CLEANER AIR FOR SCOTLAND – NATIONAL MODELLING FRAMEWORK

Air Quality Evidence Report – Glasgow

22 August 2019

Scope of Report

Air Quality modelling in Glasgow is ongoing in support of the Scottish Government Cleaner Air for Scotland Strategy (CAFS). Presented within this report, is air quality modelling evidence to support Glasgow City Council (GCC) in the development of a Low Emission Zone (LEZ). This report details work carried out until late 2018. Modelling methods are briefly outlined and the performance of the model discussed. Results are presented which provide detail on the level and extent of roadside air quality issues within the modelled area. The likely sources of the roadside pollution are outlined. Indicative modelling to inform LEZ development has been carried out. The initial focus of this work is on Nitrogen Dioxide (NO2). Particulate Matter (PM) modelling will be included in further work. Modelling output presented in this report makes use of detailed information on the Glasgow Bus Fleet. We are grateful to the Bus Operators for providing this.

Executive Summary

An Air Quality model of Glasgow has been built using detailed traffic data collected in 2017. This model performs well against observed Nitrogen Dioxide (NO2) data. Modelling output indicates that, in 2017, NO2 concentrations at many roadside locations were below the annual average limit value of 40 µgm^{-3}. However, modelling also shows that a significant number of roadside locations were likely to have exceeded the limit value in 2019. The most extensive area of roadside NO2 issues is in and around the city centre Air Quality Management Area (AQMA). Roadside NO2 levels will be higher here, than in many areas of Glasgow. The highest NO2 concentrations will occur on roads with high traffic levels, particularly those which are surrounded by tall buildings. To meet the NO2 annual average limit value at all roadside locations predicted to be above 40 µgm^{-3}, emission reductions of around X to X%, on 2017 levels, will be required.

Analysis of model output shows that emissions from buses are the single biggest source of Nitrogen Oxides (NOx) on many roads, particularly those within the two LAQMs. Diesel cars are the second biggest source of NOx on many roads, although this impact is produced by a greater number of vehicles. All cars create a similar but higher level of air quality impact to the collective impacts of non-bus commercial vehicles (LGV's, Rigid HGV's, Taxis and Artic. HGV's). Whilst this analysis has been performed for NOx rather than NO2, it does indicate which sources are likely to be responsible for high NO2 concentrations in the city.

The air quality model was run for a number of scenarios to determine the potential benefits to air quality from changing the emissions from the vehicle fleet. Results suggest that standard EURO 6 diesel cars (sold since December 2015) will bring little improvement to roadside NO2 levels, if traffic levels remain as they were in 2016. However, the newer 6c and 6d diesel vehicles will possibly bring a considerably greater benefit, if actual emissions on the road are as predicted. At present, the emission performance of these new vehicles is uncertain. Euro 6 buses have the potential to bring large improvements in roadside NO2 levels, particularly within the city centre AQMA.

List of Abbreviations

AADT	Annual Average Daily Traffic
ADMS	Atmospheric Dispersion Modelling System
ADMS-Urban	Atmospheric Dispersion Modelling System for Urban Environments
ANPR	Automatic Number Plate Recognition
AQMA	Air Quality Management Area
ATC	Automatic Traffic Counters
CAFS	Cleaner Air for Scotland
CERC	Cambridge Environmental Research Consultants
DfT	Department for Transport
DEFRA	Department for Environment Food & Rural Affairs
DVLA	Driver and Vehicle Licensing Agency
EFTv8	Emissions Factors Toolkit v8.0
EMIT	CERC Emissions Tool
GCC	Glasgow City Council
HGV	Heavy Goods Vehicle
JTC	Junction Turn Counts
LAQM	Local Air Quality Management
LEZ	Low Emission Zone
LGV	Light Goods Vehicle
NAEI	National Atmospheric Emissions Inventory
NLEF	National Low Emission Framework
NMF	National Modelling Framework
PDT	Passive Diffusion Tube
SEPA	Scottish Environment Protection Agency
SG	Scottish Government
TS	Transport Scotland

List of Chemical Abbreviations

NO2	Nitrogen dioxide
NOx	Nitrogen oxides
PM	Particulate matter

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1 Introduction

1.1 Background

The Cleaner Air for Scotland Strategy (CAFS) [1] provides a clear commitment to a National Modelling Framework (NMF). The NMF will ensure a consistent approach is taken across Scotland, particularly within those cities undertaking more detailed assessments. The CAFS sets out a series of actions to:

- Undertake detailed modelling of all four major cities and associated adjoining spaces in Scotland, covering areas associated with highest levels of poor air quality.

- Identify requirements and undertake data collection for additional urban areas within three years of implementing CAFS.

CAFS also outlines that this Air Modelling will provide tools and evidence to support the National Low Emissions Framework (NLEF). NLEF is envisaged to provide scenarios, which can be simulated by Air Quality modelling to assess the potential influence of changes which may be thought to reduce emissions.

The four major cities are: Aberdeen, Dundee, Edinburgh and Glasgow. Air Modelling will be carried out by SEPA, in consultation with local authorities, regional transport representatives and Transport Scotland.

1.2 National Modelling Framework (NMF)

Modelling work presented in this report has been carried out in line with the National Modelling Framework. NMF delivers a consistent approach to air quality modelling, utilising a method developed during a pilot project in Aberdeen. A report on this work [2] has been reviewed by Professor Margaret Bell of Newcastle University. Professor Bell has indicated that she is satisfied with our current method, but has made a number of recommendations regarding the quantification of emissions for use in the modelling. We believe these would enhance NMF modelling, but that they would be challenging to implement at this time. Our simplified approach produces good model performance against observed data. At this stage, we believe the simplified approach will point towards the most obvious, and largest, emission improvements that can be made. After these have been tackled a more detailed and sophisticated approach to emission quantification may be required.

The essential components of the current NMF can be expressed as a series of simple statements:

- Collect high quality and detailed traffic data at a similar resolution in each city. Process these in the same way.
- Build air quality models of each city using the same modelling software with identical methods and model settings, where appropriate.
- Use the same sources of data for input in to the model, such as road layout, road width and building heights.
- Use appropriate meteorological and background emission data obtained from a common source.
- Combine traffic data with published emission information to derive consistent emission estimates.
- More accurate emission information, if available, will be applied in a consistent way.
- Ensure that observations and lessons learned from one city are applied in other cities.
- Process, visualise and report on modelling output in a consistent and informative way.

By following this simple approach, we aim to ensure that all emission inputs into the models are accounted for in a consistent manner. Furthermore, pollutants in the models are subject to the same mathematical treatment of dispersion and chemical processes. Buildings and road networks are treated equally, whilst representing the unique local factors (such as the dimensions of street canyons).

ADMS-Urban is the primary modelling system to be used in the current NMF. Manufactured by CERC (Cambridge Environmental Research Consultants), ADMS-Urban has been widely used in national and international air quality studies and has been subjected to peer reviewed validation [3]. ADMS has also been used in the most recent Glasgow City Council (GCC) Detailed Assessment Modelling in Glasgow, published in 2014 [4]. ADMS-Roads, a reduced version of ADMS-Urban, has recently been used to model air quality improvements in Musselburgh [5]. Additionally, SEPA accepts many applications to discharge from industrial facilities where ADMS has been used.

Whilst other air modelling software is available, ADMS is a widely used commercial package which is supported by a third-party manufacturer. It can therefore be used by any air modeller who has access to a valid licence. This is in contrast to a proprietary system within an environmental consultancy, which can often only be operated staff within that company. Models constructed by SEPA in ADMS can be run many times for little additional cost. They can also be run by others who have access to ADMS with little effort, albeit with some cost. Should a stakeholder wish to use another air modelling system, inputs into the ADMS models can be translated to a different system, although this may require some reasonable effort on their part.

ADMS-Urban represents a pragmatic, but reasonable, choice of air modelling software at this stage of the NMF and ensures consistency between cities and with many previous smaller scale studies in Scotland.

1.3 Data Visualisation

Visualisation of data and modelling output is key to the success of the NMF. SEPA utilises a software package called Spotfire. Manufactured by TIBCO, Spotfire has allowed us to process and visualise NMF output by creating web based “apps”. Utilising existing SEPA capabilities, these have been made available to GCC and other stakeholders during the modelling work and will continue to be updated during the project. A key benefit of sharing information in this way is that data and modelling output can be examined interactively, allowing users to query data in ways not possible in a static report. Almost all of the figures presented here have been derived from Spotfire apps.

1.4 Scope of Air Quality Model

Following discussion with GCC, an ADMS Model was constructed which encompasses two of the three Glasgow Air Quality Management Areas (AQMA). These are:

- City Centre AQMA
- Byres Road and Dumbarton Road AQMA

Maps of the AQMAs are shown in Figure 1 and Figure 2. Parkhead Cross AQMA has not been included in the Glasgow AQMA model at this time.

Figure 3 details the road network of the current Glasgow NMF model. It is comprised of road links of varying size which represent the main traffic routes though the modelling zone. Examples of individual links on: X, Y and Z are highlighted in something. Figure 3 shows the road network of the current Glasgow air-quality model with the associated AQMAs.

Main urban local roads and major trunk roads including the M8 are represented within the model. Minor roads are accounted for in the air modelling in other ways, as described in section 2.3.

GCC have confirmed that the current road network is sufficient to inform initial LEZ development. Traffic modelling commissioned to support LEZ work is ongoing. It is possible that the current road network may be enhanced to match the extent of the traffic model.

The current model can be used to assess the potential effects of an LEZ in an area of the city which includes two AQMAs. The effects on other areas, outside of the ADMAs can also be assessed. The model can be extended, or refined, to assess changes in other areas, should that be required.

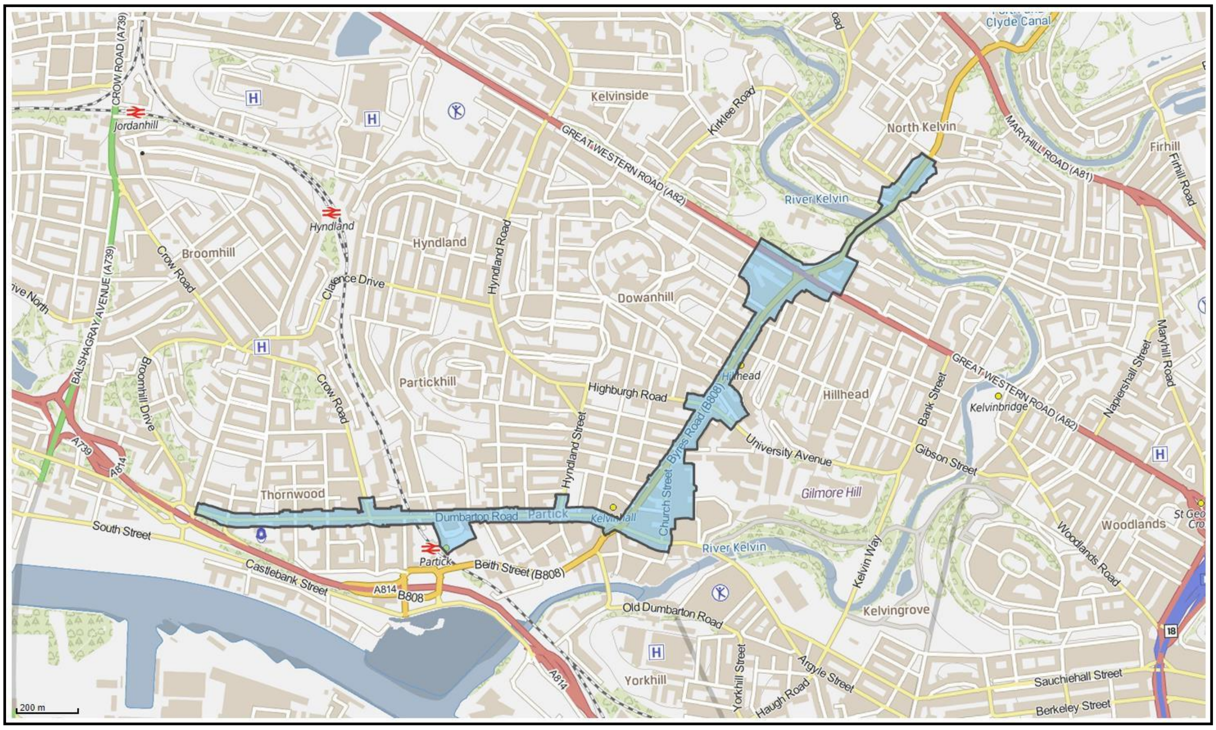

Figure 1: Byres Road and Dumbarton Road AQMA.

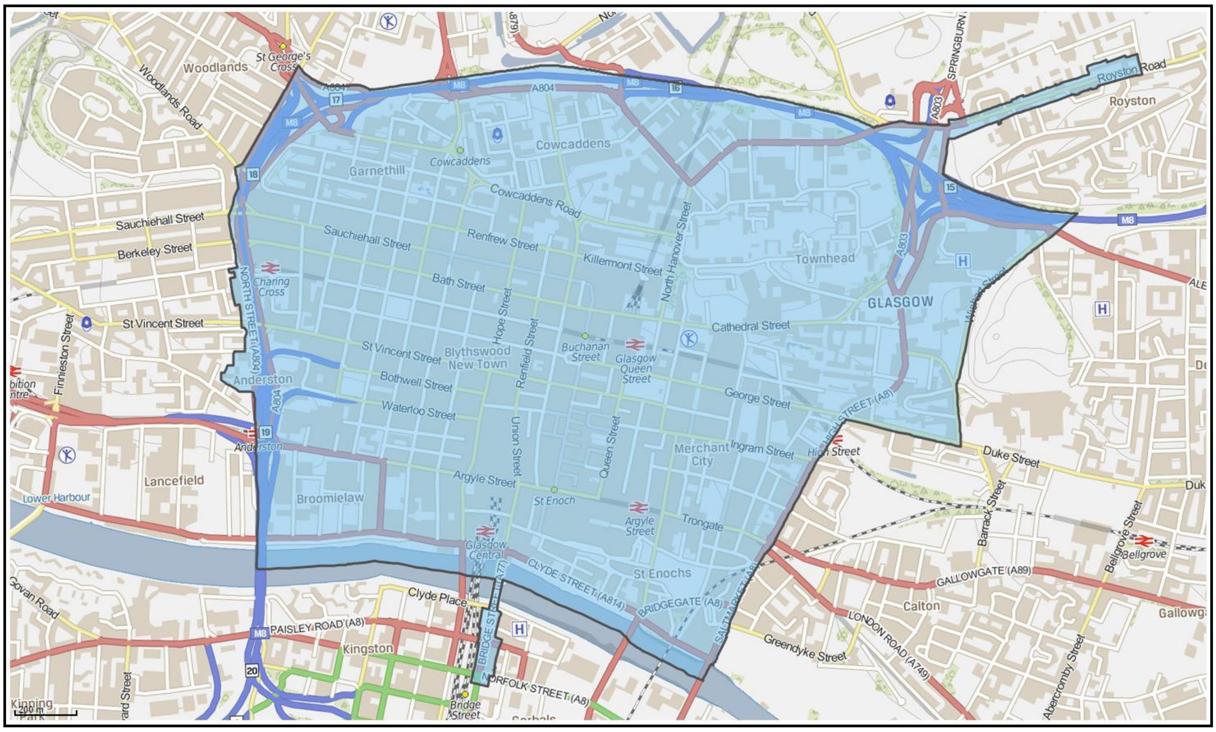

Figure 2: City Centre AQMA

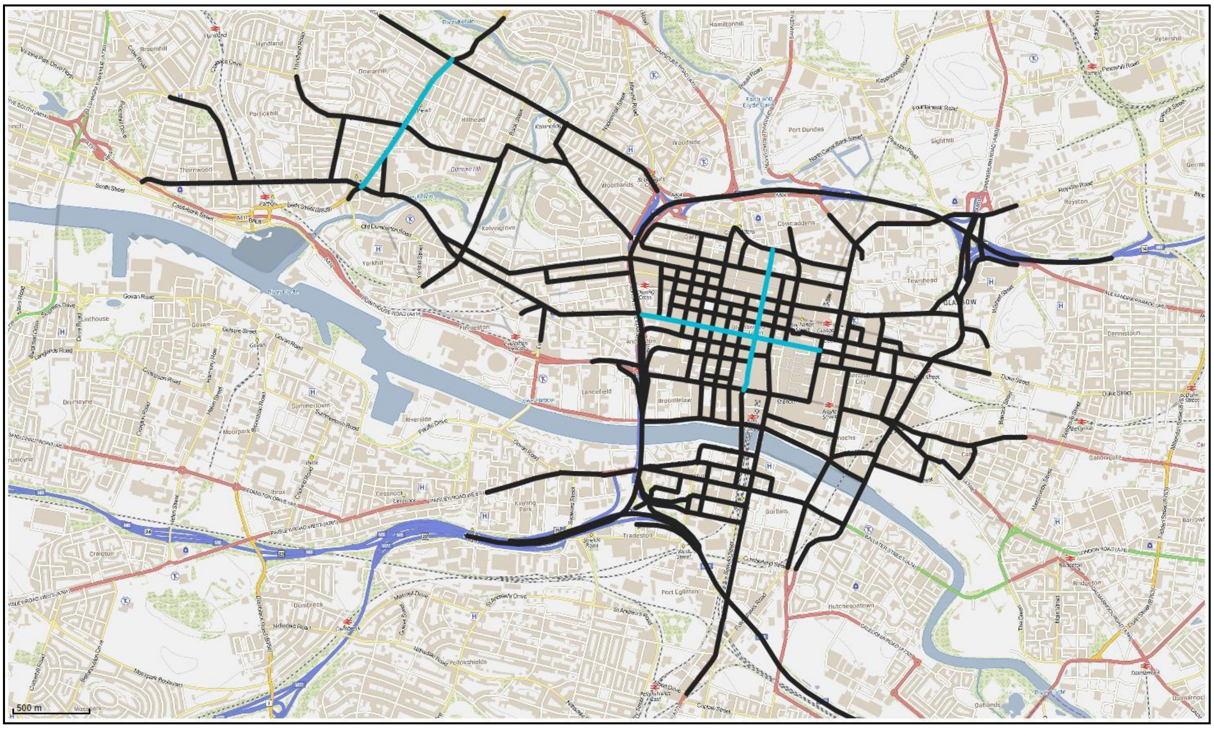

Figure 3: Glasgow Air Quality Model Road Network. Highlighted roads in blue are: Byres Road, St Vincent Street and Hope Street.

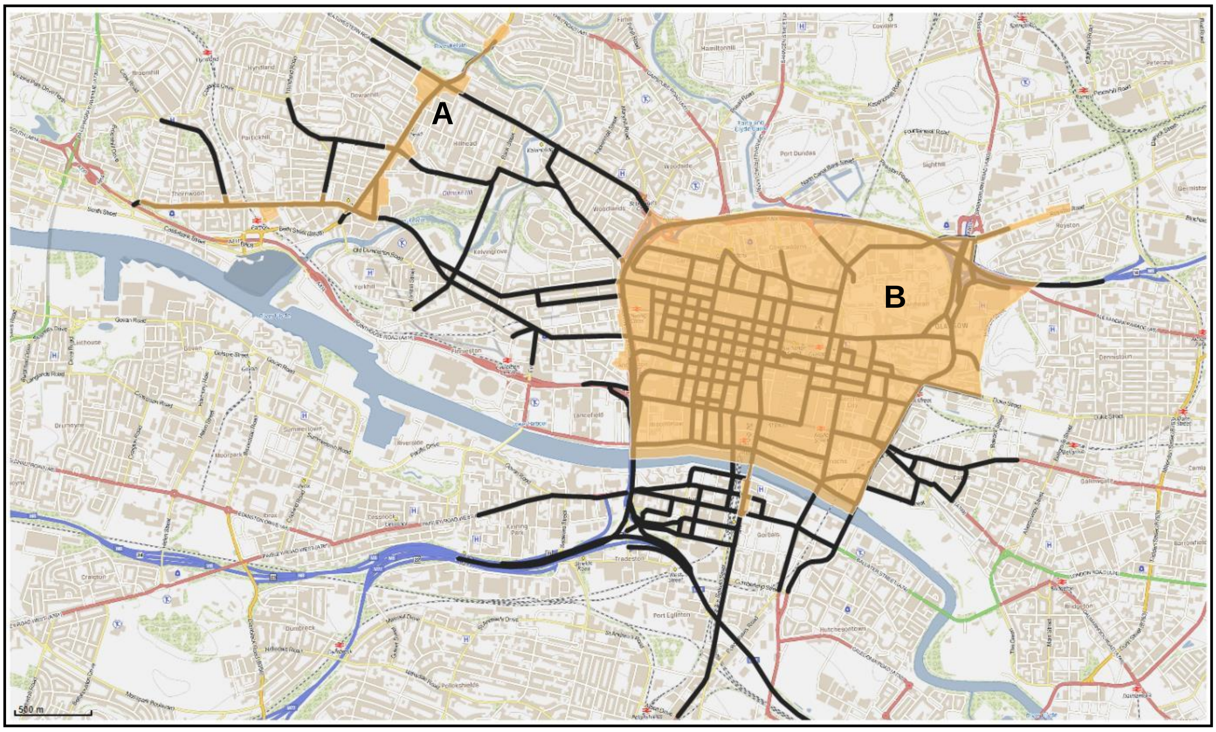

Figure 4: Glasgow Air Quality Model Road Network, Including Associated AQMAs: Byres Road and Dumbarton Road (A), City centre (B).

2 Modelling Methodology

2.1 Aberdeen Pilot Study

The modelling methodology used here is described in detail in the report produced by SEPA on the NMF pilot project in Aberdeen [2]. As stated in section 1.2 this methodology has been reviewed independently and found to be suitable for NMF modelling. Our method also takes account of the most recent Local Air Quality Management Technical Guidance (TG16) [6]. The following sections describe the relevant specific method elements relating to the Glasgow NMF modelling.

2.2 Traffic Data

Accurate emission estimates are a fundamental requirement for good quality air modelling. These must be underpinned by good quality traffic data to ensure accurate traffic flows and the distribution of vehicle types are known. At the start of the Glasgow NMF work, very little recent traffic data, with widespread coverage, were available in the area of interest.

For the NMF modelling described here, a traffic data collection programme was undertaken in order to build a more detailed picture of traffic flow and composition. Data were collected by Tracsis plc in line with current industry practice. Survey location choice was co-ordinated by Transport Scotland in consultation with GCC and SEPA.

Traffic data presented here were collected in November 2017. They consist of 72 Junction Turn Counts (JTC), 38 Automatic Traffic Counters (ATC), and 8 Automatic Number Plate Recognition (ANPR) cameras located on key routes.

The locations of the JTC traffic data collection are shown in Figure 5. A mixture of 12-hour and 24-hour JTC data were collected and these are denoted by the blue and black triangles.

Traffic data were processed to give flow as Annual Average Daily Traffic (AADT) for 11 vehicle categories. The processing method used is detailed in the Aberdeen Pilot Report [2]. The detailed class breakdown is important to correctly represent emissions, which can be highly variable between different vehicle types. The 11 vehicle categories available are shown in Table 1.

Annual Average Daily Traffic (AADT) can be thought of as the number of vehicles travelling along a section of road in 24 hours. An annual average is calculated to take account of traffic variability throughout the year. For example, a value of 5000 AADT (for all vehicles) may represent the typical flow of vehicles along a road section in 24 hours. Actual day to day values may be lower or higher than 5000, but over the entire year the average is close to 5000. Individual buses and taxis may appear many times within the AADT value as they could repeatedly travel along a road section in 24 hours.

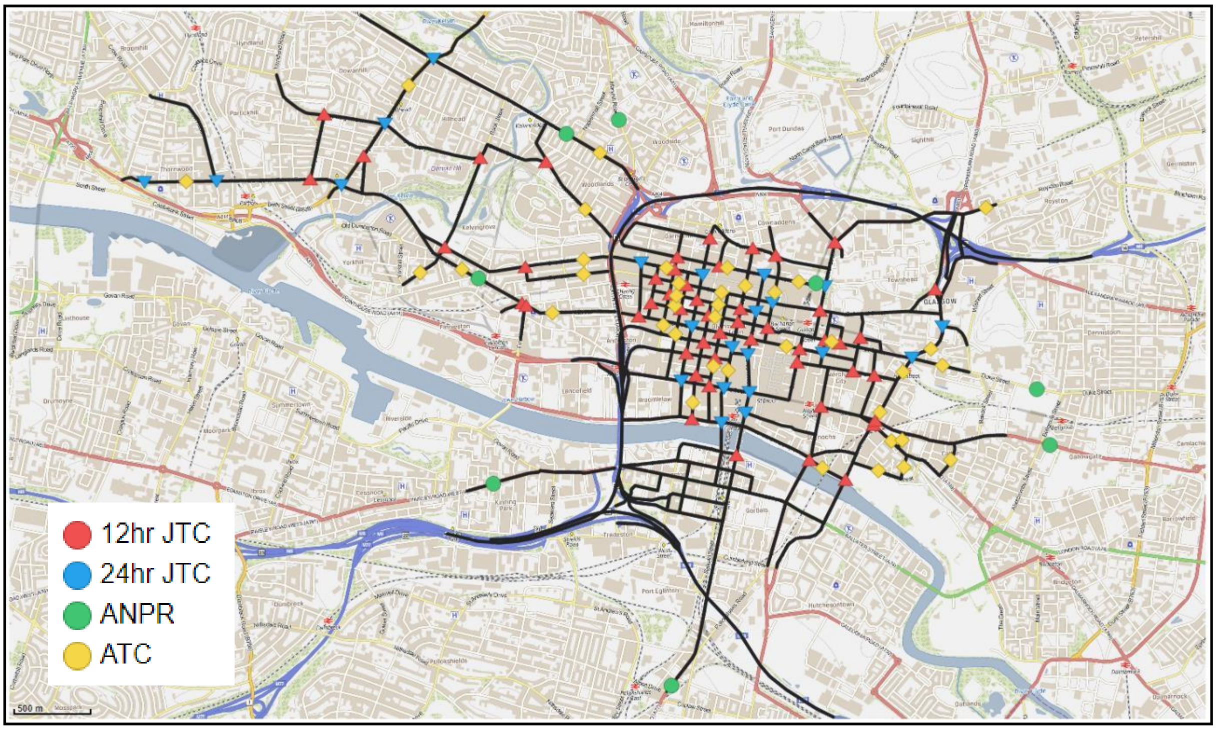

Figure 5: Traffic Data Collection Locations. Data Type Indicated by Colour and Shape key (JTC – Junction Turn Counts, ATC – Automatic Traffic Counters, ANPR – Automatic Number Plate Recognition).

Table 1: Vehicle Classes Included in Traffic Data Collection.

11 Vehicle Classes
Motorcycle
Cars
Taxi (As Classified By The DVLA)
Light Goods Vehicles (LGV's)
Buses/Coaches
2 Axle Rigid HGV's
3 Axle Rigid HGV's
4/5 Axle Rigid HGV's
3/4 Axle Artic. HGV's
5 Axle Artic. HGV's
6+ Axle Artic. HGV's

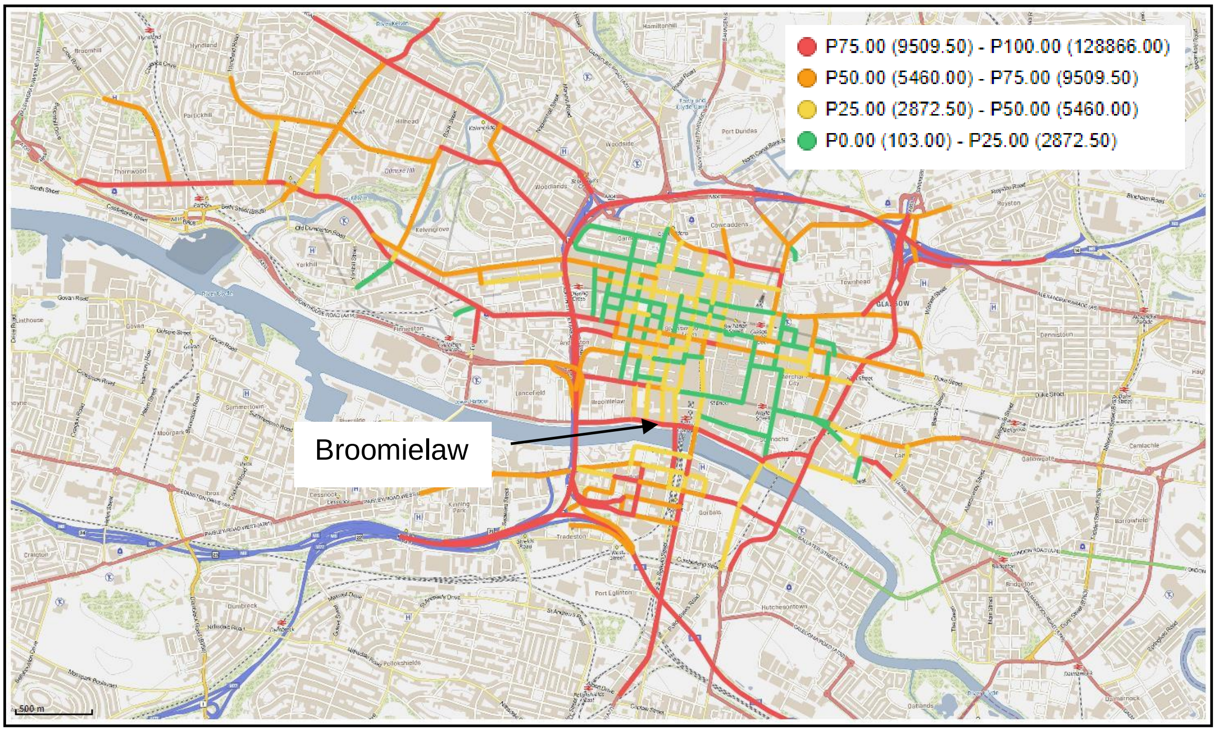

Figure 6: Car Traffic Flow across the Model Network (AADT) - Percentile.

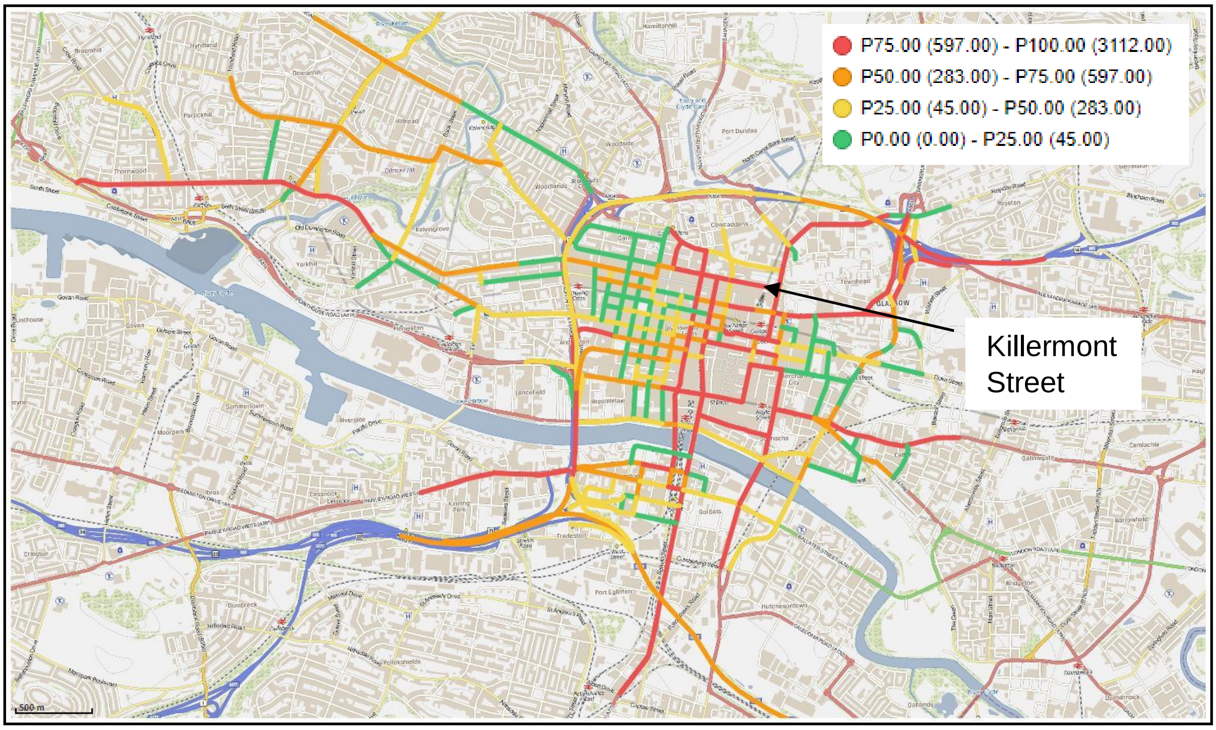

Figure 7: Bus Traffic Flow across the Model Network (AADT) - Percentile.

Figure 6 shows car AADT flow across the model network. Figure 7 shows bus AADT flow. Each link in the road network is coloured according to the percentage of the highest AADT in the network (for a particular vehicle type). For example, road links coloured red contain 75 to 100% of the highest AADT (car or bus). Clear differences can be seen in the distribution of car and bus flow, with a concentration of bus flow in the city centre and on associated bus routes into the city. Annual average car flow in the city centre is often lighter than on associated urban routes.

The maximum car AADT in the model domain occurs on a trunk road with 20907 cars. This is a section of the M8 to the north of the City Centre. The maximum car AADT on local (non-trunk) roads is 20907 on a section of the Broomielaw. The maximum bus AADT in the model domain occurs on a local (non-trunk) road with 3112 buses. This is on Killermont Street adjacent to Buchanan Bus Station. These locations are highlighted on Figures 6 and 7.

These data give a detailed picture of traffic flow and composition across the city in 2017 and are critical data to include in an Air Quality model. However, there are some uncertainties. The data are a brief snapshot of traffic movements and therefore do not represent any variability due to weather, holidays or roadworks etc. The density of the traffic collection points also mean that flow is difficult to derive accurately on some roads in the city centre.

Traffic modelling has been commissioned by GCC to inform LEZ development. Traffic modelling and further data collection will allow uncertainties in traffic data to be addressed. Estimates of future traffic flow can be made by traffic modelling.

Good traffic data, including detailed vehicle class breakdown, is essential for estimating traffic emissions accurately. Use of real traffic data is preferable to modelled traffic data in the first instance to accurately capture the distribution of vehicle classes. Detailed traffic data help to explain why we have an air quality problem in the study area in a way that is straightforward to grasp.

2.3 Emission Inputs

2.3.1 Road Link Emissions

The detailed traffic data described above are used to calculate road traffic emissions, which are defined explicitly for each road link in the model. Emission rates were calculated using the CERC emission database tool called EMIT. In the work presented here we have used the latest available information. At the time of modelling, EMIT was using values from the Emission Factor Toolkit (EFT); Version 8, (EFTv8) 2017 (11 vehicle classes).

The traffic count data collected for this study provides detailed information on flow and vehicle type. However, it does not provide information on vehicle weight or engine type/size. To calculate emissions we must estimate information such as:

- the percentages of Diesel and Petrol vehicles (particularly cars)
- the Euro class of vehicles

The Department for Transport (DfT) publish information for a "National Fleet". We have used ANPR data and Bus Operator Information to assess how closely the "National Fleet" represents the Glasgow fleet. For the base model run we have edited the percentages of Bus EURO classes but left other vehicles unaltered.

Table 2 shows the percentages of each Bus Euro class used in the "base" Glasgow NMF model (see section 2.5). The unaltered "National Fleet" values for 2016 are also presented for comparison. The percentages of petrol and diesel cars in the ANPR data closely match those in the "National Fleet" and therefore remain unaltered:

- 46 % Diesel
- 54 % Petrol

Table 2: Percentage Bus Euro Class used in Modelling vs the “National Fleet”.

Bus Class'**'	% of Bus Fleet Used in 2017 Base Run'*'	% of Bus Fleet For 2017 “National Fleet” For Comparison
Pre-Euro 1		
Euro 1		
Euro 2	0.0%	3.3%
Euro 3	41.1%	13.2%
Euro 4	12.5%	10.5%
Euro 5	31.2%	32.9%
Euro 6	15.2%	40.1%
Electric	0.0%	0.0%

It should be noted that not having exact details about vehicles does introduce some uncertainty into the emission calculations. Additionally, standard time varying emissions are used to reflect the cycle of traffic throughout the day. The same cycle is applied to all road links, introducing further uncertainty into the emission calculations. Despite these limitations we believe these uncertainties only have a small influence on model results and their effects can be managed (see section 3).

Information on the Glasgow Bus Fleet composition (kindly provided by bus operators) indicates that the assumed distribution of bus Euro classes presented in EFTv8 is not accurate for Glasgow. A more realistic bus fleet representation has been used in the modelling presented here. The assumed distribution of car Euro classes in EFTv8 appears to be more accurate. The representation of other vehicles will be kept under review.

2.3.2 Background Emissions

All other emission sources are not defined explicitly in the model. These arise from sources such as residential and industrial combustion, industry, waste, minor roads, shipping and railways. In addition, pollution can be transported over large distances to the area being modelled.

These sources can be included in the model in two main ways:

1. Use of an appropriate Rural Background monitoring station and published NAEI 1km^2 emission grids.

Or

2. Use of an appropriate Urban Background monitoring station.

The methods, and their relative merits, are discussed in detail in the SEPA Aberdeen Pilot Study Report [2]. Both methods have been used to model NO2 air quality in Glasgow. The impact of each method on model results is discussed in section 3.

2.4 Traffic Speed

An annual-average traffic speed is assigned to each road link in the model, and applies to all vehicle types on that stretch of road throughout the year. To explore the sensitivity of the model to vehicle speed it has been run for different speed scenarios.

Traffic speeds vary between local city-centre roads and trunk roads and between congested and speed-limit scenarios:

1. A speed of 10 km/h (6.2 mph) was applied to all local roads and speeds of 30 km/h (18.8 mph) and 50 km/h (31.3 mph) were applied trunk roads. This represents a heavily congested scenario and gives an indication of possible air quality concentrations where there is regular stop-starting of traffic, or regular queueing, e.g. around junctions or traffic lights.

2. A speed of 20 km/h (12.5 mph) is applied to all local roads. The speeds applied to trunk roads were either 30 km/h (18.8 mph) or 50 km/h (31.3 mph).

3. Speeds of either 30 kmh (18.8 mph) or 50 kmh (31.3 mph) were applied to local roads and speeds of either 50 kmh (31.3 mph) or 80km/h (50 mph) were applied to trunk roads. These are based on speed limit information.

The model includes the effect of vehicle-induced turbulence, i.e. local mixing of the atmosphere due to the movement of vehicles.

Output from traffic modelling may produce more accurate estimates of speed for use within the air quality model. The benefits of measures to improve traffic flow, on air quality, can be assessed in future modelling.

2.5 Air Quality Model

Meteorological data are recorded at a Met. Office station approximately 10 miles (16 km) to the north west of Glasgow, at Bishopton (OS; Easting: 241788, Northing: 671079). These data capture the large scale air movement over Glasgow reasonably well. However, they do not represent how air moves through the built-up Glasgow streets. ADMS attempts to correct for this difference using model techniques which alter the speed of the wind and other important factors.

Air movement in Glasgow is further altered by deep, and narrow, ‘street canyons’ created by relatively tall buildings. ADMS is not able to simulate the detail of these complex effects. However, it does use a well-founded simplified approach to try to take account the very complex air flow in an urban environment.

The majority of street canyons in the Glasgow model are represented using the ‘basic’ ADMS-Urban Street-Canyon module which assumes a two-sided canyon. City squares and Dumbarton Road are represented using the ‘advanced’ Street-Canyon module which allows one-sided canyons to be modelled.

Whilst the ground height does vary within the model area, tests with terrain included in the modelling indicate little influence of this on annual average predictions. As the inclusion of terrain substantially increases model run time, the results presented here do not include terrain.

The ‘base’ year of the model is 2017, which includes:

- 2017 Meteorology
- 2017 Traffic Counts
- 2017 Emission Factors (from EFT Version 8)
- 2016 Gridded Background Emissions (the most recent available)
- 2017 Rural Background Concentrations (Waulkmillglen monitoring station)

This reflects method one outlined in section 2.3.2.

We have also run the model using method two (see section 2.3.2) which is comprised of:

- 2017 Meteorology
- 2017 Traffic Counts
- 2017 Emission Factors (from EFT Version 8)
- 2017 Urban Background (Townhead Monitoring Station)

Results from these model runs are used for evaluating the performance of the model and for generating output that considers future emission scenarios.

2.6 Meteorological Data

Figure 8 shows the annual average wind speed (in metres per second: m/s) at Glasgow Bishopton for each year from 2006 to 2018. The average over all thirteen years is 3.93 m/s and this is shown as a horizontal line on the figure. The annual average wind speed measured in 2017 was 3.82 m/s. The data in the figure show that average wind speeds vary from year to year. Thus, the available dispersion to mix air pollutants is not the same from year to year. 2017 ranks amongst the lowest four average wind speed years of the thirteen analysed.

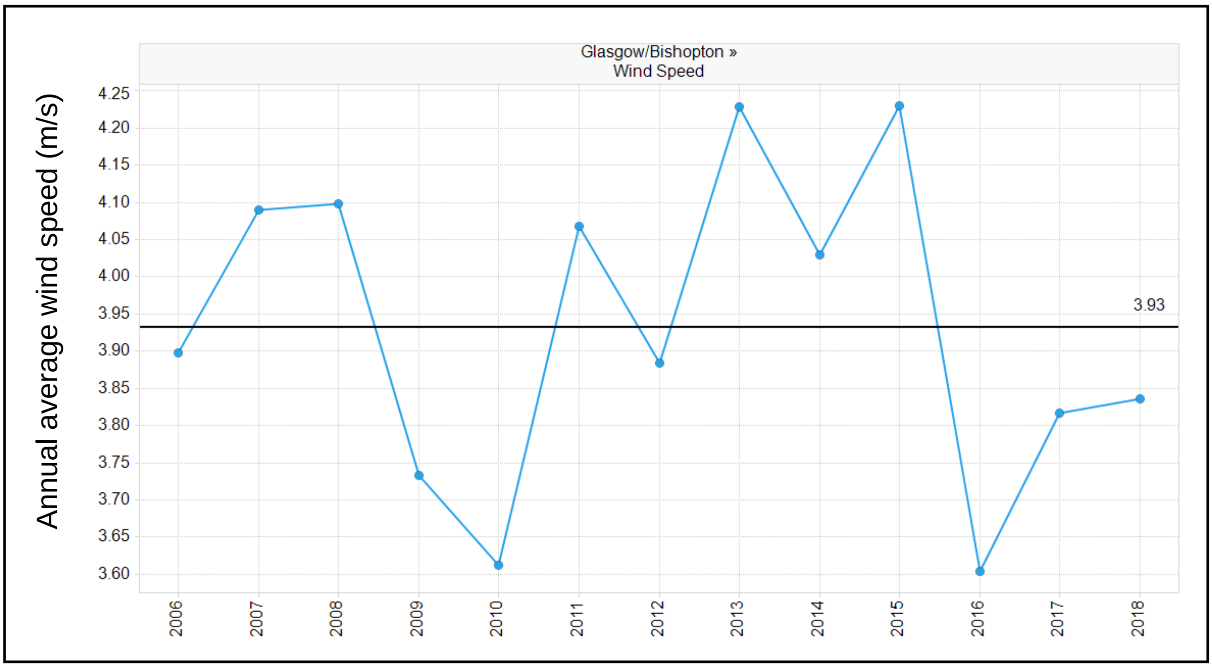

Figure 8: Annual Average Wind Speed (m/s) at Glasgow Bishopton Station from 2006 to 2018.

For the initial LEZ modelling presented in this report we have used 2017 meteorological data when modelling future emission changes. We believe that this is a precautionary approach to accounting for future dispersion. Low wind speeds in the future may not improve the air quality as much as predicted for a given reduction in emissions. Detailed LEZ scenarios will be modelled for a range of possible future conditions to establish the risk from low wind speeds.

3 Model Performance Against Real Data

A brief summary of model performance against real NO2 data is presented below. A comprehensive assessment of model performance will be documented in a separate report.

3.1 Automatic Monitoring Stations

For 2017, NO2 monitoring data at six automatic stations were available to compare with model output. These were:

- Byres Road
- Dumbarton Road
- Great Western Road
- High Street
- Kerbside
- Townhead

Full details of these stations can be found at: http://www.scottishairquality.scot/

Figure 9 shows a comparison between modelled and observed annual average NO2 for 2017. In this case, data from Waulkmillglen and Gridded Background emissions have been used. Traffic speed is set as described in speed scenario 2 (section 2.4).

Figure 10 shows similar information. However, in this case, data from the Townhead urban background station has been used to represent emissions arising from sources other than the main roads included in the model (see section 2.3.2).

Table 3 provides a summary of the data presented in Figure 9 and Figure 10.

Using the Rural Background and Gridded Emission method (Figure 9) and the Urban Background method (Figure 10), modelled annual average NO2 is reasonably close to observed data. At Townhead the annual average concentration is over predicted by 6-7 μgm^{-3} but at all other stations the concentration is predicted with approximately +/- 4 μgm^{-3}.

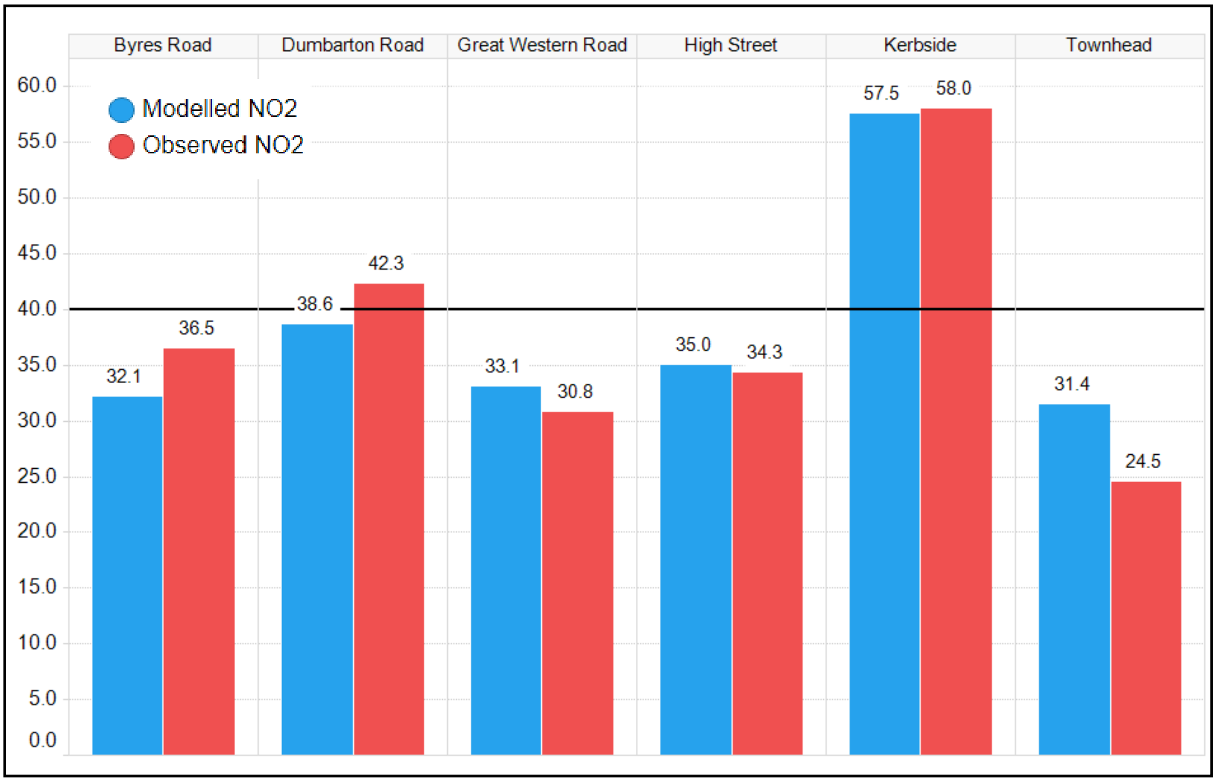

Figure 9: Comparison of 2017 Modelled and Observed Annual Average NO2 (µgm^{-3}) for Six Automatic Monitoring Stations. Background: Rural Background and Gridded Emissions.

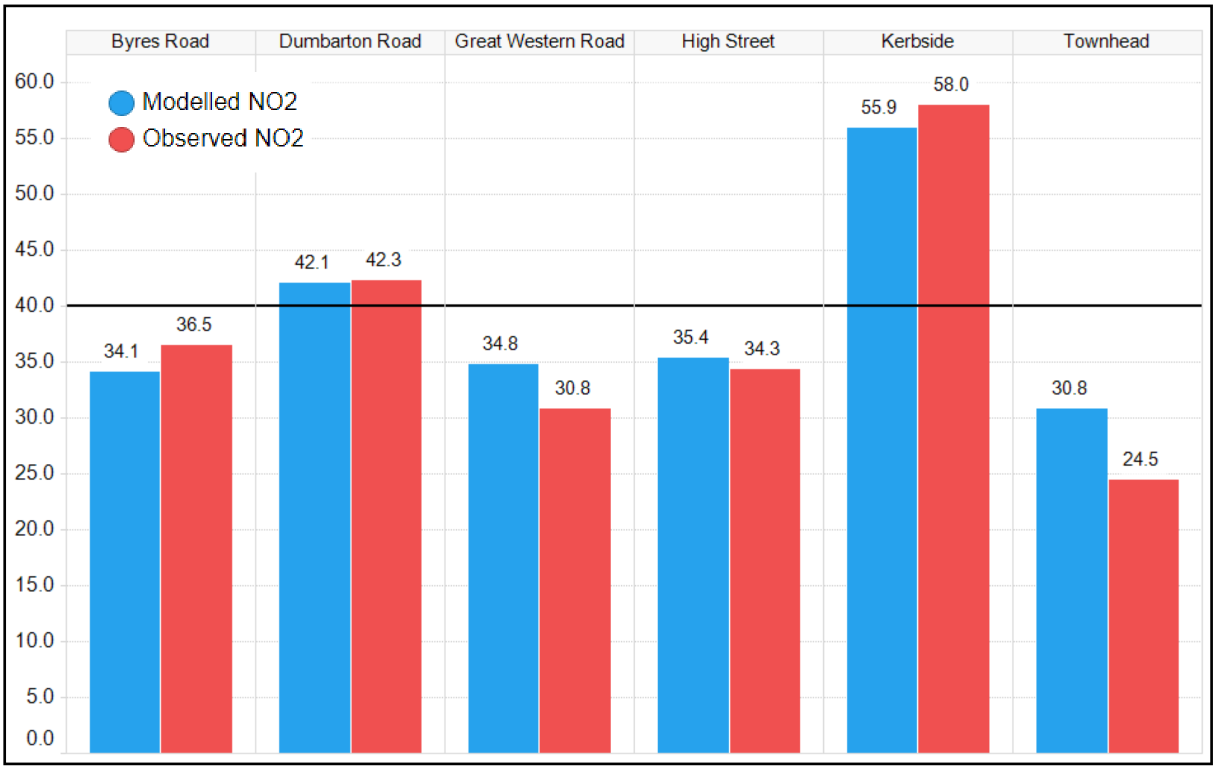

Figure 10: Comparison of 2017 Modelled and Observed Annual Average NO2 (µgm^{-3}) for Six Automatic Monitoring Stations. Background: Urban Background.

Table 3: Comparison of 2017 Observed and Modelled Annual Average NO2 (μgm^{-3}) for Six Automatic Monitoring Stations.

Background Method →		Rural/Gridded		Urban	
Station	**Annual Average NO2 (Observed) μgm^{-3}**	**Annual Average NO2 (Modelled) μgm^{-3}**	**Observed Minus Modelled μgm^{-3}**	**Annual Average NO2 (Modelled) μgm^{-3}**	**Observed Minus Modelled μgm^{-3}**
Byres Road	36.5	32.1	4.4	34.1	2.4
Dumbarton Road	42.3	38.6	3.7	42.1	0.2
Great Western Road	30.8	33.1	- 2.3	34.8	- 4.0
High Street	34.3	35.0	- 0.7	35.4	- 1.1
Kerbside	58.0	57.5	0.5	55.9	2.1
Townhead	24.5	31.4	- 6.9	30.8	- 6.3

3.2 Passive Diffusion Tubes

Measurements of NO2 from Passive Diffusion Tubes (PDTs) provide additional data for model evaluation. PDTs are less expensive to use and easier to locate than automatic stations. However, limitations and uncertainties when using diffusion tubes can lead to over-reads and under-reads [7]. Due to the uncertainties, diffusion tubes are co-located with automatic monitors and these are used to calculate a bias-adjustment factor [8]; the bias adjustment factor is applied to all diffusion tubes. **In this report, modelled NO2 is compared against bias-adjusted NO2 from diffusion tubes.** For the 2017 base run, 43 PDTs were available for comparison with modelled output [9]. Despite aggregated measurements with greater methodology uncertainties (as outlined above), PDTs can provide detailed spatial information about NO2 concentrations.

Figure 11 shows a scatter plot where 2017 observed PDT annual average NO2 values are plotted against equivalent modelled values. In this case the Rural/Gridded Background was used. Figure 12 shows similar information but for the Urban Background method. The solid line shown represents a 1 to 1 agreement between observed and modelled data. Ideally, all points on Figure 11 and Figure 12 should be as close as possible to the 1 to 1 line. In reality, due to model and measurement error, points are distributed around the 1 to 1 line by various amounts. A modelling review report for DEFRA, published by Kings College London in 2011, recommends that a model is acceptable for use if more than half of the modelled data fall within a factor of two of the observed values [10]. The two lines shown in both Figure 11 and Figure 12 represent the boundaries of this factor of two. The distribution of points within both figures indicates that all modelled values lie within a factor of two of observed values. Model performance is very similar for the two methods of quantifying background.

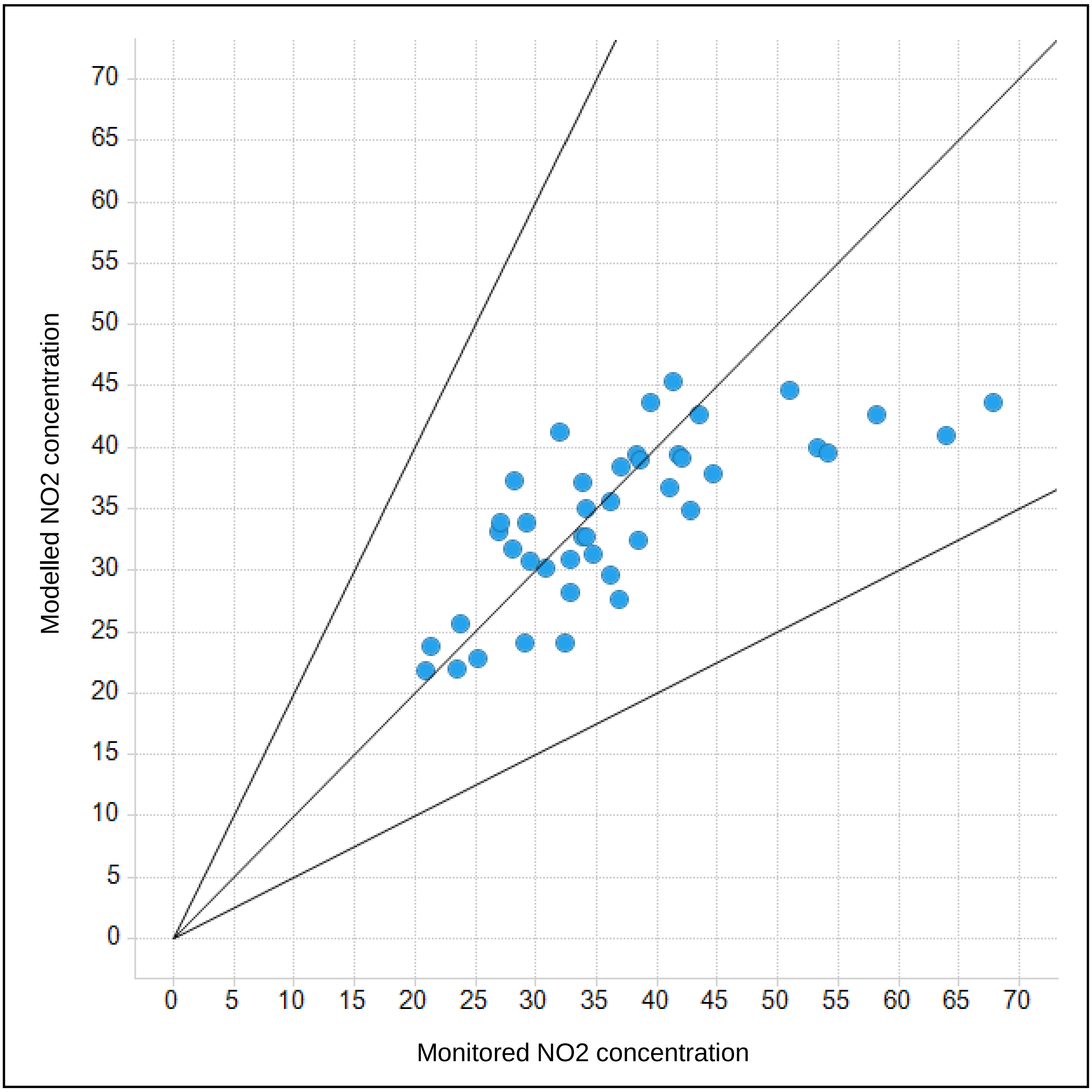

Figure 11: Scatter Plot of Passive Diffusion Tube Annual Average NO2 (µgm^{-3}) (Bias-Adjusted) vs Modelled NO2. Background: Rural Background and Gridded Emissions.

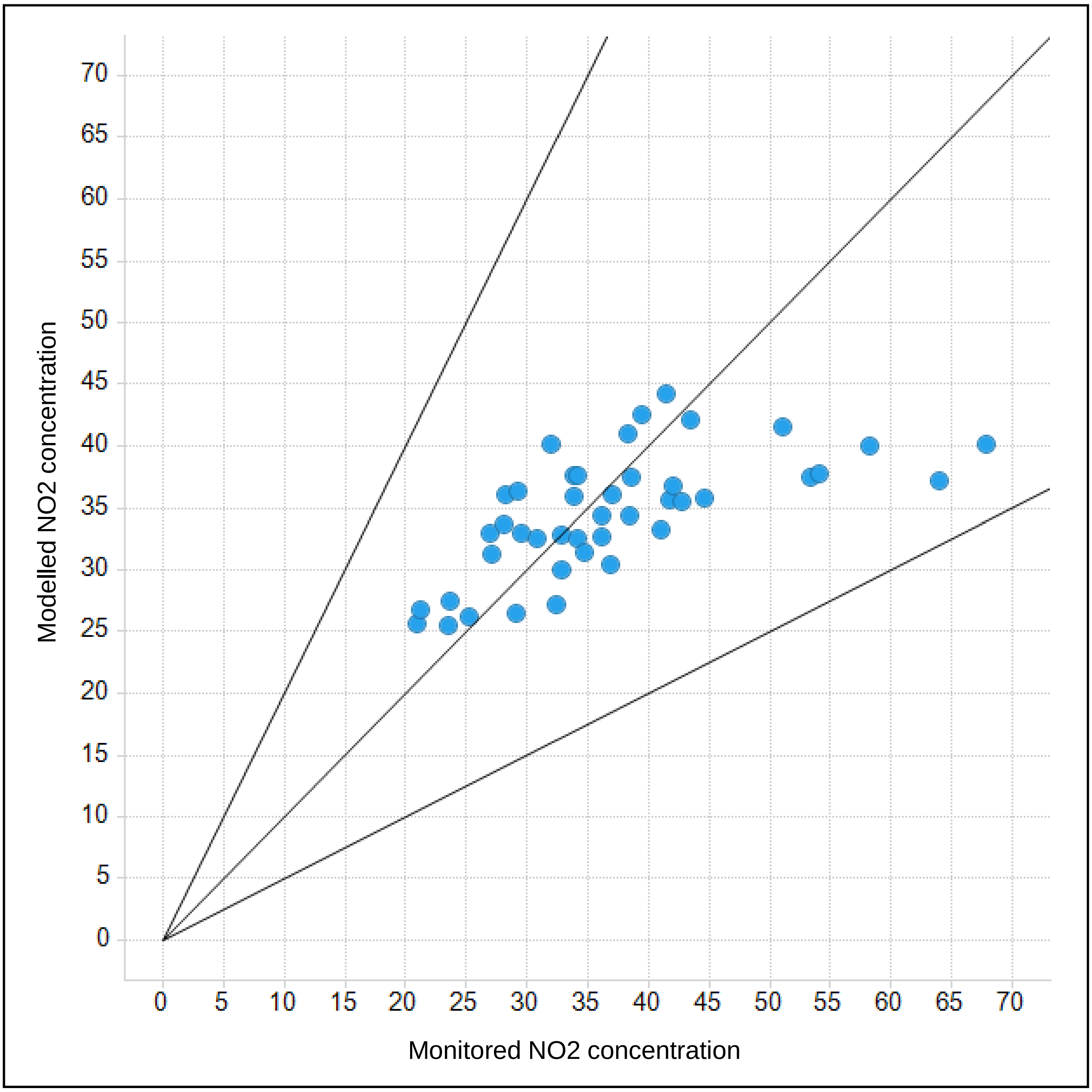

Figure 12: Scatter Plot of Passive Diffusion Tube Annual Average NO2 (µgm^{-3}) (Bias-Adjusted) vs Modelled NO2. Background: Urban Background.

3.3 Discussion of Model Performance

Models are simplifications of reality and they are often set up using incomplete or uncertain input data. The science on which models are based is not complete and including all possible scientific detail within a model may make it impractical to use. Additionally, the costs of obtaining highly detailed input data may be too high.

Despite these limitations, models can be useful tools to make predictions and to help guide decisions. Models work best when:

- Good quality input data are used to set them up.
- They are constructed with reasonable skill and care.
- Their results are checked against real data.
- Their results are treated with caution and uncertainties are taken into account.

A model prediction has a greater or lesser chance of being right, but this often depends on real world changes playing out as predicted. For example, a predicted improvement in Air Quality may not be as large as forecast if the planned emissions from new vehicles are greater than expected.

The brief summary of model performance provided in sections 3.1 and 3.2 show that the Glasgow model is not a perfect simulation of air quality in Glasgow in 2017. Reasons for the disagreement include:

- Variation in traffic flow, speed and vehicle type (and thus emissions) throughout the year.
- Complex dispersion and weather effects not represented by the ADMS modelling system.
- Incomplete information on the Car Petrol/Diesel split, the distribution of Euro vehicle classes and variations of these throughout the year.
- Uncertainty in Vehicle and Gridded Background emissions.

There is no significant difference in the performance of the model for the two background methods. However, future modelling will be carried out with both to establish the potential risks to model predictions.

We believe that the current Glasgow NMF model is acceptable for use, for the following reasons:

- **It is founded on good quality traffic data and reasonable estimates of vehicle fleet characteristics and emissions.**
- **It has been built with reasonable skill and care to provide an adequate representation of dispersion and chemical processes.**
- **100% of PDT modelled values are within a factor of two of the monitored values, a key test for the model.**
- **It shows good agreement with most automatic monitoring stations for 2017.**

We have carried out a more detailed and technical assessment of the performance of the Glasgow NMF model. We have found that it performs well against more complex statistical criteria. This will be presented in a separate report. Model performance will be kept under review throughout future NMF modelling work.

3.4 Modelling Uncertainty

All model output must be treated with caution. Air quality predictions made with the Glasgow NMF model are subject to uncertainty. In the methods described above, we have tried to minimise uncertainty as far as we can within the time available. Any remaining uncertainty is likely to pose a small/medium risk to the accuracy of model results. Typical errors in annual average NO2 concentration within the model appear to be around +/- 4 μgm^{-3} when compared against the most accurate measurement source; the automatic monitoring stations. The majority of PDT comparisons are within this error band, but some can be up to a factor of two different.

Model predictions using traffic model output are will have a greater error range, due to the uncertainty passed on from the traffic model. Predictions of future changes in traffic and vehicle fleet will also be uncertain, as will future predictions of weather.

SEPA has been working with Professor Marian Scott (University of Glasgow) and Dr Francesco Finazzi (University of Bergamo) on a method to help address model uncertainty. Their method, currently in publication, uses a statistical technique to describe the behaviour the air quality model. This allows model results to be estimated for many more sets of input data than it is usually feasible to run. SEPA have implemented this method to establish the risks posed to air quality predictions from uncertainty in future emissions and wind speeds. Although not implemented in our initial Glasgow NMF modelling, the technique will be applied to future detailed LEZ modelling. In this way we will be able to estimate the risk to the success of any measures to improve air quality.

Ultimately, modelling uncertainty can be managed by taking a cautious view of model predictions and adopting mitigation measures that can be taken if planned improvements are not as predicted.

4 Glasgow NMF Modelling Results

4.1 NO2 Concentrations in the Glasgow NMF Model

During 2017, air quality in Glasgow was monitored using six automatic (continuous) monitoring stations and 43 Passive Diffusion Tubes (PDT) [9]. Section 3 shows that the current Glasgow model represents the 2017 NO2 measurements reasonably well.

Within the model, output points can be set up along the roadside at the pavement edge. These "roadside points" show the distribution of air quality concentrations in a city. Roadside concentrations are often higher than at other locations [11]. In addition, road vehicles contribute about 80% of the NO2 pollution at the roadside [12]. The UK and Devolved Administrations have published a plan to tackle roadside NO2 concentrations [12]. Using a network of roadside points, we can assess air quality in a detailed way and estimate pollutant concentration at locations where monitoring data are not available. When modelling potential improvements to air quality we can assess the possible benefits over a larger area of the city than that represented by the current monitoring locations. Model output may also highlight potential areas for investigation by monitoring.

Within the Glasgow model, 4769 roadside points were set up along the major road links shown in Figure 3. This is the same as placing a roadside point approximately every 50 m along a road link. Using this framework, we can assess air quality in an equal way across the city. Given that we are able to reproduce the actual monitored data in a reasonable way, the network of output points can be thought of as "virtual monitoring locations".

Roadside points for the current Glasgow NMF model, for the base year of 2017, are shown in Figure 13. In this model run, speeds for each road link were set as described in scenario 2, as outlined in section 2.4. Each roadside point is represented by a coloured dot, with the colour indicating modelled annual average concentration of NO2 as follows:

- Blue: 0 up to and including 40 µgm^{-3}
- Pink: Above 40 up to and including 55 µgm^{-3}
- Black: Above 55 µgm^{-3} up to and including the maximum value.

Because of modelling uncertainty (discussed in section 3), the model may overestimate or underestimate the concentration at certain locations. Given the levels of error in the Glasgow NMF model, the higher the concentration (particularly over 55 µgm^{-3}) the more likely actual monitoring would record a value above 40 µgm^{-3}. This is most likely in areas where many modelled roadside points are predicted to be above 55 µgm^{-3}.

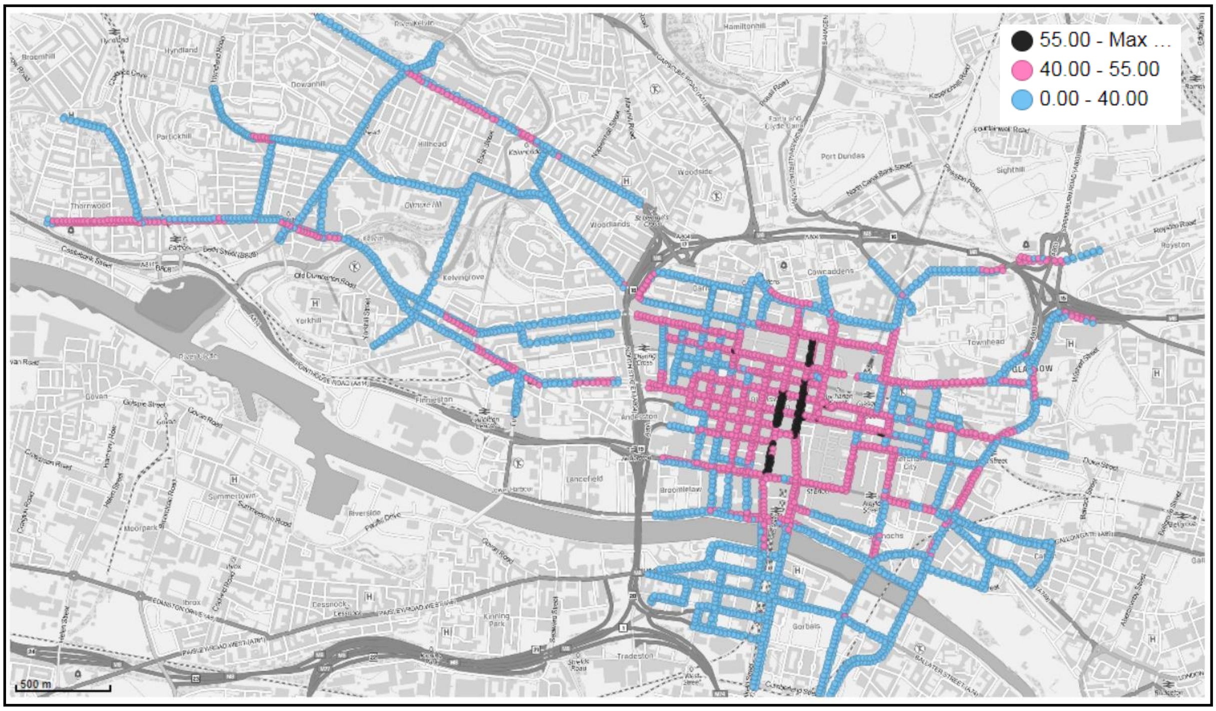

Figure 13: Modelled Roadside Annual Average NO2 (µgm^{-3}) for 2017. Annual Average Speed Scenario 2.

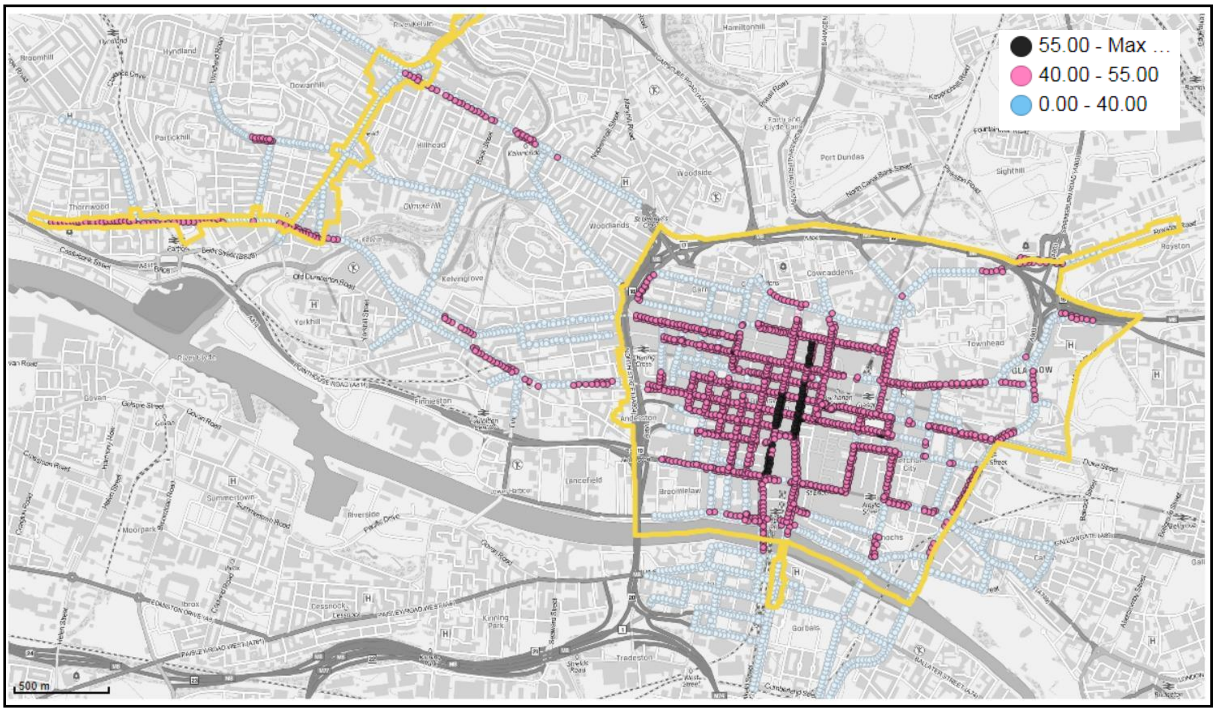

Figure 14: Modelled Roadside Annual Average NO2 (µgm^{-3}) for 2017. Values Greater Than 40 µgm^{-3} are Highlighted. AQMA boundaries are outlined in yellow.

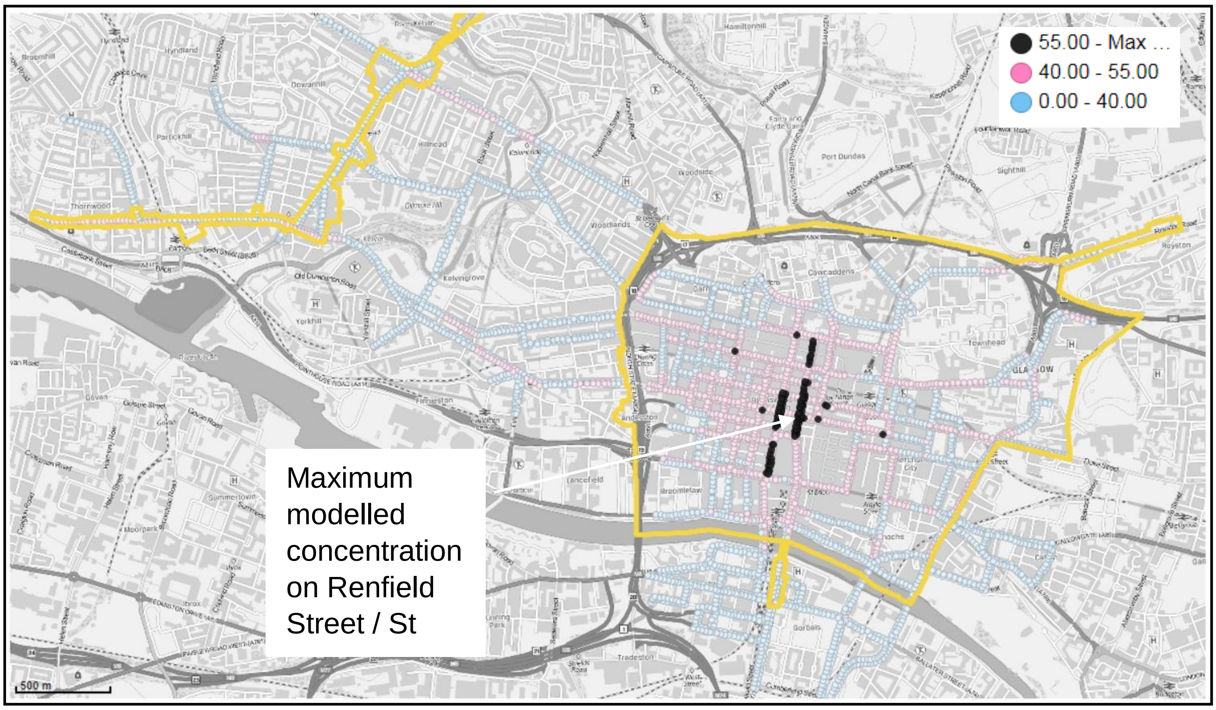

Figure 15: Modelled Roadside Annual Average NO2 (µgm^{-3}) for 2017. Values Greater Than 55 µgm^{-3} are Highlighted. AQMA boundaries are outlined in yellow.

Figure 14 and Figure 15 show the roadside points with highlighted values of NO2 greater than 40 µgm^{-3} and 55 µgm^{-3}, respectively. AQMA boundaries are also highlighted.

The highest modelled annual average for NO2 in the base year of 2017 was 72.5 µgm^{-3}. This occurred at the junction between Renfield Street and St Vincent Street which is highlighted on Figure 15.

Model results from the base run indicate the potential extent of roadside points greater than the annual average limit value for NO2 (40 µgm^{-3}). High modelled concentrations are found in the city centre. The highest concentrations are found in areas of narrow and deep "street canyons" (streets lined with high buildings). Hope Street and Renfield Street are examples of this type of street. Additionally, the city centre AQMA contains a number of roadside points above 55 µgm^{-3}.

In order to estimate the potential effects of congestion, the base model was run with all road links set to an annual average speed of 10 km/hour (6.21 miles/hour). This is shown in Figure 16. Although this is an extreme view of congestion, it does demonstrate the effect of very low annual average speed on air quality. It also highlights which areas of the city may suffer the worst congestion effects. This could be along particularly busy roads or around junctions. Whether or not high values would be measured will depend on the accurate annual average speed at a particular location. Low speed associated with congestion will increase the chance of poor air quality. Speed data from a traffic model may allow us to refine our modelling of congestion effects.

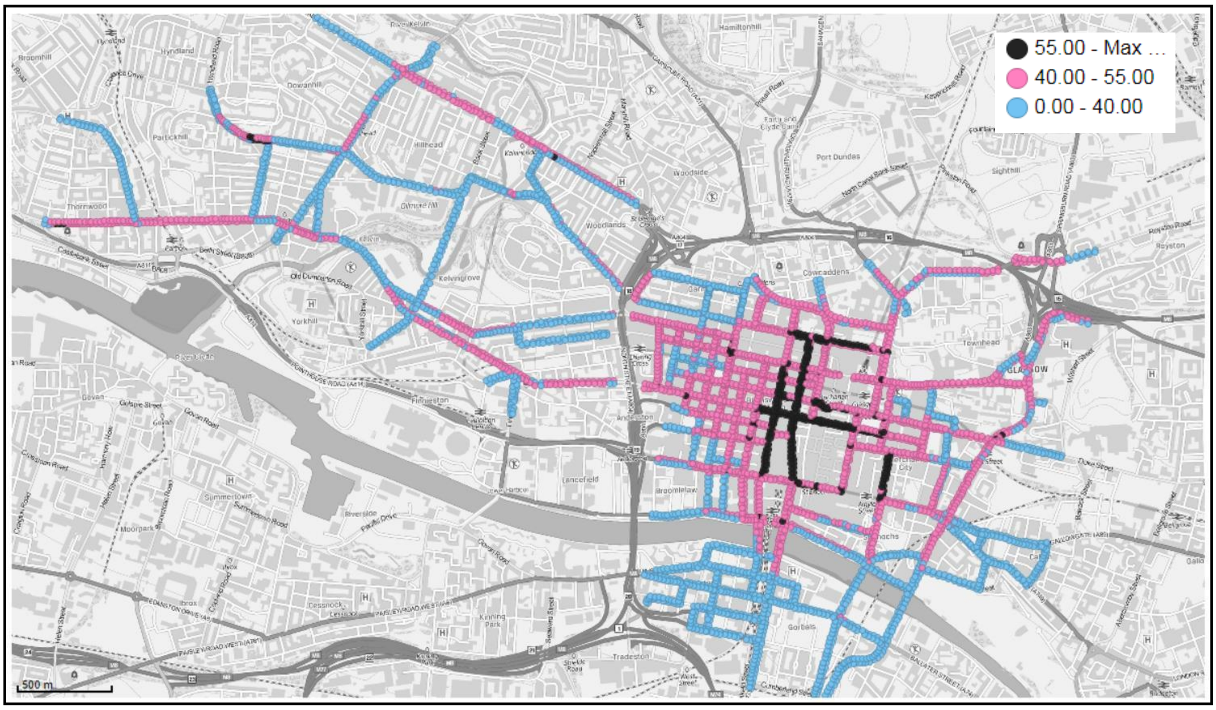

Figure 16: Modelled Roadside Annual Average NO2 (µgm^{-3}) for 2017. Annual Average Speed scenario 1.

The reduced speed of the 'Congested: 10 km/hour' run is not intended to be representative of average conditions. It is unrealistic to apply this speed over the whole model area. However, it does illustrate that congestion should be minimised in order to benefit air quality. From this point forward, all modelled results presented will be for 'Variable' speeds. Variable speeds give better agreement with observed data.

Maps of roadside points are useful to show how concentrations vary across the city. However, it is also useful to look at the variation of roadside points on a graph and using simple statistics.

Figure 17 shows the distribution of modelled roadside point annual average NO2 concentrations inside and outside the Glasgow AQMAs, for the 2017 base model run. All 4769 roadside point concentrations shown in Figure 13 have been ranked from highest to lowest. 1681 roadside points lie within AQMAs (City Centre and Byres Road and Dumbarton Road). 3088 roadside points lie outside the AQMAs. Each set of points have been assigned a colour. Due to the large number of points available, they form a smooth line showing the variation of concentrations across the chosen zone.

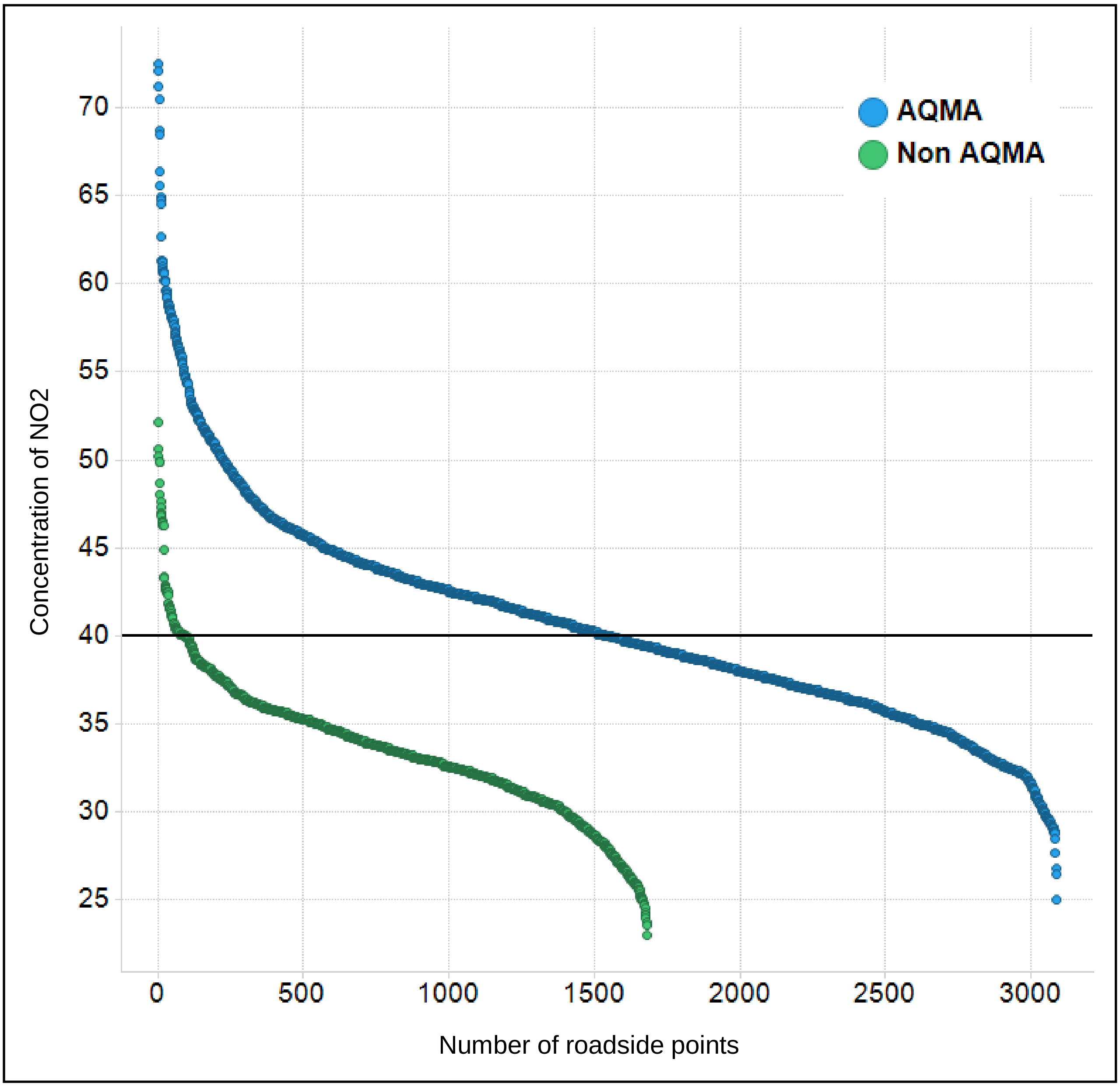

Figure 17: Distribution of Roadside Point Annual Average NO2 (µgm^{-3}) Concentrations Inside and Outside Glasgow AQMAs in 2017.

Table 4 shows various simple statistics relating to the roadside point NO2 for the 2017 base run. The number of roadside points above 40 and 55 µgm^{-3} are presented as percentages of all the roadside points and the number of roadside points within each identified zone.

Table 4: Number of Roadside Points with Modelled Annual Average NO2 above 40 and 55 μgm^{-3} In AQMA and non-AQMA Zones. Expressed as a Percentage of the Total Number of Roadside Points.

Zone	No. Of Roadside Points Above 40 μgm^{-3}	No. Of Roadside Points Above 40 μgm^{-3} as % of Total '*'	No. Of Roadside Points Above 55 μgm^{-3}	No. Of Roadside Points Above 55 μgm^{-3} as % of Total '*'
AQMA	1534	32	88	2
Non-AQMA	90	2	0	0
'*' – Total = 4769 points. '**' – There are a small number of overlapping points between these AQMAs.				

4.2 Summary of NO2 Concentrations in the Glasgow NMF Model

The information presented in section 4.1 outlines the scale of roadside NO2 air quality issues experienced in Glasgow in 2017. Air quality modelling can be used to examine potential issues that could not be easily assessed with current monitoring techniques.

Although GCC have reported a downward trend of NO2 concentrations in the Annual Progress Report, a number of observations can be made which will remain valid:

- Outside the existing AQMAs, there are only few areas where roadside NO2 concentrations are likely to be higher than the annual average limit value. Due to model uncertainty, not all areas predicted areas of exceedance will be above the limit. These areas could be investigated with additional monitoring.

- Figure 14 and Figure 15 confirm that the city centre AQMA boundaries are well founded. In particular, the city centre AQMA has roadside points with an annual average concentration of NO2 above 55 μgm^{-3}. These locations are likely to still be above the annual average NO2 limit value in 2019, particularly if they are in narrow and deep street canyons.

- Roadside locations in Glasgow which lie along congested roads with a low annual average speed, particularly within the city centre AQMA and in street canyons, may be experiencing very high annual average NO2 concentrations.

- There were 3 PDTs in 2017 where the annual average NO2 concentration was measured over 55 μgm^{-3} on Hope Street and Gordon Street, adjacent to Central Station. Analysis of the base model for 2017 indicates that are 88 roadside points which are greater than 55 μgm^{-3}. We would recommend that the highest roadside points are investigated with monitoring.

- **Modelling results suggest that the city centre AQMA, and some surrounding streets, suffer from the poorest roadside NO2 air quality in Glasgow. Significant emission reduction in, and around, the city centre AQMA will be required to improve air quality. Significant emission reduction will be required in areas of narrow and deep "street canyons".**
- **The Byres Road and Dumbarton Road AQMA will also require some form of emission reduction to improve air quality.**
- **Many of the main roads in Glasgow would benefit from some amount of emission reduction.**
- **High NO2 concentrations on congested roads will be very challenging to improve without significant emission reduction and/or measures to ease congestion.**

4.3 Contribution to Air Quality from Different Vehicle Types

The Glasgow NMF model has been used to explore the relative contribution of different vehicle sources to the annual average total NOx concentration (hereafter referred to as annual average total NOx) at a number roadside points. This 'source attribution' is helpful for understanding the behaviour of the model, and also for identifying high emitters, which could be targeted for emission reductions in future model scenarios. The attribution is calculated for NOx, rather than NO2, because it is 'chemically-conserved'. This means that the attribution is not complicated by the contribution from secondary NO2 (a complex chemical effect).

Source attribution has been carried out for eight vehicle categories:

- Articulated (Artic.) HGV
- Rigid HGV
- Buses/Coaches
- LGV
- Taxi (As Classified by the DVLA)
- Diesel Cars
- Petrol Cars
- Motorcycles

It should be noted that 'private hire' taxis are counted within the regular Petrol/Diesel car categories, as they are not easily distinguished in the traffic data. Similarly, Bus and Coach are counted as one category.

Source apportionment has been carried out for 1774 roadside points across the modelled area. These have been attached to their relevant road link so that the major emission sources for each road can be determined. The top section of Figure 18 shows that all road links in the model have been highlighted (in black). The bottom section is a graph of the percentage contribution to annual average total NOx for each roadside point. Due to the large number of points, each one is represented as a thin line. Sections of these thin lines are coloured according to the percentage contribution to annual average total NOx by each vehicle type. Thus, a long section coloured red indicates a large contribution to annual average total NOx by Bus/Coach. Figure 18 shows that contributions to annual average total NOx vary across the modelled area. Bus/Coach dominates in many areas with Diesel cars dominating in others. Figure 19 follows a similar format to Figure 18 but only includes roadside points within the

AQMA areas. The percentage contribution pattern in the AQMAs is similar to that for all modelled roads. However, Bus/Coach is a dominant source at many roadside points.

Figure 20 and Figure 21 highlight the road links in the model where contributions to annual average total NOx are greater than 40% for Bus/Coach and Cars (Diesel & Petrol), respectively. Many road links within the city centre AQMA have Bus/Coach greater than 40% (max. 86%). Fewer road links in the city centre AQMA have Car contributions greater than 40% (max 55%).

In a similar way to the NO2 concentration roadside points, we can look at the distribution and simple statistics of source attribution roadside points. As a guide to the influence of each vehicle type, we can add up the annual average total NOx contribution from each vehicle type across a range of roadside points in a particular zone. These can then be divided by the sum of the annual average total NOx from all vehicle sources across the same range of points. A percentage contribution to annual average total NOx, across a zone, from each vehicle type can then calculated.

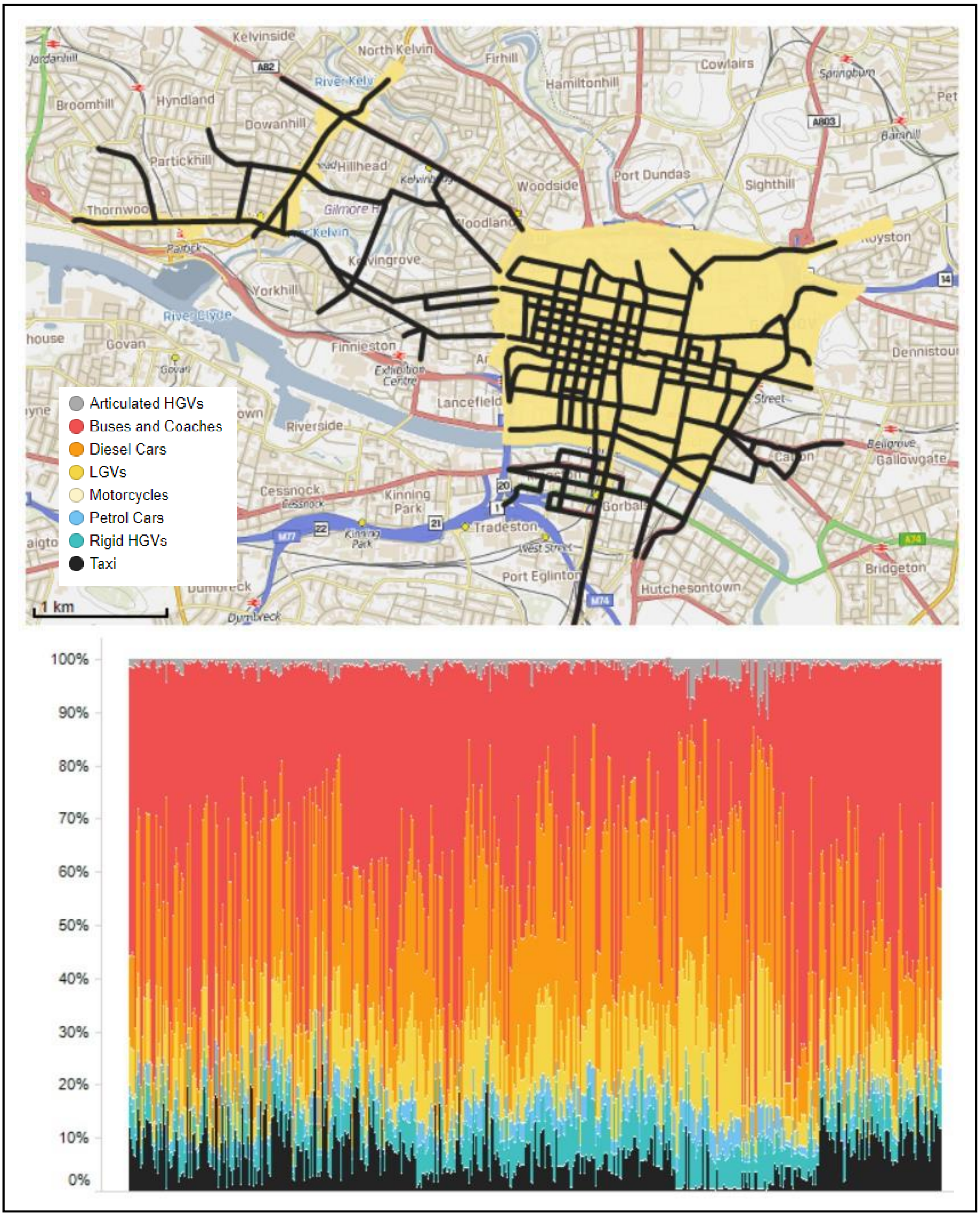

Figure 18: Percentage Contribution to Annual Average Total NOx for All Source Apportionment Roadside Points. Highlighted Roads in Black. Colour Key Refers to Lower Part of Figure.

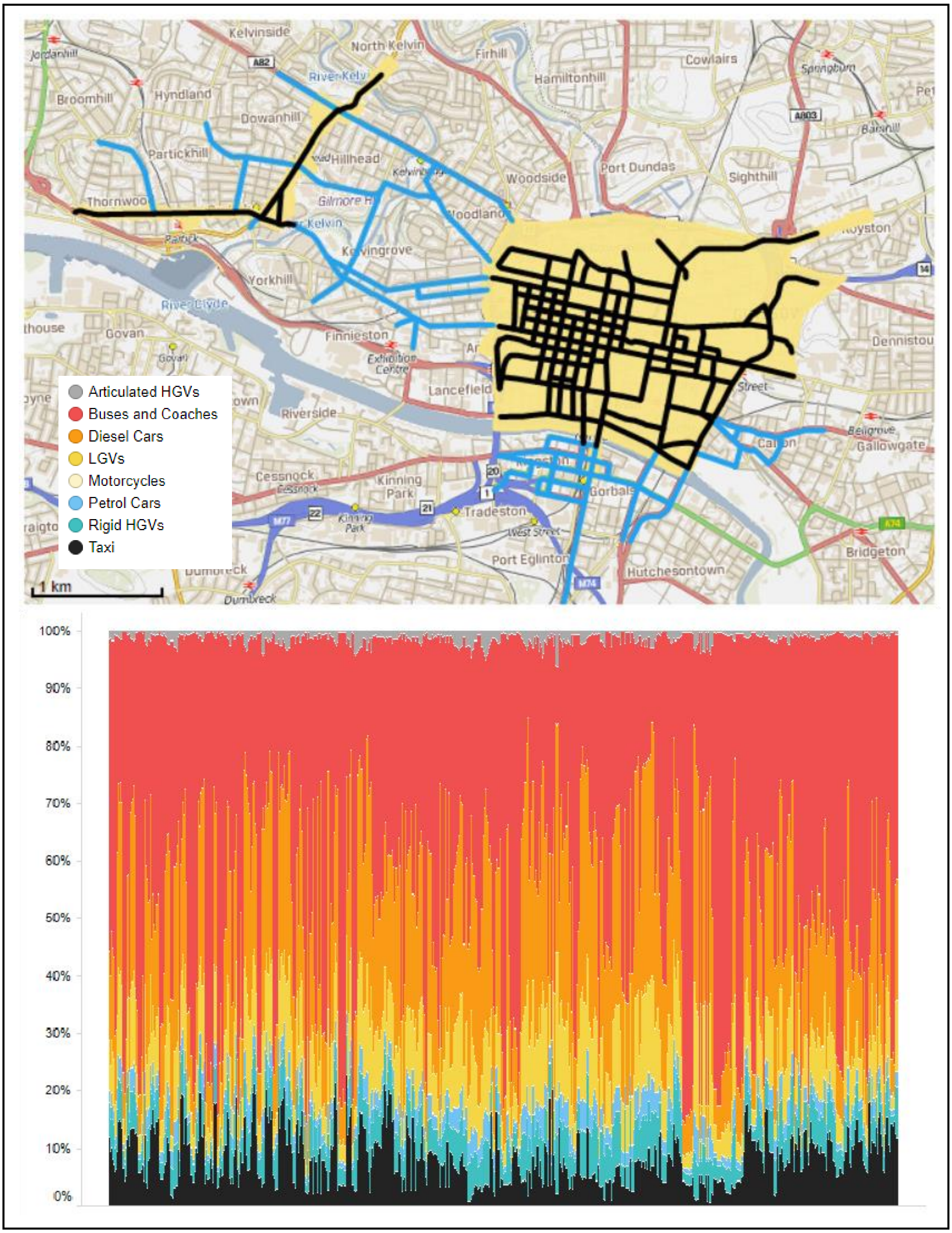

Figure 19: Percentage Contribution to Annual Average Total NOx for AQMA Source Apportionment Roadside Points. Highlighted Roads in Black. Colour Key Refers to Lower Part of Figure.

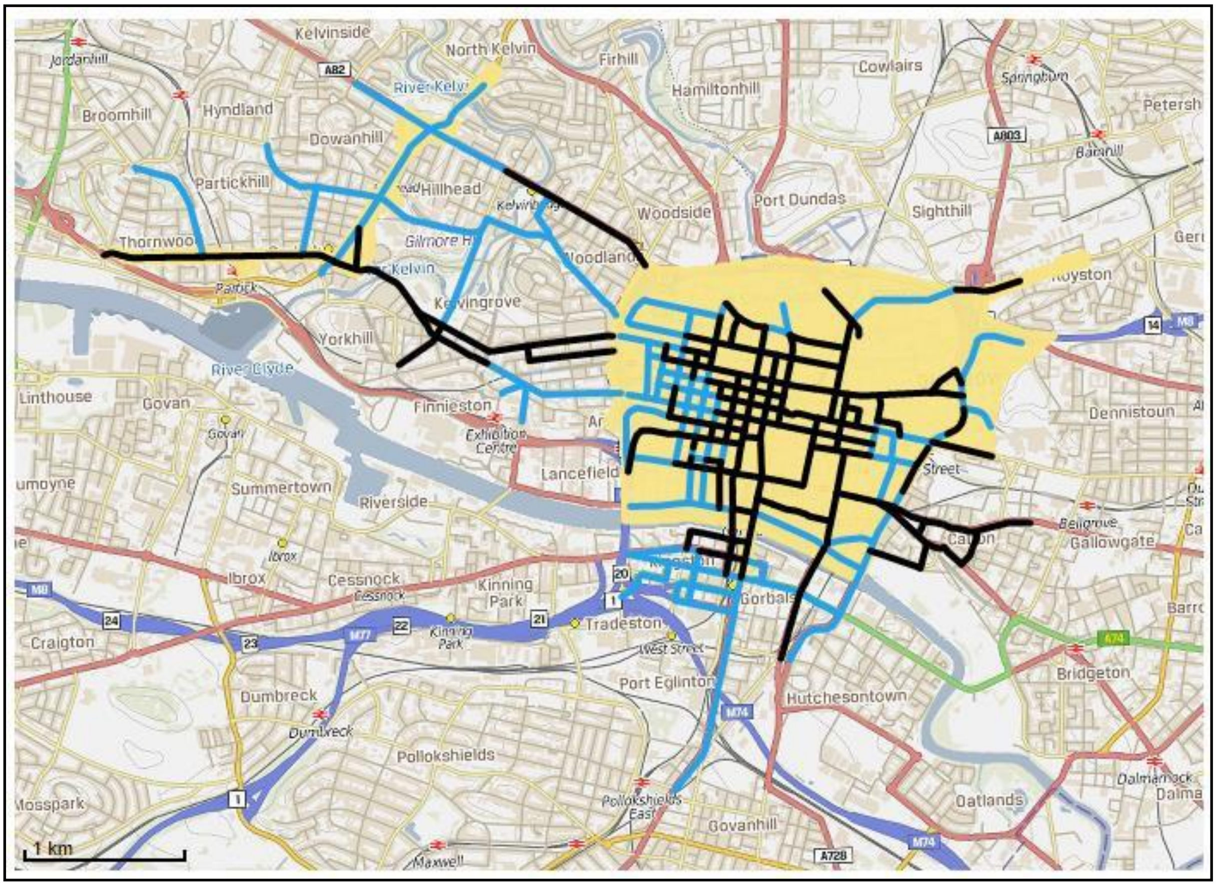

Figure 20: Road Links where the Contribution from Buses and Coaches to Annual Average Total NOx is Between 40 and 86%. Highlighted In Black.

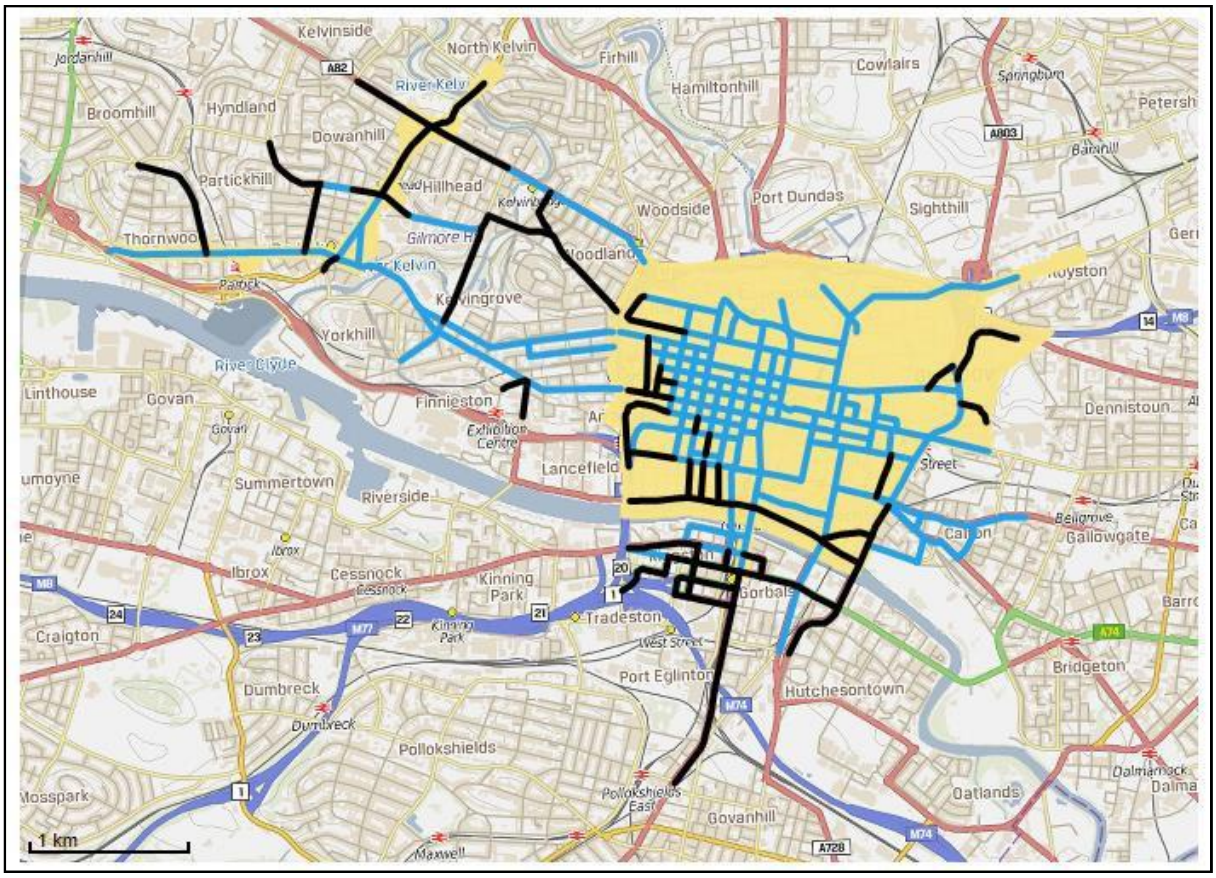

Figure 21: Road links where the Contribution from All Cars to Annual Average Total NOx is between 40 and 55%. Highlighted in Black.

Figure 22 shows the distribution of the percentage of annual average total NOx at all source attribution roadside points, for each vehicle type. Figure 23 displays similar data but is restricted to those roadside points which lie within the two AQMAs. In both figures, roadside points have been ranked from highest to lowest for each vehicle category. It is important to note that the lines for each vehicle type are independent. For example, a point with a high bus NOx contribution does not experience the Diesel car NOx contribution at the point directly below.

Figure 24 and Figure 25 show the percentage contribution to annual average total NOx for each vehicle type within a particular zone: all roadside points and the AQMAs, respectively. Whilst this does not represent an accurate emissions budget within a zone, it does highlight the relative influence, on air quality, of each type of vehicle in an area.

It is clear that Buses and Coaches and Diesel Cars provide large contributions to annual average total NOx within, and outside, the Central AQMA. LGVs are the third largest contributor with other Goods Vehicles adding smaller, but significant, amounts.

A different way of visualising these data is to aggregate so called “commercial” vehicles together. Goods vehicles and taxis are likely to be distinct from private vehicles in that they are almost exclusively used for business. We can also aggregate Diesel and Petrol Cars and acknowledge that a proportion of these vehicles will also be used exclusively for business. A more detailed study of vehicle use in Glasgow would reveal this. However, the majority of cars may be used for social and domestic purposes.

Vehicles have been aggregated in the following way:

- All Cars: Diesel and Petrol Cars.
- Buses and Coaches: No change from previous figures.
- Non-Bus Commercial Vehicles: Artic. HGV's, LGV's, Rigid HGV's and Taxis.

Taxis are clearly distinct in purpose from goods vehicles. However, they are marginally more influential in the AQMA where repeat journeys are likely. Repeat journeys may also be a factor in some goods vehicles.

Figure 26 to Figure 29 show the source apportionment information for aggregated vehicles in a similar format to that presented earlier.

The information presented shows the relative contribution from different vehicle types to annual average total NOx air quality. Additionally, detailed traffic data allow us to estimate the average number of different vehicle types contributing to the annual average total NOx issues in Glasgow.

Table 5 and Table 6 show the average and maximum AADT, for aggregated vehicle types, within the zones specified above. Table 7 shows the average number of aggregated vehicles which is related to 1 % of annual average total NOx within a zone. To calculate this, we divide the average AADT in Table 5 by the percentage of annual average total NOx in Figure 28 and Figure 29. This simple ratio is useful for showing the number of vehicles which are responsible for the levels of roadside pollution modelled. As we have seen, vehicle contribution can vary greatly from street to street. However, we believe this very general approach is useful and informative.

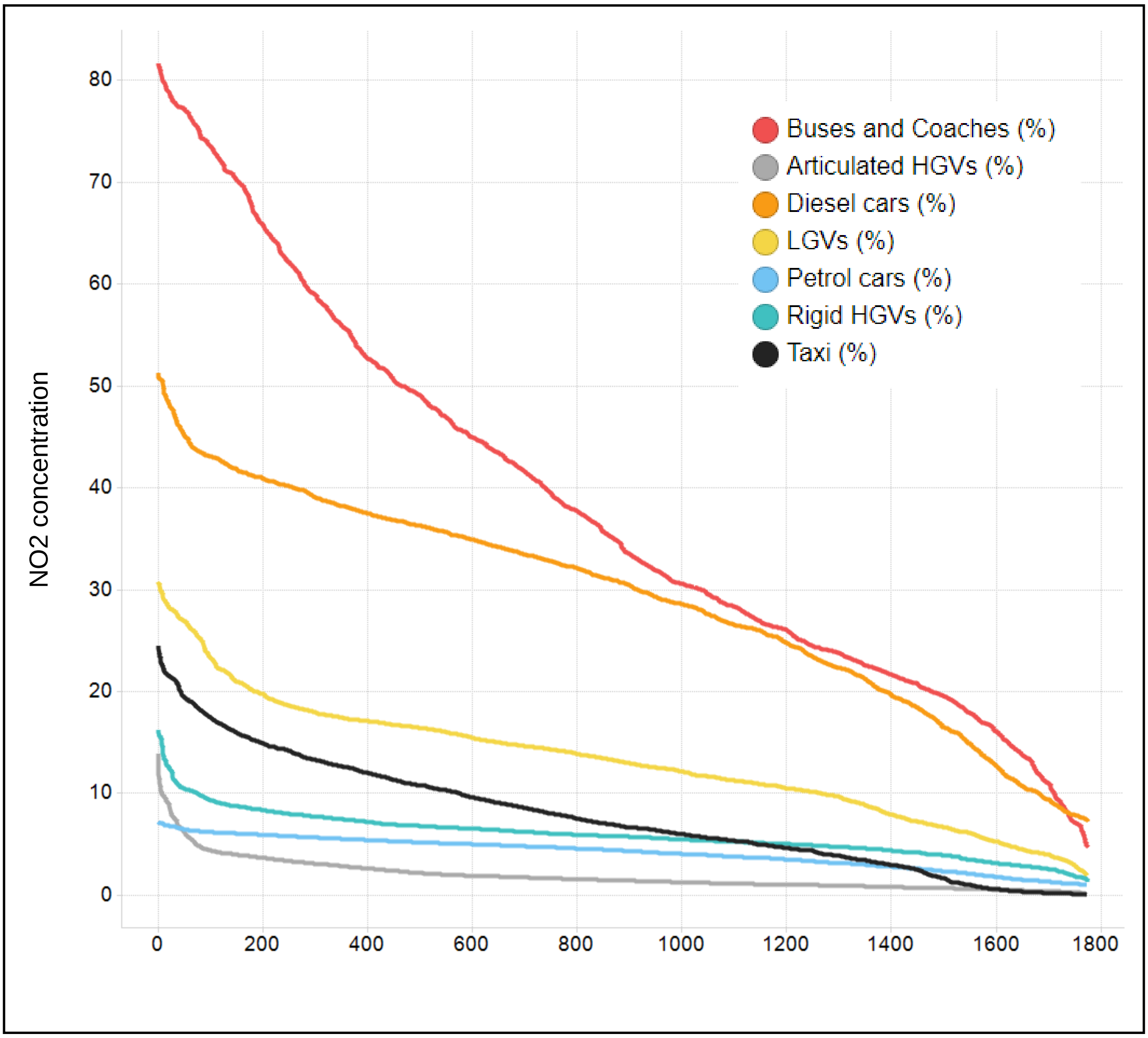

Figure 22: Distribution of the Percentage of Annual Average Total NOx at all Source Attribution Roadside Points for Each Vehicle Type.

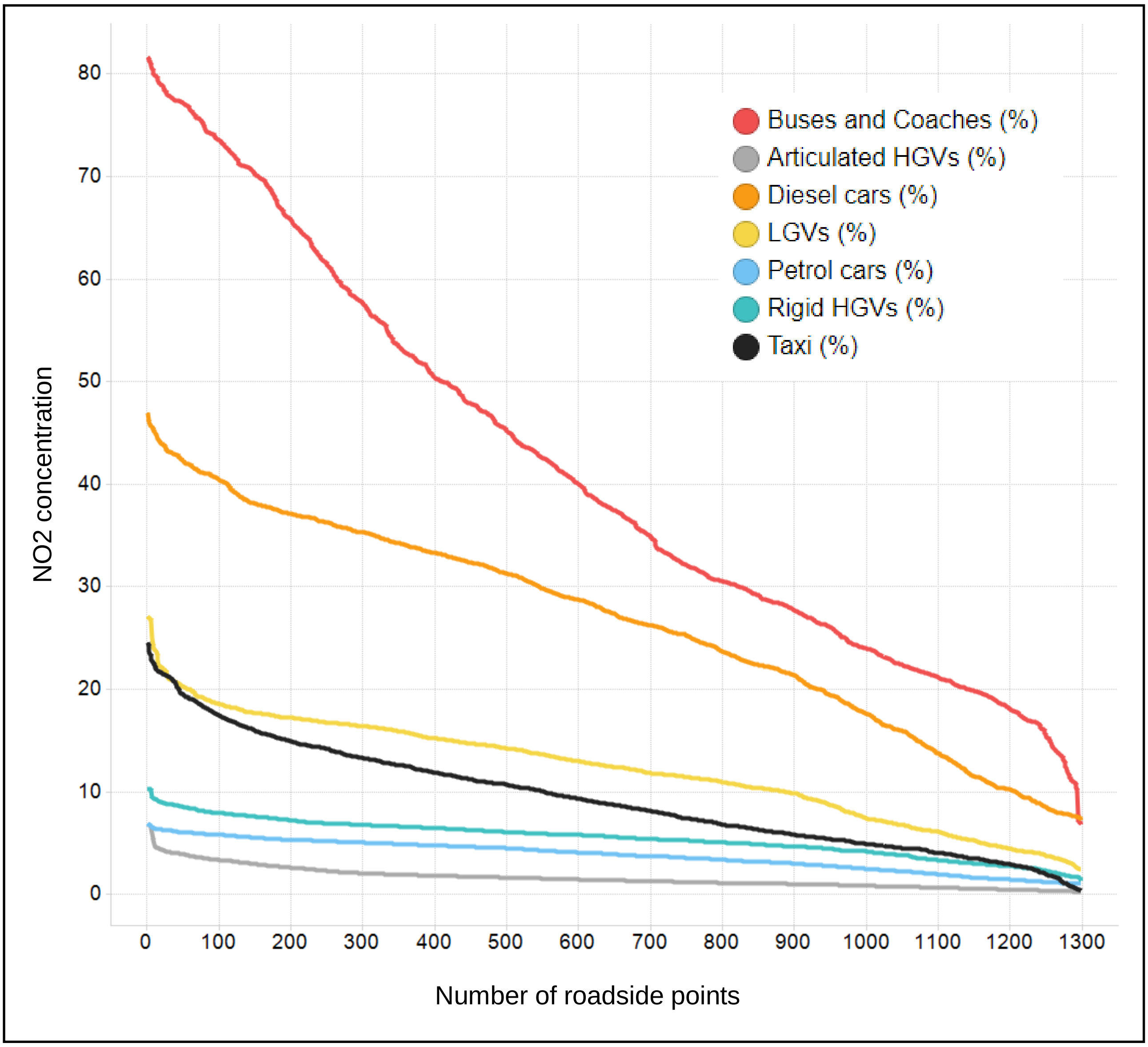

Figure 23: Distribution of the Percentage of Annual Average Total NOx at AQMA Source Attribution Roadside Points for Each Vehicle Type.

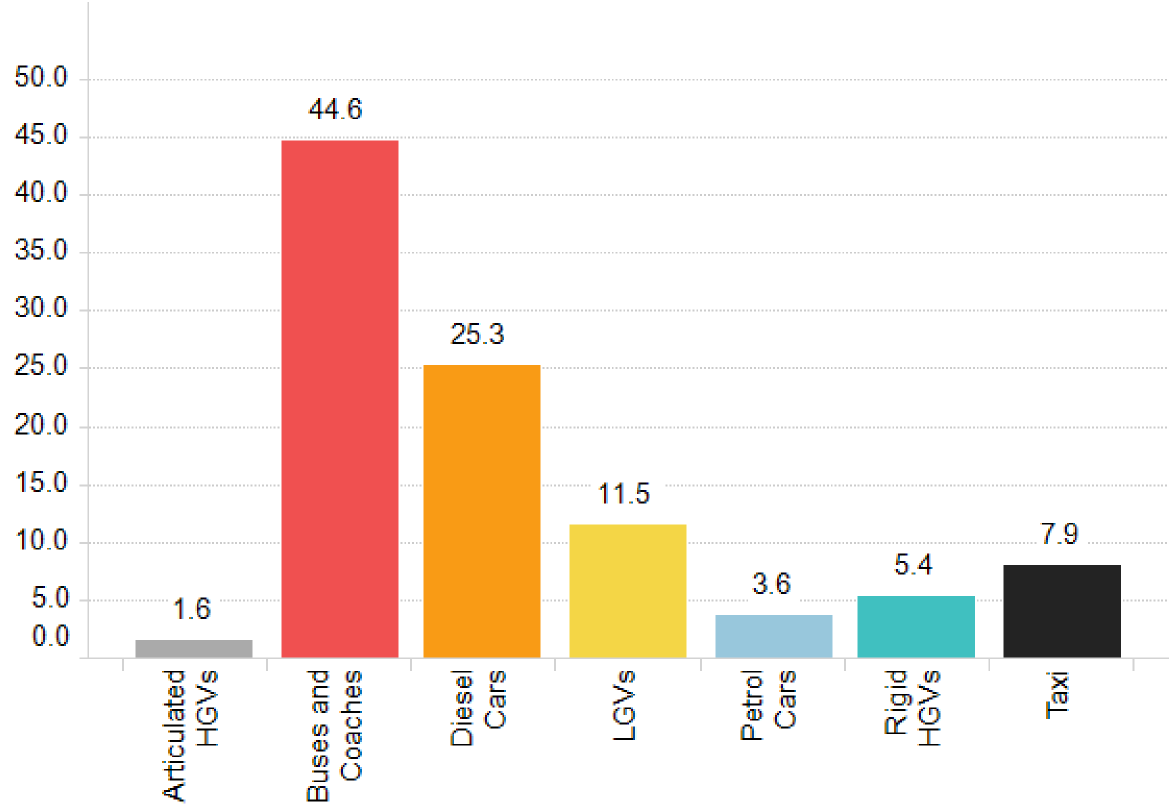

Figure 24: Percentage Contribution to Annual Average Total NOx within a Zone for Each Vehicle Type. Zone: All Roadside Points.

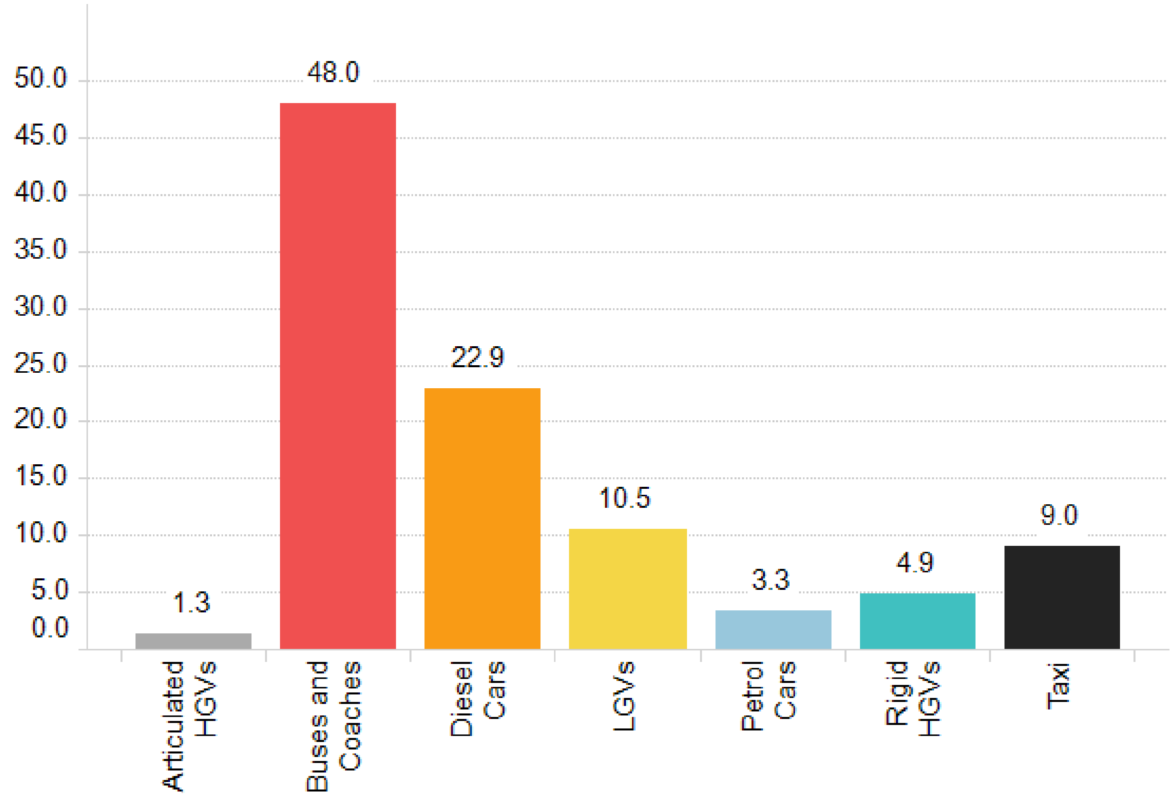

Figure 25: Percentage Contribution to Annual Average Total NOx within a Zone for Each Vehicle Type. Zone: AQMAs.

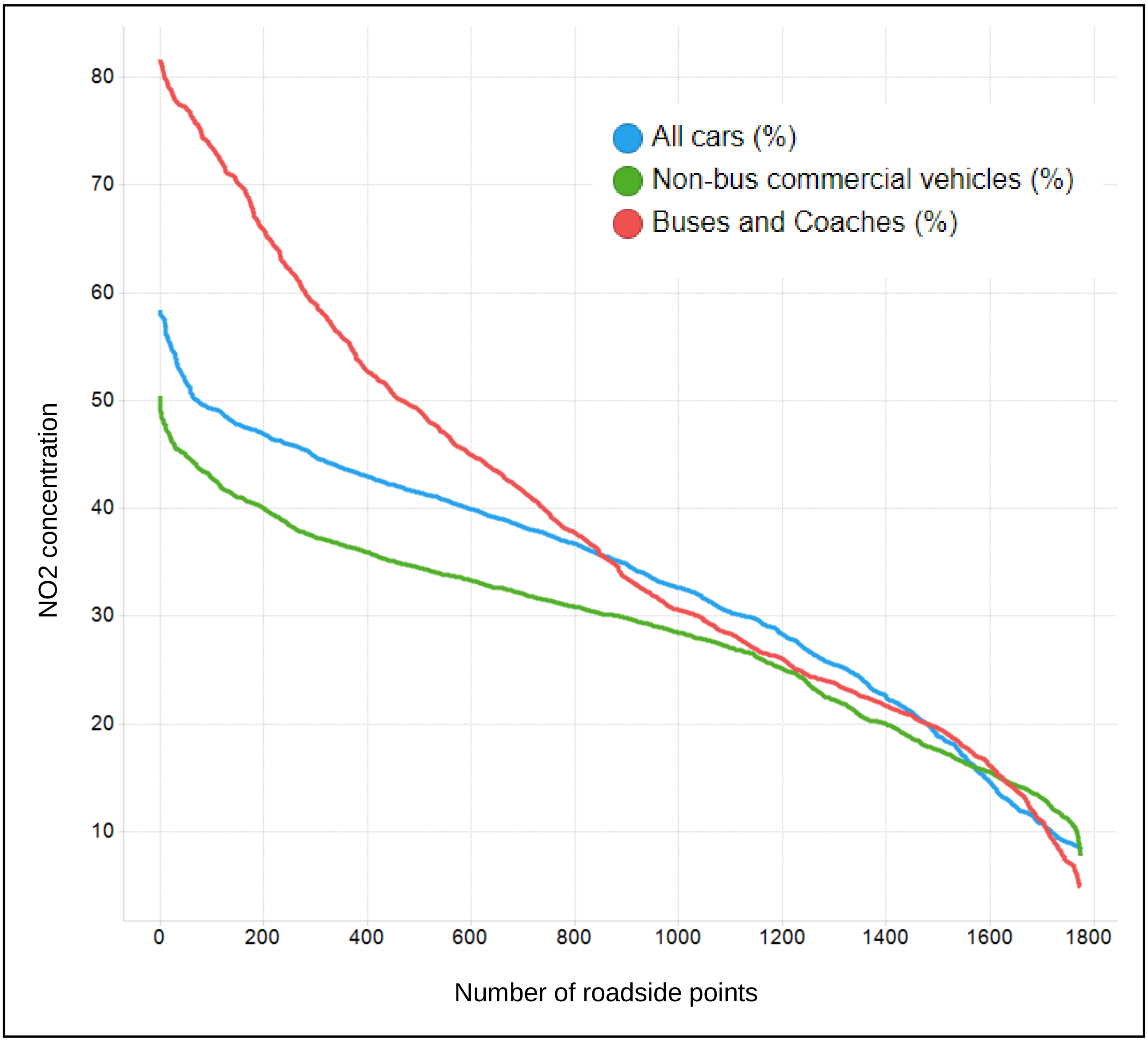

Figure 26: Distribution of the Percentage of Annual Average Total NOx at Source Attribution Roadside Points for Aggregated Vehicle Type.

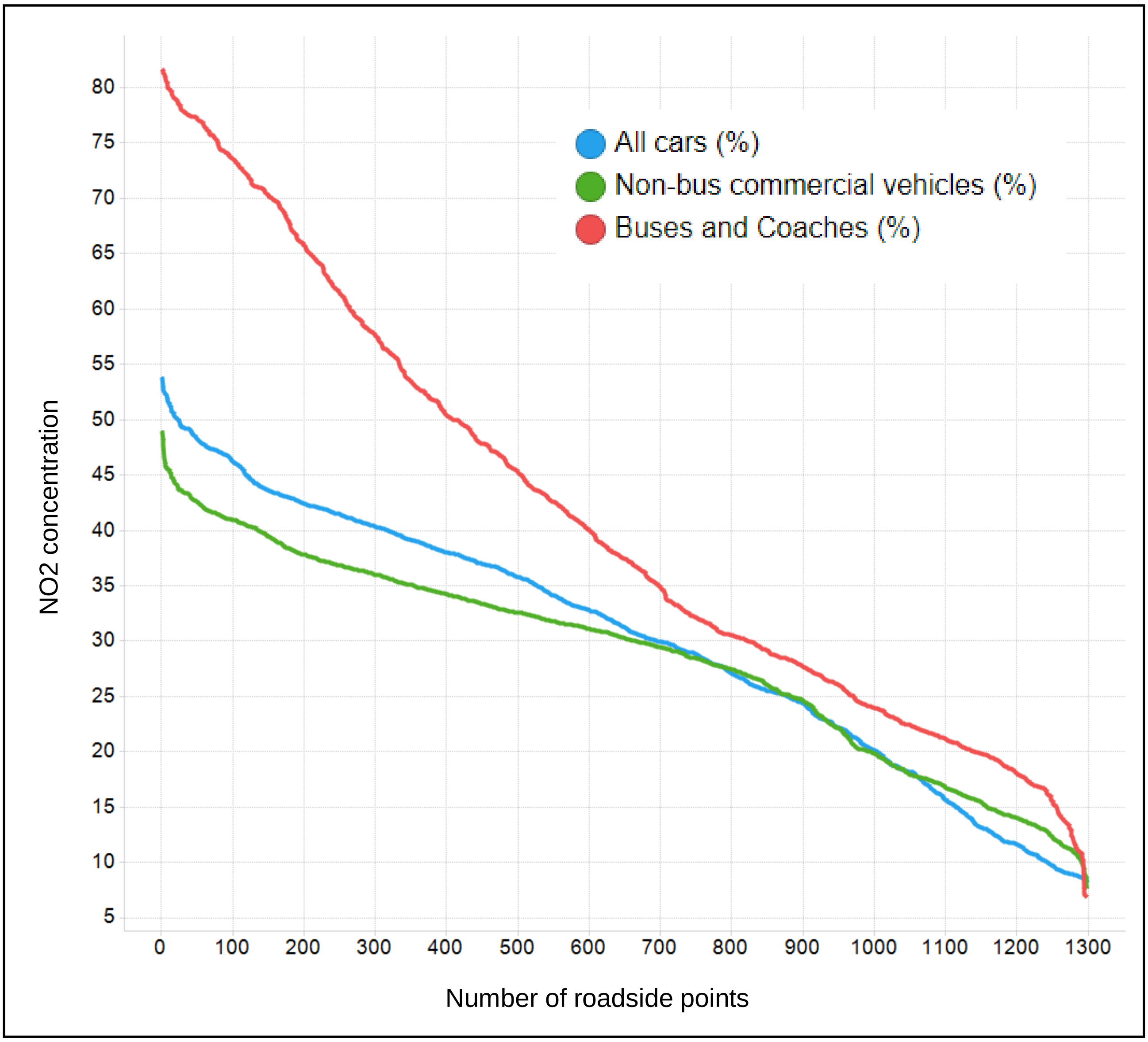

Figure 27: Distribution of the Percentage of Annual Average Total NOx at AQMA Source Attribution Roadside Points for Aggregated Vehicle Type.

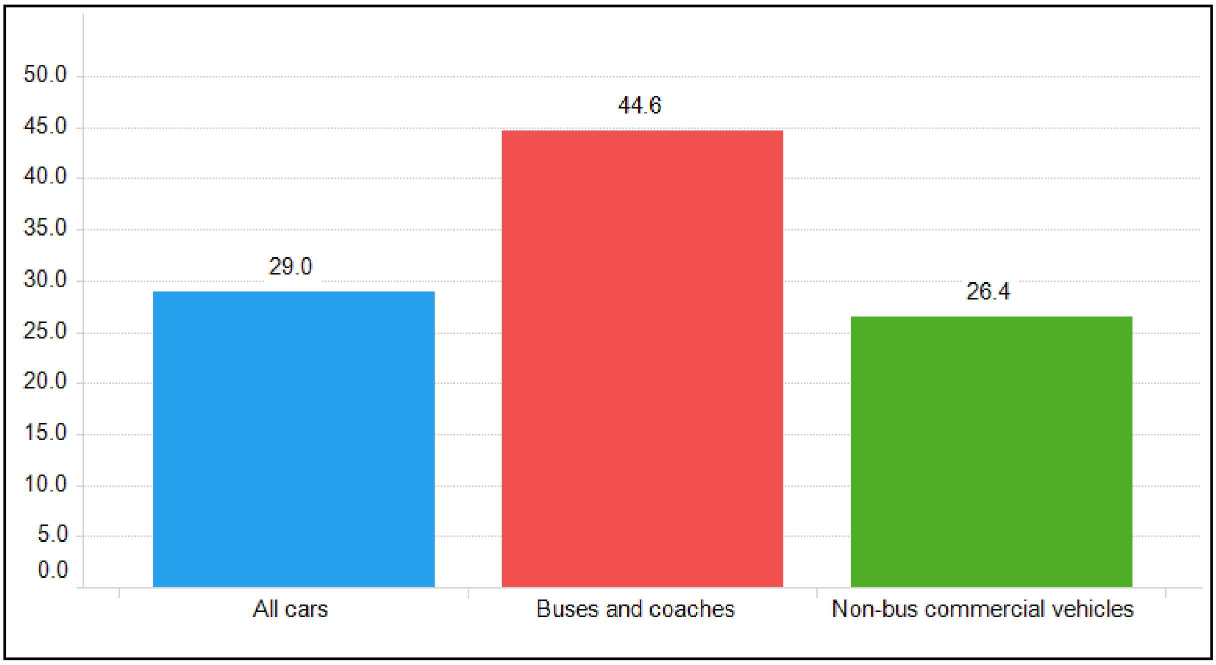

Figure 28: Percentage Contribution to Annual Average Total NOx Within a Zone for Aggregated Vehicle Type. Zone: All Roadside Points.

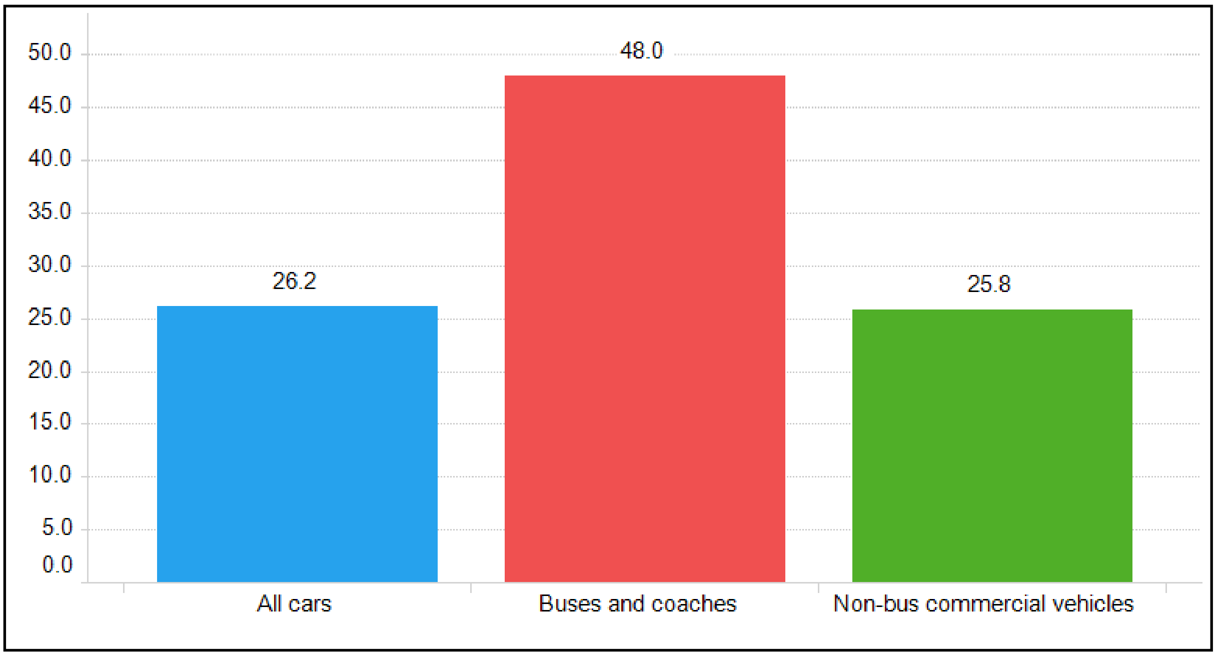

Figure 29: Percentage Contribution to Annual Average Total NOx Within A Zone for Each Vehicle Type. Zone: AQMA.

Table 5: Average AADT in Each Zone for Aggregated Vehicle Type.

	Average AADT In Zone		
Zone	**All Cars**	**Buses And Coaches**	**Non-Bus Commercial**
All Roadside Points	5647	459	1371
AQMA	5342	498	1389

Table 6: Maximum AADT in Each Zone for Aggregated Vehicle Type.

	Maximum AADT In Zone		
Zone	**All Cars**	**Buses And Coaches**	**Non-Bus Commercial**
All Roadside Points	20907	3112	3847
AQMA	20907	3112	3847

Table 7: Average AADT Related to 1% of Annual Average Total NOx. (Values Have Been Rounded).

	Average Number Of Vehicles (AADT) Related To 1% Of Total Annual Average NOx		
Zone	**All Cars**	**Buses And Coaches**	**Non-Bus Commercial**
All Roadside Points	195	10	52
AQMAs	204	10	54

4.4 Summary of Contribution to Air Quality from Different Vehicle Types

The information presented in Section 4.3 describes how different vehicle types contribute to levels of roadside NOx pollution in many areas of Glasgow. High levels of NOx are associated with high levels of NO2. The variation of annual average NO2 has been discussed in sections 4.1 and 4.2. As with concentrations, there are likely to have been some changes in vehicles and traffic between 2017 and the time of writing (2019). This will have affected the current source apportionment. However, the detailed information available for 2017 should still provide a useful guide to the relative influence of different vehicle types on air quality. Information arising from this can help to influence initial LEZ options. Further traffic data and air modelling may be necessary to assess the most recent conditions before the implementation of an LEZ.

Throughout the rest of this section the following terms will apply, unless stated otherwise:

- **NOx means annual average total NOx**
- **NO2 means annual average NO2**

If we accept that 2017 model output is a useful guide, the following observations, **for the entire modelled area**, appear to be supported by the source apportionment information:

- The contribution of different vehicle types to NOx pollution in Glasgow can vary substantially from street to street, even within a relatively small area.

- Almost all vehicle types provide some consistent level of contribution to NOx on most modelled streets. The exception to this is Buses and Coaches; which provide a more variable contribution that increases towards the city centre.

- Buses and Coaches provide the highest contribution to NOx of any vehicle type in the modelled area, and are the largest single contributor at most roadside locations. This occurs at around 1000 of 1774 source apportionment roadside points.

- Diesel cars provide the next largest contributor to NOx at most roadside locations and are the single largest contributor at around 600 of 1774 source apportionment roadside points. The maximum contribution to NOx from diesel cars is 50%.

- LGV's are the third biggest contributor to NOx at roadside locations. They contribute between 10 and 30% of NOx at over 1000 of 1774 roadside points.

- Rigid HGV's, Taxis, Petrol Cars and Artic HGV's provide smaller contributions to NOx. However, in certain locations these vehicles are likely to contribute to levels of roadside NO2 which are greater than the annual average limit value.

- LGV's, Rigid HGV's, Taxis, and Artic. HGV's can be aggregated into a Non-Bus Commercial vehicle group. Contributions to NOx from this grouping are lower than the contribution from all cars (Diesel and Petrol) at many roadside locations. However, the difference is relatively small; typically, less than 10%.

- Contributions to NOx from Buses and Coaches and Non-Bus Commercial are associated with many fewer vehicles than all cars. This means a significant amount of pollution is coming from relatively few vehicles which tend to have higher emissions than cars. Within the emissions database (see section 2.3) Non-Bus Commercial vehicles often have higher emissions of NOx (in g/km) than Diesel cars. Buses and Coaches (particularly those which are Euro 5 or older) have substantially higher emissions than Diesel cars.

- Information in Table 7 is a very basic attempt to consider how many vehicles of each type contribute to 1% of the NOx from that vehicle type. For the entire modelled area, on average:
  - Each Bus and Coach contributes to around 20 times the NOx of a car.
  - Each Non-Bus Commercial vehicle contributes to around 5 times the NOx of a car.

The majority of car NOx in this simple assessment will come from Diesel Cars.

- **Source apportionment results indicate that Buses and Coaches, Diesel Cars and LGV's are significant sources of NOx in Glasgow.**
- **Non-Bus Commercial vehicles (LGV's, Rigid HGV's, Taxis, and Artic. HGV's) contribute a similar amount of NOx to Diesel and Petrol Cars. There are far fewer Non-Bus Commercial vehicles than Cars.**
- **Within the AQMAs Buses and Coaches are the dominant source of NOx. They are therefore likely to be the biggest contributor to the roadside NO2 issues in this area.**
- **Diesel Cars play a large role in roadside NOx issues outside of the AQMAs, where they are often the dominant source of NOx. They are therefore likely to play a large role in the roadside NO2 issues in this area.**

4.5 Potential Improvements to Air Quality and Initial LEZ Options

Within a town or city, air quality impacts from vehicles can often be reduced by doing three things:

1. Reduce the total number of vehicles travelling through the area.
2. Reduce emissions from the vehicles travelling through the area.
3. Improve traffic flow within the area.

These real world changes can be reflected in air quality models in a simplified way. Ultimately, changes to vehicle numbers, type and speed is dependent on complex factors. Model output can be a useful guide to what may happen if measures are introduced to reduce emissions; such as a LEZ.

Within a model, it is easiest to change the emissions from vehicles. This can allow us to estimate what the air quality may have been, if emissions from vehicles had been lower or estimate future possible air quality related to predicted changes in the vehicle fleet.

It is possible to change vehicle flow and speed on each road link of an air quality model. However, doing this in isolation will lead to potentially unrealistic estimates of air quality. In order to more accurately model the effect of speed and flow change, output from a traffic model will be required.

The 2017 base model has been run for a number of scenarios where the vehicle fleet has been adjusted in some way to reflect a reduction in emissions. For some scenarios we can estimate what the air quality may have been in 2017, with reduced emissions from vehicles. Other scenarios use predicted fleet changes included in the emissions database (see section 2.3) to estimate what the future air quality may be, if the predictions come true.

Model output for the various scenarios are presented below and these follow a similar format to the NO2 air quality results presented in section 4.1. The same roadside points are presented as curves and summarised with simple statistics.

The emission changes made in the scenarios have been applied to the whole model. Results are presented for the entire modelled area and also for AQMAs.

Seven scenario groupings have been chosen to represent large changes to the vehicle fleet. These groupings have been run for different years to generate a total of 15 scenarios. They are intended to indicate the scale of improvement that may be possible if an LEZ was introduced to affect certain vehicle classes. Further work will be necessary to identify more realistic scenarios which may include the influence of an LEZ on traffic patterns or planned changes to traffic flows.

The Euro class of vehicles refers to a particular level of emission. Euro classes for Heavy vehicles (e.g., Bus and HGV) are expressed as Roman numerals whereas numbers are used to denote other vehicle types. For ease of reporting, we have used numbers to represent all Euro classes in this report.

Table 8: LEZ Scenario Details.

Scenario Group	Description '*'	Years Modelled
LEZ1	Vehicles classed as Euro 1 to 5 have been changed to Euro 6.	2017
LEZ1a	Buses and Coaches, HGV's have been changed to Euro 6. Petrol Cars and Petrol LGV's have been changed to Euro 6c. Diesel Cars, LGV's and Taxis have been changed to Euro 6d.	2017
LEZ2	Buses and Coaches have been changed to Euro 6. Other vehicles are unchanged.	2017, 2019, 2023
LEZ3	Buses and Coaches classed as Euro 1 to 4 have been changed to Euro 5. Other vehicles are unchanged.	2017, 2019
LEZ4	Buses and Coaches, HGV's, Diesel LGV's, Taxis, Diesel Cars have been changed to Euro 6. Petrol Cars classed as Euro 1 to 3 have been changed to Euro 4.	2017, 2019
LEZ5	Buses and Coaches, HGV's, LGV's and Taxis (**i.e., Buses/Coaches and Non-Bus Commercial**) classed as Euro 1 to 5 have been changed to Euro 6. Diesel and Petrol Cars are unchanged.	2017, 2019, 2023
LEZ6	Diesel and Petrol Cars classed as Euro 1 to 5 have been changed to Euro 6. Buses and Coaches, HGV's, LGV's and Taxis unchanged.	2017, 2019, 2023
'*' – The Euro class of vehicles refers to a particular level of emission. Euro classes for Heavy vehicles (e.g., Bus and HGV) are usually expressed as Roman numerals whereas numbers are used to denote other vehicle types. For ease of reporting, we have used numbers to represent all Euro classes.		

The scenario groups detailed in

Table 8 benefit from further explanation in simple terms:

- LEZ1: All vehicles are brand new Euro 6 class. None are any better than standard Euro 6; such as Euro 6c/d or Hybrid.

- LEZ1a: All vehicles are the best Euro 6 class they can possibly be, including new Euro 6c and 6d. This is an extremely optimistic scenario where almost all Euro 6 vehicles in Edinburgh would be brand new at all times. **Note that Euro 6c applies to: Petrol Cars, Diesel Cars, Taxi, Petrol LGV and Diesel LGV. Euro 6d applies only to Diesel Cars, Taxi and Diesel LGV.**

- LEZ2: All buses are changed to Euro 6 but the rest of vehicle fleet remains unchanged.

- LEZ3: Older buses are changed to Euro 5 but the rest of the fleet remains unchanged. A proportion of Euro 6 buses is included as these are already in the fleet.

- LEZ4: Similar to LEZ1 but older petrol cars have not been changed to Euro 6 (or better), they have only been changed to Euro 4. Existing Euro 6 petrol cars are included.

- LEZ5: Cars remain unchanged but all other vehicles are upgraded to Euro 6. This is equivalent to upgrading the Non-Bus Commercial Vehicles and Buses and Coaches.

- LEZ6: Cars are upgraded to Euro 6 but all other vehicles remain unchanged.

Figure 30 shows the distribution of 2017 annual average NO2 at all roadside points for the various scenarios described above.

Figure 31 shows similar information but only for AQMA roadside points. Curves in the figures are denoted by a key which describes a particular scenario group. For example, “2017; EF6 (LEZ1)” indicates that the 2017 base fleet was modified as described in LEZ1 above.

Each curve (from right to left) in the figures shows a decreasing number of roadside points lying above the annual average NO2 limit value of 40 μgm^{-3}. Almost all scenarios show a small number of points above 55 μgm^{-3}. Curves for the 2019 and 2023 scenarios are very close together and have not been presented. However, these results have been presented in tables alongside those already presented in the figures for 2017.

Table 9 to Table 12 summarise the potential benefits to annual average NO2 for all 15 scenarios modelled. Results are presented for all roadside points and roadside points within the AQMAs. In each scenario the percentage of roadside points which remain above the annual average limit value of 40 μgm^{-3} is given; as are the number of roadside points which remain above 55 μgm^{-3}. Percentages for the base 2017 run are given for comparison. The year of each scenario is given at the top of the tables and a brief description of the emission changes is shown.

In addition to the roadside points we can also look at the potential benefits, of selected scenarios, to 43 of the Passive Diffusion Tubes (PDT), and automatic monitoring stations, deployed in Glasgow in 2017.

Table 13 and Table 14 display information about the potential benefits to PDTs from the some of the scenarios described above.

Figure 32 shows the potential benefit to annual average NO2 measured at automatic monitoring stations for 2017 scenarios.

Figure 33 and Figure 34 shows a map of all modelled annual average roadside NO2 concentrations for the 2016 LEZ1 and LEZ2 scenario, respectively.

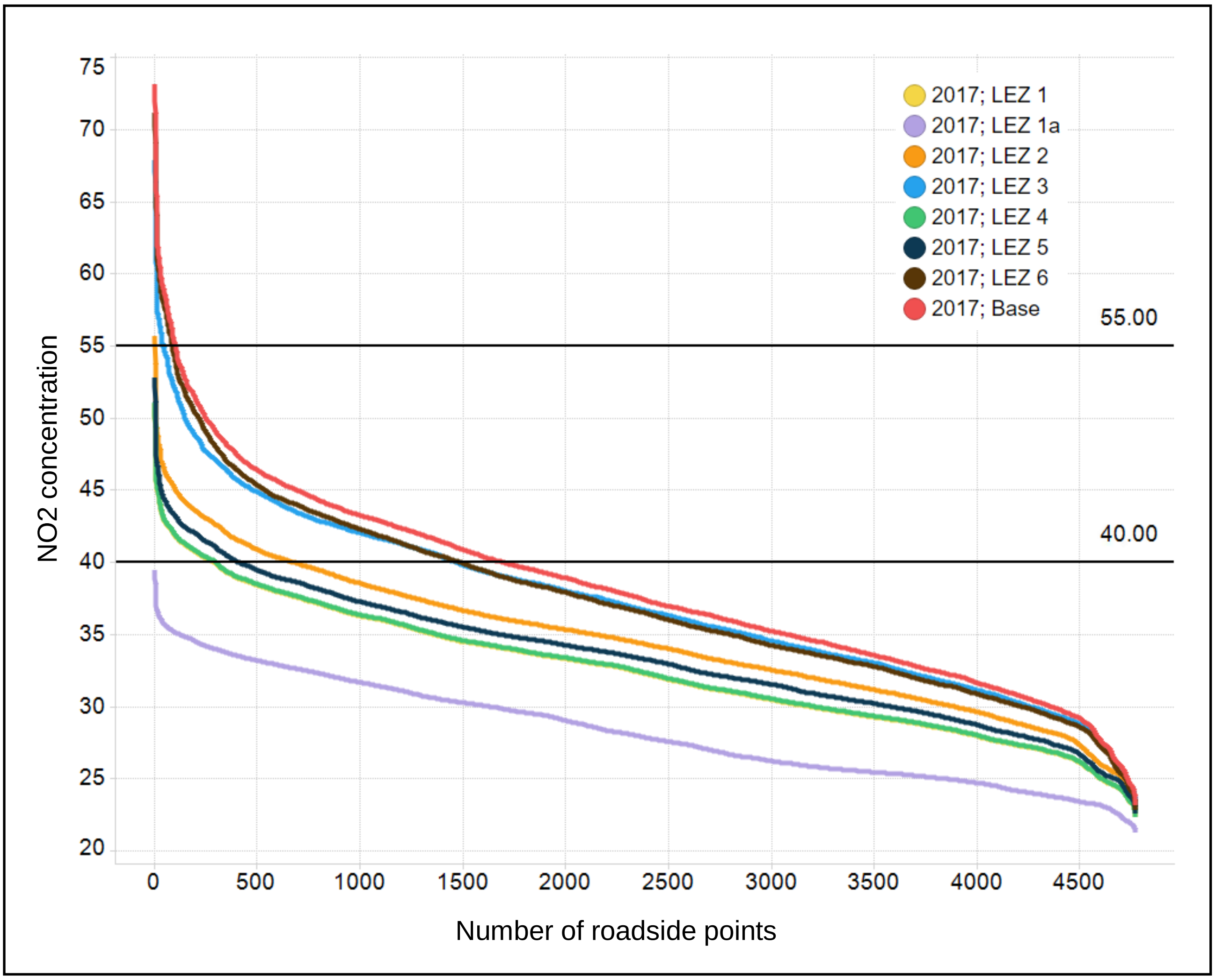

Figure 30: Distribution Of All Roadside Point Annual Average NO2 (μgm^{-3}) for Various Emissions Changes to 2017 Base Run. Annual average speed scenario 2.

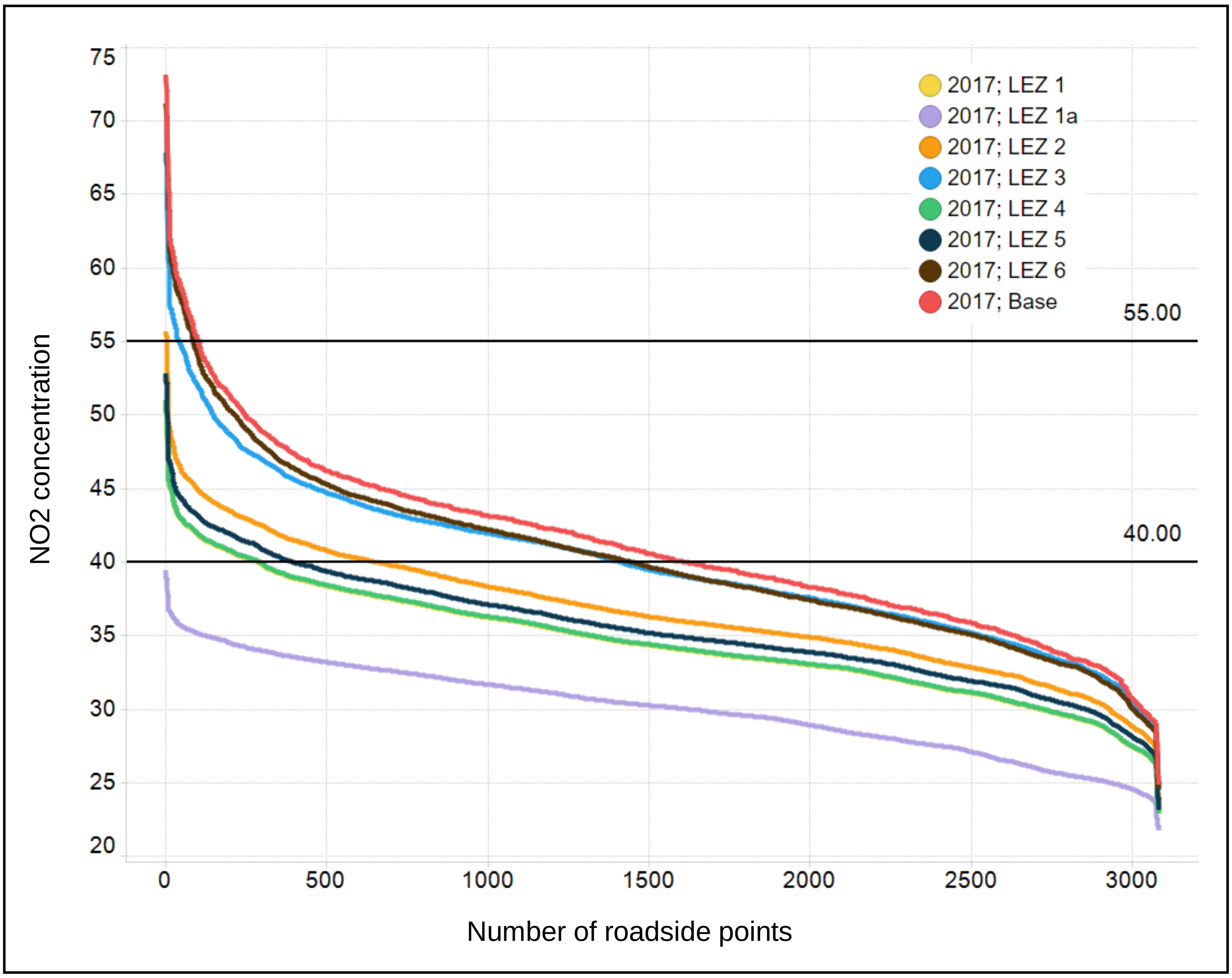

Figure 31: Distribution Of Central AQMA Roadside Point Annual Average NO2 (µgm^{-3}) for Various Emissions Changes to 2017 Base Run. Annual average speed scenario 2.

Table 9: Percentage Of All Roadside Points Above Annual Average NO2 of 40 µgm-3 For Various Emissions Changes to 2017 Base Run.

Year →	2017	2019	2023	
Scenario	**% Of Roadside Points Above 40 µgm-3 '*'**	**% Of Roadside Points Above 40 µgm-3 '*'**	**% Of Roadside Points Above 40 µgm-3 '*'**	**Brief Description Of Vehicle Emission Changes**
Base Run	35.37	28.77	15.81	As Base
LEZ1	6.08	N/A	N/A	All E(1-5) to E(6).
LEZ1a	0.00	N/A	N/A	All E(6),(6c),(6d).
LEZ2	14.17	6.88	0.46	Buses E(6); Others No Change.
LEZ3	30.87	14.09	N/A	Buses E(1-4) to E(5); Others No Change.
LEZ4	6.23	2.73	N/A	Buses, HGV's, Diesel LGV's, Taxis, Diesel Cars E(6), Petrol Cars E(1-3) to E(4).
LEZ5	8.56	4.74	0.25	Buses, HGV's, LGV's and Taxis E(1-5) to E(6); Cars No Change.
LEZ6	31.16	12.29	1.55	Cars E(1-5) to E(6); Buses, HGV's, LGVs, Taxis No Change.
'*' – Total = 4769 points.				

Table 10: Percentage Of All Roadside Points Above Annual Average NO2 of 55 µgm-3 For Various Emissions Changes to 2017 Base Run.

Year →	2017	2019	2023	
Scenario	**% Of Roadside Points Above 55 µgm-3 '*'**	**% Of Roadside Points Above 55 µgm-3 '*'**	**% Of Roadside Points Above 55 µgm-3 '*'**	**Brief Description Of Vehicle Emission Changes**
Base Run	2.16	1.53	0.48	As Base
LEZ1	0.00	N/A	N/A	All E(1-5) to E(6).
LEZ1a	0.00	N/A	N/A	All E(6),(6c),(6d).
LEZ2	0.06	0.00	0.00	Buses E(6); Others No Change.
LEZ3	0.86	0.13	N/A	Buses E(1-4) to E(5); Others No Change.
LEZ4	0.00	0.00	N/A	Buses, HGV's, Diesel LGV's, Taxis, Diesel Cars E(6), Petrol Cars E(1-3) to E(4).
LEZ5	0.00	0.00	0.00	Buses, HGV's, LGV's and Taxis E(1-5) to E(6); Cars No Change.
LEZ6	1.78	0.13	0.00	Cars E(1-5) to E(6); Buses, HGV's, LGVs, Taxis No Change.
'*' – Total = 4769 points.				

Table 11: Percentage of AQMA Roadside Points Above Annual Average NO2 of 40 μgm^{-3} For Various Emissions Changes to 2017 Base Run.

Year →	**2017**	**2019**	**2023**	
Scenario	**% Of Roadside Points Above 40 μgm^{-3} '*'**	**% Of Roadside Points Above 40 μgm^{-3} '*'**	**% Of Roadside Points Above 40 μgm^{-3} '*'**	**Brief Description Of Vehicle Emission Changes**
Base Run	52.03	43.49	24.05	As Base
LEZ1	9.25	N/A	N/A	All E(1-5) to E(6).
LEZ1a	0.00	N/A	N/A	All E(6),(6c),(6d).
LEZ2	21.19	10.22	0.71	Buses E(6); Others No Change.
LEZ3	45.89	21.13	N/A	Buses E(1-4) to E(5); Others No Change.
LEZ4	9.44	4.19	N/A	Buses, HGV's, Diesel LGV's, Taxis, Diesel Cars E(6), Petrol Cars E(1-3) to E(4).
LEZ5	12.79	7.14	0.39	Buses, HGV's, LGV's and Taxis E(1-5) to E(6); Cars No Change.
LEZ6	46.90	18.57	2.40	Cars E(1-5) to E(6); Buses, HGV's, LGVs, Taxis No Change.
'*' – Total = 3081 points.				

Table 12: Percentage of Central AQMA Roadside Points Above Annual Average NO2 of 55 μgm^{-3} For Various Emissions Changes to 2017 Base Run.

Year →	**2017**	**2019**	**2023**	
Scenario	**% Of Roadside Points Above 55 μgm^{-3} '*'**	**% Of Roadside Points Above 55 μgm^{-3} '*'**	**% Of Roadside Points Above 55 μgm^{-3} '*'**	**Brief Description Of Vehicle Emission Changes**
Base Run	3.34	2.37	0.75	As Base
LEZ1	0.00	N/A	N/A	All E(1-5) to E(6).
LEZ1a	0.00	N/A	N/A	All E(6),(6c),(6d).
LEZ2	0.10	0.00	0.00	Buses E(6); Others No Change.
LEZ3	1.33	0.19	N/A	Buses E(1-4) to E(5); Others No Change.
LEZ4	0.00	0.00	N/A	Buses, HGV's, Diesel LGV's, Taxis, Diesel Cars E(6), Petrol Cars E(1-3) to E(4).
LEZ5	0.00	0.00	0.00	Buses, HGV's, LGV's and Taxis E(1-5) to E(6); Cars No Change.
LEZ6	2.76	0.19	0.00	Cars E(1-5) to E(6); Buses, HGV's, LGVs, Taxis No Change.
'*' – Total = 3081 points.				

Table 13: Percentage Of PDTs Above Annual Average NO2 of 40 µgm^{-3} For Various Emissions Changes to 2016 Base Run.

Year →	2016	2019	2023	
Scenario	**% Of PDTs Above 40 µgm^{-3} '*'**	**% Of PDTs Above 40 µgm^{-3} '*'**	**% Of PDTs Above 40 µgm^{-3} '*'**	**Brief Description of Vehicle Emission Changes**
Base Run	8.42	6.32	3.16	As Base
LEZ1	0.00	N/A	N/A	All E(1-5) to E(6).
LEZ1a	0.00	N/A	N/A	All E(6),(6c),(6d).
LEZ2	2.11	0.00	0.00	Buses E(6); Others No Change.
LEZ3	6.32	0.00	N/A	Buses E(1-4) to E(5); Others No Change.
LEZ4	0.00	0.00	N/A	Buses, HGV's, Diesel LGV's, Taxis, Diesel Cars E(6), Petrol Cars E(1-3) to E(4).
LEZ5	0.00	0.00	0.00	Buses, HGV's, LGV's and Taxis E(1-5) to E(6); Cars No Change.
LEZ6	8.42	0.00	0.00	Cars E(1-5) to E(6); Buses, HGV's, LGVs, Taxis No Change.
'*' – Total = 95PDTs				

Table 14: Percentage Of PDTs Above Annual Average NO2 of 55 µgm^{-3} for Various Emissions Changes to 2016 Base Run.

Year →	2016	2019	2023	
Scenario	**% Of PDTs Above 55 µgm^{-3} '*'**	**% Of PDTs Above 55 µgm^{-3} '*'**	**% Of PDTs Above 55 µgm^{-3} '*'**	**Brief Description of Vehicle Emission Changes**
Base Run	0.00	0.00	0.00	As Base
LEZ1	0.00	N/A	N/A	All E(1-5) to E(6).
LEZ1a	0.00	N/A	N/A	All E(6),(6c),(6d).
LEZ2	0.00	0.00	0.00	Buses E(6); Others No Change.
LEZ3	0.00	0.00	N/A	Buses E(1-4) to E(5); Others No Change.
LEZ4	0.00	0.00	N/A	Buses, HGV's, Diesel LGV's, Taxis, Diesel Cars E(6), Petrol Cars E(1-3) to E(4).
LEZ5	0.00	0.00	0.00	Buses, HGV's, LGV's and Taxis E(1-5) to E(6); Cars No Change.
LEZ6	0.00	0.00	0.00	Cars E(1-5) to E(6); Buses, HGV's, LGVs, Taxis No Change.
'*' – Total = 95 PDTs				

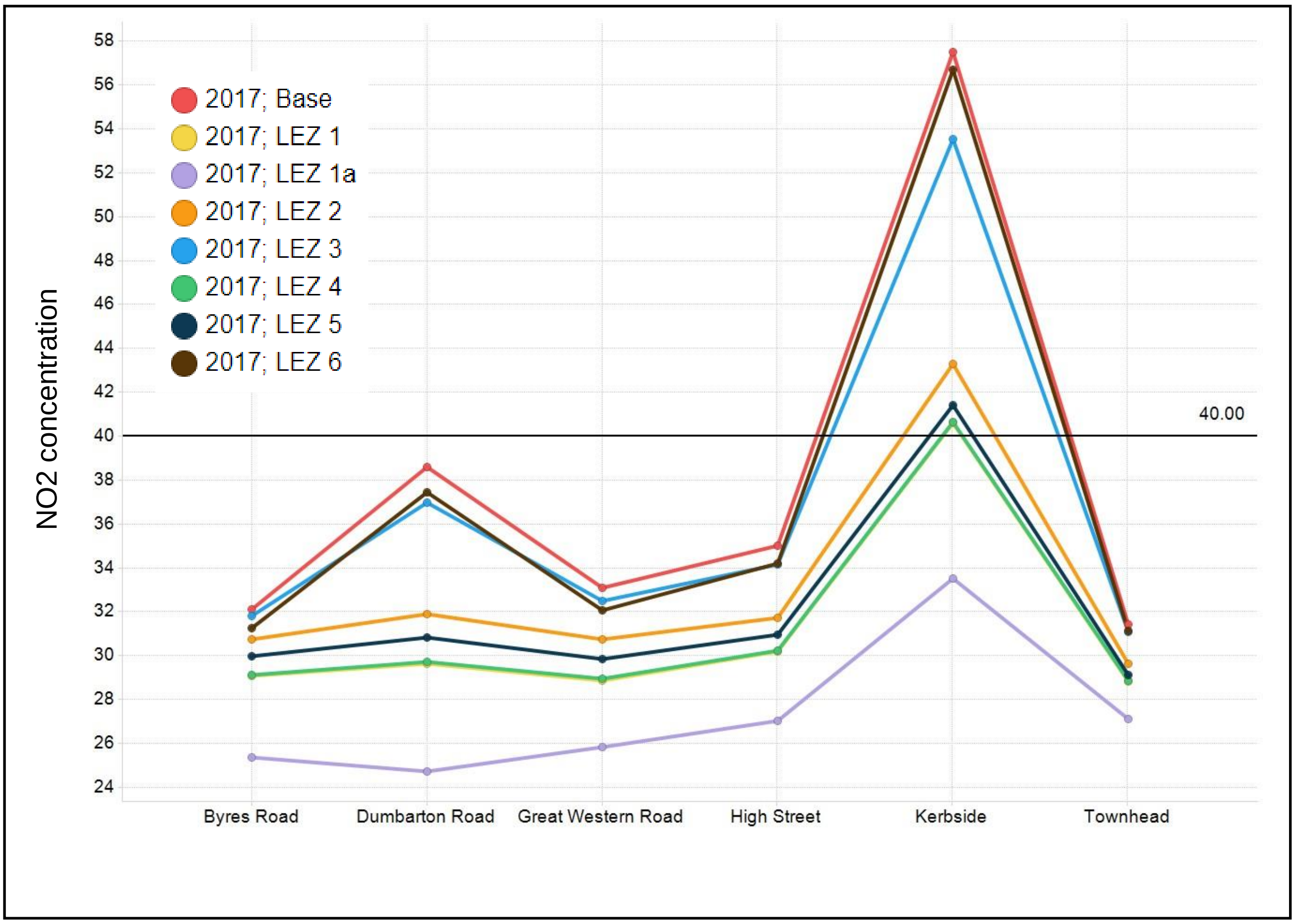

Figure 32: Potential Change in Glasgow Automatic Monitoring Station Annual Average NO2 (µgm^{-3}) for Emissions Changes to 2017 Base Run. Annual Average Speed Scenario 2.

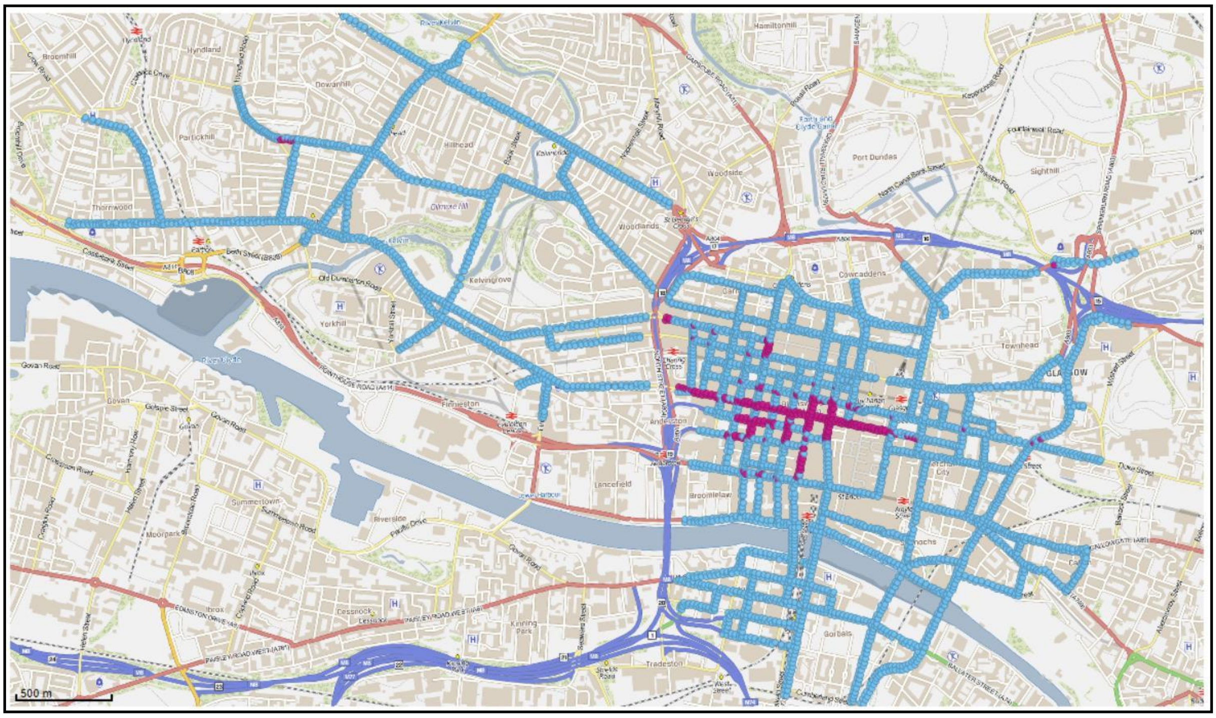

Figure 33: Modelled Annual Average NO2 (µgm^{-3}) for 2017. Scenario: LEZ1 (All E(1-5) to E(6)). Annual Average Speed Scenario 2.

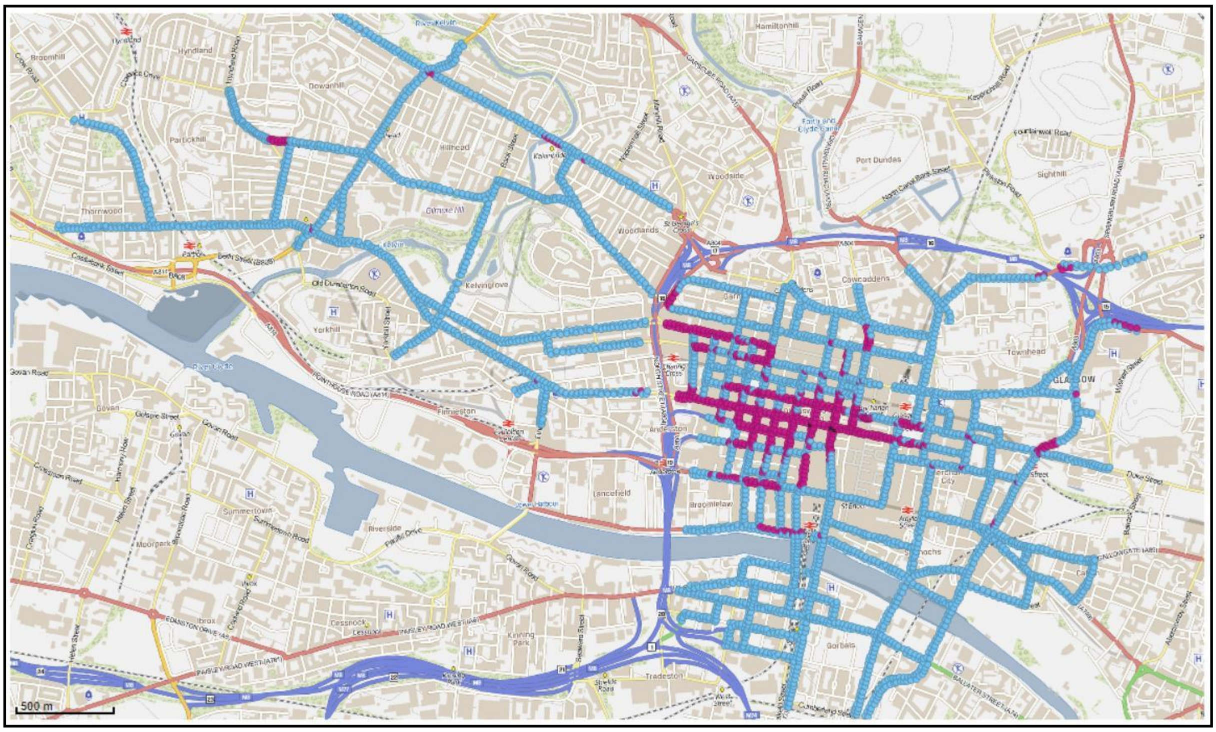

Figure 34: Modelled Annual Average NO2 (µgm^{-3}) for 2017. Scenario: LEZ2 (Buses E(6); Others No Change). Annual Average Speed Scenario 2.

4.6 Summary of Potential Improvements to Air Quality and Initial LEZ Options

Initial LEZ modelling has focussed on assessing the potential benefits of making large scale changes to vehicle emissions. In effect, we are estimating what the air quality may have been like in 2017, had vehicle emissions been lower. We have also assessed the potential changes in air quality, on 2017 traffic patterns, due to the predicted changes in the vehicle fleet made in Version 8 of the Emissions Factors Toolkit. Each of these will be discussed below.

4.6.1 Large Scale Changes to the 2017 Vehicle Fleet

The scenarios presented represent a useful guide to the potential benefits of setting emission limits on certain types of vehicles via an LEZ. The key points emerging from these scenarios are:

- If all cars within the modelled area had been “standard” Euro 6 (i.e., not Euro 6c or 6d) in 2017, with no changes to other vehicles and a similar Petrol/Diesel split (LEZ6) there may only have been a small benefit to air quality. As most of the car fleet would have been Euro 4/5, a change to standard Euro 6 would only represent a relatively small reduction in emissions. A similar outcome would have occurred if, in addition, all Petrol cars had been Euro 4 instead of Euro 6.
- If all Buses and Coaches had been Euro 6 in 2017 (LEZ2) there may have been a considerable benefit to air quality across many roads in Glasgow and particularly within the AQMAs. Improvements in Bus emission technology suggest that Euro 6 buses emit far less NOx than older Euro classes. However, this action would not be enough to bring all roadside points below the annual average NO2 limit value.
- If all Buses and Coaches had been Euro 5 in 2017 (LEZ3) the benefit to roadside NO2 levels would have been relatively small.
- If all Buses and Coaches, HGV’s, Diesel LGV’s and Taxis had been Euro 6 in 2017 (LEZ5) there could have been a significant improvement in air quality. Around two thirds of this benefit would have been due to changes in the Bus and Coach fleet.
- If all vehicles had been Euro 6 in 2017 (LEZ1) there could have been a substantial improvement in NO2 air quality. However, there may have been some roadside points above the annual average limit value, particularly within the city centre AQMA. These areas would have required further emission reductions.
- New Euro 6c and 6d vehicles, when matched with Euro 6 heavy vehicles (LEZ1a), appear able to be able to offer much improved roadside NO2 concentrations compared to 2017 levels, for similar levels of traffic. Benefits would only be realised if emissions from these vehicles are as predicted in EFTv8.
- Tackling emissions from Cars (particularly Diesel cars) will affect a far greater number of vehicles than tackling emissions from other vehicle types. The very newest Diesel vehicles will need to be on the roads, to substantially reduce emissions from this source.
- Emission reductions estimated by the LEZ1 and LEZ2 scenarios do not bring all NO2 roadside concentrations below the annual average limit value in the city centre AQMA. These areas will require further emission reductions, or other measures, to bring annual average NO2 concentrations below the limit. Locations which are difficult to improve are associated with narrow and deep street canyons where dispersion of the pollutants can be poor.

4.6.2 Predicted Future Changes in Vehicles for 2019 and 2023

Taken at face value, the modelled predictions for 2019 and 2023 appear to forecast substantial improvements in roadside NO2 in the next few years. These predictions assume that:

- Traffic flow and vehicle breakdown (e.g., the relative proportion of Buses to Cars) is identical to that measured in 2017.

- There is no change in background concentration (which may occur due to changes in other sources).
- The vehicle fleet changes as forecast in EFTv8 and that emissions from new vehicles are as predicted.

We believe it is important to evaluate the predicted changes and determine whether they are likely to happen.

Figure 35 shows a comparison of Euro class percentages for various vehicle types. Percentages captured by the Glasgow ANPR data in 2017 (see section 2.2) are presented alongside predicted fleet percentages made in EFTv8 for the "national fleet" (a prediction of the fleet mix in Scotland). Also shown on the figure is the predicted and observed Diesel/Petrol split. Predictions for Artic HGV's appear to be accurate for Glasgow. Bus predictions are not as expected; these have been adjusted using bus operator data. The number of EURO 6 Rigid HGVs is slightly under predicted by EFT8, and the number of EURO 6 LGVs is over predicted. The number of EURO 5 cars is under predicted, but the forecast Diesel/Petrol split is accurate.

Figure 36 also shows a comparison of Euro class percentages for various vehicle types. Percentages captured by the ANPR data in 2017 (see section 2.2) are presented alongside predicted "national fleet" percentages for 2019 and 2023, from both the NAEI 2012 and EFTv8. Also shown on the figure are the predicted percentages of Euro 6, 6c and 6d, vehicles.

HGV's appear to have the highest percentage of Euro 6 vehicles in 2017 of any vehicle type. However, considerable change in the fleet in Glasgow will be required in the following years to meet the 2019 and 2023 values. Large changes in the Bus fleet Euro 6 numbers, on 2017 values, are predicted. Given the 2017 fleet mix detailed in Table 2 **(i.e., Euro 5: 31.2%, Euro 6: 15.2%) this represents a substantial expected investment in the Glasgow Bus Fleet. A similar expectation is placed on LGV's and Cars. It is unclear whether the level of investment predicted will occur. Therefore, the NO2 concentration predictions for 2019 and 2023 should be treated with a great deal of caution.**

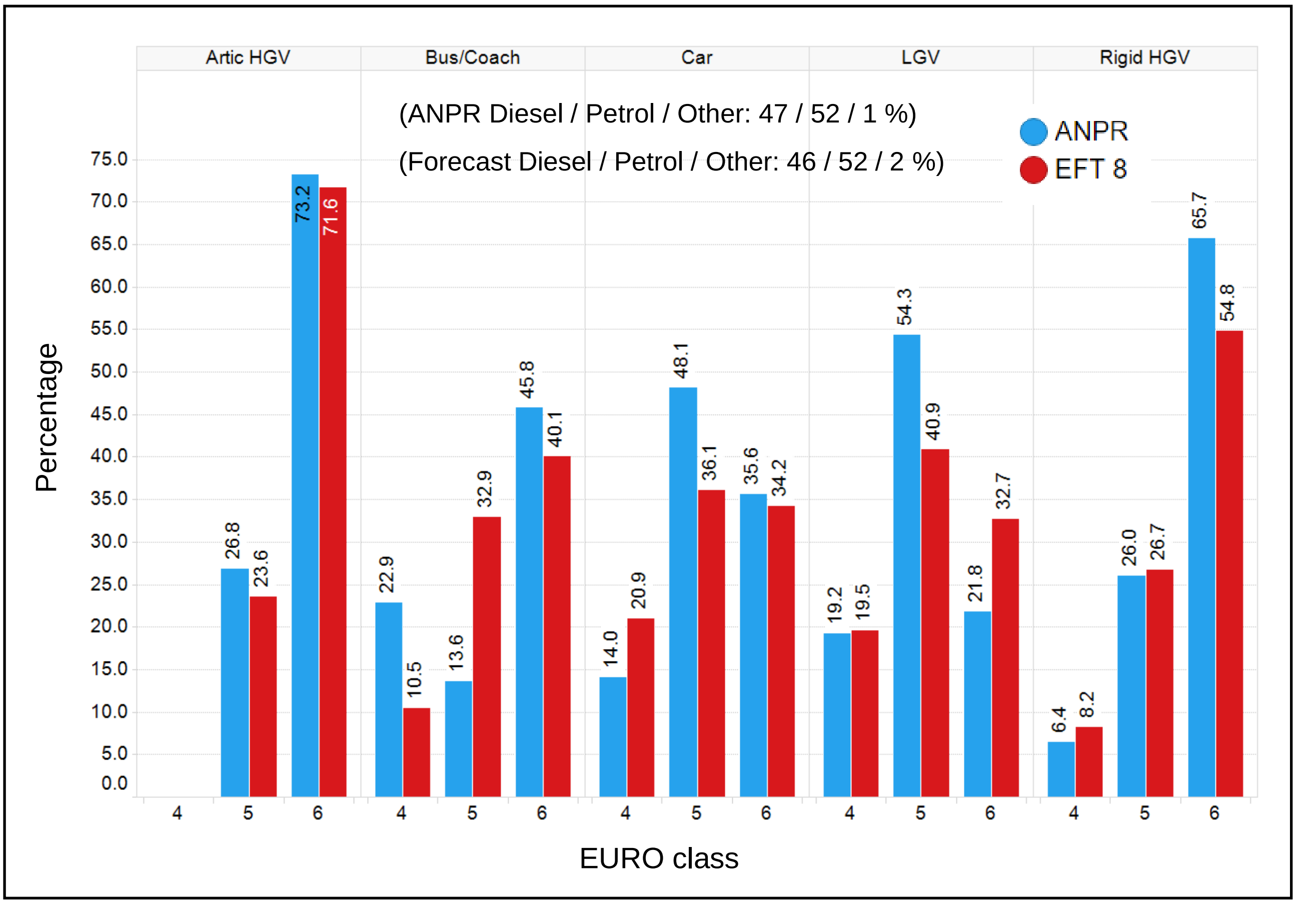

Figure 35: Comparison of 2017 ANPR Euro Class Percentage Mix with EFT8 Predictions for 2017. All Euro Classes Shown as Numbers.

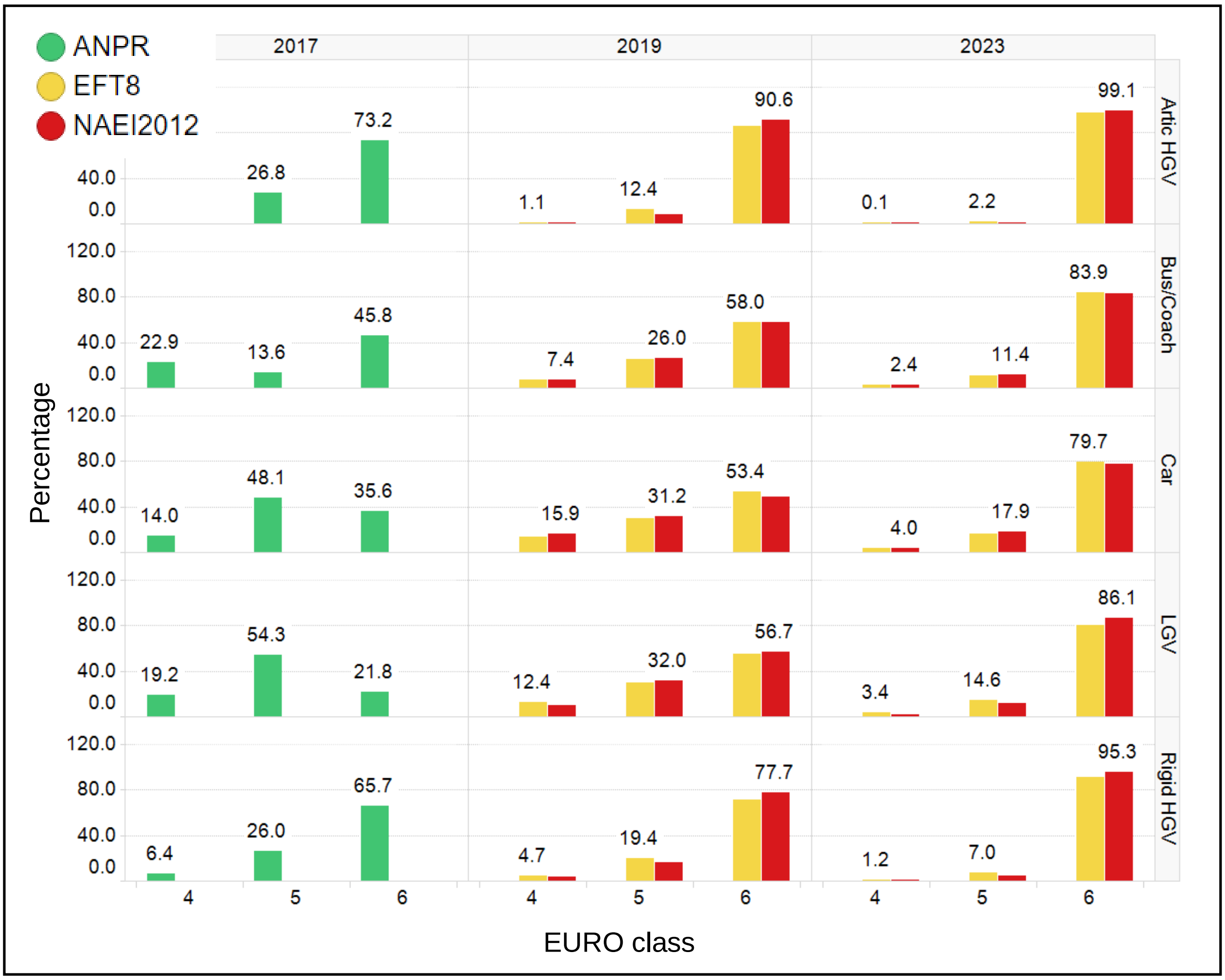

Figure 36: Comparison Of 2017 ANPR Euro Class Percentage Mix With NAEI 2012 and EFTv8 Predictions for 2019 and 2023. All Euro Classes Shown as Numbers.

5 Discussion of Glasgow NMF Modelling Results

Modelling output presented in section 4 represents the initial modelling work to support LEZ development. Additional work will be required to refine LEZ options which will take account of factors outside of air quality modelling; such as traffic pattern changes. We believe we have presented robust information which provides an evidence base for moving forward with LEZ design and any other measures to improve roadside air quality.

5.1 NO2 Modelling Evidence

Modelling evidence indicates that roadside NO2 is likely to be below the annual average limit value of 40 μgm^{-3} in most areas of Glasgow. However, many of the roadside locations within the AQMAs are still likely to be above the NO2 annual average limit value in late 2019. The highest concentrations are likely to be found in the city centre AQMA in the vicinity of Central Station. At these locations, annual average NO2 concentrations of between 50 and 70 are possible. As other background sources account for up to 30% of NO2 at this and similar locations, traffic emissions contribute over 70% of the total concentration at these locations. This means that emission reductions of around 40 to 60% may be required on 2017 levels. Significant modifications to the vehicle fleet are required to reduce emissions. At some locations, the deep street canyons mean that changes in the vehicle fleet may not reduce emissions sufficiently to meet the NO2 limit value. Additional measures will be needed to bring emissions down in these areas.

5.2 Source Apportionment Evidence

Source apportionment calculations for 2017 are likely to still broadly reflect the situation in late 2019. Although source apportionment is calculated for NOx, it will reflect the relative contribution to NO2 air quality issues. Emissions from buses and coaches dominate NO2 issues on many roads particularly in the city centre AQMA. Diesel cars appear to be the second biggest NO2 source on many roads, which is produced by far more vehicles. Source apportionment can be highly variable from street to street.

5.3 Evidence of Potential LEZ Benefits

City-wide changes to the vehicle fleet have been modelled to indicate the potential benefits of cleaner vehicles in Glasgow. Given the influence of Diesel cars, it may seem surprising that setting all cars to the basic Euro 6 standard (i.e., cars sold since September 2015) results in only a marginal improvement in NO2 concentrations (see scenario LEZ 6 in Figure 30 and Figure 31 and supporting tables in section 4.6). In contrast, changes to Buses and Coaches results in a much larger improvement (see scenario LEZ 2 in Figure 30 and Figure 31 and supporting tables in section 4.6). Figure 37 and Figure 38 show the NOx emission rate (g/km) for various vehicle type Euro classes at 10 km/hr (6.2 miles/hr) and 25 km/hr (15.5 miles/hr) respectively.

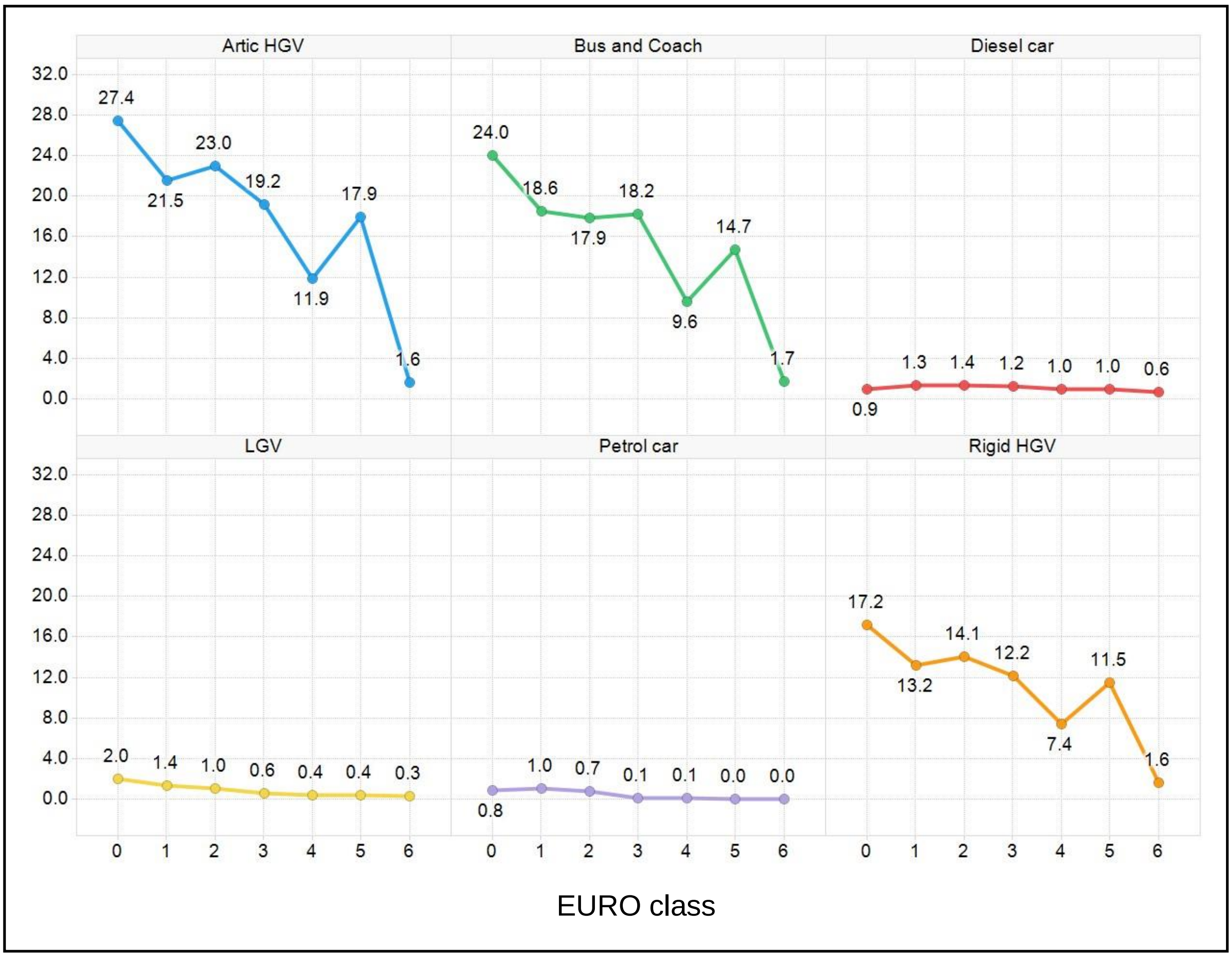

Figure 37: NOx Emission Rate (g/km) For Various Vehicle Type Euro Classes at 10 km/hr (6.2 miles/hr). Source: EFTv8, Scotland, Urban (not London). Year: 2017. All Euro Classes Shown as Numbers.

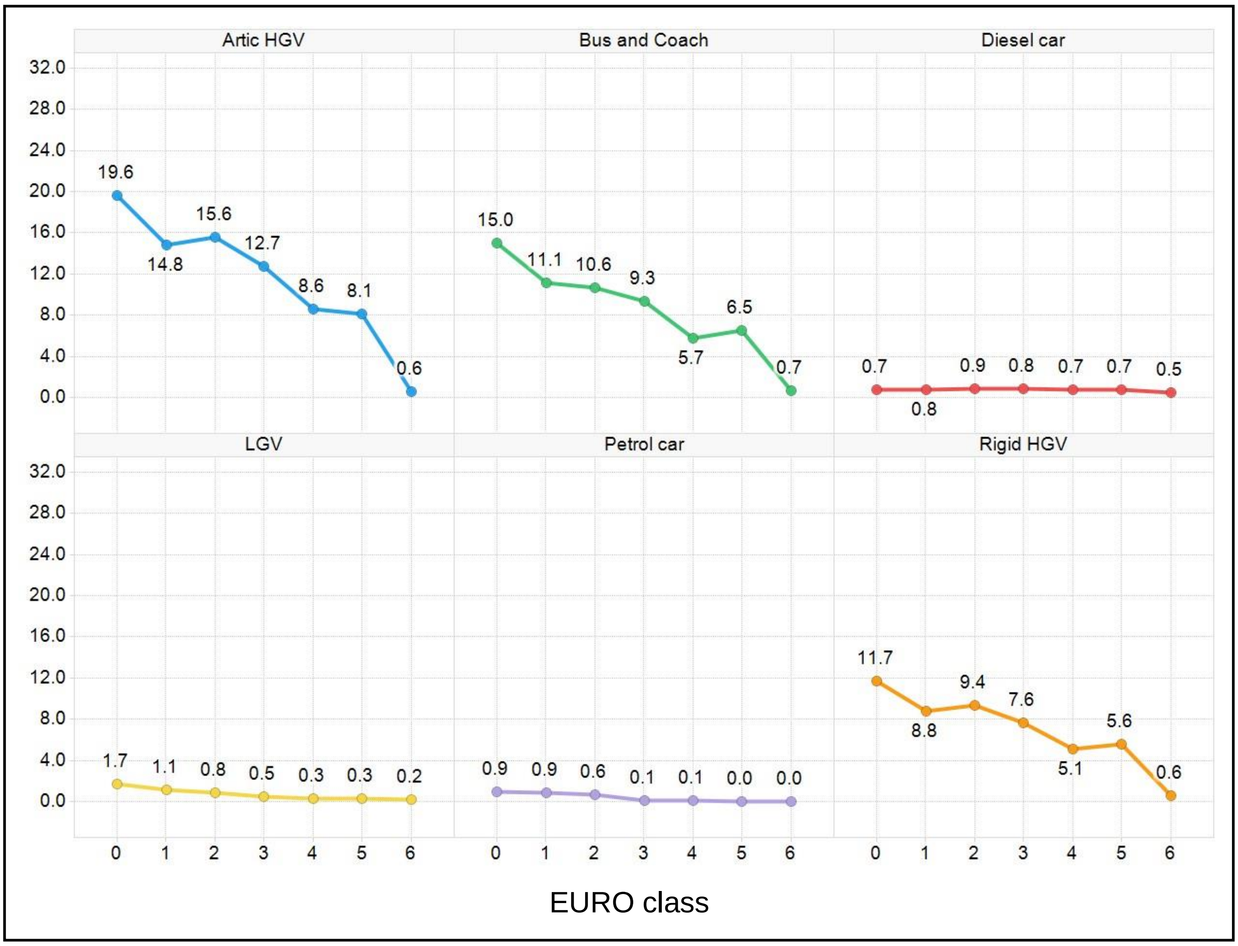

Figure 38: NOx Emission Rate (g/km) For Various Vehicle Type Euro Classes at 25 km/hr (15.5 miles/hr). Source: EFTv8, Scotland, Urban (not London). Year: 2017. All Euro Classes Shown as Numbers.

We have obtained these data from EFTv8 and they represent emissions in 2017. Emission factors are complex and vary according to speed and exact vehicle type. The data shown represent average emission rates for different vehicle types at the chosen speeds.

Euro 6 for Bus and HGV is expected to deliver considerable reductions in NOx on previous Euro classes. The equivalent change for Diesel cars which move from Euro 4 or Euro 5 to standard Euro 6 is not as large. This explains the relatively modest improvement in roadside NO2 in scenario LEZ6 compared to the larger improvement shown in LEZ2 (where all Buses are Euro 6).

Changes to emission testing are expected to drive a reduction in emissions from cars sold from September 2017 onwards [13]. We have factored these changes into the LEZ1a scenario, which represents almost every vehicle reaching the best Euro 6 standard it can over the next few years. This appears to deliver a considerable improvement in NO2 air quality on 2017 levels. LEZ1a is an unrealistic scenario, but it establishes the potential level of change possible from a reduction in vehicle emissions if traffic remains as it was in 2017. It also relies on new vehicles meeting the emissions expected from them in EFTv8.

Modelling for 2019 and 2023 presented in section 4.6.2 show improving air quality in response to predicted fleet Euro class changes and improved vehicle emissions. However a number of things must happen for these predicted changes to occur:

- The vehicle fleet must change as shown in Figure 36. This represents a considerable investment in all vehicles.
- Traffic must be very similar to that in 2017.
- Urban Background remains similar to 2017 levels.
- New vehicles meet the emission rates specified in EFTv8.

Clearly, almost all of these assumptions are subject to varying amounts of uncertainty. Actual air quality in 2019 and 2023 is likely to be worse than predicted using the assumptions included in EFTv8. However, an LEZ, and other emission reduction measures, may be able to accelerate change and ensure the largest improvements are made in the areas which have the poorest NO2 air quality.

6 Conclusions and Recommendations for Further Work

Robust evidence has been presented to show that vehicle emissions in Glasgow will need to be reduced in order to meet the annual average NO2 limit value at the roadside. Moving towards this target will increase the likelihood of complying with the NO2 limit value at locations which are critical to the various Air Quality Management Areas. In this section we present the key conclusions emerging from initial work to support LEZ development. Further work will be required to refine LEZ options and explore different scenarios for reducing emissions. Recommendations for this additional work are also presented here.

6.1 Conclusions

- An LEZ based on the city centre AQMA would appear to be the highest priority.

- Tackling Bus and Diesel Car emissions in the city centre AQMA should be a priority. Depending on the type of LEZ chosen, benefits may extend to the other AQMAs and roads.

- Bus emission reduction is also likely to significantly benefit roads outside the city centre AQMA with high bus traffic.

- Moving Diesel Cars to standard Euro 6, does not appear to have a large impact on roadside NO2 levels. More significant improvements appear possible from moving Diesel Cars to Euro 6c and 6d. However, the on-road emissions from these new vehicles is uncertain.

- Non-Bus Commercial vehicles (LGV's, Rigid HGV's, Taxis, and Artic. HGV's) contribute proportionally more to NOx, per vehicle, than Cars. The majority of Car NOx comes from Diesel Cars. Non-Bus Commercial vehicles and Cars create a similar level of air quality impact, particularly within the Central AQMA.

- Moving all vehicles to standard Euro 6 in the AQMAs is unlikely to bring roadside NO2 levels below the annual average limit value at all locations. There is a risk that monitoring, particularly in areas of deep and narrow street canyons, would still show values greater than the annual average NO2 limit value. Significant emission reductions will be required, on 2017 levels, or roadside concentrations may remain above the annual average NO2 limit value for many years to come.

- Predicted fleet changes for 2019 and 2023 may be very optimistic, particularly for Buses and LGV's. Other fleet changes may also not meet predicted levels. The large benefits predicted by future fleet changes should be treated with caution.

- All conclusions presented here are based on 2017 traffic levels and composition. Significant increases in traffic, or an increase in a particular vehicle type, may reduce the effectiveness of any LEZ.

6.2 Recommendations for Further Work

- We would recommend carrying out Traffic Modelling to examine the feasibility of various city centre AQMA LEZ options. In particular this would examine the potential vehicle displacement to areas outside any LEZ. Displacement of vehicles may increase NO2 concentrations in areas which are currently below the annual average limit value. Output from the traffic modelling should feed into further Air Quality Modelling.

- Work to establish a more detailed understanding of the behaviour (e.g., origin and destination or repeat journeys) of the Glasgow Fleet would be worthwhile. This could include gathering information on the behaviour of Non-Bus commercial vehicles.

- We recommend deployment of additional PDTs and automatic monitors in the city centre AQMA to verify high NO2 concentrations and monitor the effectiveness of any measures to improve air quality.

- Additional Air Quality Modelling should be carried out including:
    - Particulate matter modelling to quantify any benefits or risks from LEZ measures.
    - Assessing the benefits of increasing the proportion of petrol cars in the modelled area.
    - Assessing the benefits of retro-fitting a proportion of the Euro 5 Bus Fleet to reduce emissions.
    - Modelling against the 2018 and 2019 PDT and Automatic Monitoring data, and other years as they become available.
    - Updating the model using future traffic data and fleet information.

7 References

[1] *The Scottish Government. Cleaner Air for Scotland, The Road to a Healthier Future. Published online; 2015.*

[2] *SEPA. Aberdeen Air Quality Modelling Pilot Project Technical Report. 2017.*

[3] *CERC (Cambridge Environmental Research Consultants). ADMS-Urban model evaluation summary. Published online; 2015.*

[4] *Glasgow City Council. Glasgow City Council Detailed Assessment 2014. Published online; 2014.*

[5] *Ricardo-AEA for East Lothian Council. Air Quality Further Assessment for Musselburgh. Published online; 2014.*

[6] *Defra and the Devolved Administrations. Local Air Quality Management Technical Guidance (TG16). s.l. : Department for Environment, Food and Rural Affairs, 2016.*

[7] *AEA Energy and Environment. Diffusion Tubes for Ambient NO2 Monitoring: Practical Guidance for Laboratories and Users. s.l. : DEFRA and the Devolved Administrations, 2008.*

[8] *Defra and the Devolved Administrations. Local Air Quality Management Technical Guidance LAQM.TG(09). s.l. : Department for Environment, Food and Rural Affairs,2009.*

[9] *City of Edinburgh Council. 2017 Air Quality Annual Progress Report (APR) for City of Edinburgh Council. Published Online; 2017.*

[10] *Williams, M., Barrowcliffe, R., Laxen, D., Monks, P., 2011. Review of Air Quality modelling in Defra. Defra.*

[11] *Defra and the Devolved Administrations. Nitrogen Dioxide in the United Kingdom - Summary. s.l. : Department for Environment, Food and Rural Affairs, 2004.*

[12] *Defra and the Devolved Administrations. UK plan for tackling roadside nitrogen dioxide concentrations - An overview. s.l. : Department for Environment, Food and Rural Affairs, 2017.*

[13] *EU action to curb air pollution by cars: Questions and Answers. European Commision - Fact Sheet. 31 August 2017.*