOx to NO_2 Calculator[11] calculates NO_2 concentrations from NOx concentrations, based on the reactions of mixing of nitric oxide, nitrogen dioxide and ozone. This relies on tabulated concentrations of ozone above the surface layer for each local authority, which have been modelled for each year between 2015 and 2030. There is an uncertainty in these predictions. Other NOx to NO_2 approaches are available, but none are clearly more appropriate and the use of Defra's NOx to NO_2 Calculator, which is the recommended method in the JAQU guidance. This issue will contribute to the overall uncertainty in the conclusions of the assessment.

[11] Defra (2018) Local Air Quality Management (LAQM) Support Website. Retrieved from http://laqm.defra.gov.uk/

3.9 Lower uptake of Bus Retrofitting

All buses within the core modelling have been assumed to be compliant. At the request of JAQU an additional sensitivity test has been undertaken to determine the proportion of bus movements that could be non-compliant, without affecting the compliance of the scheme.

In order to consider this, the number of bus movements on each road link was adjusted within the model. This was undertaken by increasing the number of non-compliant bus movements on each link with a corresponding decrease in compliant bus movements and re-running the model.

The test has identified that the scheme will just remain compliant if approximately 2.5% of bus movements across the study area were non-compliant. It should be noted that this is the proportion of non-compliant bus movements averaged across the study area, rather than the number of buses which could remain non-compliant. The number of non-compliant buses, rather than movements, will be influenced by a number of factors including the bus routing, travel distance and time within the study area. A greater number of non-compliant bus movements could be accommodated if non-compliant buses were routed away from areas driving compliance.

3.10 Other Emission Sources

3.10.1 Non-Road Sources

Pollutant emissions from vehicles using local roads are explicitly included in the model and other sources are generally accounted for within the background concentrations. There may, however, be a number of emission sources that are not included within the background maps provided by Defra[11], and may not be fully represented in the locally measured concentrations at the background monitoring site used to calibrate the Defra maps. Such sources include centralised energy plant and generators of buildings within Bath and locomotives using the Great Western Main Line, as well as construction traffic and Non-Road Mobile Machinery (NRMM) within construction sites.

Any emissions relating to construction works for local developments will be temporary and have therefore not been explicitly included in the model. It is possible that a specific location in Bath at a particular time may be affected by a construction site. The effect is likely to be greater for particulate matter (PM), than for NO_2, although generators and Non-Road Mobile Machinery (NRMM) will increase NOx emissions in the vicinity. It is judged that the emissions from NRMM on construction sites cannot be included in the model in a robust manner, and although it is not possible to estimate any uncertainty in the resulting concentrations, the effect will be the same whether a CAZ is implemented or not. Additionally, on-site construction activities as well as dust tracked out from construction sites may have an effect on PM concentrations in close proximity to these activities. This is particularly important to consider for the PM verification, where some demolition works took place in 2017 approximately 40 m west of the Windsor Bridge automatic monitoring station, potentially causing a study-wide bias. There is no way to differentiate the measured PM concentrations between these works and road traffic emissions, but measured concentrations have remained relatively stable at this monitoring site over the past six years suggesting that these works had little influence on the measured concentrations. Construction works may cause a localised increase in PM concentrations in the future at certain locations, but it is not possible to quantify the uncertainty in the resulting concentrations and the effect will be the same whether a CAZ is implemented or not.

When considering the effect of existing centralised energy plant and generators, given that the model has been verified at 44 monitoring sites spread across Bath, it is reasonable to assume that the effect of this may be partially taken into account during the verification process. It is not possible to estimate the remaining uncertainty, but the effect will be the same whether a CAZ is implemented or not.

Emissions associated with the Great Western Main Line have been considered in the Diesel Train Emissions Technical Note. It is considered that using current Defra emissions factors will overstate the contribution from trains (and hence underestimate any modelled air quality impacts of the Clean Air Zone scenarios). Although emissions factors as published by Hobson and Smith (2001) could be used, there are no emissions factors published or endorsed by Defra which are considered appropriate to accurately reflect emissions from diesel trains, and current evidence suggests that at locations relevant to the Limit Values or air quality objectives, the contribution from diesel trains is likely to be minimal. Electrification of the Great Western Main Line will reduce the contribution from trains to nitrogen dioxide concentrations in the near future.

3.11 Summary

The sensitivity testing undertaken for CAZ C + TM shows that the scheme is compliant in every test in relation to PCM receptors. Where the scheme is non-compliant this is at only one to four LAQM receptors.

4. Impact of a Simultaneous CAZ in Bristol

4.1 Overview

Like B&NES, Bristol City Council (BCC) is one of the 28 English local authorities that have been directed by the UK Government to produce a Clean Air Plan to set out how levels of NO_2 air pollution will be reduced. As a result, Jacobs are assessing and designing a Clean Air Plan for BCC, potentially including a Clean Air Zone. Alternative boundaries are being considered, the largest of which is a “medium” size CAZ that approximately covers the area shown in Figure 4-1.

The implementation of an additional CAZ in Bristol alongside the proposed Bath CAZ would likely influence drivers beyond what had been considered in the core scenario. Drivers of non-compliant vehicles who regularly travel between Bristol and Bath (in either direction) would be more likely to change their behaviour if they faced the possibility of being charged in two cities instead of one.

Figure 4-1: Provisional Medium Clean Air Zone Boundary for Bristol[12]

It is expected that a proportion of drivers of non-compliant vehicles in Bath could enter the Bristol CAZ and Bath CAZ on the same day. As both CAZs would have separate charging systems, the current expectation is that these drivers would pay a separate charge for each zone. Therefore, this analysis aims to estimate how many drivers would be affected by simultaneous CAZs in Bath and Bristol, and how it might impact the success of the clean air zone in Bath.

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The following sections will analyse data acquired from various sources to estimate the effects of a simultaneous CAZ in Bristol, assuming the medium boundary shown in Figure 4-1. First, Census Travel to Work data will provide information regarding how many people regularly commute between these two proposed zones, and how many of them chose to make the journey in their private vehicle. Secondly, responses from Stated Preference surveys conducted on drivers in Bath and Bristol will be analysed to estimate how many, and how often, drivers travel into one or both CAZ regions. A final analysis will use records from automatic number plate recognition (ANPR) cameras in Bristol and Bath to understand more about the composition of vehicles that travel into both city centres most frequently.

4.2 Analysis of Census Data

The Office for National Statistics' 2011 Census provides information on commuting trips between Bath and Bristol. This analysis utilizes the census travel to work dataset WU03EW, which records individuals' place of residence, workplace, and travel mode to and from work. Locations are organized into zones known as Middle Layer Super Output Areas (MSOAs). As seen in Figure 4-2, eleven MSOAs are located mainly within the Bristol CAZ boundary and two within the Bath CAZ Boundary. These zones (highlighted in red) were used for analysis. Note that one of the selected MSOAs in Bath has a large area outside of the Bath CAZ boundary; however, this area is largely undeveloped, with most of its population residing within the boundary.

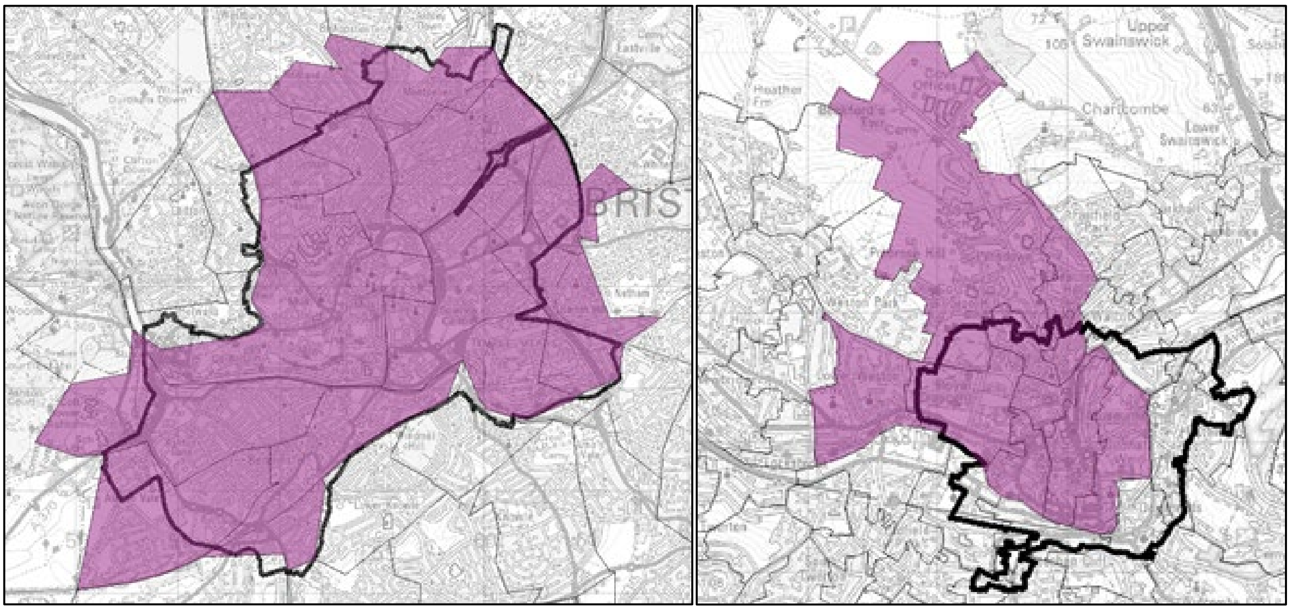

Figure 4-2: Map of MSOAs selected for analysis in Bristol (left) and Bath (right) with CAZ boundaries[13]

According to the 2011 Travel to Work data (dataset WU03EW), the combined population of the MSOAs in the Bath and Bristol CAZ regions was 59,010, and 33% of them drove a car or van to travel to work. 763 of these residents commuted between one CAZ region and the other, and 28% of them chose to drive. The results are shown for the Bristol and Bath CAZ regions individually in Figure 4-3.

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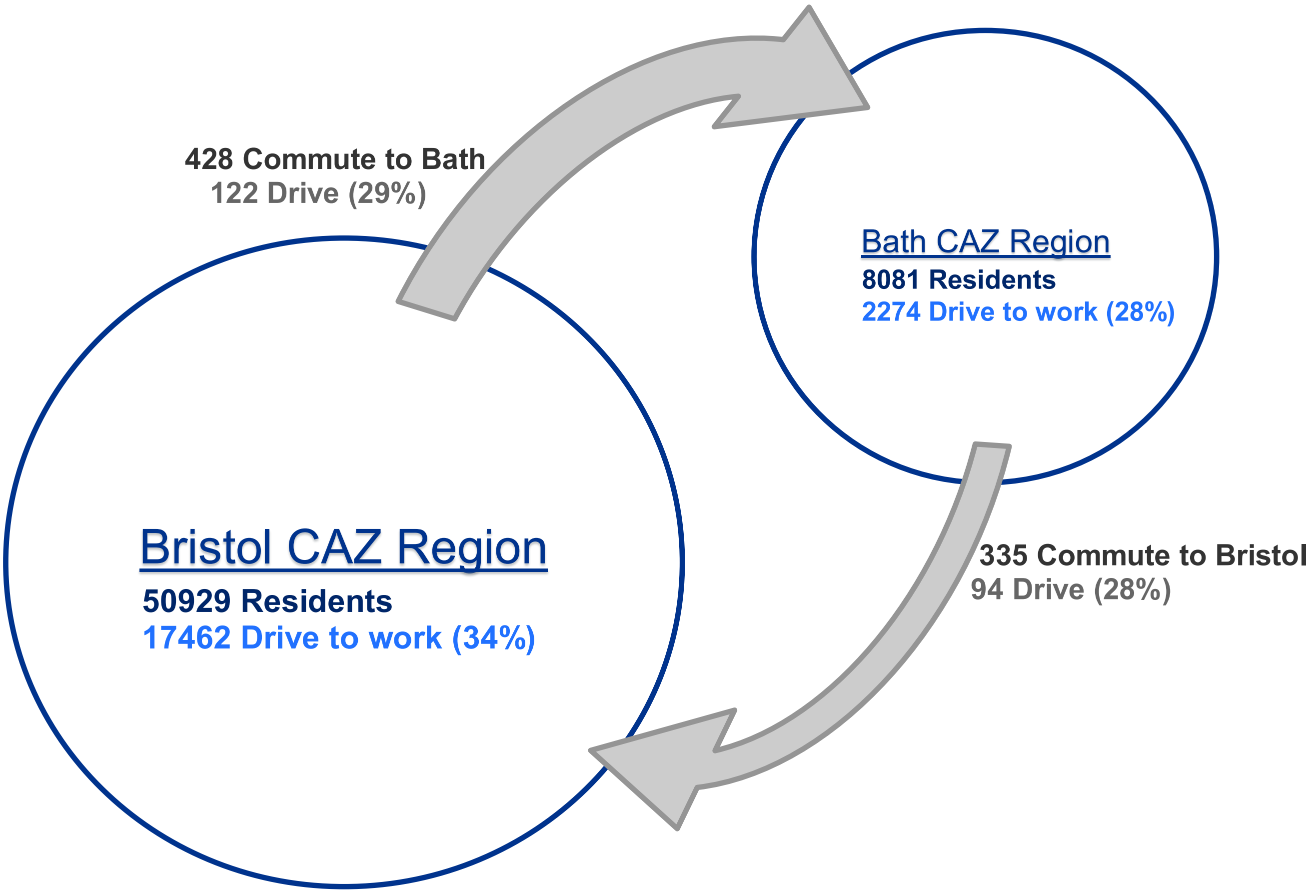

Figure 4-3: Representation of Census Data for Residents of MSOAs near Bath and Bristol CAZ

The census data shows that only 4% of Bath CAZ residents (335 of 8081) commute to the Bristol CAZ region, likewise only 0.8% of Bristol CAZ residents (428 of 50929) commute to the Bath CAZ region. When considering only those that drive to work, these proportions are lower at 3% for Bath drivers and 0.7% for Bristol drivers. Therefore, at least 3% of drivers who are residents of the Bath CAZ region will be affected by a simultaneous CAZ in Bristol. In reality, the implementation of clean air zones affects far more than just those who live and work within their boundaries. For example, a resident of Bathampton who travels to Clifton in Bristol may drive through both CAZs even though their journey does not begin or terminate in a CAZ. The effects of simultaneous CAZs on the wider driving population will be explored further in section 4.3.

4.3 Analysis of Stated Preference Survey Data

Two stated preference (SP) surveys were previously conducted to better understand the travel behaviour and preferences of drivers who would be affected by CAZs in Bath or Bristol. One survey focused on the proposed Bath CAZ, while another focused on the proposed Bristol CAZ. Both surveys included questions related to the possibility of a simultaneous CAZ in the other region, and the results from these questions can provide another perspective on the impact of a second CAZ. These surveys were restricted to drivers who:

1) Are residents of Bath, Bristol, or the surrounding local authorities
2) Own and drive a non-compliant car or LGV under 3.5t
3) Are responsible (solely or jointly) for decisions regarding the replacement of their vehicle
4) Use their vehicle within the Bath CAZ boundary at least once every six months (for the Bath survey) or within the Bristol CAZ boundary at least once every six months (for the Bristol survey).

Due to these restrictions, the data from the SP Surveys can provide insight into the impacts for those who would be most directly impacted by a clean air zone and are therefore most instrumental to the success of the scheme. After filtering out any questionnaires that were flagged during sense checks as illogical, there were 1,050 valid questionnaires for the Bath survey and 943 for the Bristol survey. For this assessment, the following questions from these surveys will be analysed:

In the Bath Survey:

- “In general, how often do you use your vehicle in this area of Bath?” (image of CAZ boundary given)
- “In general, how often do you use your vehicle in Bristol City Centre?”

In the Bristol Survey:

- “In general, how often do you use your vehicle in this area of Bristol?” (image of CAZ boundary given)
- “In general, how often do you use your vehicle in Bath City Centre?”

Respondents of both surveys were provided with images of their respective region’s CAZ boundary, which are similar to those shown in Figure 4-2. Respondents were not shown the CAZ boundary of the other region. Therefore, in this analysis, “Bristol City Centre” is assumed to be equivalent to the Bristol medium CAZ, while “Bath City Centre” is assumed to be equivalent to the Bath CAZ. While both surveys had respondents from both regions, quotas were set for each survey so that most respondents were residents of the survey’s respective region. Furthermore, respondents were not eligible to take a particular region’s survey unless they drove within that region’s CAZ at least once every 6 months. Therefore, the Bath SP survey will provide a better representation of those affected by a Bath CAZ, and likewise for the Bristol SP survey.

For each of the above questions, respondents could choose various frequencies between “less than once every 6 months” and “6-7 days per week”. The results from these questions are summarized in Table 4-1 for the Bath survey and Table 4-2 for the Bristol survey.

These tables reveal how driving behaviour is different for the two survey populations. For the Bath survey, the results in Table 4-1 tended towards a central diagonal, with respondents driving into the Bath and Bristol CAZ with equal frequency. On the other hand, results from the Bristol survey in Table 4-2 tended more towards Bristol (top left) than Bath. A further analysis of these results, as seen in Figures 4-4 and 4-5, found that Bath SP Survey respondents indeed travel into Bristol more frequently than Bristol SP survey respondents travel into Bath. This suggests that residents affected by the Bath CAZ are more likely to be affected by a simultaneous CAZ in Bristol than the other way around. Furthermore, Figure 4-4 shows that Bath respondents drive into the Bristol CAZ just as often as they drive into the Bath CAZ, and will therefore be equally affected by both. For Bristol respondents (Figure 4-5), however, the Bristol CAZ will have a significantly higher effect than the Bath CAZ. This is likely because the Bristol CAZ covers a much larger area and attracts a larger proportion of traffic from the surrounding areas.

Table 4-1: Bath SP Survey Responses (1050 Total)

		Trip Frequency to Bristol CAZ										
		Less than once every 6 months	About once every 6 months	About once every 4-5 months	About once every 2 months	About once a month	About once a fortnight	1 day a week	2 days a week	3-4 days a week	5 days a week	6-7 days a week
Trip Frequency to Bath CAZ	Less than once every 6 months	0	0	0	0	0	0	0	0	0	0	0
	About once every 6 months	10	23	9	8	9	5	4	0	3	1	1
	About once every 4-5 months	8	3	15	4	6	8	2	0	2	0	1
	About once every 2 months	4	10	5	28	16	22	1	3	4	3	0
	About once a fortnight	17	6	2	13	53	18	8	3	10	7	6
	About once a month	2	1	1	6	14	40	13	6	5	16	0
	1 day a week	3	1	0	3	13	6	41	20	31	7	2
	2 days a week	1	3	0	2	3	11	23	54	29	9	1
	3-4 days a week	3	1	4	1	4	13	10	26	63	11	1
	5 days a week	1	1	1	5	8	5	7	15	14	66	3
	6-7 days a week	3	0	0	0	3	3	6	4	12	3	25

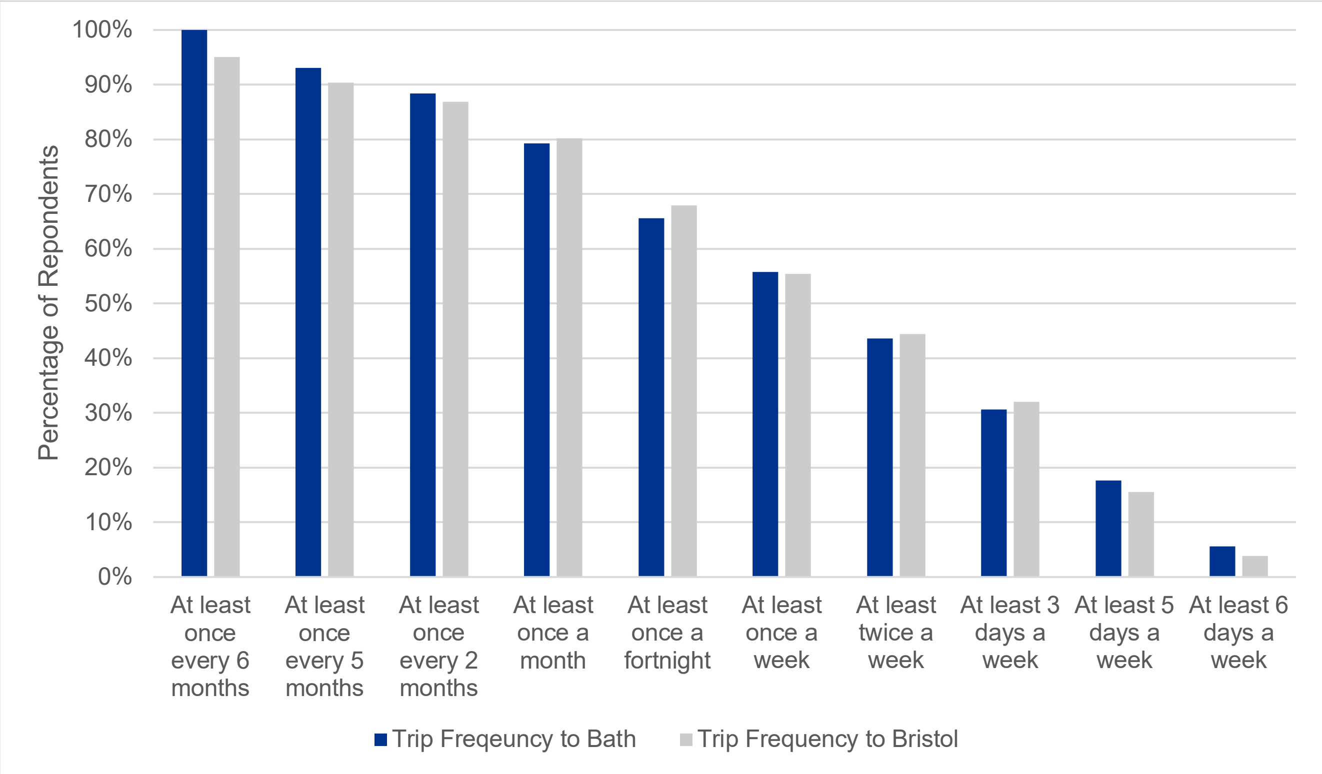

Figure 4-4: Comparison of Trips to Bath and Bristol according to Bath SP Survey Respondents

Table 4-2: Bristol SP Survey Responses (943 Total)

Trip Frequency to Bath CAZ	Trip Frequency to Bristol CAZ: Less than once every 6 months	About once every 6 months	About once every 4-5 months	About once every 2 months	About once a month	About once a fortnight	1 day a week	2 days a week	3-4 days a week	5 days a week	6-7 days a week
Less than once every 6 months	0	22	20	17	19	10	6	9	12	6	8
About once every 6 months	0	14	20	8	9	10	4	2	3	5	3
About once every 4-5 months	0	3	14	8	10	5	2	3	7	2	2
About once every 2 months	0	3	2	15	13	13	5	4	4	5	4
About once a fortnight	0	3	1	8	29	18	11	9	16	10	7
About once a month	0	0	0	5	8	19	9	7	16	9	6
1 day a week	0	1	0	4	2	7	27	9	8	7	3
2 days a week	0	0	0	0	3	6	19	67	27	8	5
3-4 days a week	0	0	0	2	3	0	0	29	68	19	7
5 days a week	0	0	0	1	0	1	2	10	10	37	2
6-7 days a week	0	0	0	0	0	2	2	3	0	1	19

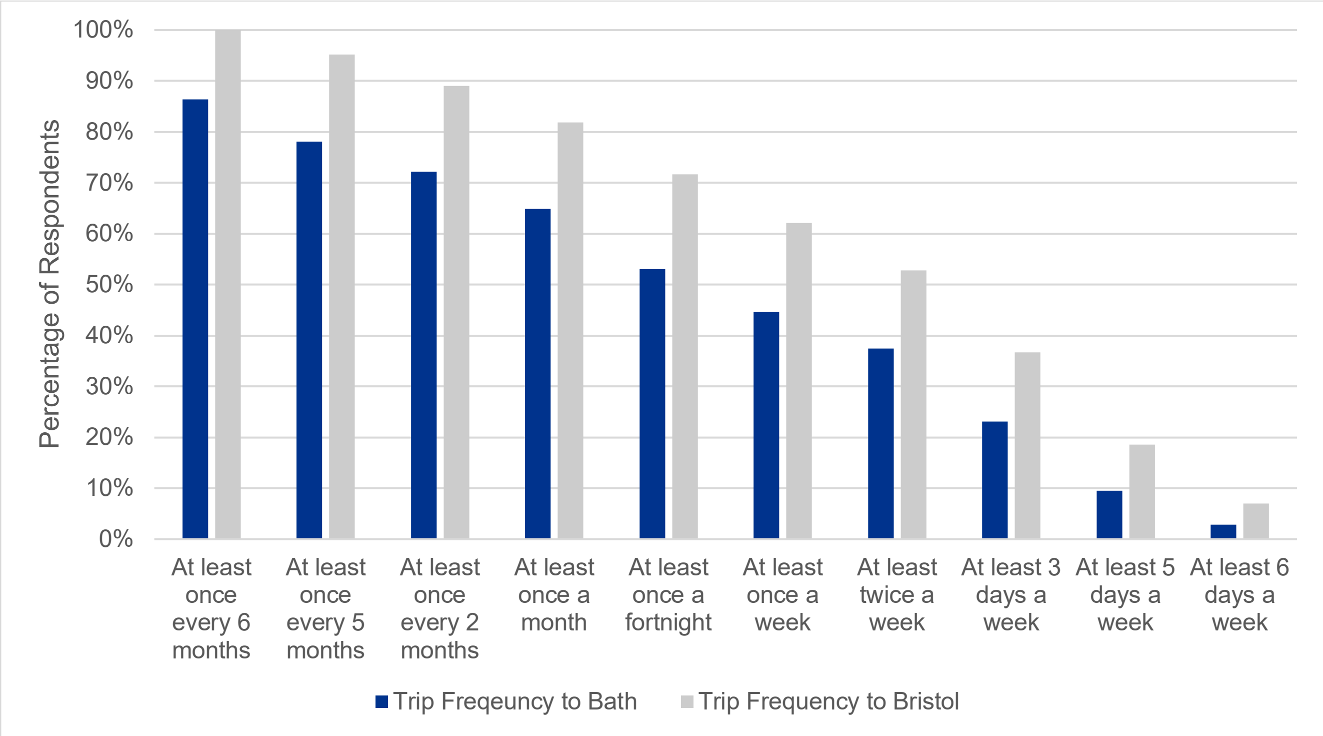

Figure 4-5: Comparison of Trips to Bath and Bristol according to Bristol SP Survey Respondents

Responses from the two SP surveys were further analysed to determine how often respondents drive to both regions regardless of which survey they initially took part in. Respondents were split into Car and LGV drivers to see how their behaviours would differ. Results from this analysis are shown in Figure 4-6.

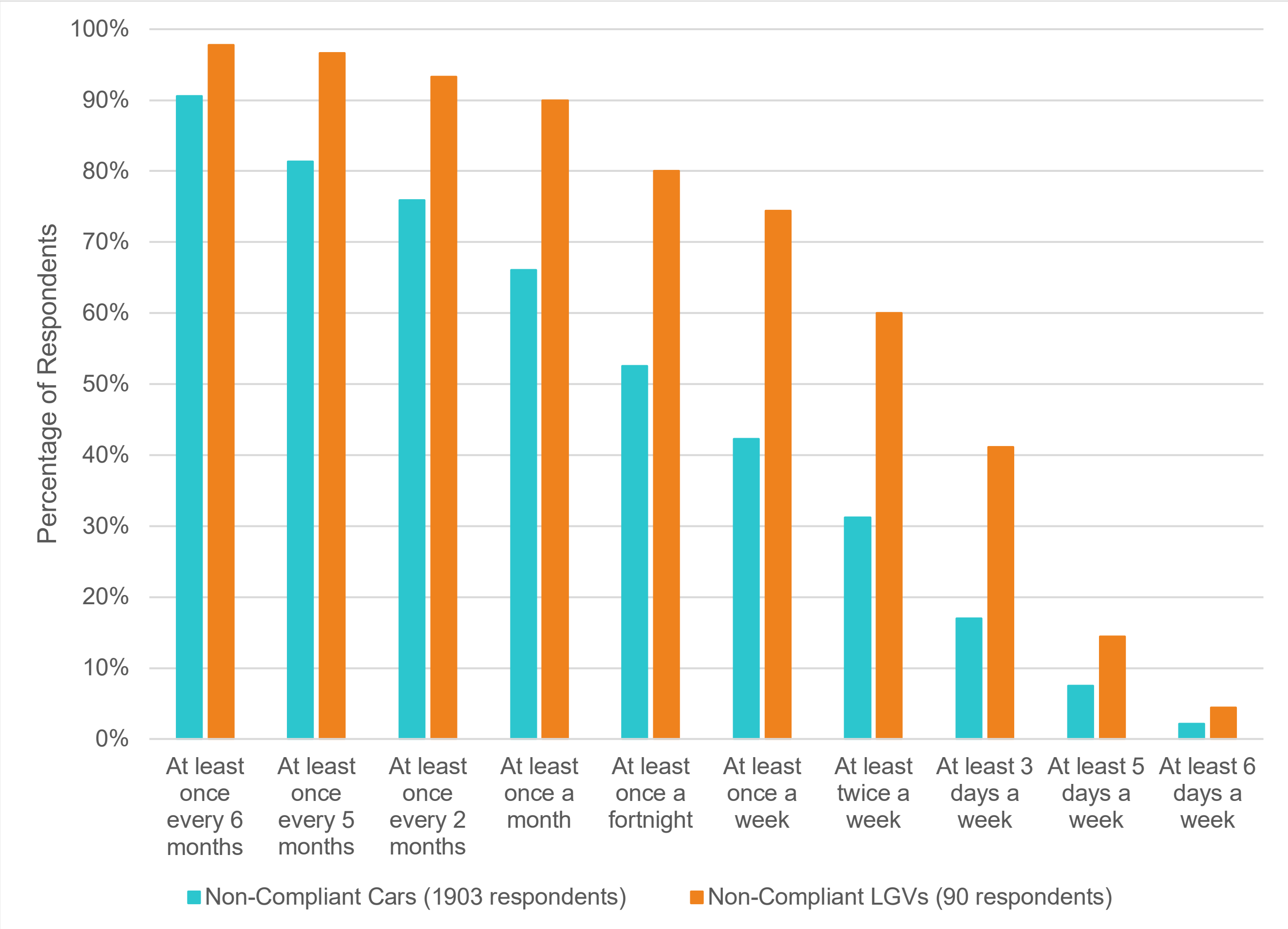

Figure 4-6: Percentage of Non-Compliant Car and LGV Drivers that Travel to Both Clean Air Zones

It should be noted that the survey did not ask respondents if or how often they drive to both CAZs on the same day. However, Figure 4-6 shows that 17% of car drivers and 41% of LGV drivers travel through both CAZ regions at least 3 times per week. As this is more than half of the work week, these drivers are likely to enter both CAZs on the same day at least once per week.

It should be also be noted that the survey shows a higher percentage of LGVs travelling between Bristol and Bath on any given day compared with cars. This is most likely due to the nature of journeys by vehicle type: LGV's are more likely to be used for trips which may involve more journeys across the boundaries on a given day whereas cars are likely to be used for commuting and crossing the boundaries once a day (i.e. from Bath to Bristol in the morning and returning in the evening). In addition, LGVs are used more for carrying goods, whereas commuters may be more inclined to use other forms of transport (i.e. trains, buses) to avoid issues such as car parking costs and peak-hour congestion.

4.4 Analysis of ANPR Data

Automatic Number Plate Recognition (ANPR) is a technology that can capture number-plates of vehicles travelling through a specific site and is commonly used for toll collection, police enforcement and surveying traffic patterns.

ANPR data was collected by Jacobs to study the fleet composition of traffic in Bath and Bristol. In Bath, the ANPR surveys were undertaken for a two-week period from 31/10/2017 to 13/11/2017 (14 days). In Bristol, data was collected from both permanent ANPR stations maintained by Bristol City Council and a separate survey commissioned by Jacobs. Permanent ANPR data was available for the months of June 2017 and July 2017 (61 days), and the survey was carried out for one week between 18/07/2017 and 24/07/2017 (7 days).

The ANPR camera locations were initially selected to capture both traffic into the city centre and traffic through key routes outside the city centre. For this analysis, only sites that captured traffic entering the CAZs or within CAZs were considered. As ANPR captures the unique identity of vehicles passing them, their data can be used to match registrations of vehicles that travelled through Bath's future CAZ with those that travelled through Bristol's future CAZ.

A grand total of 238,141 unique number-plates were captured in Bath during their 14-day study, of which 80,133 were also captured in Bristol. For each number plate, a record was created for each day that a vehicle passed through an ANPR site within a given CAZ boundary. Individual number-plates could have a maximum of one record per boundary per day, so any number-plate could have a maximum of 14 appearances in the Bath CAZ and 61 appearances in the Bristol CAZ. Table 4-3 shows how many number plates are associated with different ranges of appearances within each CAZ boundary. Note that in this table, appearances in Bath can be approximated into number of days per week, however, appearances in Bristol cannot due to the different timescales of the data from Bristol City Council and the survey.

Table 4-3: Count of Number Plates Detected According to Number of Appearances in Each CAZ Region

		Appearances in Bristol CAZ Region (days)							
		None	1 – 7	8 – 15	16 - 23	24 - 31	32 - 41	42 - 51	52 - 61
Appearances in Bah CAZ Region	1 - 2 (approx. 1x per week)	118,025 (50%)	36,574 (15%)	6,715 (3%)	3,350 (1%)	2,221 (1%)	2,063 (1%)	1,123 (0%)	511 (0%)
	3 - 4 (approx. 2x per week)	15,864 (7%)	7,735 (3%)	1,115 (0%)	525 (0%)	368 (0%)	357 (0%)	170 (0%)	68 (0%)
	5 - 6 (approx. 3x per week)	8,236 (3%)	4,636 (2%)	521 (0%)	242 (0%)	165 (0%)	119 (0%)	57 (0%)	17 (0%)
	7 - 8 (approx. 4x per week)	5,931 (2%)	3,408 (1%)	380 (0%)	135 (0%)	94 (0%)	68 (0%)	55 (0%)	7 (0%)
	9 - 10 (approx. 5x per week)	5,096 (1%)	2,895 (1%)	296 (0%)	113 (0%)	72 (0%)	89 (0%)	51 (0%)	13 (0%)
	11 -12 (approx. 6x per week)	3,252 (1%)	2,103 (1%)	150 (0%)	64 (0%)	34 (0%)	42 (0%)	26 (0%)	13 (0%)
	13 - 14 (approx. every day)	1,604 (1%)	1,186 (0%)	100 (0%)	38 (0%)	17 (0%)	11 (0%)	9 (0%)	12 (0%)

Due to the different timescales of the ANPR studies, the numbers on table 4-3 cannot be used to make conclusions about how often drivers travel to one CAZ in relation to the other. Furthermore, vehicles occasionally pass ANPR cameras undetected, and the image processors sometimes misread the number plates. These limitations are likely to cause a significant underestimation of the number of drivers that travel to one or both CAZs multiple times. Therefore, the results from this data are not directly comparable to the results from the SP survey or Census data.

Even though this ANPR data is not reliable for determining how *many* drivers travel to the CAZ regions at different frequencies, it is useful for examining the *composition* of vehicles depending on how often they enter both regions. For the ANPR studies, all the recorded number-plates were cross-referenced with records from the DfT to gain information on vehicle types, fuel types, and emissions standards. This information was used to determine which vehicles would be considered non-compliant according to the rules of the clean air zone. Using this data, the proportion of non-compliant vehicles was determined for each of the subsets given in Table 4-3, and the results are shown in Table 4-4

Table 4-4: Percentage of all Vehicles that are Non-Compliant According to Number of Appearances in Each CAZ

		Appearances in Bristol CAZ Region							
		None	1 – 7	8 – 15	16 – 23	24 – 31	32 – 41	42 – 51	52 - 61
Appearances in Bah CAZ Region	1 - 2 (approx. 1x per week)	51%	53%	54%	57%	57%	57%	57%	64%
	3 - 4 (approx. 2x per week)	50%	53%	59%	58%	60%	66%	66%	54%
	5 - 6 (approx. 3x per week)	50%	54%	58%	63%	56%	63%	55%	65%
	7 - 8 (approx. 4x per week)	51%	52%	51%	61%	61%	64%	58%	86%
	9 - 10 (approx. 5x per week)	51%	52%	60%	54%	69%	62%	51%	69%
	11 -12 (approx. 6x per week)	50%	51%	58%	45%	71%	55%	65%	69%
	13 - 14 (approx. every day)	50%	53%	66%	61%	47%	64%	89%	83%

According to Table 4-4, vehicles that travel through the future CAZ boundaries more often are more likely to be non-compliant, with the highest non-compliance ratios associated with the highest number of appearances. Further analysis determined average non-compliance ratios of 52% overall, 54% for vehicles detected in both CAZs at least once, and 62% for vehicles detected in both CAZs at least half of the days in each study (at least 7 for the Bath study, at least 32 for the Bristol study). A similar analysis was performed based on fuel type and vehicle type, with results shown in Table 4-5.

Table 4-5: Vehicle Characteristics According to Number of Appearances in Bath CAZ and Bristol CAZ

Vehicle Characteristic	All Vehicles Detected in Bath CAZ	Vehicles detected in both Bath CAZ and Bristol CAZ at least once	Vehicles detected in both Bath CAZ and Bristol CAZ at least half of the days in the study
Non-compliant	52%	54%	62%
Diesel	54%	59%	70%
Car	84%	80%	63%
LGV	11%	14%	22%
HGV	4%	5%	8%
Bus or Coach	0.4%	0.5%	5.9%

The data from Table 4-5 can be used to show the composition of vehicles that would most likely be affected by both CAZs. If a vehicle enters both CAZs at least half of the number of days in the ANPR studies, then it is assumed that vehicle is likely to often enter both CAZs on the same day.

The table also shows that of all the vehicles travelling between Bath and Bristol at least half of the number of days in the ANPR studies, they are more likely to be non-compliant or diesel. They are also twice as likely to be an LGV or HGV and are over ten times more likely to be a bus or coach.

4.5 Discussion and Conclusion

The core scenario utilised results from the Bath SP survey to estimate avoidance rates, upgrade rates, and journey cancellation / mode change rates based on fixed charges in Bath only. An additional CAZ in Bristol would likely have a significant impact on these response rates: an analysis of Bath SP survey responses revealed that on average, drivers from around Bath drive into Bristol City Centre as often as they drive into Bath City Centre. Therefore, it is estimated that the impact of a Bristol CAZ on local drivers would be equal to that of the Bath CAZ. This was not the same for respondents of the Bristol SP survey: for those drivers, the impact of the Bath CAZ would be significantly less than that of the Bristol CAZ.

An analysis of 2011 census data revealed that approximately 28% of regular commutes between Bath and Bristol city centres occur by private vehicle. The ANPR data suggests that approximately two-thirds of these vehicles would be non-compliant and therefore be charged to enter a CAZ. If another CAZ were to be introduced in Bristol, then these commuters could face being charged on both ends of their journey, and therefore be up to twice as likely to change their behaviour. However, it should be noted this dataset mainly relates to cars which wouldn't be charged with a CAZ C + TM.

A statistical analysis of the SP survey (found in FBC-30 Stated Preference Survey in Appendix L of the FBC) revealed that if faced with higher charges, more drivers would change their travel mode, route, or vehicle. Therefore, it is likely that a simultaneous CAZ in Bristol will lead to an underestimate in the core scenario's assumptions regarding upgrade rates, avoidance rates, and the overall reduction in trips made by non-compliant vehicles. As a result, it is estimated that a simultaneous CAZ in Bristol would lead to a reduction in emissions and NO_2 concentrations from the core scenario model.

Since the preferred scheme is a CAZ C + TM, the above conclusions are still valid, especially since the data indicates that LGV's, HGV's and buses/coaches are more likely to frequently travel in both Bristol and Bath.

5. Results Summary Table

For all sensitivity tests, a summary and key results is provided in Table 5-1 below:

Table 5-1: Summary of sensitivity analysis

Test	Section Number	Summary	Key Results
Uncertainties in the Traffic Modelling			
Uncertainties in the Transport Model at the National Level	2.2	Defined high and low growth scenarios based on WebTAG guidance. Compared emissions and NO_2 concentrations to core scenario (CAZ C + TM) and Baseline (no CAZ).	The interzonal matrix totals in the high and low scenarios differed from the core scenario by ±4.68%. The CAZ C + TM high scenario is compliant at all receptors. All baseline scenarios were non-compliant.
Fleet Composition: Splits by Fuel Type	2.3.1	Defined alternative scenario based on using fuel type splits from the DfT's WebTAG databook instead of the Bath ANPR study. Compared emissions and NO_2 concentrations to core scenario.	Compared to the core scenario, the WebTAG data had a slightly higher proportion of cars that were diesel and a slightly lower proportion of LGVs that were diesel. The WebTAG scenario was compliant at all PCM-equivalent receptors and non-compliant at one LAQM receptor by 0.2 µg/m^3 (0.6%)
Fleet Composition: Splits by Euro Emissions Standard, Comparison of EFT Option 1 and Option 2	2.3.2	Defined alternative scenario based on using future euro emissions standard splits developed using option 2 of the EFT's fleet projection tool instead of option 1. Compared resulting non-compliance ratios to the core scenario.	Option 2 consistently gave lower future non-compliance ratios than option 1 and occasionally gave unrealistic results. No air quality analysis was performed because the core scenario was already based on the more conservative option.
Fleet Composition: Splits by Euro Emissions Standard, High and Low Fleet Renewal	2.3.3	Defined high and low scenario based on 2020 and 2022 projections, respectively, instead of the 2021 projections used in the core scenario. Compared emissions and NO_2 concentrations to core scenario (CAZ C + TM) and baseline (no CAZ).	Later years had higher proportions of Euro 6c (cars and LGVs) or Euro 6 (HGV, buses, coaches) and lower proportions of all other categories. The CAZ C + TM high scenario was compliant at all PCM-equivalent receptors and non-compliant at one LAQM receptor by 0.2µg/m^3 (0.5%). All baseline scenarios were non-compliant.
Behavioural Reponses to Charging	2.4	Defined pessimistic and optimistic response rates based on confidence intervals of SP survey statistical modelling and adjusted assumptions for other vehicle types. Compared emissions and NO_2 concentrations to core scenario.	Pessimistic and optimistic scenarios differed the most for LGVs and HGVs as their response rates were the most uncertain. The CAZ C + TM high scenario was compliant at all PCM-equivalent receptors and non-compliant at one LAQM receptor by 0.4µg/m^3 (1%). All baseline scenarios were non-compliant

Uncertainties in the Air Quality Modelling			
Differential Bias	3.1.1	Model outputs have been verified and adjusted based on the bias across the current vehicle split, which is likely to be different in future.	It is not possible to quantify the overall effects of model-specific bias in the EFT without referring to alternative emissions models or emissions test data.
Euro 6 Vehicles	3.1.2	The EFT is based on COPERT 5 which predicts different NOx emissions from Euro 6 diesel vehicles registered in different years (based on the expectation that Euro 6 emissions will reduce over time). Sensitivity test outlined in JAQU's 'Supplementary Note on Sensitivity Testing' has been run.	The High scenario would cause non-compliance at 4 LAQM receptors. All PCM receptors are compliant. The central scenario lies closer to the High scenario than the Low scenario.
Diesel LGV Emissions	3.1.3	The EFT is based on COPERT 5. However, COPERT 5 has not updated pre-Euro 5 vehicles. Pre-Euro 5 diesel LGV emission factors in the EFT are lower than Euro 5 and 6 emission factors, which are considered to be unrealistic since older vehicles are typically more polluting.	Emissions for pre-Euro 5 Diesel LGVs have been increased. The CAZ C + TM is compliant in all scenarios while all baseline scenarios were non-compliant.
Lower Uptake of Compliant LGVs	3.1.4	A 20% reduction in the uptake of compliant LGVs was tested.	The CAZ C + TM is compliant in this scenario
Inappropriate Emissions Groupings	3.1.5	CAZ definition of compliant and non-compliant vehicles is based on the fundamental assumption that compliant vehicles will emit less NOx than non-compliant vehicles. As a fleet-weighted average, this is expected to be the case, but on an individual vehicle basis, it often will not be.	It is not possible to carry out any sensitivity testing of this issue and is accepted to contribute to the uncertainty in the conclusions of the assessment.
Engine Size and Weight	3.1.6	The EFT contains default vehicle size distributions, which specify the proportion of passenger cars with different engine sizes and the proportion of LGVs and HGVs with different kerb weights. Low and High vehicle size distribution scenarios have been modelled (whereby vehicles are moved to a different size group within the vehicle type classification within the EFT)	Neither the 'High' or 'Low' scenario impacts on compliance (in both scenarios the CAZ C + TM is compliant).
Average Speed Emissions Factors	3.2.1	The EFT provides emissions for different vehicle types which vary based on the average vehicle speed. An average speed of, say, 20kph could be achieved in a number of different ways (i.e. accelerating from 0kph, stop start driving, decelerating from a higher speed or driving at a constant 20kph) which will have different emissions associated with them.	It is not possible to carry out any sensitivity testing of this issue and is accepted to contribute to the uncertainty in the conclusions of the assessment.

Emissions at Low Speeds	3.2.2	Roads with queuing traffic or lots of start/stop 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. The speeds in the traffic model are based on the average speed along a road. In reality, the speed will very often be slower at the start and end of a road and faster in the middle. JAQU has set out a methodology to assess the uncertainty of emissions from vehicles travelling at low speeds in their 'Supplementary Note on Sensitivity Testing' which involves using a polynomial equation provided by JAQU which is based on using the COPERT emissions functions beyond their intended speed ranges.	Neither the 'High' or 'Low' scenario impacts on compliance (in both scenarios the CAZ C + TM is compliant).
Background Concentrations	3.3	The background pollutant concentrations across the study area have been defined using the national pollution maps published by Defra, calibrated against local measurements made at a single background diffusion tube monitoring site in Bath in 2017. There may be inaccuracies in the measurements, or the site may be affected by some unidentified local emission source. To test the sensitivity of the results to this issue, NO_2 concentrations have been predicted for 2021 for both the baseline and CAZ C + TM scenarios, with and without the local calibration applied to the background concentrations.	Without a local calibration factor being applied to Defra's national pollution maps, the predicted concentrations are generally lower than if backgrounds are calibrated, but the maximum concentration is marginally higher and non-compliant at one LAQM receptor by 0.1 µg/m^3 (0.2%). The scheme is compliant at all PCM-equivalent receptors.
Model Verification	3.4	The model verification for NOx and NO_2 concentrations has been investigated in detail. A large number of parameters have been investigated. As set out in the Technical Note on Gradient Emissions in Appendix 1 of FBC-11 'AQ3 Air Quality Modelling Report' in Appendix D of the OBC, the only parameter that was found to have a systematic effect on the verification was the combined percentage of light goods vehicles and heavy duty vehicles on hilly roads adjacent to monitoring sites. Verification for PM_{10} is based on a single monitoring site, and there is thus a significant amount of uncertainty around the adjustment factor.	Since no other correlations were found, there is no justification for sensitivity testing the verification for any other parameters for NOx and NO_2. For PM_{10} it is judged that compliance is the likely scenario.

Receptor Locations	3.5	There is uncertainty around the LAQM receptor locations being worst case. A height of 1.5m has been used, which could be interpreted differently in different situations. NO_2 concentrations have been predicted at intervals of 0.5m from a height of 0 m to 12 m at three receptor locations.	The predicted concentrations fall off with height, thus if there is relevant exposure higher than 1.5m then concentrations will be lower and thus compliant with a 2021 CAZ C + TM scheme. Below 1.5m concentrations remain very similar to those predicted at 1.5m and all concentrations remain compliant.
Road Widths and Geometries	3.6.1	Road widths and geometries have been included in the model manually. Although this is time consuming, this is judged to be the most accurate way of reflecting a complex local situation within the model.	Because of the large numbers of roads and street canyons, within the model, any disparity in interpretation is unlikely to be standard across the whole modelled network. There is no objective basis for testing the effect of this issue and this will contribute to the uncertainty in the conclusions of the assessment.
Road Gradients	3.6.2	Vehicle emissions on gradients have been uplifted and the decision on whether an individual road should have this adjustment applied is important. The gradients are based on Lidar data, which will have inherent uncertainties associated with them, and with their application. A 'Low' scenario has been run where the change in height along each road has been reduced by 2m to a shallower gradient and a 'High' scenario has been run where the change in height along the road has been increased by 2m.	The results of the sensitivity tests for 2021 CAZ C + TM scenario show higher concentrations in the 'Low' scenario and lower concentrations in the 'High' scenario, with the scenarios being non-compliant and compliant respectively. The scheme is non-compliant at one LAQM receptor by 0.9%. The scheme is compliant at all PCM-equivalent receptors.
Gradient Adjustment Factor Caerphilly Study	3.6.2	A study undertaken by Caerphilly Borough Council identified that in Hadodyrynys a calibration of approximately 2 was appropriate for cars and vans, and that a sensitivity test uplifting non-LGV/HGV emissions was required.	When applying a factor of 2 CAZ C + TM remained compliant. When applying a factor of 3 the CAZ C + TM was non-compliant at two LAQM receptors. The scheme is compliant at all PCM-equivalent receptors.
Gradient Adjustment Factor Grouping LDVs with Cars	3.6.2	At the request of JAQU a sensitivity test has been undertaken in which LGVs are grouped with cars on gradient roads rather than HDVs to further test the implications of the approach taken to gradients and verification.	When grouping LGVs with cars CAZ C + TM remains compliant while the baseline scenarios were non-compliant.
Junctions	3.6.3	As with road widths, and geometries, junctions have been included in the model manually and there is thus potential for uncertainty from subjective decisions.	Any disparity in the interpretation of a junction is likely to be junction-specific, and as such there is no basis for testing any different conditions.

Meteorological Data	3.7.1	Meteorological conditions, in particular wind speed and direction, play a key role in the dispersion of pollution in the atmosphere. The air quality modelling has been carried out using one year of meteorological data (2017) from a single meteorological station (Filton Airfield). Although this meteorological station and year of meteorology are considered to be representative of conditions in Bath, conditions will vary from year to year and locally over different topographies.	Wind roses over 5 years, from 2 sites clearly demonstrate that the dominant wind direction is west southwesterly, between 245° and 265°, and is generally consistent for all of the wind roses.
Meteorological Parameters	3.7.2	The ADMS dispersion model requires a number of meteorological parameters to be set for both the meteorological station and the study area. These are: latitude, surface roughness, surface albedo, minimum Monin-Obukhov length and Priestley-Taylor parameter. The values used for these parameters have been set subjectively and there is thus scope to introduce uncertainty. Three tests have been undertaken with differing metrological parameters.	The CAZ C + TM is compliant in all of the scenarios tested. The meteorological parameters do not have an impact on compliance.
Primary NO_2 Fraction	3.8.1	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. 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.	If the f-NO_2 values are reduced by 40% then the predicted concentrations are slightly lower, with the maximum predicted concentration being 4 µg/m^3 lower than the 'Central' scenario. Although this suggests that an earlier year could be compliant if f-NO_2 values decrease, the earliest year B&NES may be able to implement a CAZ C + TM would be 2020 in any event and f-NO_2 values are unlikely to be as low as 40% of current values by 2020.
Regional Ozone	3.8.2	Defra's NOx to NO_2 Calculator calculates NO_2 concentrations from NOx concentrations, based on the reactions of mixing of nitric oxide, nitrogen dioxide and ozone. This relies on tabulated concentrations of ozone above the surface layer for each local authority, for which there is an uncertainty.	There is no basis for an alternative approach, but it is acknowledged that this issue will contribute to the overall uncertainty in the conclusions of the assessment.
Lower uptake of Bus Retrofitting	3.9	All buses have been assumed to be compliant. A test considering what proportion of bus movements could be non-compliant has been carried out.	Approximately 2.5% of bus movements could be non-compliant and the scheme would just remain compliant.

Non-Road Sources	3.10.1	Pollutant emissions from vehicles using local roads are explicitly included in the model and other sources are generally accounted for within the background concentrations. There may, however, be a number of emission sources that are not included within the background maps and may not be fully represented.	Emissions from construction works will be temporary and have therefore not been explicitly included in the model. The effect is likely to be greater for particulate matter than for NO_2. Generators and Non-Road Mobile Machinery cannot be included in the model in a robust manner. The effect of existing centralised energy plant and generators will be partially taken into account in the verification process. Emissions associated with the Great Western Main Line have been considered separately in the Diesel Train Emissions Technical Note.
Impact of Simultaneous CAZ in Bristol			
Analysis of Census Data	4.2	Review of census Travel to Work data for residents who live approximately within the Bath and Bristol CAZ regions.	4% of Bath CAZ residents commute to Bristol CAZ, while 0.8% of Bristol CAZ residents commute to Bath CAZ. 28% of commutes between Bristol and Bath CAZs occur by private vehicle.
Analysis of SP Survey Data	4.3	Comparison of results from the Bath SP survey to results from the Bristol SP survey. Combination of results from both surveys to estimate how often non-compliant drivers travel to both CAZs.	Bath SP survey respondents would drive into the Bristol CAZ with approximately the same frequency that they would drive into the Bath CAZ. Therefore, the Bristol CAZ would likely have just as strong an effect on these residents as the Bath CAZ. Combining both surveys, approximately 17% of car drivers and 41% of LGV drivers are estimated to drive into both CAZs on the same day at least once per week.
Analysis of ANPR Data	4.4	Review of ANPR data from both Bath and Bristol to determine how fleet composition changes based on frequency of trips into one or both CAZs.	Simultaneous CAZs in both cities would disproportionately affect more polluting vehicles.