SEPA
Scottish Environment Protection Agency
Buidheann Dìon Àrainneachd na h-Alba

CLEANER AIR FOR SCOTLAND – NATIONAL MODELLING FRAMEWORK

Air Quality Evidence Report – Edinburgh

November 2018

Scope Of Report

Air Quality modelling in Edinburgh 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 The City of Edinburgh Council (CEC) 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 Edinburgh Bus Fleet. We are grateful to the Bus Operators for providing this.

Executive Summary

An Air Quality model of Edinburgh has been built using detailed traffic data collected in 2016. This model performs well against observed Nitrogen Dioxide (NO2) data. Modelling output indicates that, in 2016, 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 this NO2 limit in 2016. Many of these locations are still likely to exceed the limit in late 2018. The most extensive area of roadside NO2 issues is in and around the Central Air Quality Management Area (AQMA). Roadside NO2 levels will be higher here, than in many areas of Edinburgh. The highest NO2 concentrations will often 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 at least 50 to 75%, on 2016 levels, will be required.

Analysis of model output shows that emissions from Diesel cars appear to be a city-wide problem. They are the single biggest source of Nitrogen oxides (NOx) on many roads. Large numbers of vehicles are associated with this source. Light Goods Vehicles (LGV's) are the second biggest source of NOx on many roads, but this impact is produced by far fewer vehicles. Buses are a large source of NOx and dominate the roadside issues at many locations, particularly within the Central AQMA. Non-Bus Commercial vehicles (LGV's, Rigid HGV's, Taxis, and Artic. HGV's) contribute proportionally more to NOx concentrations, 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. 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 Euro 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 Central AQMA.

An LEZ based on the Central AQMA should be investigated further. Depending on the vehicles chosen, the benefits to roadside NO2 levels may extend to areas outside the LEZ, including other AQMAs. Tackling Bus emissions within the Central AQMA should be a high priority, as improvements are likely bring down the highest NO2 levels. Despite the potential for improvement by vehicle fleet changes, it will be difficult to bring roadside NO2 in some areas of the Central AQMA below the annual average limit value. Busy narrow streets with tall buildings will be particularly challenging. In these locations, other measures to reduce emissions will be required, such as a reduction in overall traffic. Published predicted changes in the national Scottish vehicle fleet suggest large improvements in NO2 may occur in the next five years. These national Scottish vehicle fleet predictions should be treated with caution as they have not been found to be accurate for all vehicle types across a range of Scottish cities, including Edinburgh.

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
CEC	The City of Edinburgh Council
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
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 CEC 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 CEC, an ADMS Model was constructed which encompasses five of the six Edinburgh Air Quality Management Areas (AQMA). These are:

- Central Air Quality Management Area
- Great Junction Street Air Quality Management Area
- Inverleith Air Quality Management Area
- St Johns Road Air Quality Management Area
- Salamander Street Air Quality Management Area

Maps of the AQMAs are shown in Figure 1 to Figure 5 respectively. Glasgow Road Air Quality Management Area has not been included in the Edinburgh NMF model at this time.

Figure 6 details the road network of the current Edinburgh NMF model. It is comprised of "road links" of varying size which represent the main traffic routes through the modelling zone. Examples of individual links on: Princes Street, Queensferry Road, Gorgie Road and St John's Road, are highlighted in black. Figure 7 shows the road network of the current Edinburgh air quality model together with the associated AQMAs.

Only the main urban local "road links" are represented within the model as major road sources. Minor roads, and major trunk roads such as the M8 and A720, are accounted for in the air modelling in other ways, as described in section 2.3.

CEC 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.

AQMAs in Edinburgh are spread over the City. The current model can be used to assess the potential effects of an LEZ in one area of the city. However, the effects on other areas, even those outside AQMAs, can also be assessed. The model can also be extended, or refined, to assess changes in other areas, should that be required.

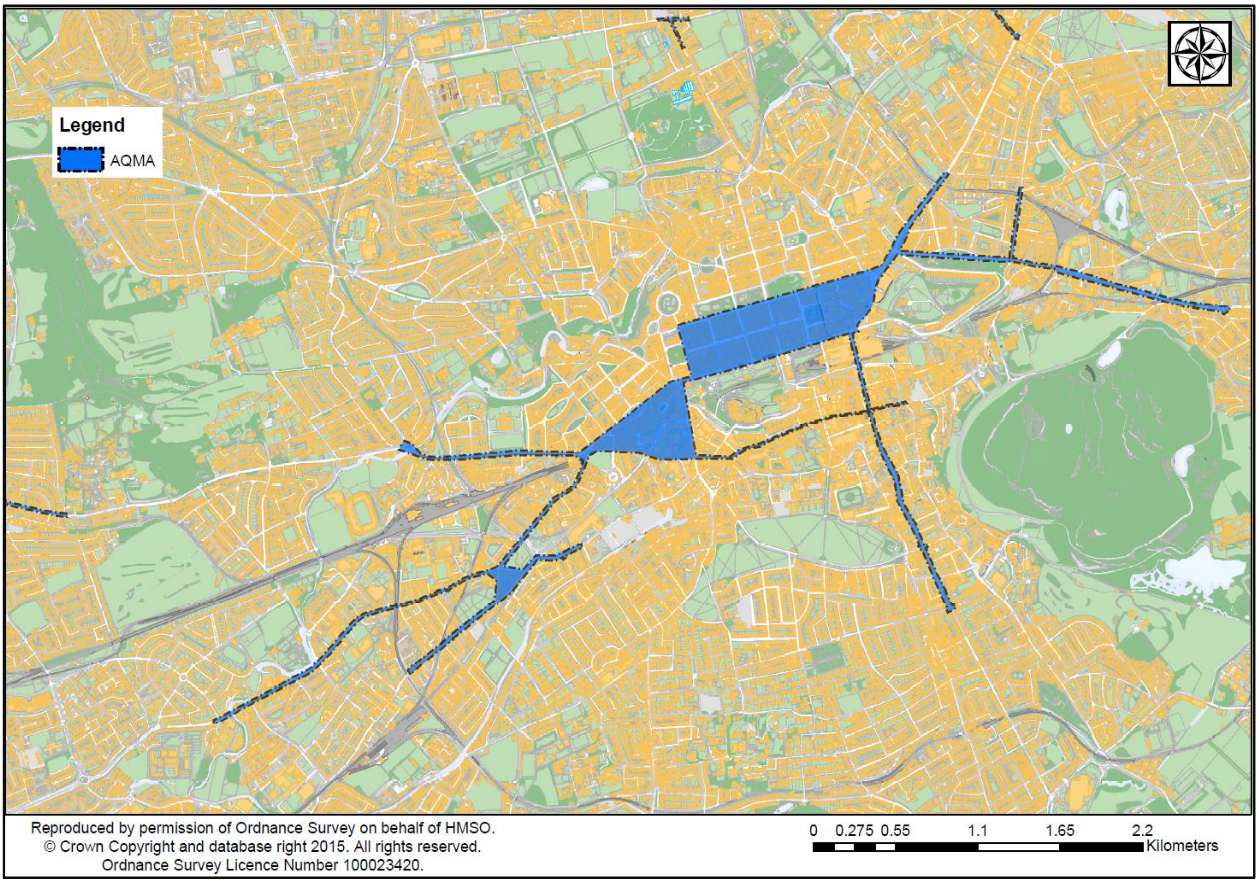

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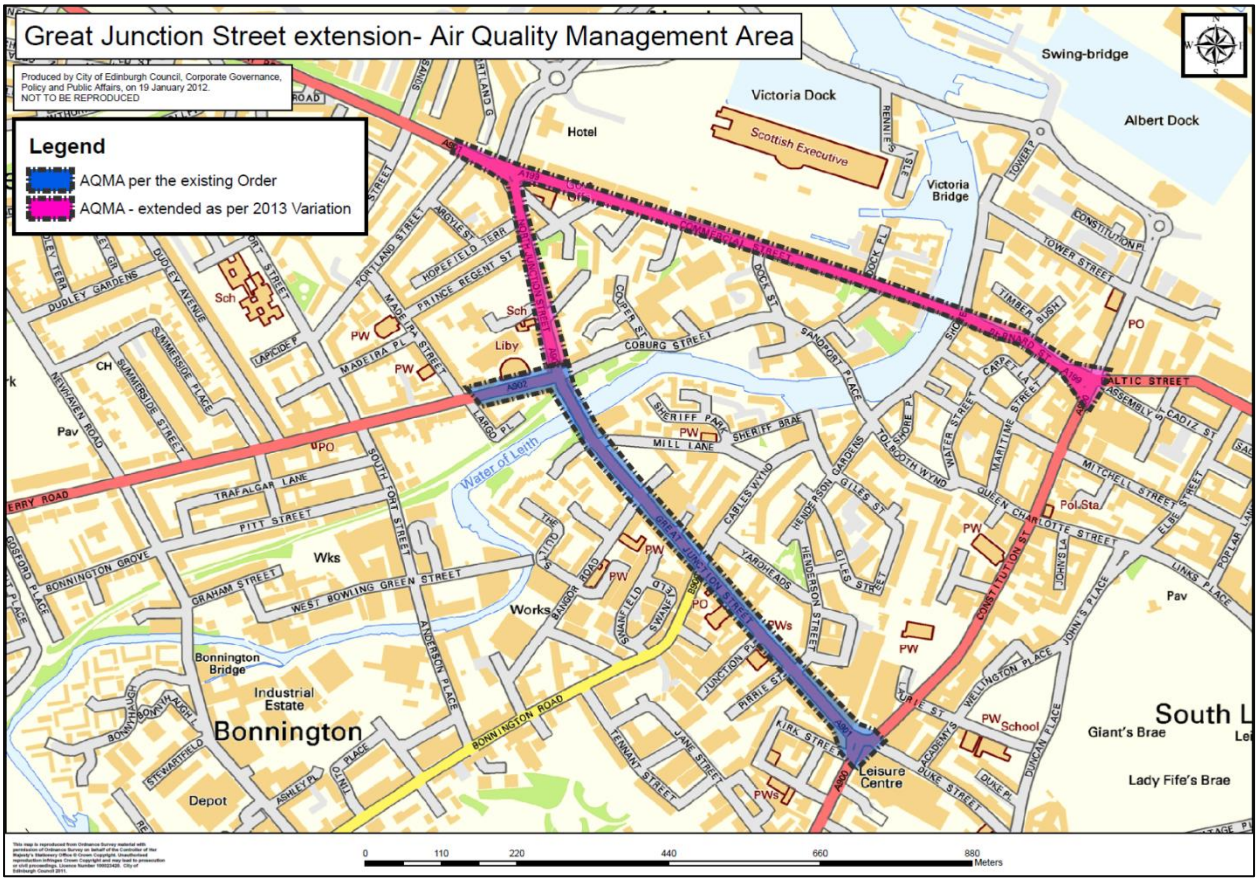
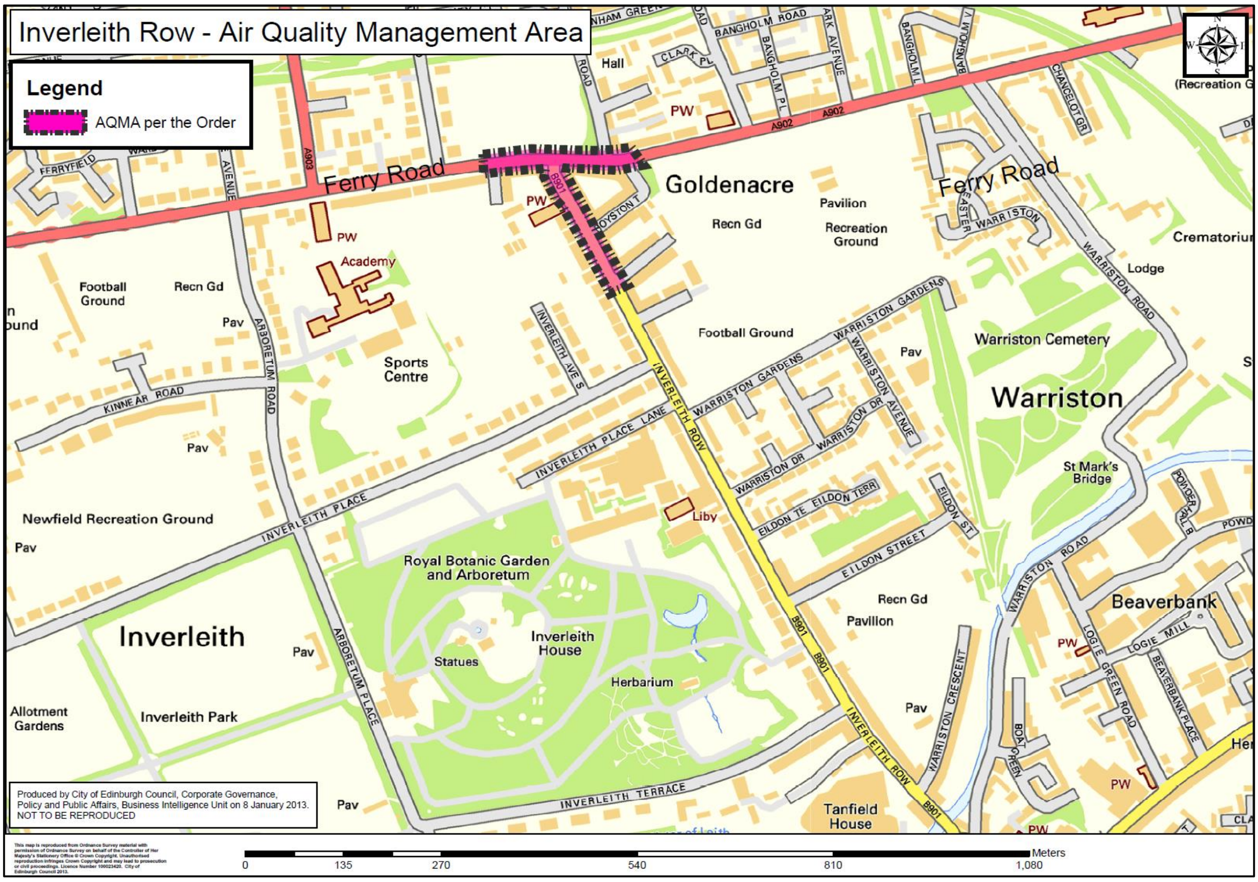
Figure 1: Central Air Quality Management Area.


Great Junction Street extension- Air Quality Management Area

Produced by City of Edinburgh Council, Corporate Governance, Policy and Public Affairs, on 19 January 2012.
NOT TO BE REPRODUCED

Legend
🟦 AQMA per the existing Order
🟪 AQMA - extended as per 2013 Variation

Figure 2: Great Junction Street Air Quality Management Area.


Inverleith Row - Air Quality Management Area

Legend
🟪 AQMA per the Order

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Figure 3: Inverleith Air Quality Management Area.

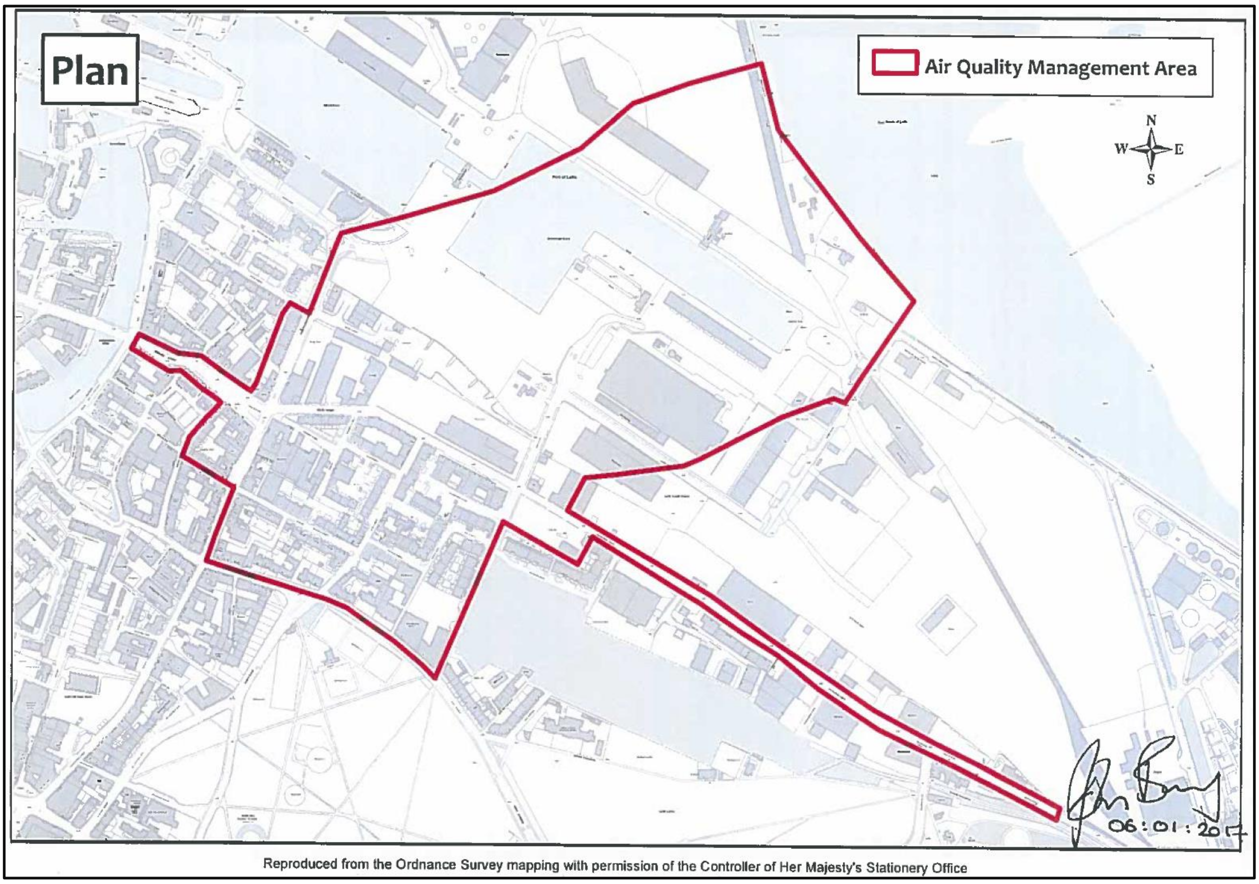

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Figure 4: Salamander Street Air Quality Management Area.

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Figure 5: St John's Road Air Quality Management Area.

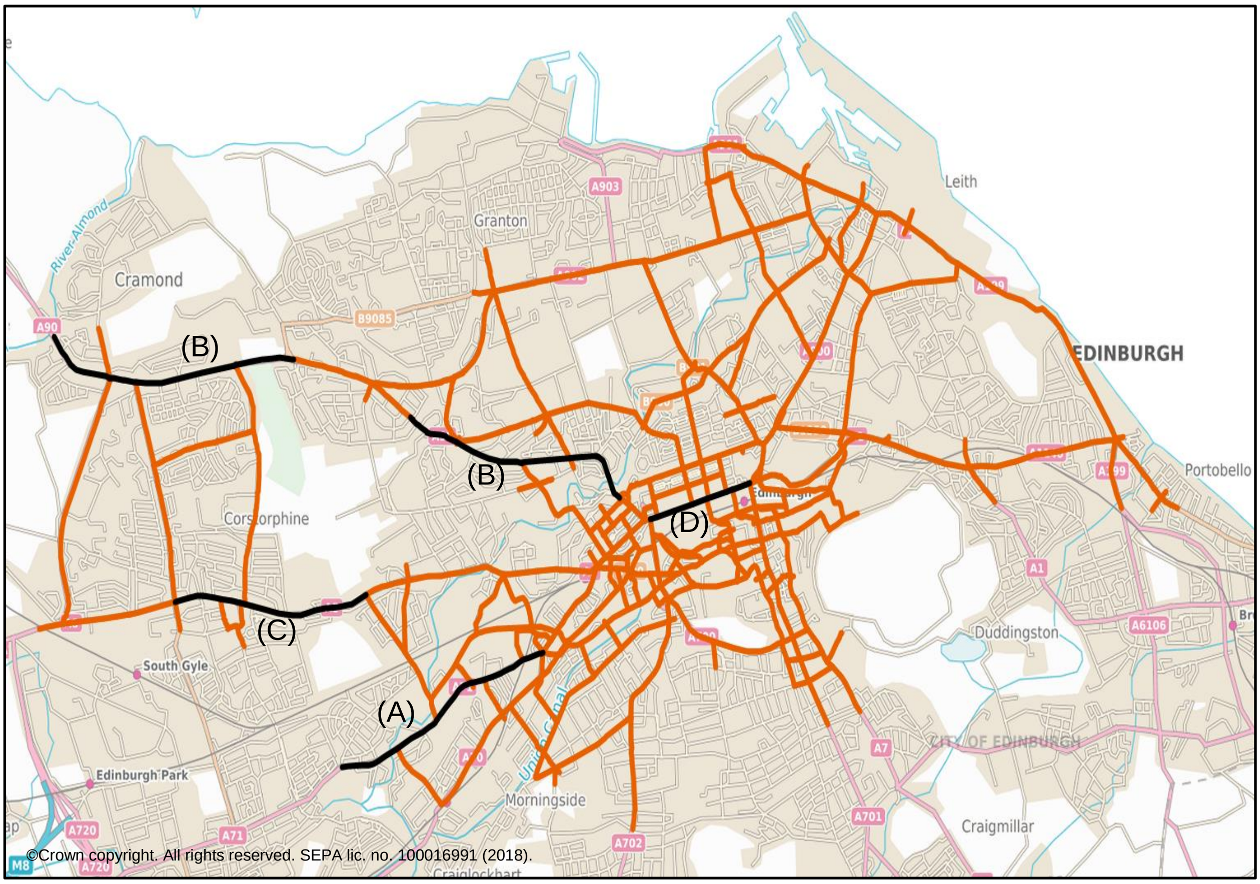

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Figure 6: Edinburgh Air Quality Model Road Network. Highlighted Roads Are: Gorgie Road (A), Queensferry Road (B), St John's Road (C) and Princes Street (D).

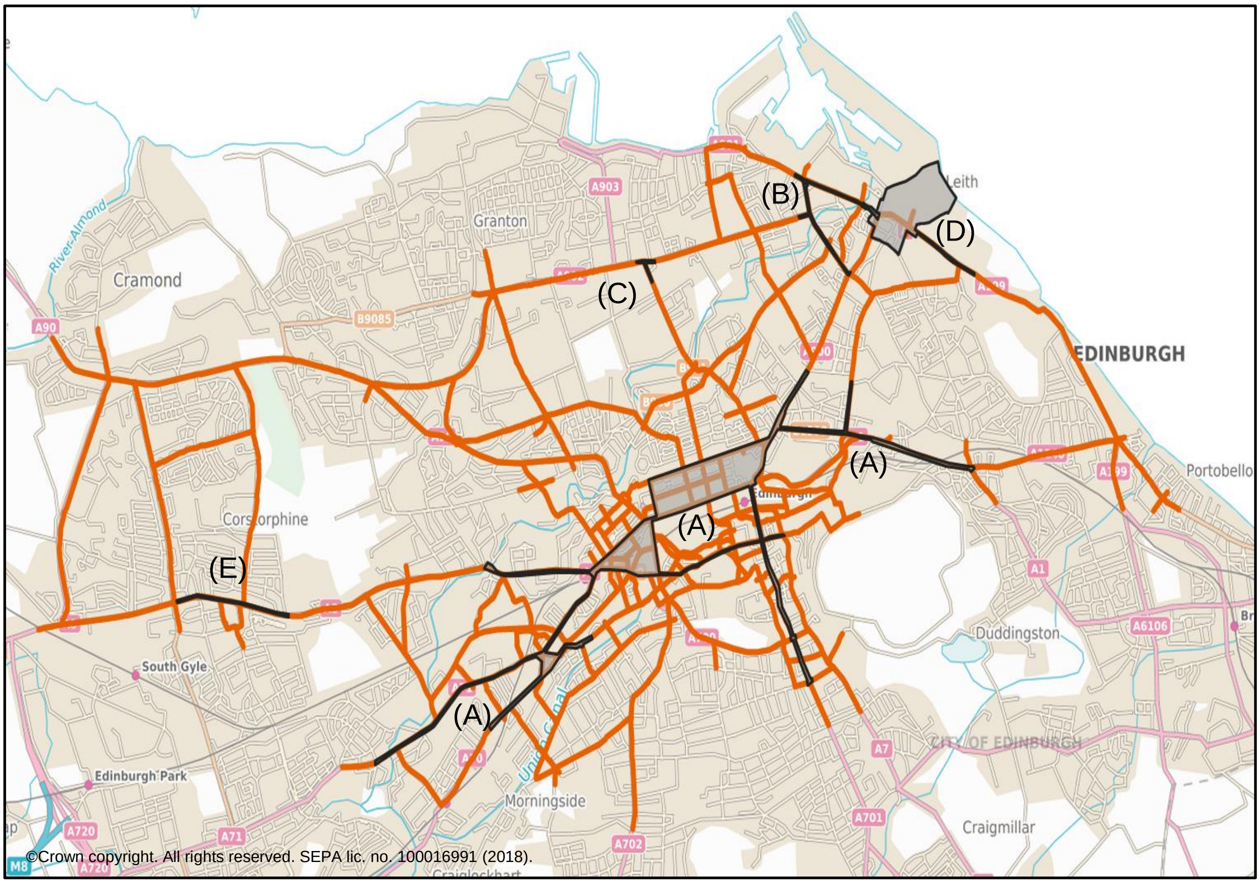

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Figure 7: Edinburgh Air Quality Model Road Network, Including Associated AQMAs: Central (A), Great Junction Street (B), Inverleith (C), Salamander Street (D), St John's Road (E).

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 Edinburgh 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 Edinburgh 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/Jacobs in consultation with CEC and SEPA.

Traffic data presented here were collected in November 2016. They consist of 113 Junction Turn Counts (JTC), 21 Automatic Traffic Counters (ATC), and 10 Automatic Number Plate Recognition (ANPR) cameras located on key routes.

The locations of the JTC traffic data collection are shown in Figure 8. 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.

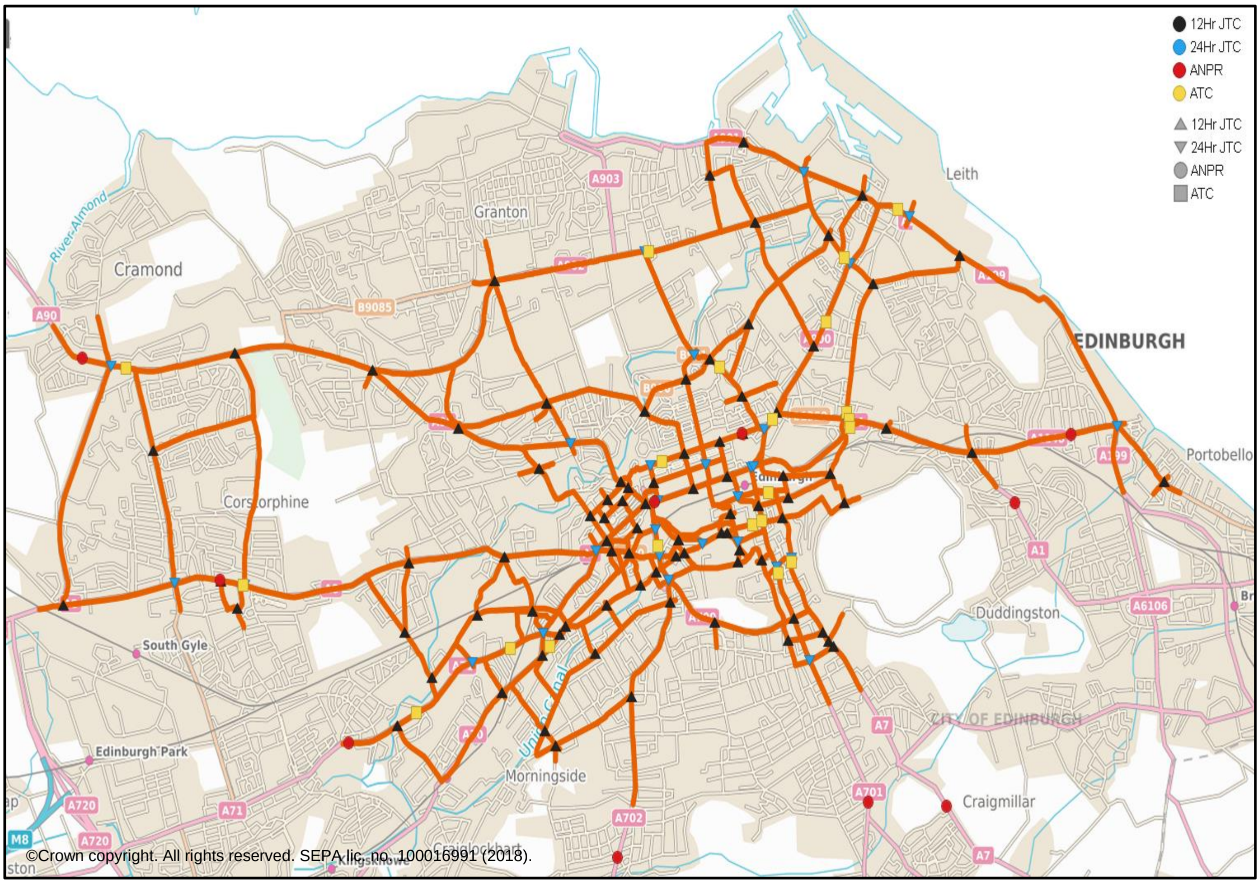

Figure 8: Traffic Data Collection Locations. Data Type Indicated By Colour And Shape key (JTC – Junction Turn Counts, ATC – Automatic Traffic Counters, ANPR – Automatic Number Plate Recognition).

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

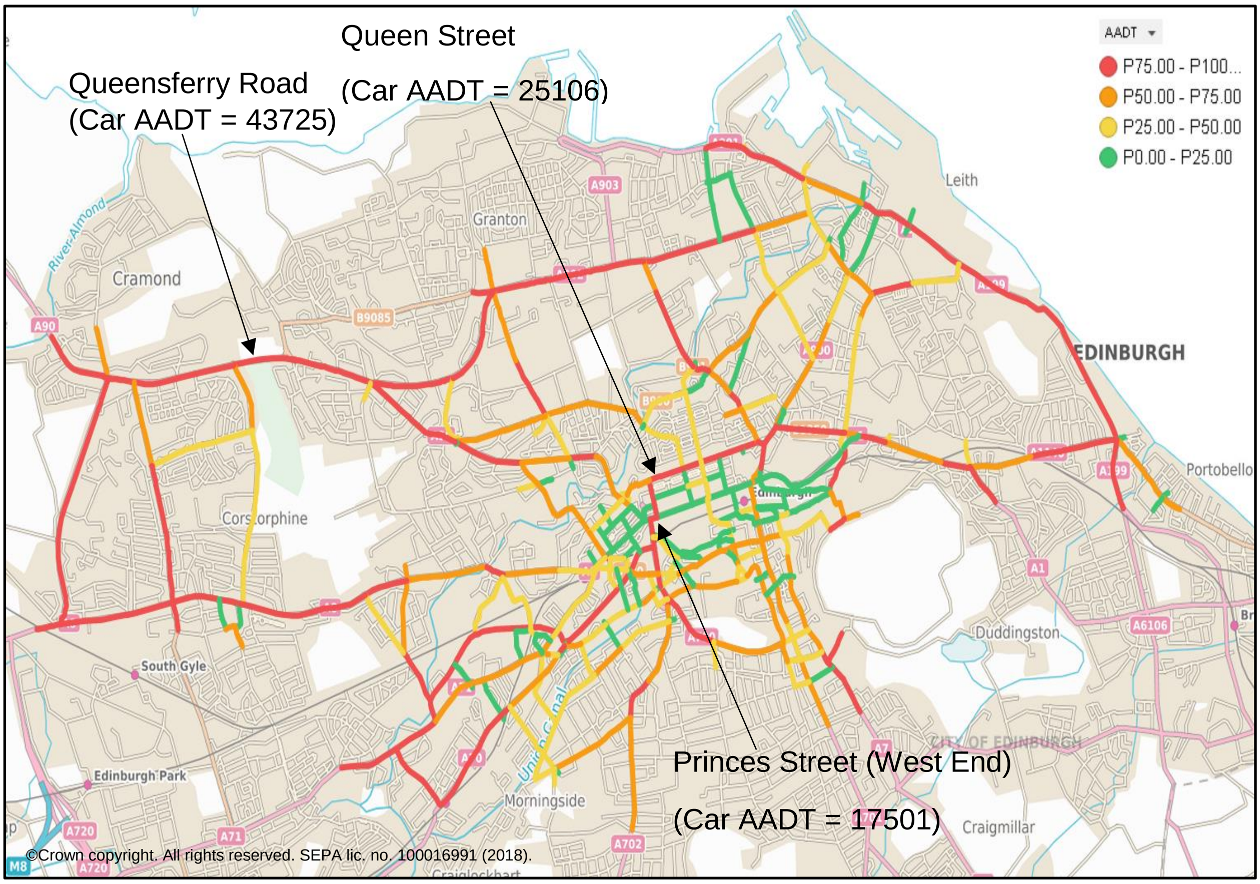

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Figure 9: Car Traffic Flow Across The Model Network (AADT) - Percentile.

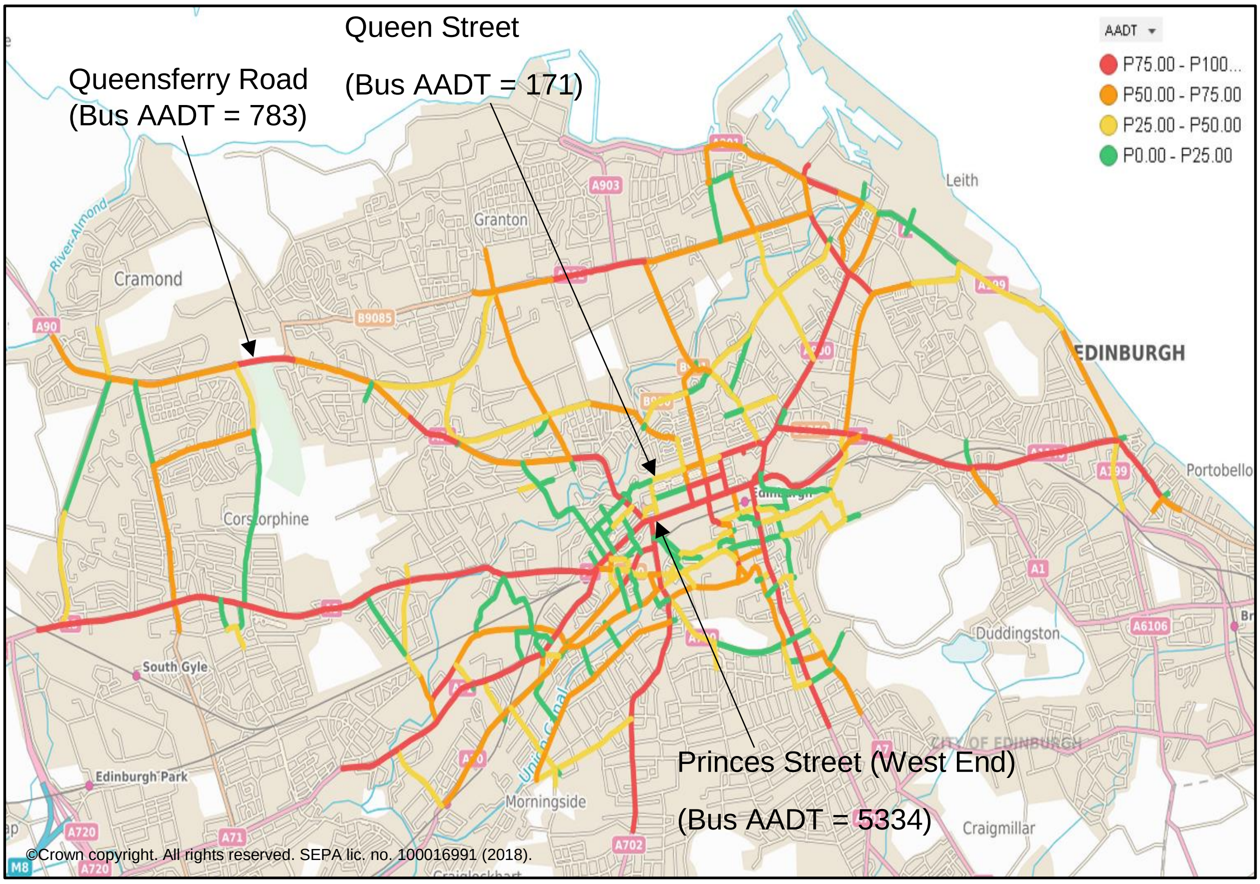

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Figure 10: Bus Traffic Flow Across The Model Network (AADT) - Percentile.

Figure 9 shows car AADT flow across the model network. Figure 10 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 is 43725. This is on a section of Queensferry Road. The maximum car AADT the city centre model domain is 25106. This is on a section of Queen Street. The maximum bus AADT in the model domain is 5334 at the western end of Princes Street. Car AADT on this road link is 17501. These locations are highlighted on Figure 9 and Figure 10.

Further east along Princes Street (where private cars are not allowed) bus AADTs range from 5062 to 3643. Although not shown, taxi AADT on these same streets range from 1694 to 1334.

These data give a detailed picture of traffic flow and composition across the city in 2016 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 CEC 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 (see Figure 6) 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”. For the modelling presented here, we have altered the “National Fleet” information to better represent the fleet in Edinburgh. We have used ANPR and Bus Operator information to make local estimates of the vehicle information outlined above.

Table 2 shows the various percentages of each Bus and Car Euro class used in the “base” Edinburgh NMF model (see section 2.5). The unaltered “National Fleet” values for 2016 are also presented for comparison. Additionally, we have used a percentage split between Diesel and Petrol Cars of:

- 45 % Diesel
- 55 % Petrol

Table 2: Percentage Bus And Car Euro Class Used In Modelling vs The “National Fleet”.

Bus Class‘’**	**% of Bus Fleet Used in 2016 Base Run‘*’**	**% of Bus Fleet For 2016 “National Fleet” For Comparison**	**Car Class‘**’**	**% of Car Fleet Used in 2016 Base Run‘*’**	**% of Car Fleet For 2016 “National Fleet” For Comparison**
Pre-Euro 1	N/A	N/A	**Pre - Euro 1**	0.07%	0.11%
Euro 1	0.02%	0.10%	**Euro 1**	0.08%	0.07%
Euro 2	0.09%	4.32%	**Euro 2**	0.77%	1.06%
Euro 3	20.66%	16.60%	**Euro 3**	7.46%	11.64%
Euro 4	5.43%	13.13%	**Euro 4**	26.74%	24.38%
Euro 5	49.75%	34.83%	**Euro 5**	42.61%	40.26%
Euro 6	24.05%	31.02%	**Euro 6**	22.11%	22.50%
Electric	0.00%	0.00%	**Electric**	0.00%	0.00%

‘*’ → Bus percentage derived from Bus Operator Data and ANPR. Car derived from ANPR.

‘’ → 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. This convention is used throughout the rest of this report.**

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 Edinburgh Bus Fleet composition (kindly provided by bus operators) indicates that the assumed distribution of bus Euro classes presented in EFTv8 is not accurate for Edinburgh. 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 Urban Background monitoring station.

Or

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

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 Edinburgh. 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 two different speed scenarios:

1. A variable speed across the model area using speed information derived from Automatic Traffic Counter data and Speed Limit information. The speeds used were either:
    a. 25 kilometres per hour (15.53 miles per hour)
    b. 35 kilometres per hour (21.75 miles per hour)
    c. 45 kilometres per hour (27.96 miles per hour)

2. A speed of 10 kilometres per hour (6.21 miles per hour) is applied to all roads to represent a heavily congested scenario. This gives give 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.

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 6 miles (10 km) to the west of Edinburgh City Centre, at Gogarbank (OS; Easting: 316100, Northing:671400). These data capture the large scale air movement over Edinburgh reasonably well. However, they do not represent how air moves through the built-up Edinburgh 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 Edinburgh 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.

Street canyons in the Edinburgh model are represented using the 'advanced' ADMS-Urban Street-Canyon module. This allows both one and two 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. Including terrain does improve some statistical aspects of the model performance, however it does take the model much longer to run. As annual average concentrations are the focus of this work, the results presented here do not include terrain. Additionally, the distances from which pollutants are dispersed from the road to locations on streets are relatively small. Terrain will be included in important future model runs which examine more detailed LEZ options.

The 'base' year of the model is 2016, which includes:

- 2016 Meteorology
- 2016 Traffic Counts
- 2016 Emission Factors (from EFT Version 8)
- 2016 Urban Background (St Leonards Monitoring Station – Incomplete)

This reflects method one outlined in section 2.3.2.

For 2016, NO2 "background" monitoring data at St Leonards station is only available from May to December. Missing data has been accounted for using a method detailed in the SEPA Aberdeen Pilot Report [2]**.**

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

- 2016 Meteorology
- 2016 Traffic Counts
- 2016 Emission Factors (from EFT Version 8)
- 2015 Gridded Background Emissions (the most recent available)
- 2016 Rural Background Concentrations (Bush Estate 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 11 shows the annual average wind speed (in metres per second: m/s) at Edinburgh Gogarbank for each year from 1999 to 2017. The average over all nineteen years is 4.14 m/s and this is shown as a horizontal line on the figure. The annual average wind speed measured in 2016 was 3.88 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. 2016 ranks amongst the lowest three average wind speed years of the nineteen analysed. These are highlighted as green dots in Figure 11.

For the initial LEZ modelling presented in this report we have used 2016 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.

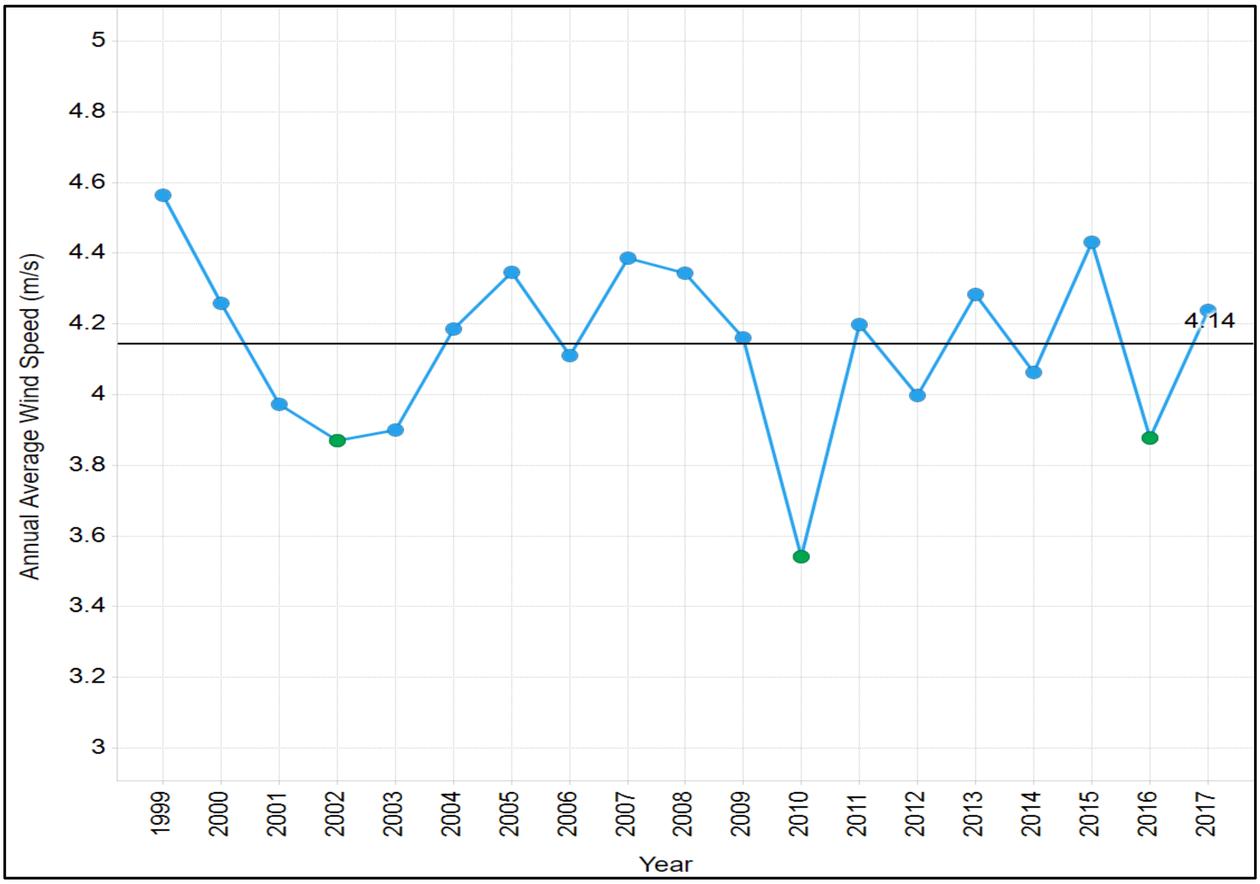

Figure 11: Annual Average Wind Speed (m/s) At Edinburgh Gogarbank Station From 1999 To 2017.

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 2016, NO2 monitoring data at six automatic stations were available to compare with model output. These were:

1. Gorgie Road
2. Queen Street
3. Queensferry Road (Barnton)
4. Salamander Street
5. St John's Road (Corstorphine)
6. St Leonards

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

Figure 12 shows a comparison between modelled and observed annual average NO2 for 2016. In this case, data from the St Leonards 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). Figure 13 shows similar information. However, in this case, data from the Bush Estate and Gridded Background emissions have been used. Table 3 provides a summary of the data presented in Figure 12 and Figure 13.

When using the Urban Background method (Figure 12), modelled annual average NO2 is reasonably close to observed data, often within +/- 6.1 µgm^{-3}. The exception is Salamander Street where the model has overestimated the annual average concentration by 14.9 µgm^{-3}. At this time, we have not been able to improve the performance at Salamander Street.

Using the Rural Background and Gridded Emission method (Figure 13) agreement between modelled and observed NO2 data is not as good. At almost all stations, the model overestimates concentrations by 6.1 to 15.3 µgm^{-3}. Salamander street performance is no better using Rural/Gridded method.

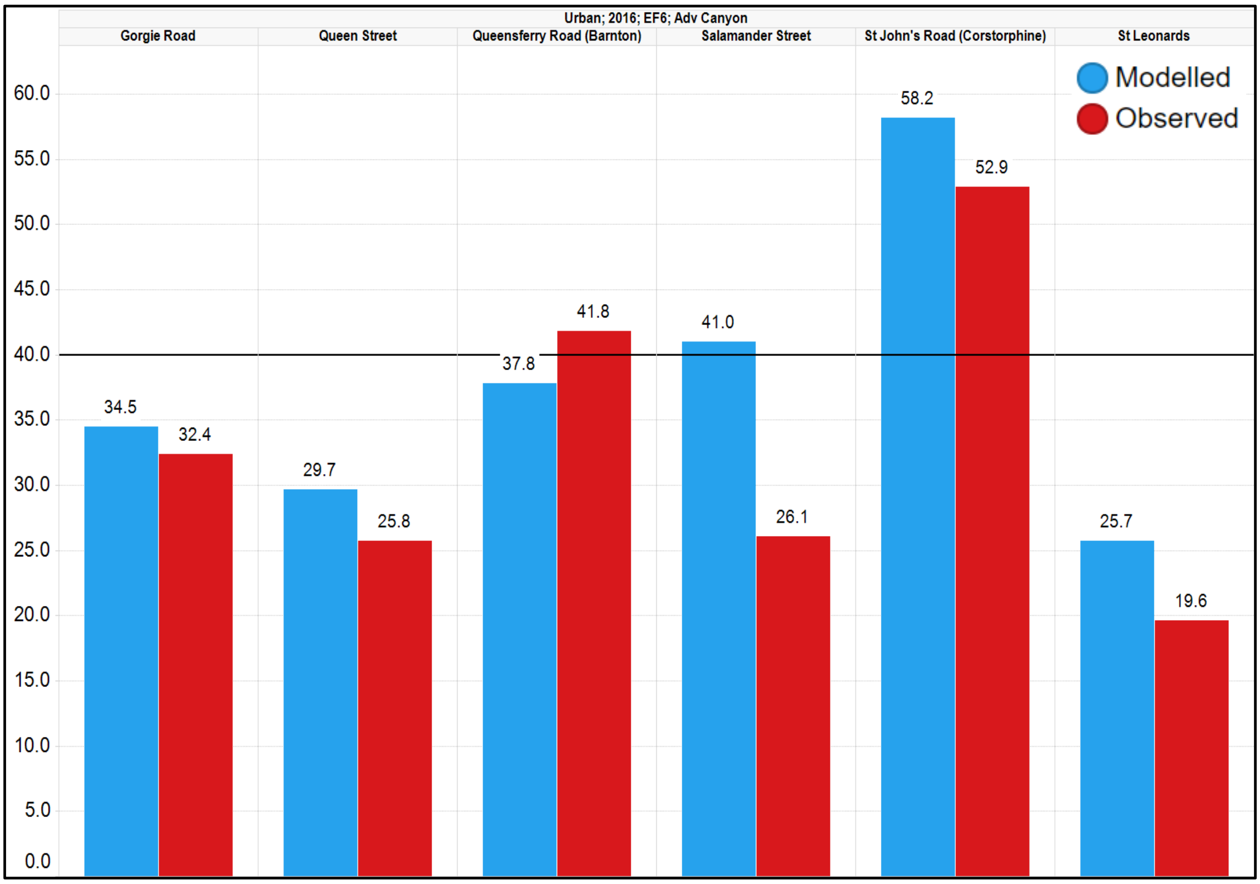

Figure 12: Comparison Of 2016 Modelled And Observed Annual Average NO2 (µgm^{-3}) For Six Automatic Monitoring Stations. Background: Urban Background.

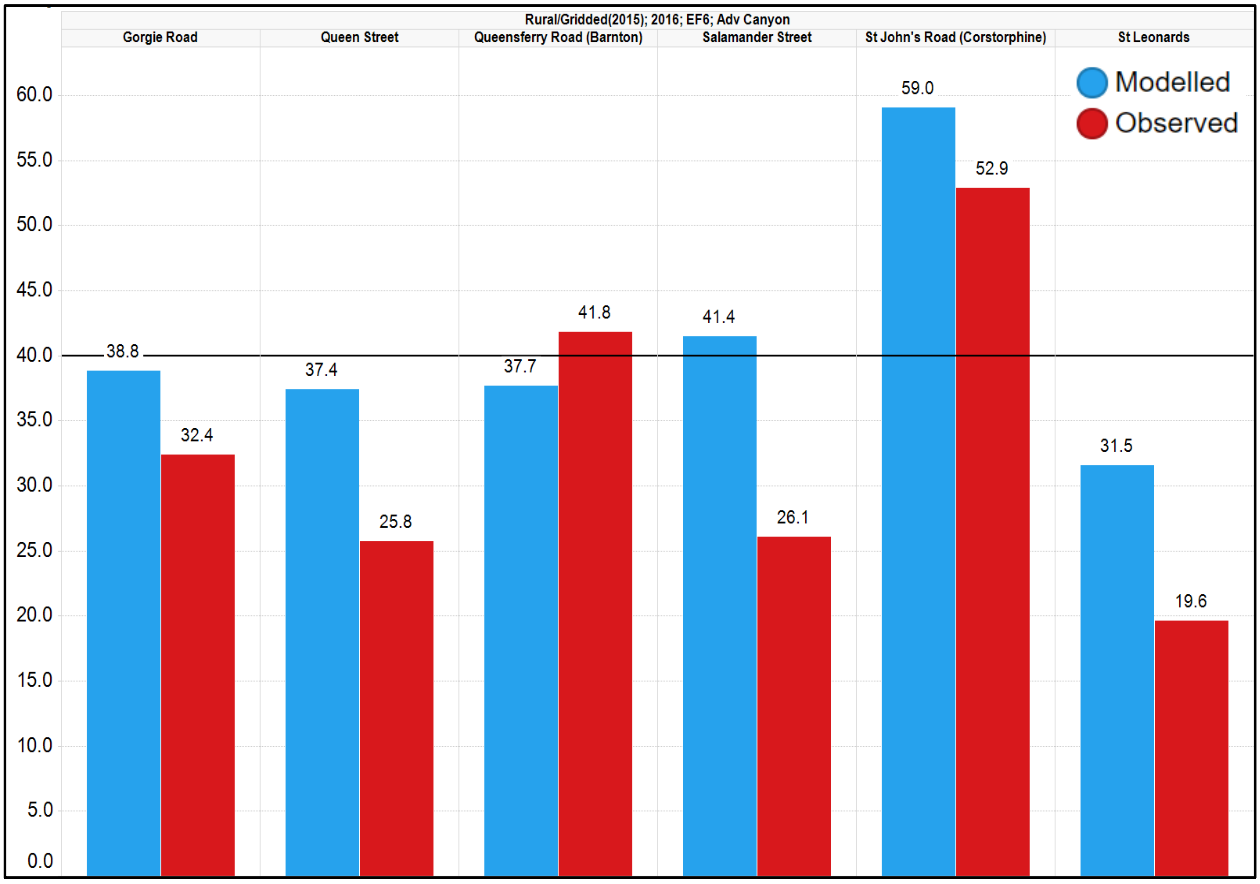

Figure 13: Comparison Of 2016 Modelled And Observed Annual Average NO2 (µgm^{-3}) For Six Automatic Monitoring Stations. Background: Rural Background And Gridded Emissions.

Table 3: Comparison Of 2016 Observed And Modelled Annual Average NO2 (μgm^{-3}) For Six Automatic Monitoring Stations.

Background Method →		**Urban**		**Rural/Gridded**	
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}**
Gorgie Road	32.4	34.5	-2.1	38.8	-6.4
Queen Street	25.8	29.7	-3.9	37.4	-11.6
Queensferry Road (Barnton)	41.8	37.8	4	37.7	4.1
Salamander Street	26.1	41.0	-14.9	41.4	-15.3
St John's Road (Corstorphine)	52.9	58.2	-5.3	59.0	-6.1
St Leonards	19.6	25.7	-6.1	31.5	-11.9

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 2016 base run, 116 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 14 shows a scatter plot where 2016 observed PDT annual average NO2 values are plotted against equivalent modelled values. In this case the Urban Background method was used. Figure 15 shows similar information but for the Rural/Gridded Background method. The solid line shown represents a 1 to 1 agreement between observed and modelled data. Ideally, all points on Figure 14 and Figure 15 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 dashed lines shown in both Figure 14 and Figure 15 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. It can also be seen that using the Rural/Gridded Background method moves many modelled values upward, placing more points above the 1 to 1 line. This means that concentrations at many PDTs is overestimated using the Rural/Gridded method. This is similar to the situation for automatic monitoring stations.

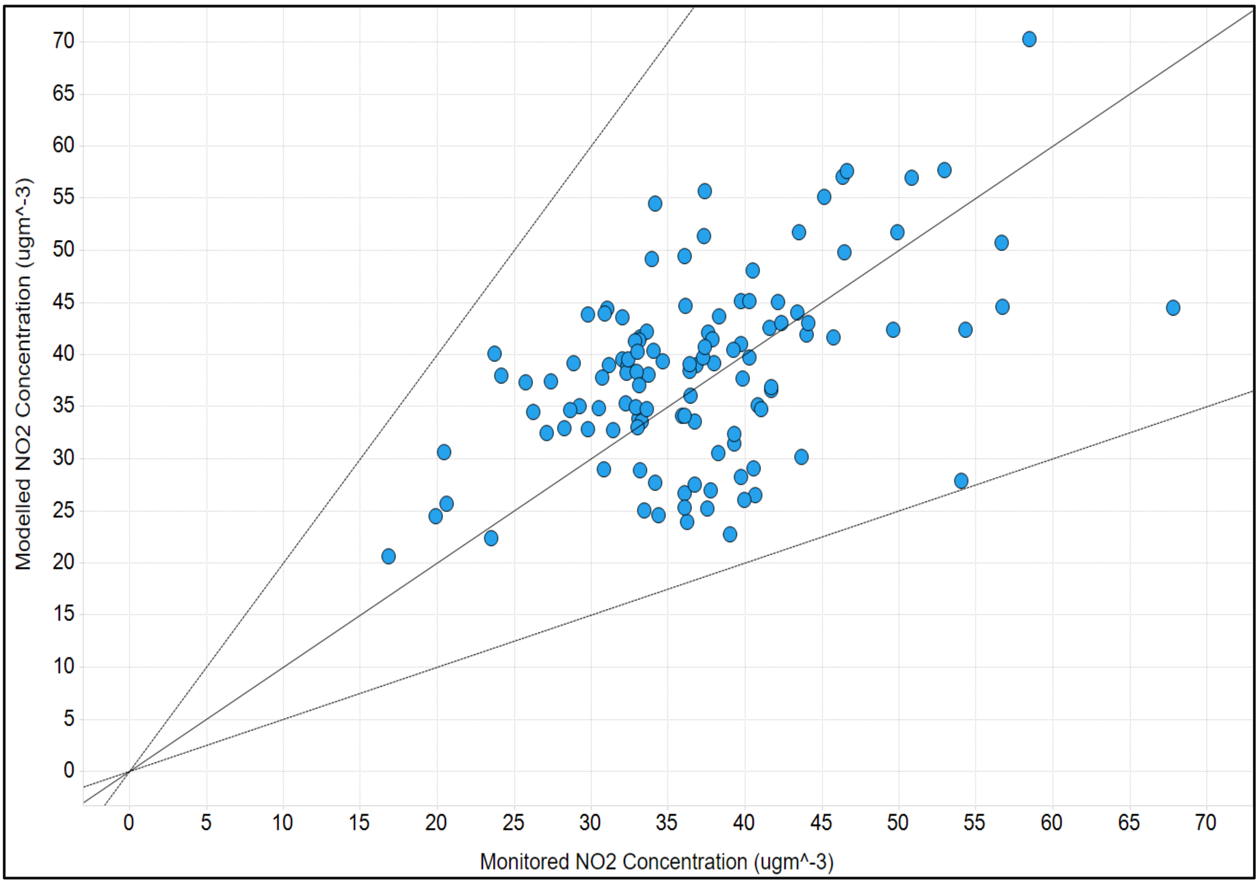

Figure 14: Scatter Plot Of Passive Diffusion Tube Annual Average NO2 (µgm^{-3}) (Bias-Adjusted) VS Modelled NO2. Background: Urban Background.

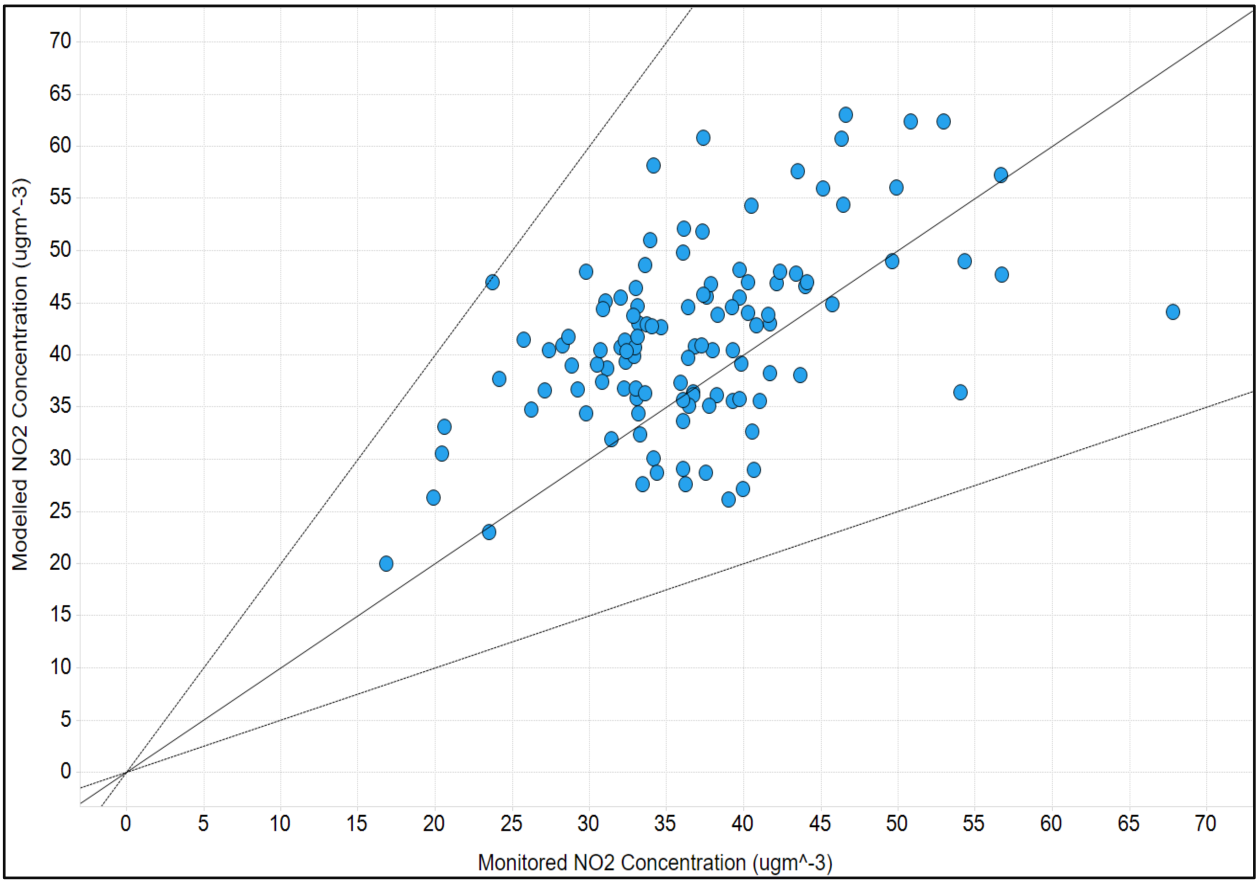

Figure 15: Scatter Plot Of Passive Diffusion Tube Annual Average NO2 (µgm^{-3}) (Bias-Adjusted) VS Modelled NO2. Background: Rural Background And Gridded Emissions.

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 Edinburgh model is not a perfect simulation of air quality in Edinburgh in 2016. 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.

It seems clear that using an Urban Background method for background emissions gives the best model performance. However, future modelling will be carried out with both to establish the potential risks to model predictions.

We believe that the current Edinburgh 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 reasonable agreement with most automatic monitoring stations for 2016, with the exception of Salamander Street.**

We have carried out a more detailed and technical assessment of the performance of the Edinburgh 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 Edinburgh 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 +/- 6.1 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 Edinburgh 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 Edinburgh NMF Modelling Results

4.1 NO2 Concentrations In The Edinburgh NMF Model

During 2016, air quality in Edinburgh was monitored using eight automatic (continuous) monitoring stations and 127 Passive Diffusion Tubes (PDT) [9]. Section 3 shows that the current Edinburgh model represents the 2016 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 Edinburgh model, 5789 roadside points were set up along the major road links shown in Figure 6. This is the same as placing a roadside point 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 Edinburgh NMF model, for the base year of 2016, are shown in Figure 16. In this model run, speeds for each road link were set as 'Variable' 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 Edinburgh 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}.

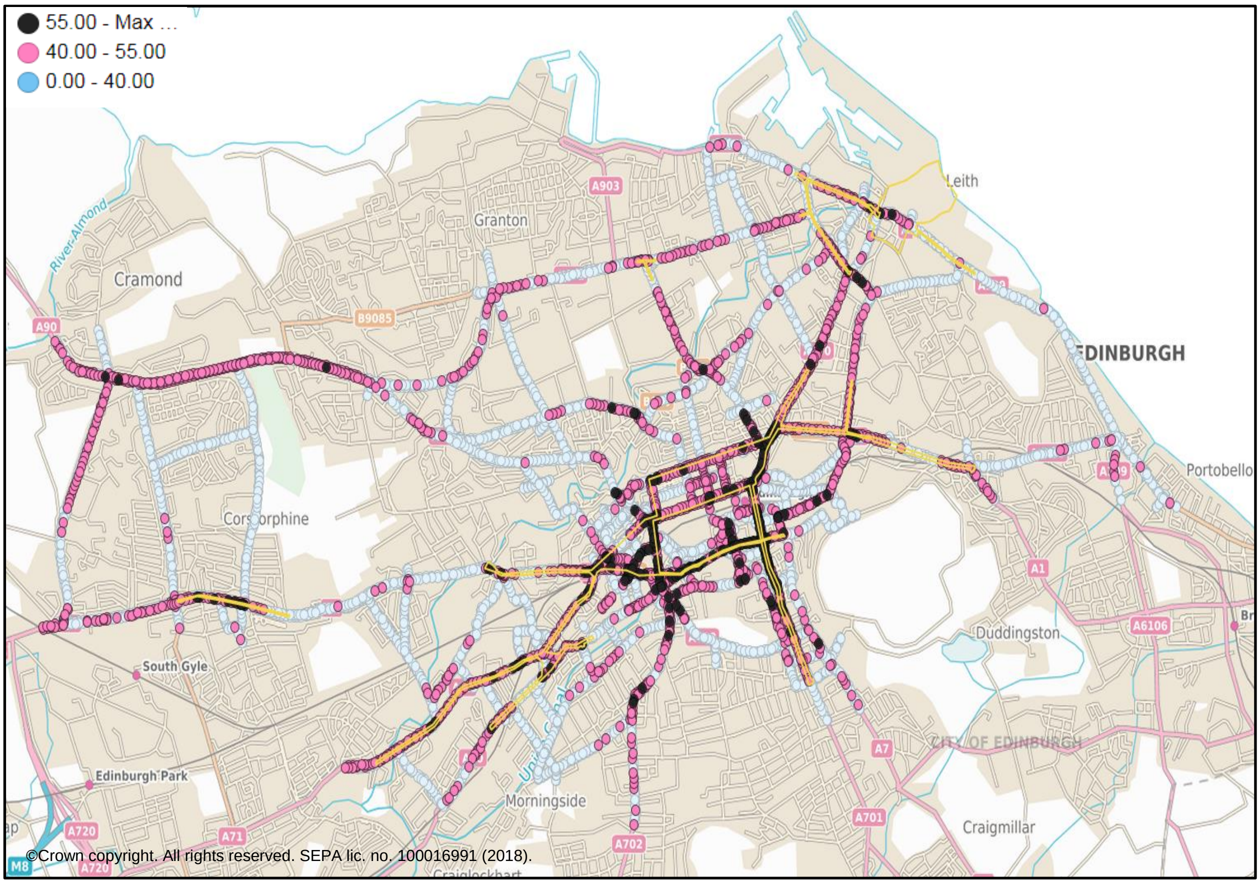

Figure 16: Modelled Roadside Annual Average NO2 (µgm^{-3}) For 2016. Annual Average Speed: 'Variable'. Values Greater Than 40 µgm^{-3} Are Highlighted.

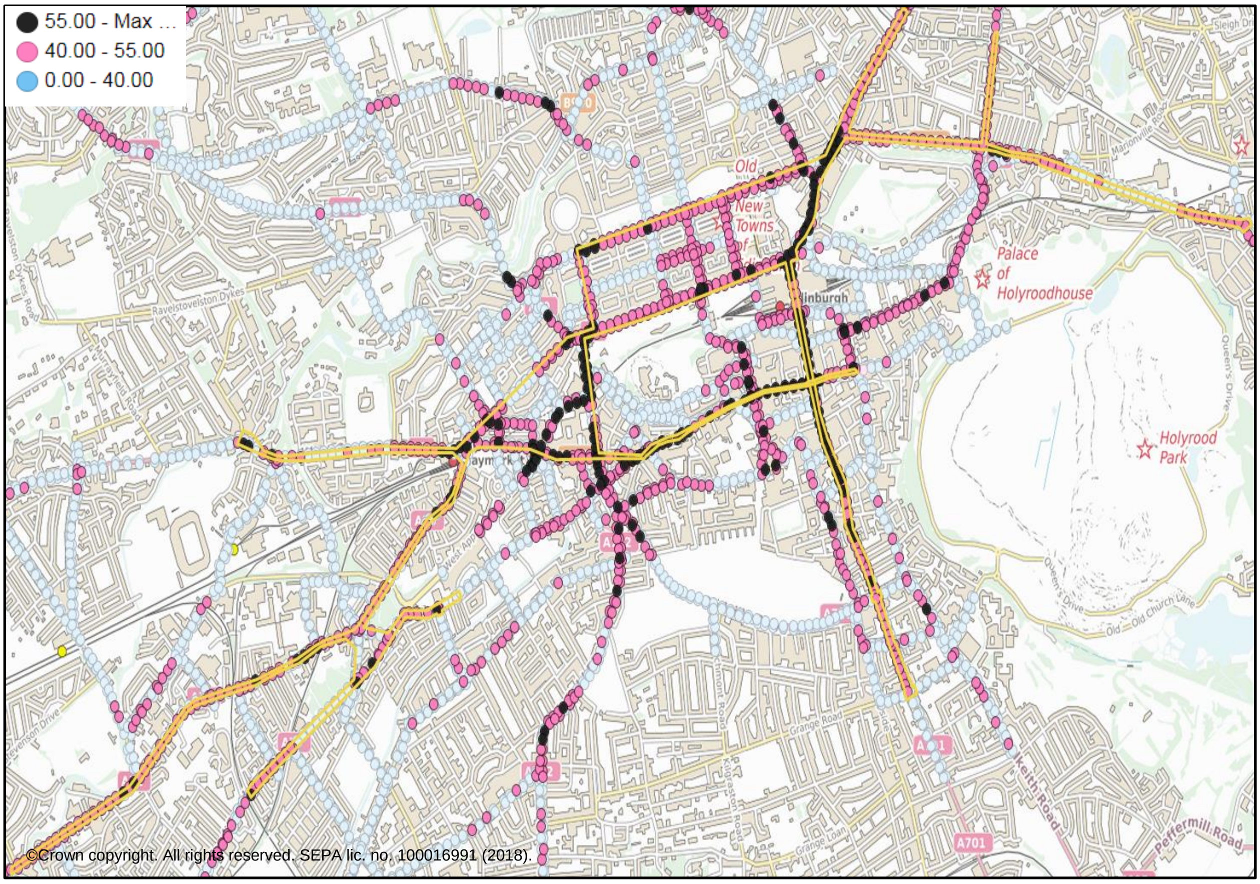

Figure 17: Modelled Roadside Annual Average NO2 (µgm^{-3}) For 2016 (Central AQMA). Annual Average Speed: 'Variable'. Values Greater Than 40 µgm^{-3} Are Highlighted.

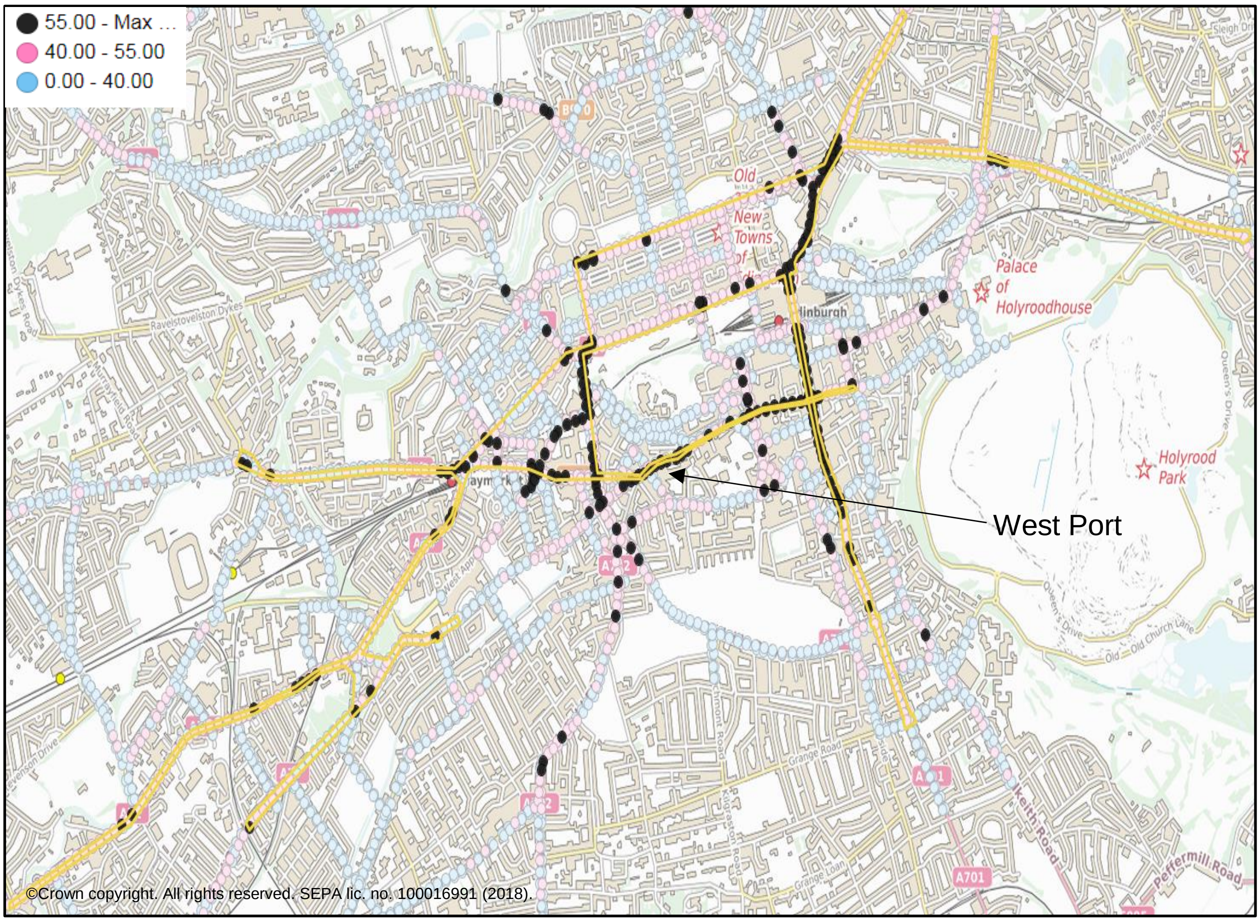

Figure 18: Modelled Roadside Annual Average NO2 (µgm^{-3}) For 2016 (Central AQMA). Annual Average Speed: ‘Variable’. Values Greater Than 55 µgm^{-3} Are Highlighted.

40 µgm^{-3} is the annual average limit value for NO2. Modelled values above this limit have been highlighted in Figure 16. AQMA boundaries are outlined in yellow. Figure 17 and Figure 18 show the roadside points for the Central AQMA with highlighted values of NO2 greater than 40 µgm^{-3} and 55 µgm^{-3}, respectively.

The highest modelled annual average for NO2 in the base year of 2016 was 96.72 µgm^{-3}. This occurred on West Port Street which is highlighted on Figure 18.

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, often within the Central AQMA. The highest concentrations are found in areas of narrow and deep “street canyons” (streets lined with high buildings). West Port, Grassmarket and Cowgate are examples of this type of street. Additionally, the Central AQMA contains a high 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). 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.

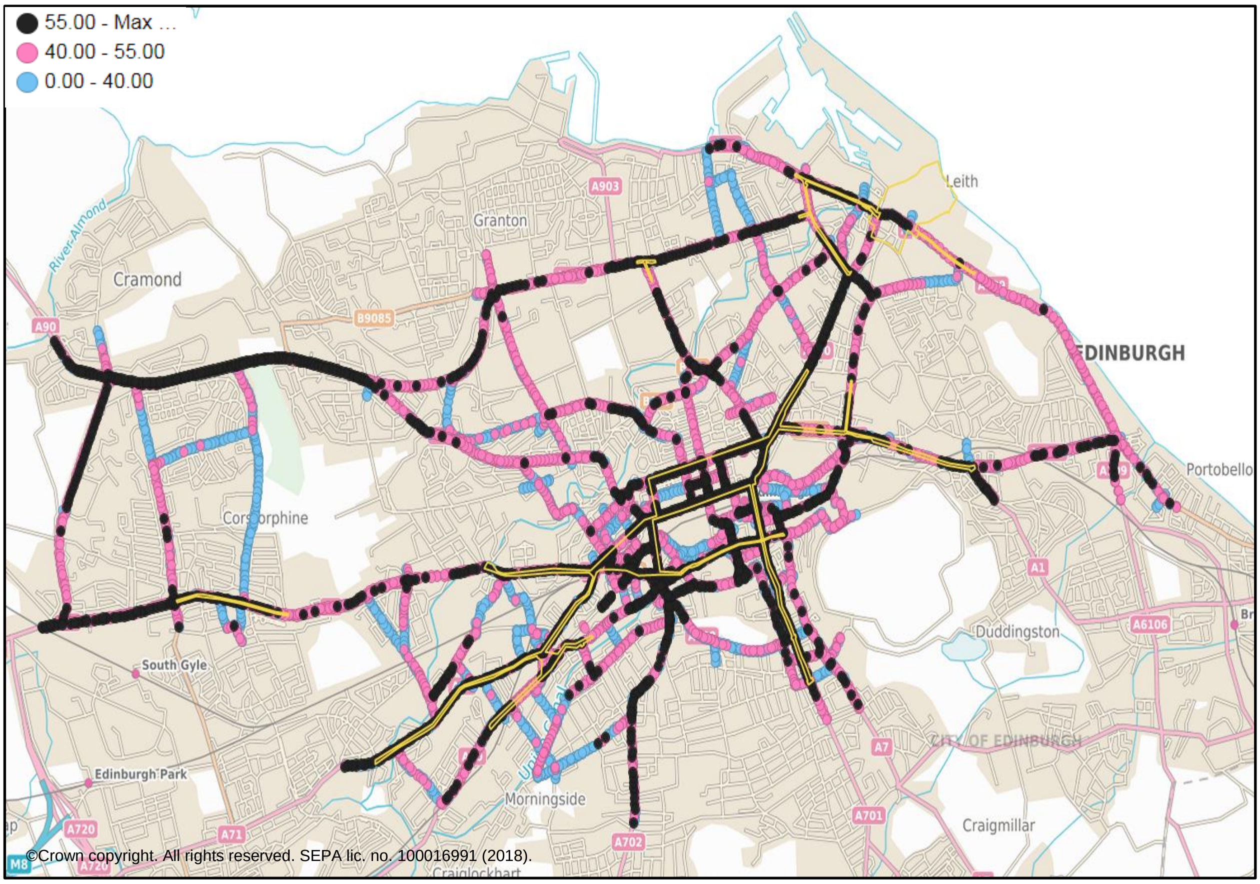

Figure 19: Modelled Roadside Annual Average NO2 (µgm^{-3}) For 2016. Annual Average Speed: ‘Congested: 10 km/hour’.

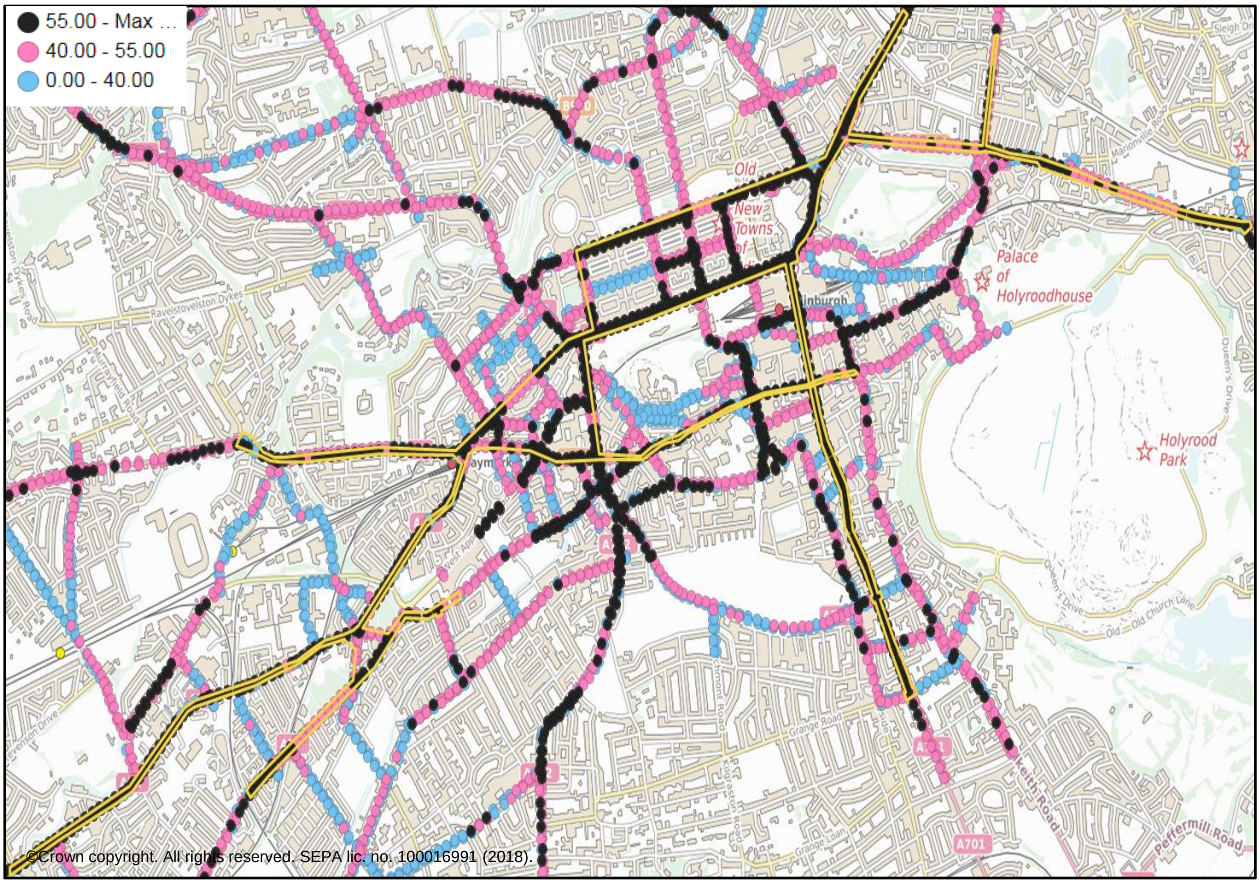

Figure 20: Modelled Roadside Annual Average NO2 (µgm^{-3}) For 2016 (Central AQMA). Annual Average Speed: ‘Congested: 10 km/hour’.

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 21 shows the distribution of modelled roadside point annual average NO2 concentrations inside and outside the Edinburgh AQMAs, for the 2016 base model run. All 5789 roadside point concentrations shown in Figure 16 have been ranked from highest to lowest. 1357 roadside points lie within the chosen AQMAs (Central, Great Junction Street, Inverleith, Salamander Street, St John's Road). 4432 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. Many of the AQMA points (1087) lie within the Central AQMA.

Table 4 and Table 5 show various simple statistics relating to the roadside point NO2 for the 2016 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.

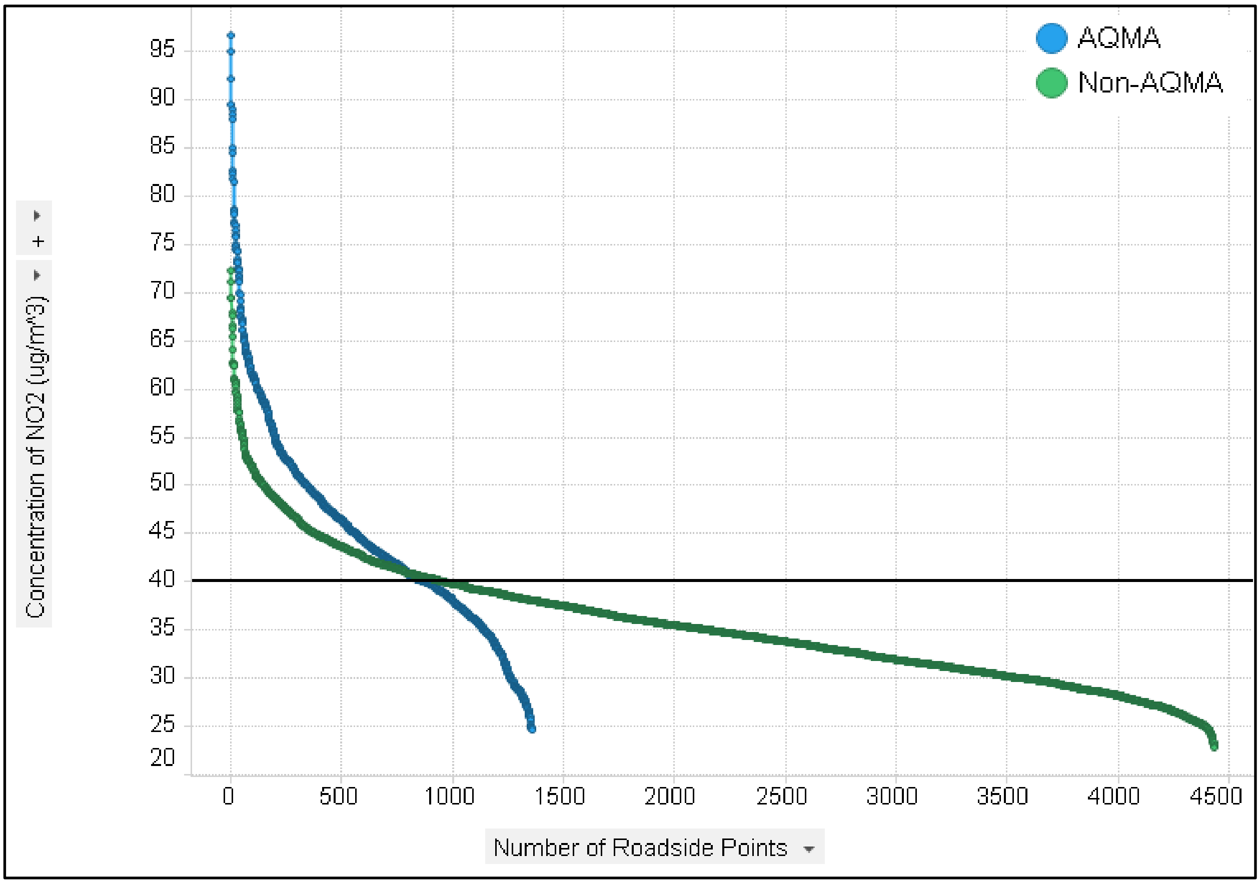

Figure 21: Distribution Of Roadside Point Annual Average NO2 (µgm^{-3}) Concentrations Inside and Outside Edinburgh AQMAs In 2016. Annual Average Speed: 'Variable'.

Table 4: Number Of Roadside Points With Modelled Annual Average NO2 Above 40 And 55 µgm^{-3} In Various 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	878	15.17 %	200	3.45 %
Non-AQMA	960	16.58 %	54	0.93 %
Central AQMA	769	13.28 %	187	3.23 %
Great Junction AQMA ''**	52	0.90 %	2	0.03 %
St John's Road AQMA	37	0.64 %	9	0.16 %
Salamander Street ''**	20	0.35 %	3	0.05 %
Inverleith AQMA	8	0.14 %	1	0.02 %
'*' – Total = 5789 points. '**' – There are a small number of overlapping points between these AQMAs.				

Table 5: Number Of Roadside Points With Modelled Annual Average NO2 Above 40 And 55 µgm^{-3} In Various Zones. Expressed As A Percentage Of The Number Of Roadside Points Within The Zone.

Zone	Total No. Of Points In Zone	No. Of Roadside Points Above 40 µgm^{-3}	No. Of Roadside Points Above 40 µgm^{-3} As % Of Points In Zone	No. Of Roadside Points Above 55 µgm^{-3}	No. Of Roadside Points Above 55 µgm^{-3} As % Of Points In Zone
AQMA	1357	878	64.70 %	200	14.74 %
Non-AQMA	4432	960	21.66 %	54	1.22 %
Central AQMA	1087	769	70.75 %	187	17.20 %
Great Junction AQMA '*'	114	52	45.61 %	2	1.75 %
St John's Road AQMA	64	37	57.81 %	9	14.06 %
Salamander Street '*'	88	20	22.73 %	3	3.41 %
Inverleith AQMA	19	8	42.11 %	1	5.26 %
'*' – There are a small number of overlapping points between these AQMAs. The total, in the table, for Central, Great Junction, St John's Road, Salamander St. and Inverleith is 1372.					

4.2 Summary Of NO2 Concentrations In The Edinburgh NMF Model

The information presented in section 4.1 outlines the scale of roadside NO2 air quality issues experienced in Edinburgh in 2016. Air quality modelling can be used to examine potential issues that could not be easily assessed with current monitoring techniques.

CEC report a downward trend of NO2 concentrations in the 2017 progress report [9]. At the time of writing (late 2018) some improvement on the values presented above is expected. However, a number of observations can be made which will remain valid:

- Outside the existing AQMAs, there are likely to be areas of roadside NO2 concentrations higher than the annual average limit value. Due to model uncertainty, not all areas predicted to be above the limit value will be above the limit if monitored.
- Areas outside the AQMAs with a large number of roadside points which have high concentrations should be investigated with monitoring. Some areas in the vicinity of the Central AQMA may be the highest priority. More detailed information will be provided to CEC.
- Within, and outside, the AQMAs there are a similar number of roadside points above the NO2 annual average limit value. However, the average and maximum concentrations within the AQMAs are higher, as shown in Figure 21.
- The Central AQMA has the highest number of roadside points with an annual average concentration of NO2 above 55 µgm^{-3}. These locations are very likely to still be above the annual average NO2 limit value in 2018, particularly if they are in narrow and deep “street canyons”.
- Figure 16 and Figure 17 confirm that the current Central AQMA boundaries are well founded. They contain the most extensive number of roadside points above the annual average NO2 limit value within the modelled area. Figure 18 also indicates that the majority of the highest modelled concentrations lie within the Central AQMA.
- There are some areas close to the current AQMA which we would recommend are investigated with monitoring. More detailed information will be provided to CEC.
- Roadside locations in Edinburgh which lie along congested roads with a low annual average speed, particularly within the Central AQMA and in street canyons, may be experiencing very high annual average NO2 concentrations. Again, we recommend that this is investigated with monitoring.
- The highest annual average NO2 concentration measured by PDT in 2016 was 59 µgm^{-3}. This level was measured at two different locations in the Central AQMA: West Port and Leith Street [9]. Analysis of the base model run for 2016 indicates that there are 142 roadside points which are greater than 59 µgm^{-3}. We would recommend that the highest roadside points are investigated with monitoring.

- **Modelling results suggest that the Central AQMA, and some surrounding streets, suffer from the poorest roadside NO2 air quality in Edinburgh. Significant emission reduction in, and around, the Central AQMA will be required to improve air quality. Significant emission reduction will be required in areas of narrow and deep “street canyons”.**
- **Other AQMAs will require some form of emission reduction to improve air quality. Of these, St Johns Road and the Great Junction AQMAs are likely to be the most challenging to improve.**
- **Many of the main roads in Edinburgh 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 Edinburgh 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. Coach numbers in Edinburgh are likely to be significant. However, this category is dominated by local Buses.

Source apportionment has been carried out for 1951 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 22 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 22 shows that contributions to annual average total NOx vary substantially across the modelled area. Bus/Coach dominate in many areas with Diesel cars dominating in others. Figure 23 follows a similar format to Figure 22 but only includes roadside points within the Central AQMA. The percentage contribution pattern in the Central AQMA is similar to that for all modelled roads. However, Bus/Coach is a dominant source at many roadside points.

Figure 24 and Figure 25 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 Central AQMA have Bus/Coach greater than 40% (max. 85%). Fewer road links in the Central AQMA have Car contributions greater than 40%. In contrast, many roads close to, but not inside, the Central AQMA have Car contributions greater than 40% (max. 67%).

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.

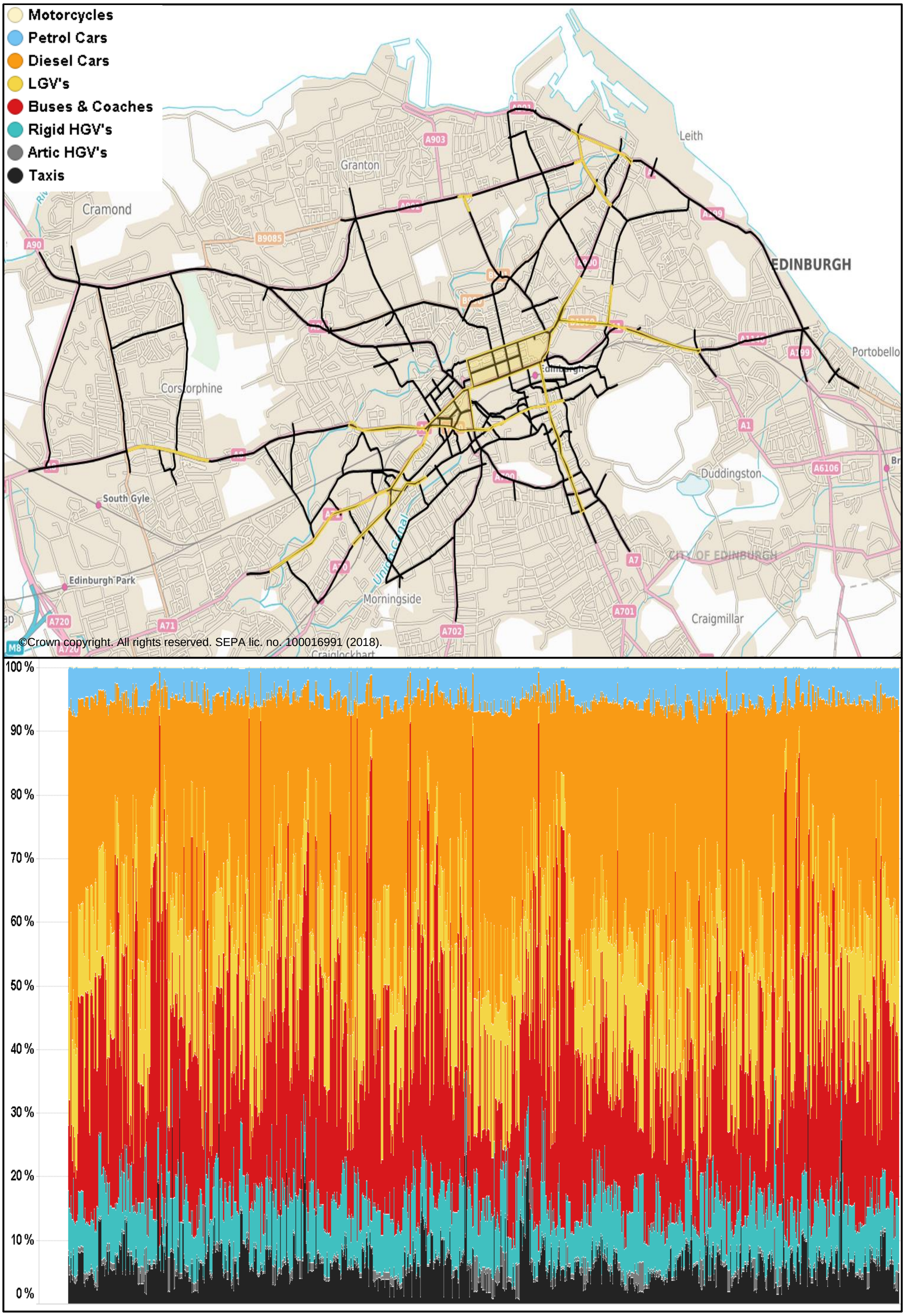

Figure 22: Percentage Contribution to annual average total NOx for All Source Apportionment Roadside Points. Highlighted Roads in Black. Colour Key Refers to Lower Part of Figure.

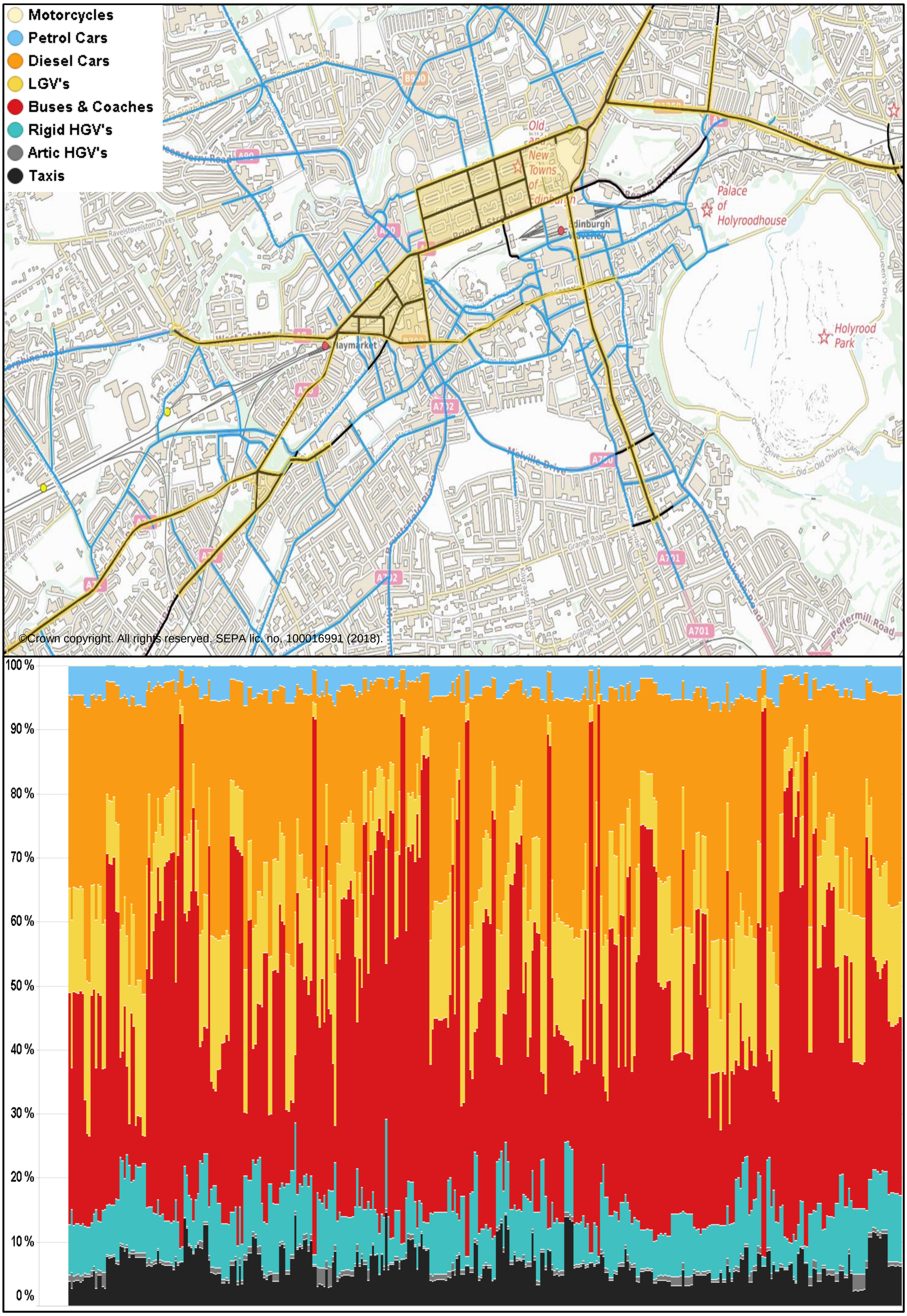

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Figure 23: Percentage Contribution To Annual Average Total NOx For Central AQMA Source Apportionment Roadside Points. Highlighted Roads In Black. Colour Key Refers To Lower Part Of Figure.

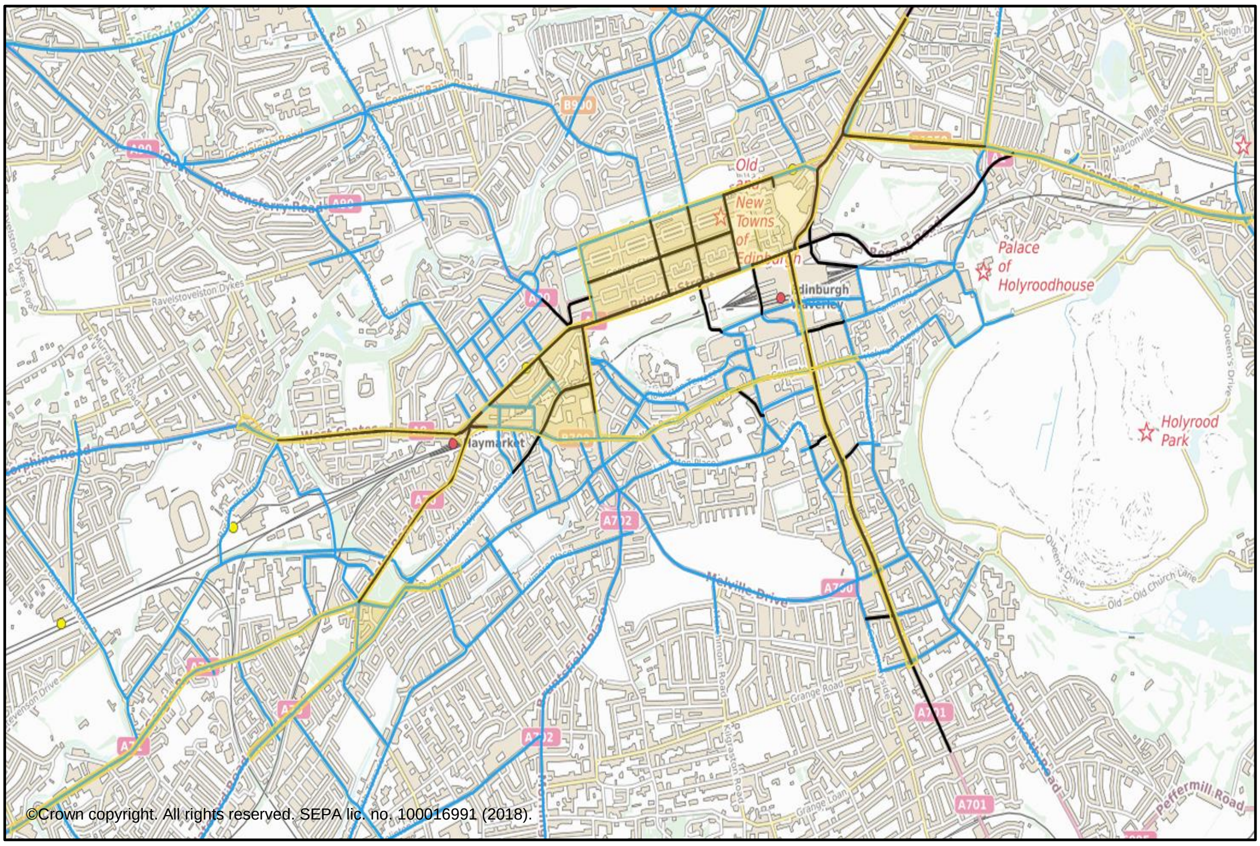
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Figure 24: Road Links, In And Around The Central AQMA, Where The Contribution From Buses And Coaches To Annual Average Total NOx Is Between 40 And 85%. Highlighted In Black.

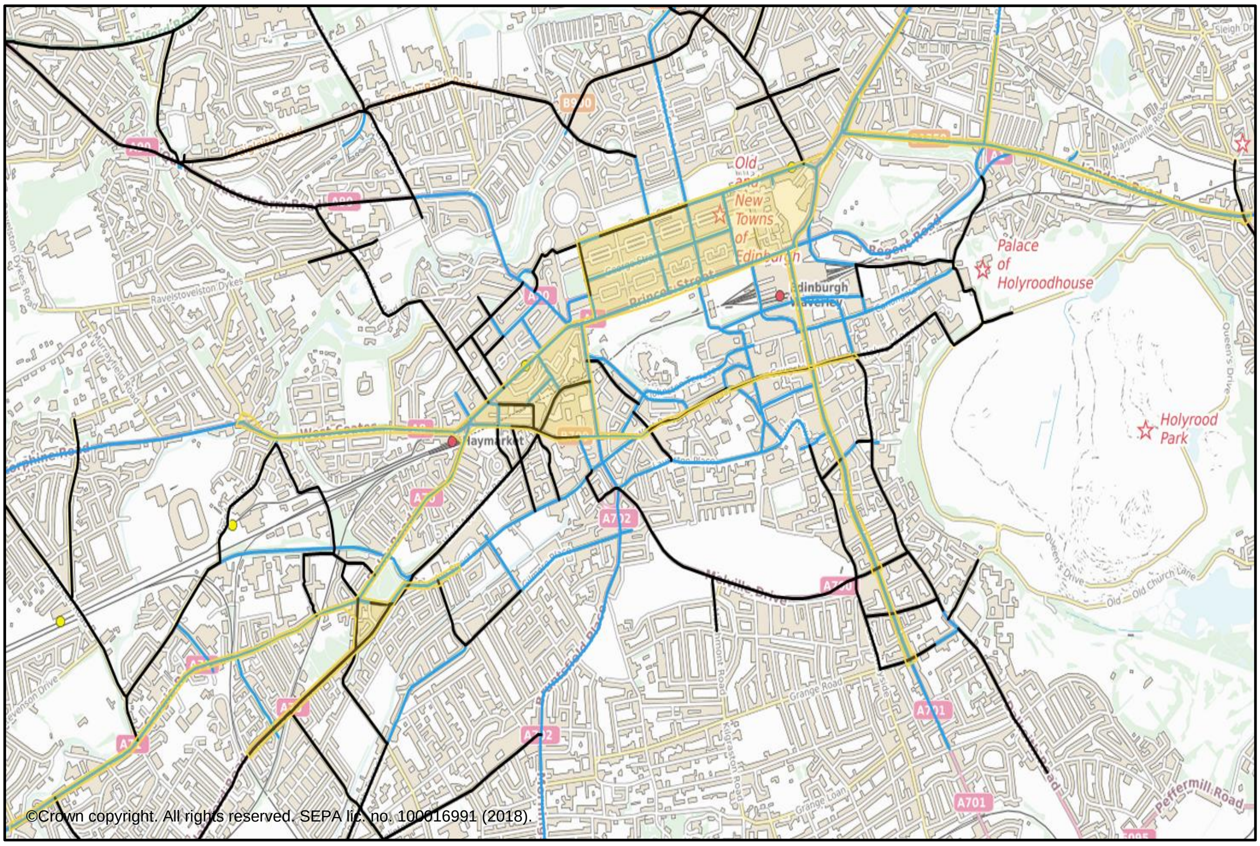
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Figure 25: Road links, In And Around The Central AQMA, Where The Contribution From All Cars To Annual Average Total NOx Is Between 40 and 67%. Highlighted In Black.

Figure 26 shows the distribution of the percentage of annual average total NOx at all source attribution roadside points, for each vehicle type. Figure 27 displays similar data but is restricted to those roadside points which lie within the Central AQMA. In both figures, roadside points have been ranked from highest to lowest for each vehicle category. Due to the density of points, a continuous line is displayed. 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 28 and Figure 29 show the percentage contribution to annual average total NOx for each vehicle type within a particular zone: all roadside points and the Central AQMA, 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 Edinburgh 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 Central AQMA where repeat journeys are likely. Repeat journeys may also be a factor in some goods vehicles.

Figure 30 to Figure 33 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 Edinburgh.

Table 6 and Table 7 show the average and maximum AADT, for aggregated vehicle types, within the zones specified above. Table 8 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 6 by the percentage of annual average total NOx in Figure 32 and Figure 33. 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.

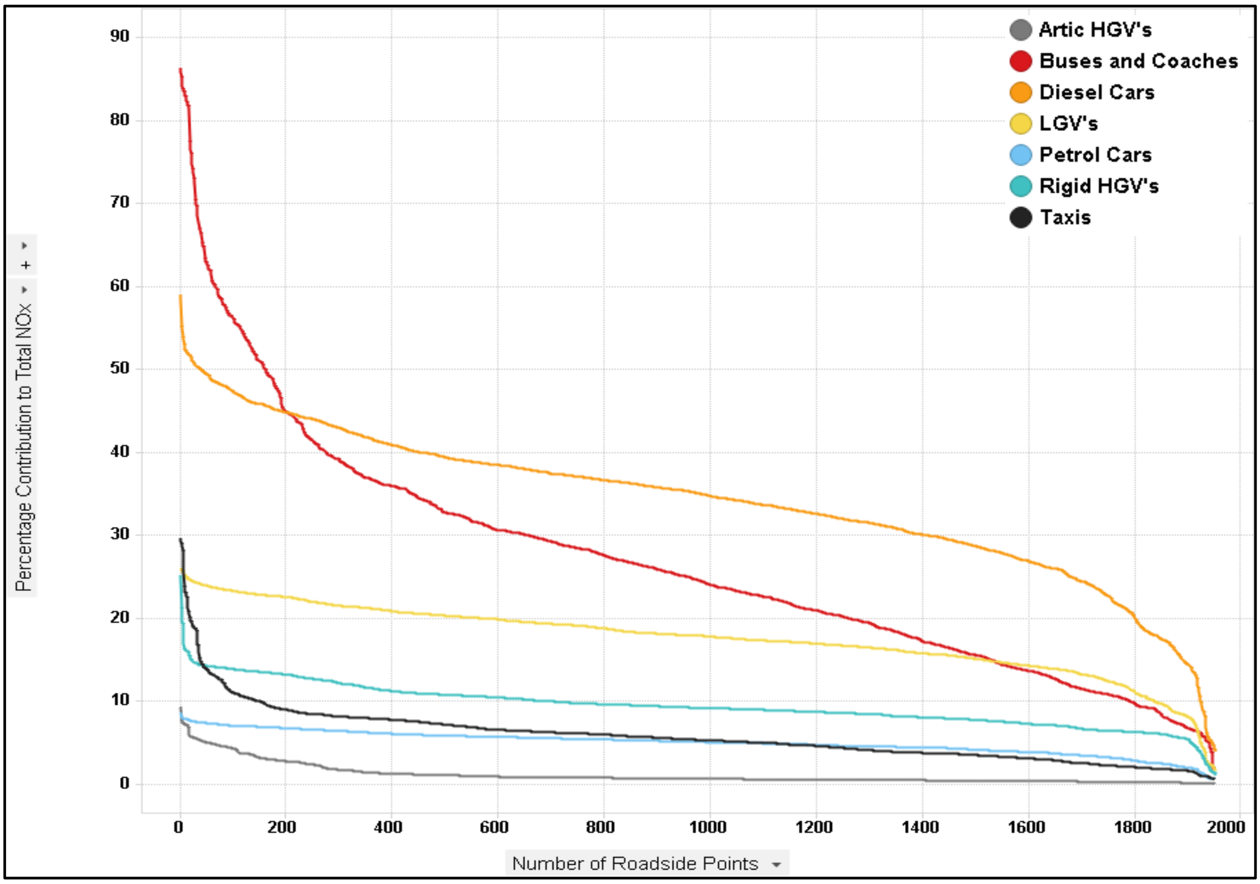

Figure 26: Distribution Of The Percentage Of Annual Average Total NOx At All Source Attribution Roadside Points For Each Vehicle Type.

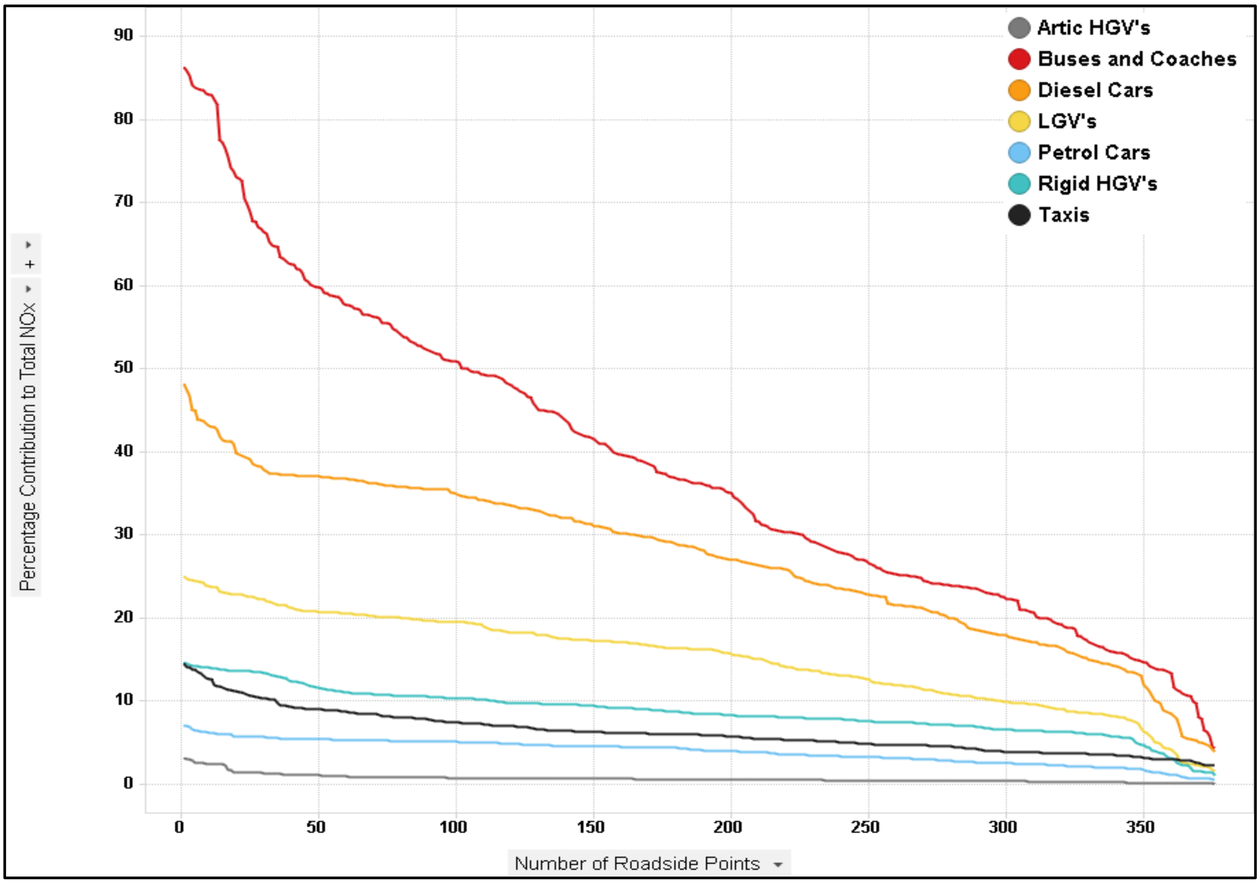

Figure 27: Distribution Of The Percentage Of Annual Average Total NOx At Central AQMA Source Attribution Roadside Points For Each Vehicle Type.

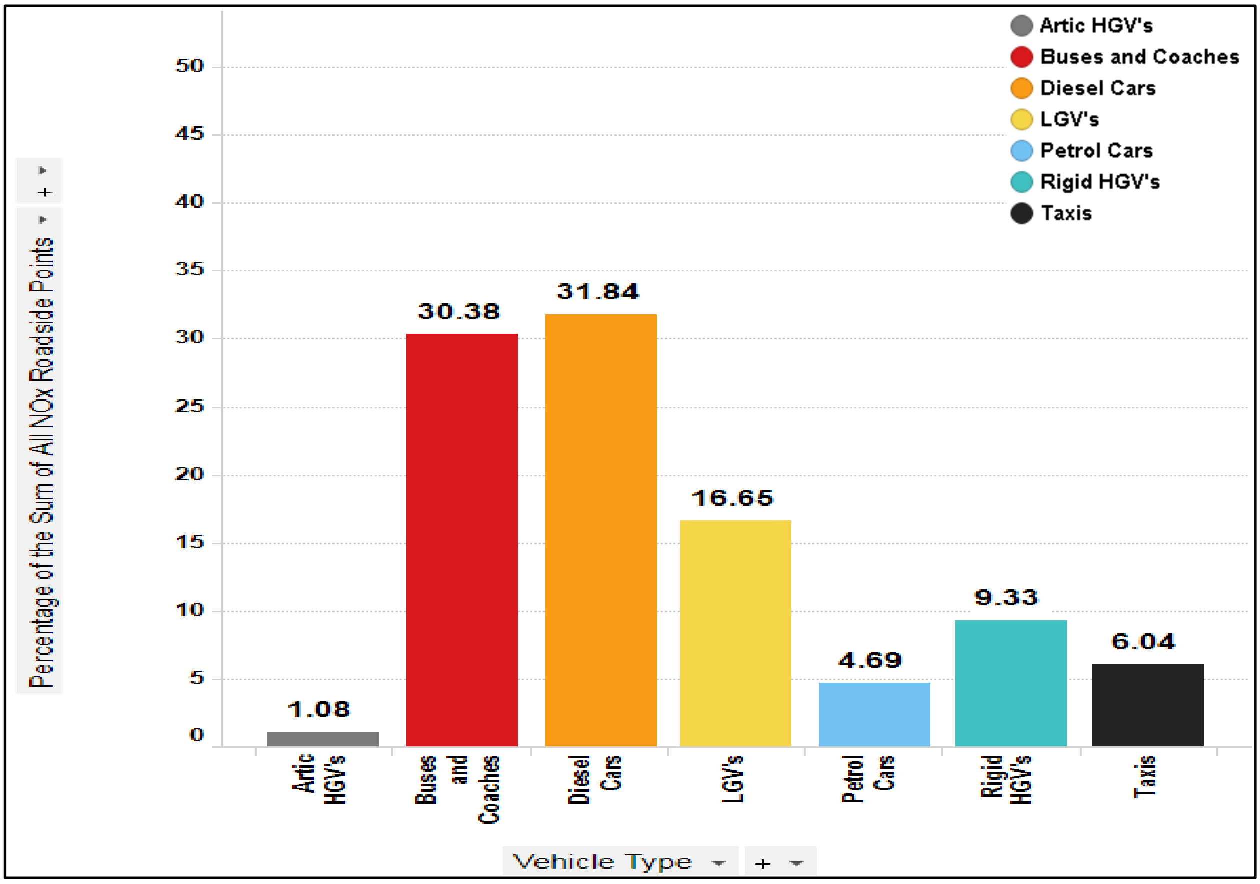

Figure 28: Percentage Contribution To Annual Average Total NOx Within A Zone For Each Vehicle Type. Zone: All Roadside Points.

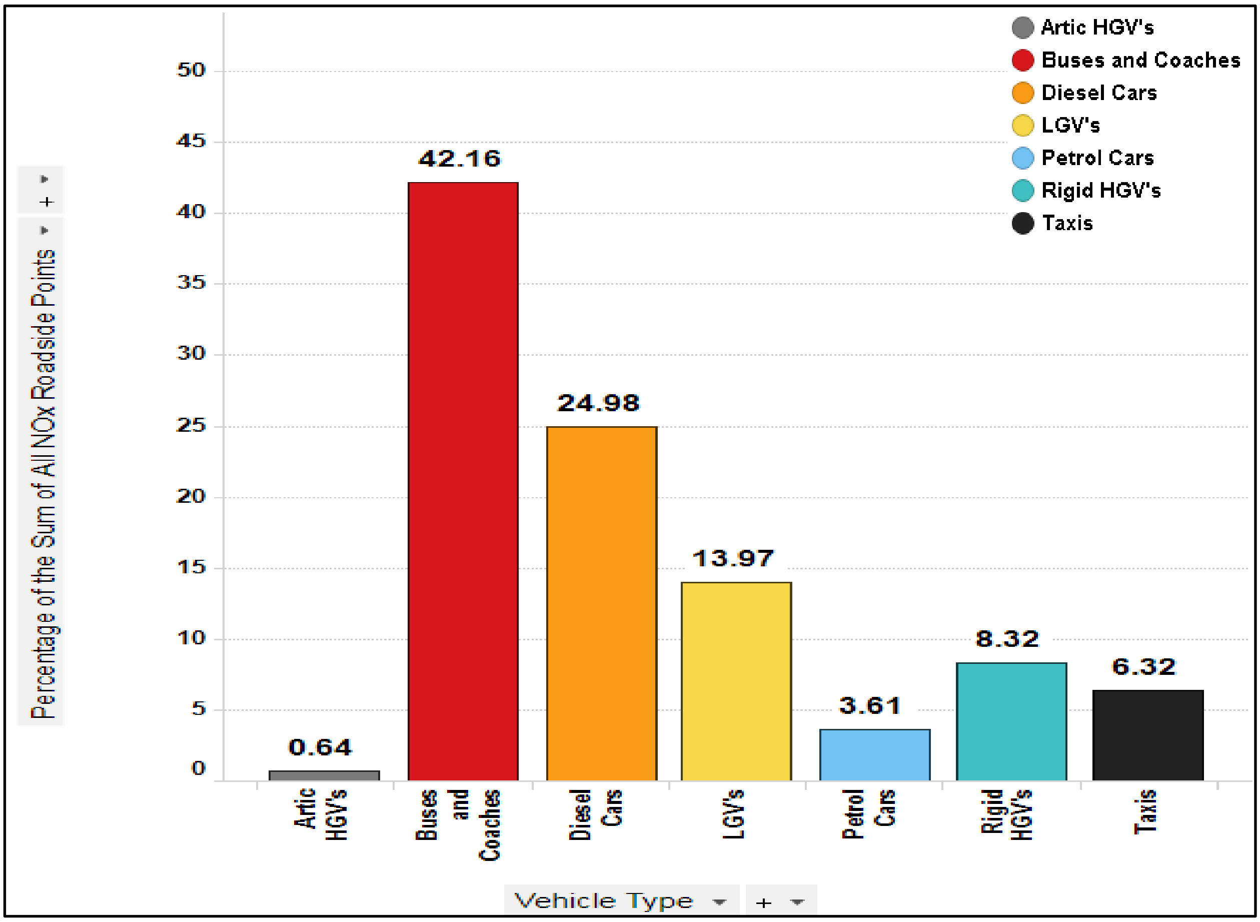

Figure 29: Percentage Contribution To Annual Average Total NOx Within A Zone For Each Vehicle Type. Zone: Central AQMA.

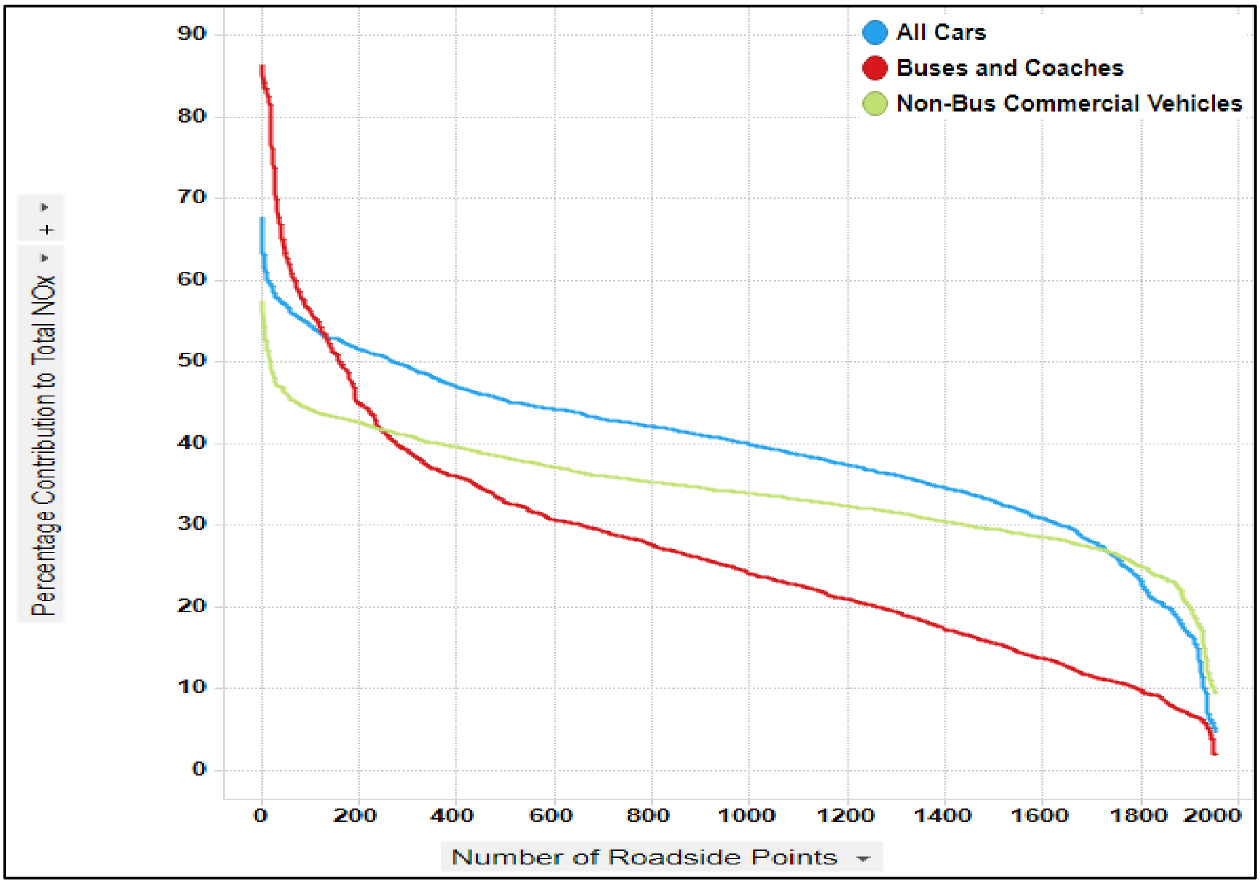

Figure 30: Distribution Of The Percentage Of Annual Average Total NOx At All Source Attribution Roadside Points For Aggregated Vehicle Type.

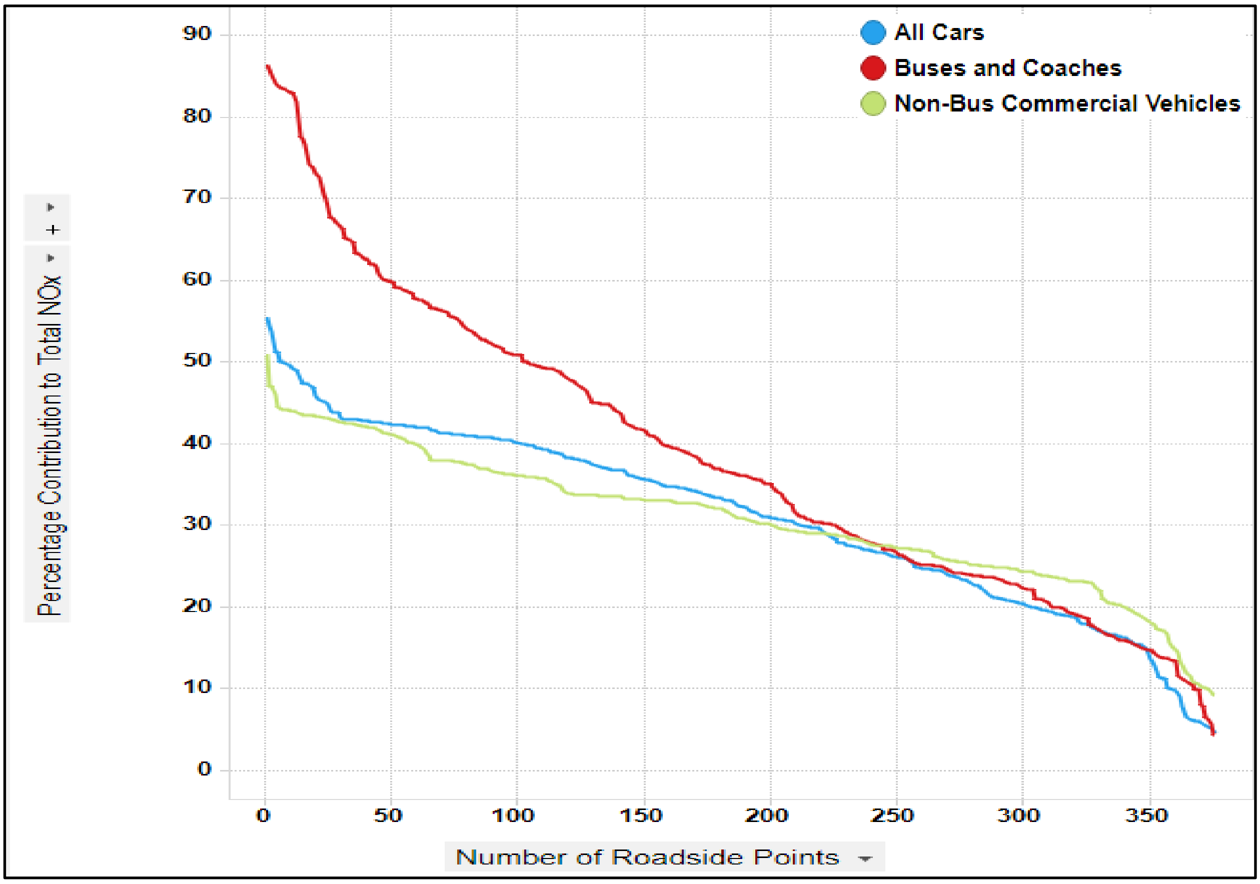

Figure 31: Distribution Of The Percentage Of Annual Average Total NOx At Central AQMA Source Attribution Roadside Points For Aggregated Vehicle Type.

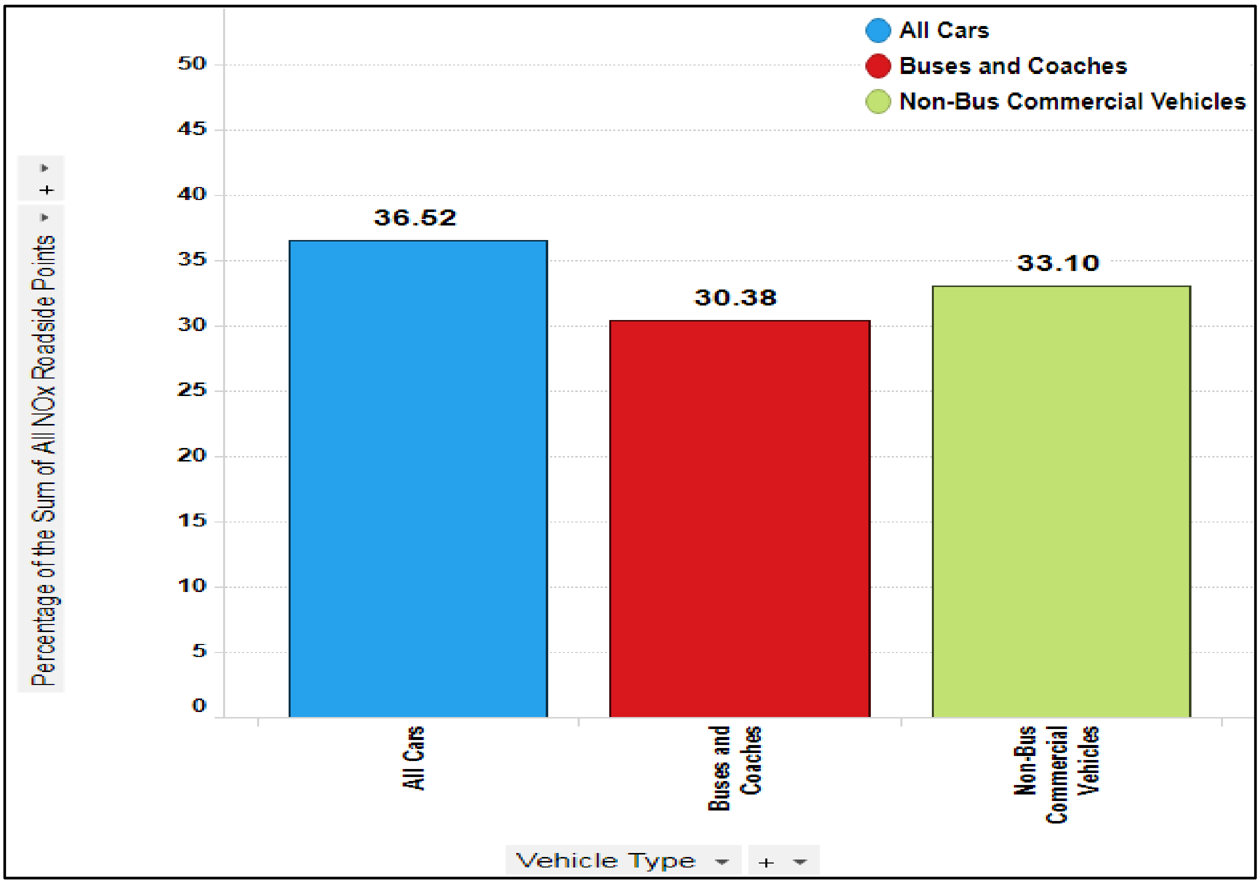

Figure 32: Percentage Contribution To Annual Average Total NOx Within A Zone For Aggregated Vehicle Type. Zone: All Roadside Points.

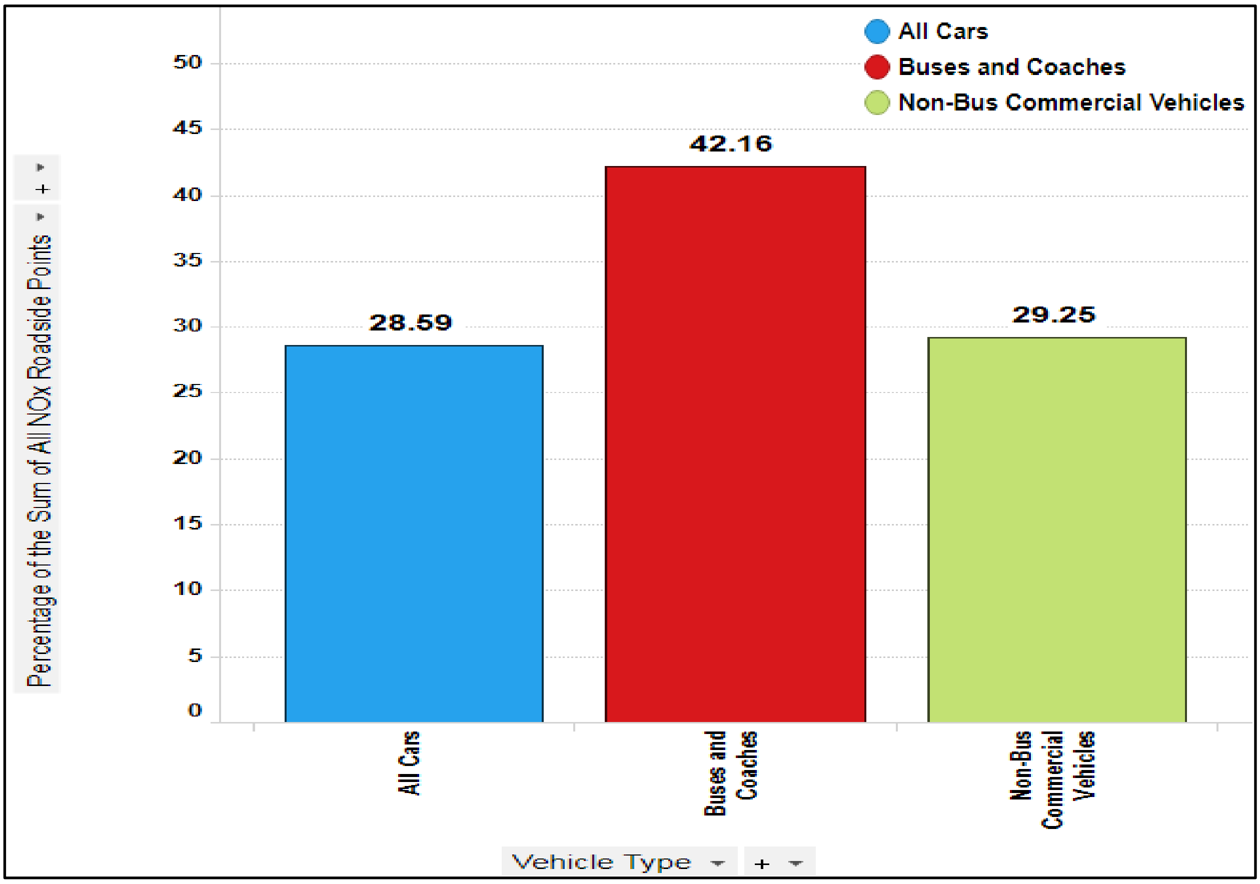

Figure 33: Percentage Contribution To Annual Average Total NOx Within A Zone For Each Vehicle Type. Zone: Central AQMA.

Table 6: 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	9138	551	2139
Central AQMA	9345	1088	2639

Table 7: 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	43725	5334	8785
Central AQMA	23127	5334	6788

Table 8: 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	250	18	65
Central AQMA	327	26	90

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 Edinburgh. 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 2016 and the time of writing (late 2018). This will have affected the current source apportionment. However, the detailed information available for 2016 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 2016 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 Edinburgh 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. This occurs at around 100 source apportionment roadside points which lie within the Central AQMA.
- At many roadside locations, Diesel cars provide a contribution of between 30 and 45% to NOx. This is the largest single contribution at most roadside locations.
- After Diesel cars, Buses and Coaches provide the next largest contribution to NOx at most roadside locations. However, this contribution varies between 15 to 45% and tends to be restricted to high bus and coach traffic routes.
- LGV’s are the third biggest contributor to NOx at roadside locations, often varying between 15 to 25%.
- 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%.
- At many roadside locations, the contribution to NOx from Non-Bus Commercial vehicles is greater than that from Buses and Coaches.
- 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 8 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 14 times the NOx of a car.
    - Each Non-Bus Commercial vehicle contributes to around 4 times the NOx of a car.

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

In section 4.2 we found that the Central AQMA, and some surrounding streets, suffer from the poorest roadside NO2 air quality in Edinburgh. Source apportionment information has been presented in section 4.3 for the Central AQMA. The following observations appear to be supported by this information:

- Buses and Coaches provide the highest contribution to NOx of any vehicle type in the Central AQMA.
- Buses and Coaches are a major source of NOx on many modelled streets within the Central AQMA.

- Diesel Cars are the second largest contributor to NOx on many modelled streets within the Central AQMA, followed by LGV's.
- 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 very similar to the contribution from all cars (Diesel and Petrol) at many roadside locations within the Central AQMA. Within the Central AQMA, Non-Bus Commercial vehicles contribute as much to NOx levels as all cars travelling within the Central AQMA. At some locations, within the Central AQMA, the contribution to NOx from Non-Bus Commercial vehicles is relatively large.
- Contributions to NOx from Buses and Coaches and Non-Bus Commercial are associated with many fewer vehicles than all cars, within the Central AQMA.
- The average number of cars within the Central AQMA is slightly higher than across the whole modelled area, although the maximum number is much lower. The average number of buses within the Central AQMA is almost double that found over the whole modelled area. The average number of Non-Bus Commercial vehicles is higher within the Central AQMA than over the entire modelled area.
- Information in Table 8 is a very basic attempt to consider how many vehicles of each type contribute to 1% of the NOx from that vehicle type. Within the Central AQMA, on average:
    - Each Bus and Coach contributes to around 13 times the NOx of a car.
    - Each Non-Bus Commercial vehicle contributes to around 4 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 Edinburgh.**

- **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. Within the Central AQMA, their emissions are almost equivalent. There are far fewer Non-Bus Commercial vehicles than Cars.**

- **Within the Central AQMA 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. Consideration of the Lothian Bus network map reveals that many Bus journeys pass through the Central AQMA. This is likely to explain the high Bus and Coach contribution in this area and the increasing contribution to NOx in the model towards the Central AQMA.**

- **Diesel Cars play a large role in roadside NOx issues within the Central AQMA. They are therefore likely to play a large role in the roadside NO2 issues in this area. However their contribution appears to be matched by a far smaller number of Non-Bus Commercial vehicles, particularly LGV's.**

- **The contribution of different vehicle types to roadside NOx/NO2 issues within the Central AQMA varies from street to street. The detail of this is challenging to present in a report. Detailed information on a street by street basis is available from the model results. These will be used to support LEZ discussions.**

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 2016 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 2016, 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 the Central AQMA.

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 9: LEZ Scenario Details.

Scenario Group	**Description '*'**	**Years Modelled**
LEZ1	Vehicles classed as Euro 1 to 5 have been changed to Euro 6.	2016
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.	2016
LEZ2	Buses and Coaches have been changed to Euro 6. Other vehicles are unchanged.	2016, 2019, 2023
LEZ3	Buses and Coaches classed as Euro 1 to 4 have been changed to Euro 5. Other vehicles are unchanged.	2016, 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.	2016, 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.	2016, 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.	2016, 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 9 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 34 shows the distribution of 2016 annual average NO2 at all roadside points for the various scenarios described above.

Figure 35 shows similar information but only for the Central AQMA roadside points. Curves in the figures are denoted by a key which describes a particular scenario group. For example, “2016; EF6 (LEZ1) (Urban)” indicates that a 2016 fleet was used and modified as described in LEZ1 above. EF6 and Urban denote that an Edinburgh specific fleet mix was used and that the Urban background was used (see section 2).

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 2016.

Table 10 to Table 13 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 Central AQMA. 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 2016 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 116 of the Passive Diffusion Tubes (PDT), and automatic monitoring stations, deployed in Edinburgh in 2016. Table 14 and Table 15 display information about the potential benefits to PDTs from the some of the scenarios described above.

Figure 36 shows the potential benefit to annual average NO2 measured at automatic monitoring stations for 2016 scenarios.

Figure 37 shows a map of all modelled annual average roadside NO2 concentrations for the 2016 LEZ1 scenario. Similar information is shown for the Central AQMA in Figure 38 and Figure 39 for LEZ1 and LEZ2 respectively. These maps highlight the areas of roadside NO2 which will be the most difficult to improve, despite the emission reductions modelled in LEZ1 and LEZ2.

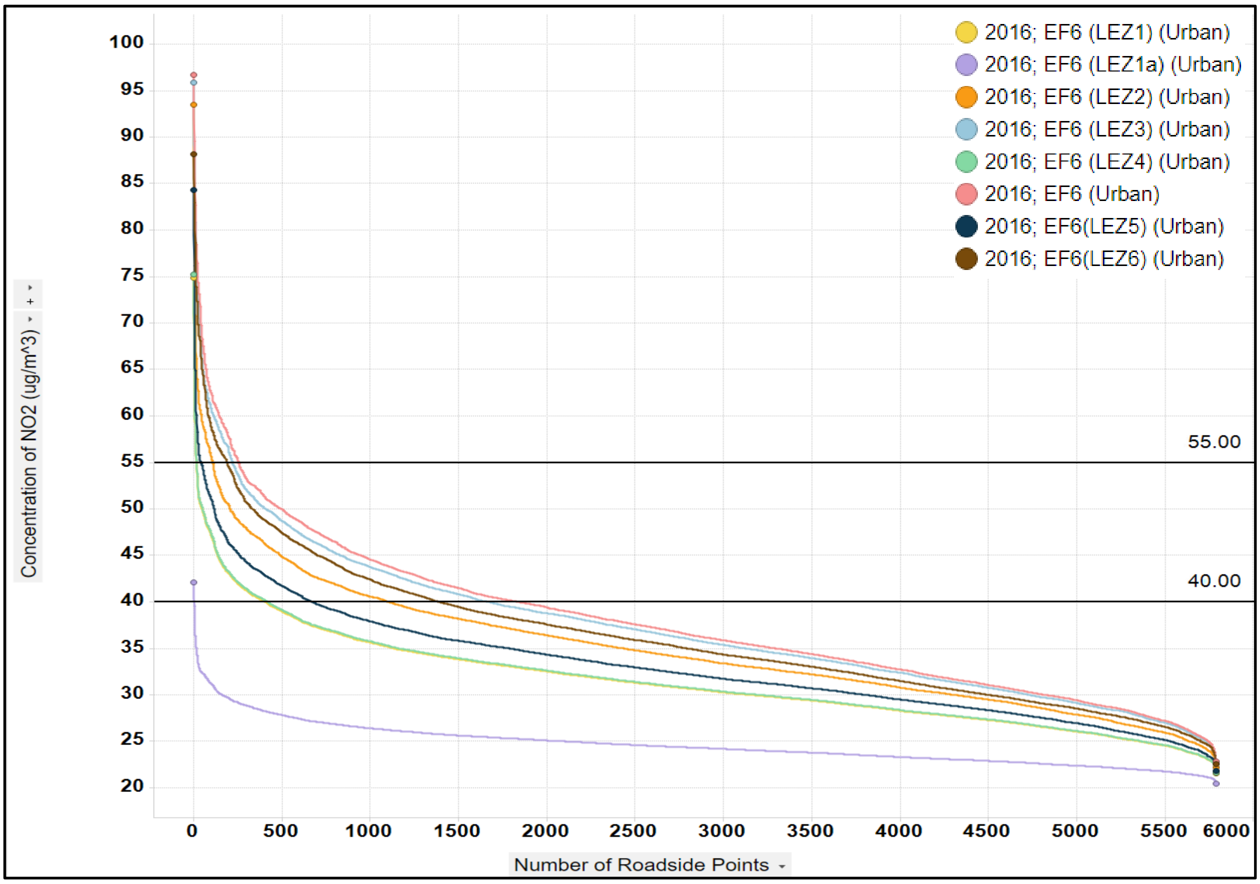

Figure 34: Distribution Of All Roadside Point Annual Average NO2 (µgm^{-3}) For Various Emissions Changes To 2016 Base Run. Annual Average Speed: 'Variable'.

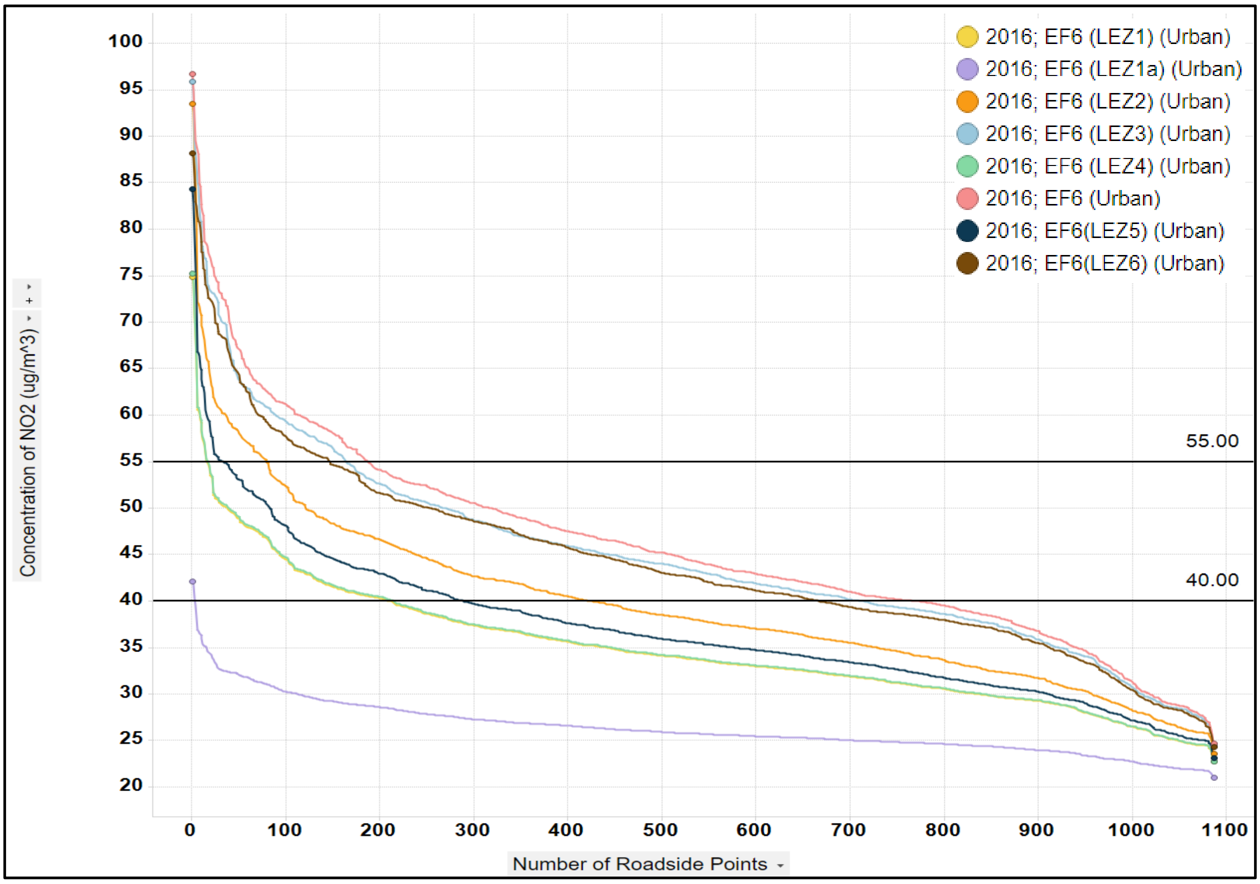

Figure 35: Distribution Of Central AQMA Roadside Point Annual Average NO2 (µgm^{-3}) For Various Emissions Changes To 2016 Base Run. Annual Average Speed: 'Variable'.

Table 10: Percentage Of All Roadside Points Above Annual Average NO2 Of 40 µgm^{-3} For Various Emissions Changes To 2016 Base Run.

Year →	**2016**	**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	31.75	16.39	2.80	As Base
LEZ1	7.00	N/A	N/A	All E(1-5) to E(6).
LEZ1a	0.05	N/A	N/A	All E(6),(6c),(6d).
LEZ2	19.05	10.26	1.90	Buses E(6); Others No Change.
LEZ3	28.87	15.13	N/A	Buses E(1-4) to E(5); Others No Change.
LEZ4	7.24	5.74	N/A	Buses, HGV's, Diesel LGV's, Taxis, Diesel Cars E(6), Petrol Cars E(1-3) to E(4).
LEZ5	11.59	8.46	1.83	Buses, HGV's, LGV's and Taxis E(1-5) to E(6); Cars No Change.
LEZ6	24.03	12.80	2.18	Cars E(1-5) to E(6); Buses, HGV's, LGVs, Taxis No Change.
'*' – Total = 5789 points.				

Table 11: Percentage Of All Roadside Points Above Annual Average NO2 Of 55 µgm^{-3} For Various Emissions Changes To 2016 Base Run.

Year →	**2016**	**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	4.40	1.35	0.09	As Base
LEZ1	0.28	N/A	N/A	All E(1-5) to E(6).
LEZ1a	0.00	N/A	N/A	All E(6),(6c),(6d).
LEZ2	1.87	0.48	0.07	Buses E(6); Others No Change.
LEZ3	3.78	1.14	N/A	Buses E(1-4) to E(5); Others No Change.
LEZ4	0.29	0.24	N/A	Buses, HGV's, Diesel LGV's, Taxis, Diesel Cars E(6), Petrol Cars E(1-3) to E(4).
LEZ5	0.71	0.38	0.07	Buses, HGV's, LGV's and Taxis E(1-5) to E(6); Cars No Change.
LEZ6	3.26	0.88	0.07	Cars E(1-5) to E(6); Buses, HGV's, LGVs, Taxis No Change.
'*' – Total = 5789 points.				

Table 12: Percentage Of Central AQMA Roadside Points Above Annual Average NO2 Of 40 µgm^{-3} For Various Emissions Changes To 2016 Base Run.

Year →	2016	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	70.75	43.88	10.76	As Base
LEZ1	19.23	N/A	N/A	All E(1-5) to E(6).
LEZ1a	0.28	N/A	N/A	All E(6),(6c),(6d).
LEZ2	39.10	24.93	7.18	Buses E(6); Others No Change.
LEZ3	65.50	39.65	N/A	Buses E(1-4) to E(5); Others No Change.
LEZ4	19.69	16.56	N/A	Buses, HGV's, Diesel LGV's, Taxis, Diesel Cars E(6), Petrol Cars E(1-3) to E(4).
LEZ5	26.59	21.53	6.90	Buses, HGV's, LGV's and Taxis E(1-5) to E(6); Cars No Change.
LEZ6	61.18	36.98	8.92	Cars E(1-5) to E(6); Buses, HGV's, LGVs, Taxis No Change.
'*' – Total = 1087 points.				

Table 13: Percentage Of Central AQMA Roadside Points Above Annual Average NO2 Of 55 µgm^{-3} For Various Emissions Changes To 2016 Base Run.

Year →	2016	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	17.20	5.61	0.46	As Base
LEZ1	1.47	N/A	N/A	All E(1-5) to E(6).
LEZ1a	0.00	N/A	N/A	All E(6),(6c),(6d).
LEZ2	7.27	2.12	0.37	Buses E(6); Others No Change.
LEZ3	15.09	4.69	N/A	Buses E(1-4) to E(5); Others No Change.
LEZ4	1.56	1.29	N/A	Buses, HGV's, Diesel LGV's, Taxis, Diesel Cars E(6), Petrol Cars E(1-3) to E(4).
LEZ5	3.04	1.93	0.37	Buses, HGV's, LGV's and Taxis E(1-5) to E(6); Cars No Change.
LEZ6	13.52	4.05	0.37	Cars E(1-5) to E(6); Buses, HGV's, LGVs, Taxis No Change.
'*' – Total = 1087 points.				

Table 14: 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	40.52	16.38	2.59	As Base
LEZ1	6.90	N/A	N/A	All E(1-5) to E(6).
LEZ1a	0.00	N/A	N/A	All E(6),(6c),(6d).
LEZ2	18.97	11.21	0.00	Buses E(6); Others No Change.
LEZ3	35.34	15.52	N/A	Buses E(1-4) to E(5); Others No Change.
LEZ4	6.90	6.03	N/A	Buses, HGV's, Diesel LGV's, Taxis, Diesel Cars E(6), Petrol Cars E(1-3) to E(4).
LEZ5	11.21	8.62	0.00	Buses, HGV's, LGV's and Taxis E(1-5) to E(6); Cars No Change.
LEZ6	31.03	13.79	0.86	Cars E(1-5) to E(6); Buses, HGV's, LGVs, Taxis No Change.
'*' – Total = 116 PDTs				

Table 15: 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	6.03	0.86	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	4.31	0.86	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	2.59	0.86	0.00	Cars E(1-5) to E(6); Buses, HGV's, LGVs, Taxis No Change.
'*' – Total = 116 PDTs				

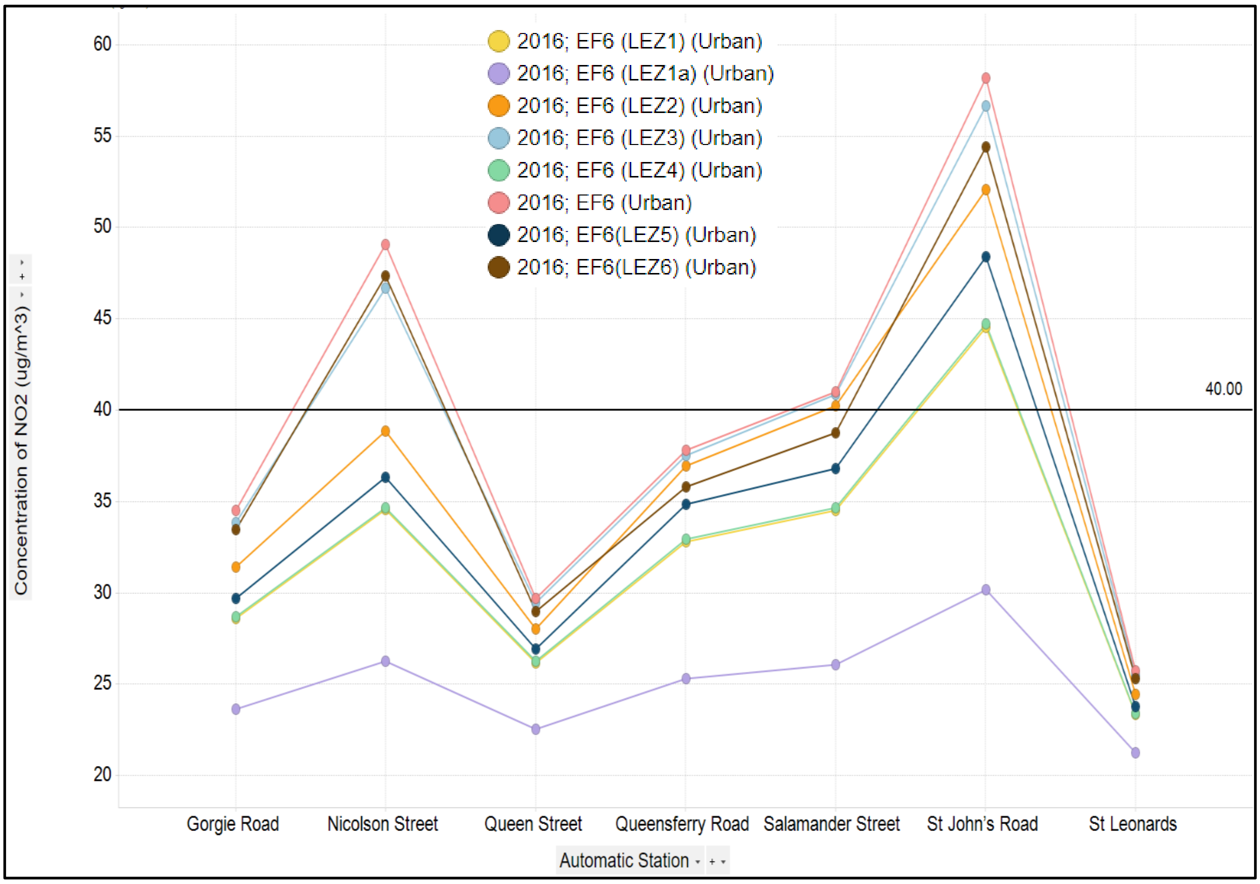

Figure 36: Potential Change In Edinburgh Automatic Monitoring Station Annual Average NO2 (µgm^{-3}) For Emissions Changes To 2016 Base Run. Annual Average Speed: 'Variable'.

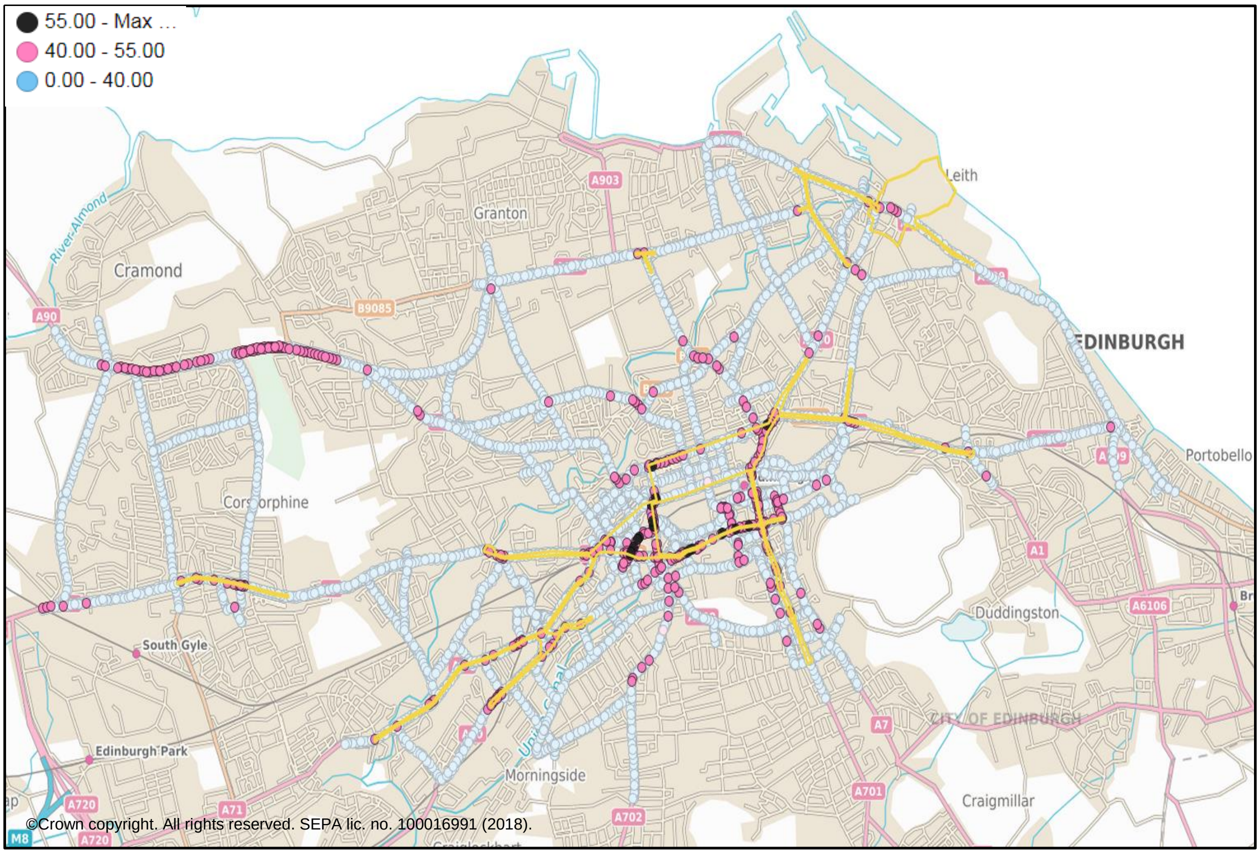

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Figure 37: Modelled Annual Average NO2 (µgm^{-3}) For 2016. Scenario: LEZ1 (All E(1-5) to E(6)). Annual Average Speed: 'Variable'. Values Greater Than 40 µgm^{-3} Are Highlighted.

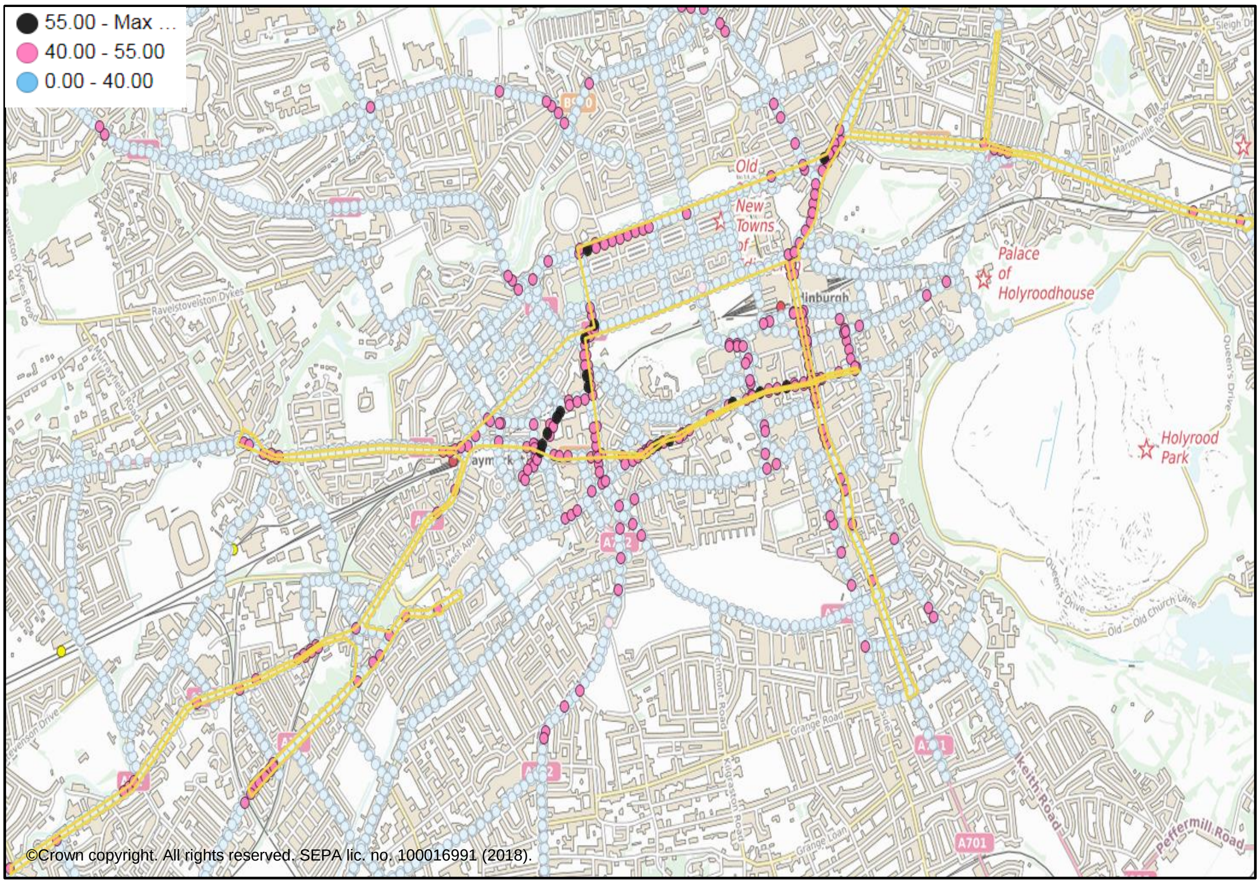

Figure 38: Modelled Annual Average NO2 (µgm^{-3}) For 2016 (Central AQMA). Scenario: LEZ1 (All E(1-5) to E(6)). Annual Average Speed: 'Variable'.

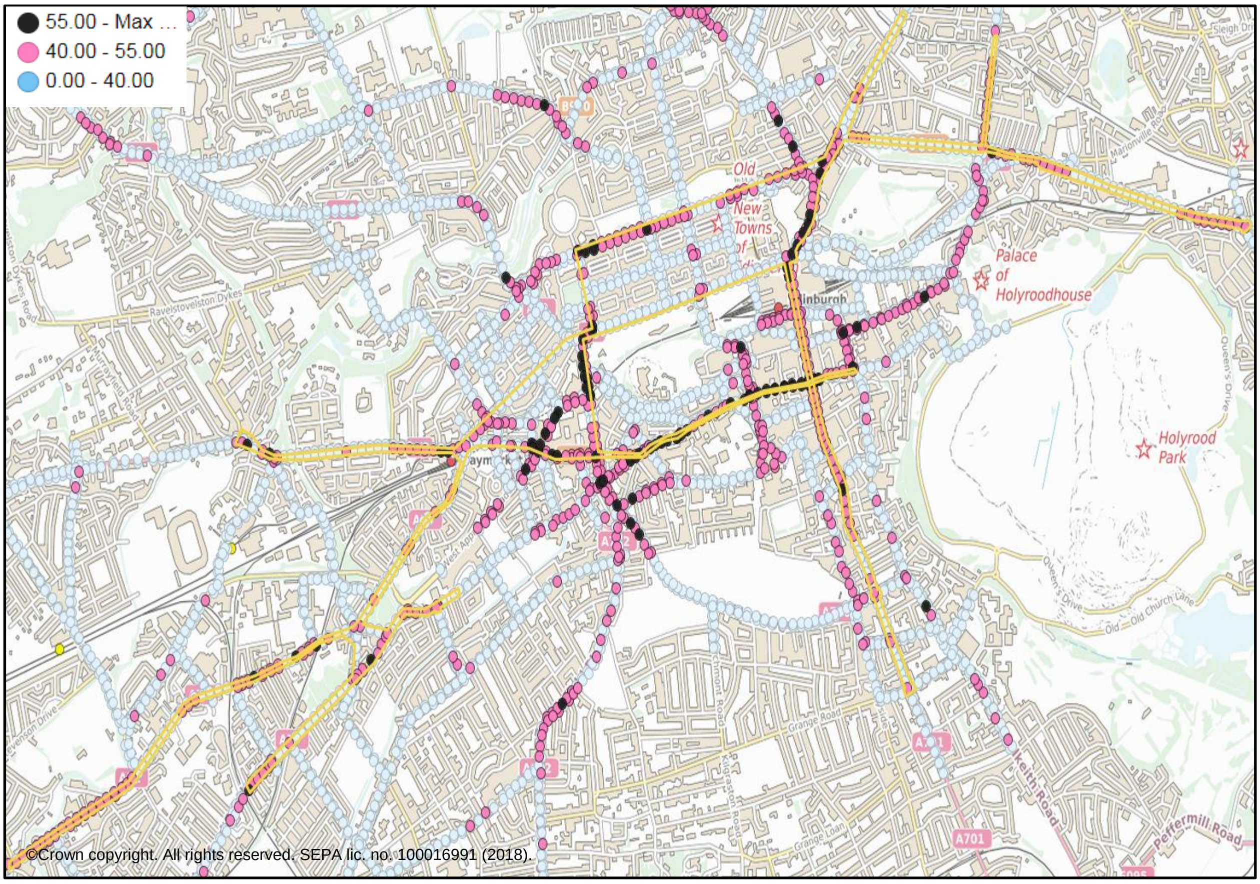

Figure 39: Modelled Annual Average NO2 (µgm^{-3}) For 2016 (Central AQMA). Scenario: LEZ2 (Buses E(6); Others No Change.). Annual Average Speed: 'Variable'.

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 2016, had vehicle emissions been lower. We have also assessed the potential changes in air quality, on 2016 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 2016 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 2016 (with no changes to other vehicles and a similar Petrol/Diesel split) 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 2016 there may have been a considerable benefit to air quality across many roads in Edinburgh and particularly within the Central AQMA. 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 2016 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 2016 there could have been a significant improvement in air quality, particularly within the Central AQMA. 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 2016 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 some areas of the Central AQMA. These areas would have required further emission reductions.
- New Euro 6c and 6d vehicles, when matched with Euro 6 heavy vehicles, appear able to be able to offer much improved roadside NO2 concentrations compared to 2016 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 Central 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 2016.
- There is no change in Urban 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 40 shows a comparison of Euro class percentages for various vehicle types. Percentages captured by the Edinburgh ANPR data in 2016 (see section 2.2) are presented alongside predicted fleet percentages made in the NAEI 2012 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 Rigid HGV’s, Artic HGV’s and Cars appear to have been accurate for Edinburgh. LGV’s have been reasonably well forecast, but there appear to be fewer Euro 6 vehicles in Edinburgh than predicted. Bus predictions are not as expected; fewer Euro 5 vehicles and more Euro 6 vehicles were forecast. The forecast Diesel/Petrol split was marginally inaccurate. However, having fewer Diesel vehicles than forecast will have been of benefit to NO2 air quality in Edinburgh.

Figure 41 also shows a comparison of Euro class percentages for various vehicle types. Percentages captured by the ANPR data in 2016 (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 2016 of any vehicle type. However, considerable change in the fleet in Edinburgh will be required in the following years to meet the 2019 and 2023 values. Large changes in the Bus fleet Euro 6 numbers, on 2016 values, are predicted. Given the 2016 fleet mix detailed in Table 2 (i.e., Euro 5: 49.75%, Euro 6 24.05%) this represents a substantial expected investment in the Edinburgh 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.

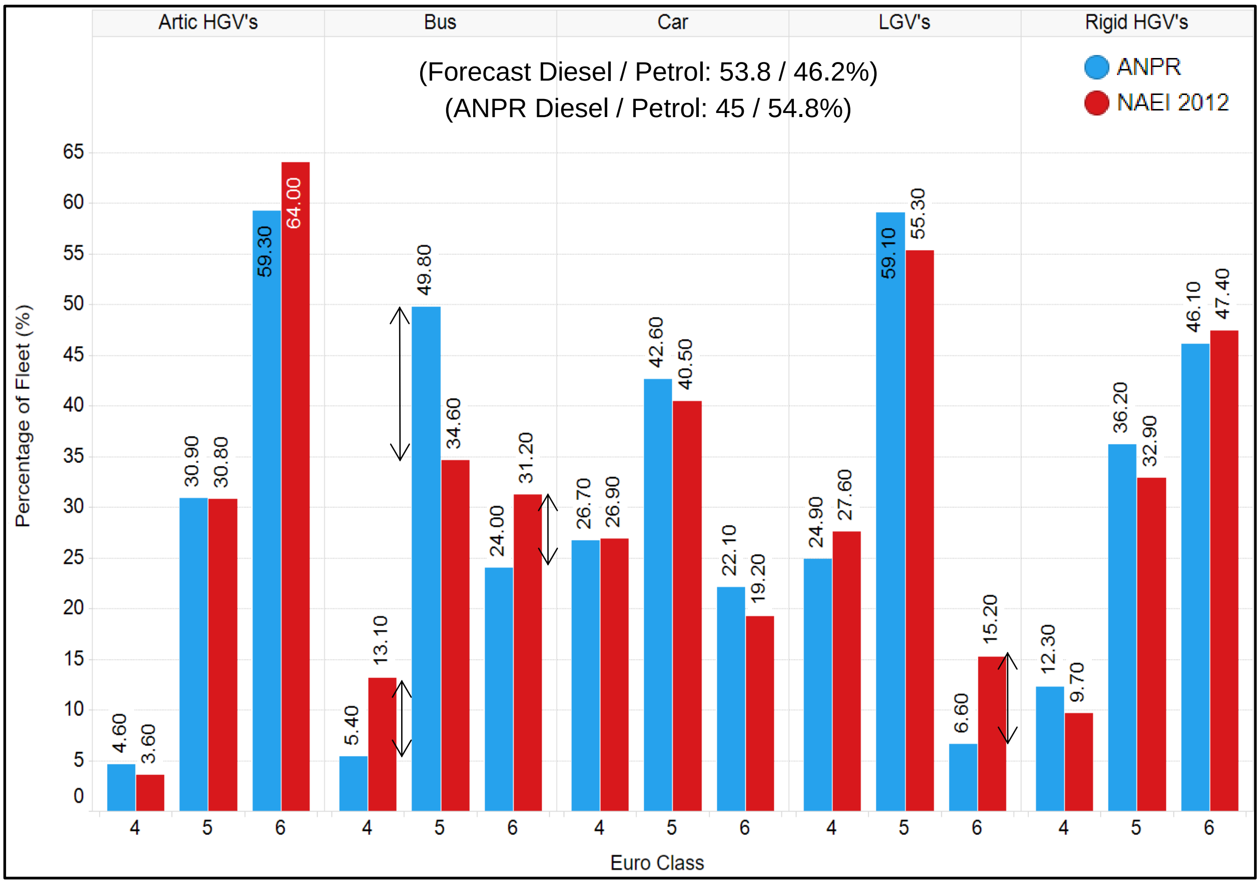

Figure 40: Comparison Of 2016 ANPR Euro Class Percentage Mix With NAEI 2012 Predictions For 2016. All Euro Classes Shown As Numbers.

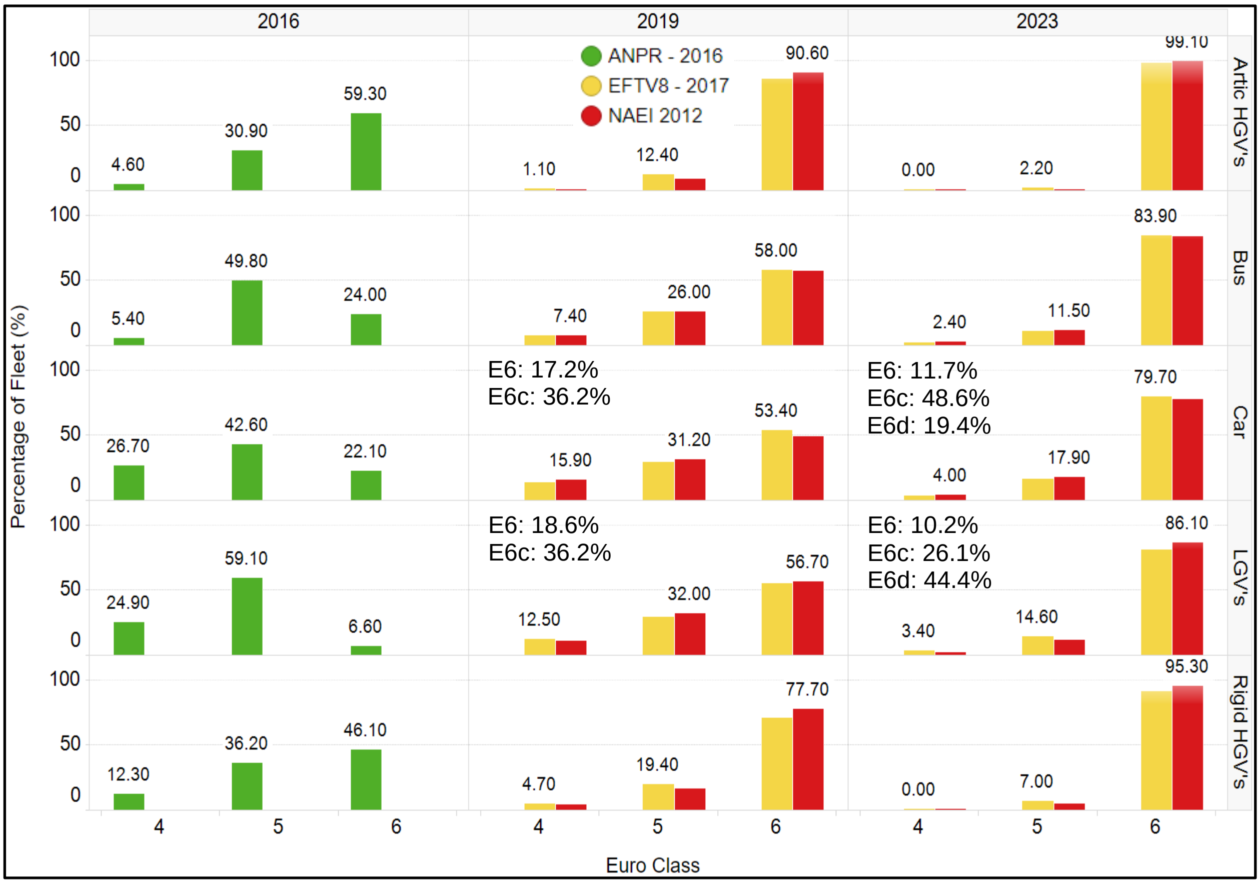

Figure 41: Comparison Of 2016 ANPR Euro Class Percentage Mix With NAEI 2012 And EFTv8 Predictions For 2019 And 2023. All Euro Classes Shown As Numbers.

5 Discussion of Edinburgh 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 Edinburgh. However, many of the roadside locations within the Central AQMA are still likely to be above the NO2 annual average limit value in late 2018. Other NO2 based AQMAs, and some areas outside these, are also likely to have roadside locations which exceed the NO2 annual average limit value in 2018. The highest concentrations are likely to be found in the Central AQMA (Leith Street, South Bridge, Cowgate and Lothian Road). At these locations, annual average NO2 concentrations of between 60 and 90 µgm^{-3} are possible. To meet the 40 µgm^{-3} NO2 limit value, emission reductions of between 50 to 75% may be required on 2016 levels. As other background sources account for between 10 to 30% of NO2 at locations where the highest NO2 concentrations are predicted to be found, traffic emissions therefore contribute 70 to 90% of the total concentration at these locations. Significant modifications to the vehicle fleet are required to reduce emissions. At some locations, the deep street canyons (e.g. Cowgate) 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 2016 are likely to still broadly reflect the situation in late 2018. Although source apportionment is calculated for NOx, it will reflect the relative contribution to NO2 air quality issues. Emissions from Diesel cars appear to be a city-wide problem and they are the biggest source of NO2 on many roads. Large numbers of vehicles are associated with this source. In areas of poor traffic flow, NO2 concentrations may be very high. LGV's appear to be the second biggest NO2 source on many roads, but this is produced by far fewer vehicles. Buses are a large source and dominate the NO2 issues on many roads, particularly in the Central AQMA. Source apportionment is highly variable from street to street and this reflects the complex traffic patterns in Edinburgh.

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 Edinburgh. 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 34 and Figure 35 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 34 and Figure 35 and supporting tables in section 4.6). Figure 42 and Figure 43 show the NOx emission rate (g/km) for various vehicle type Euro classes at 10 km/hr (6.21 miles/hr) and 25 km/hr (15.53 miles/hr) respectively.

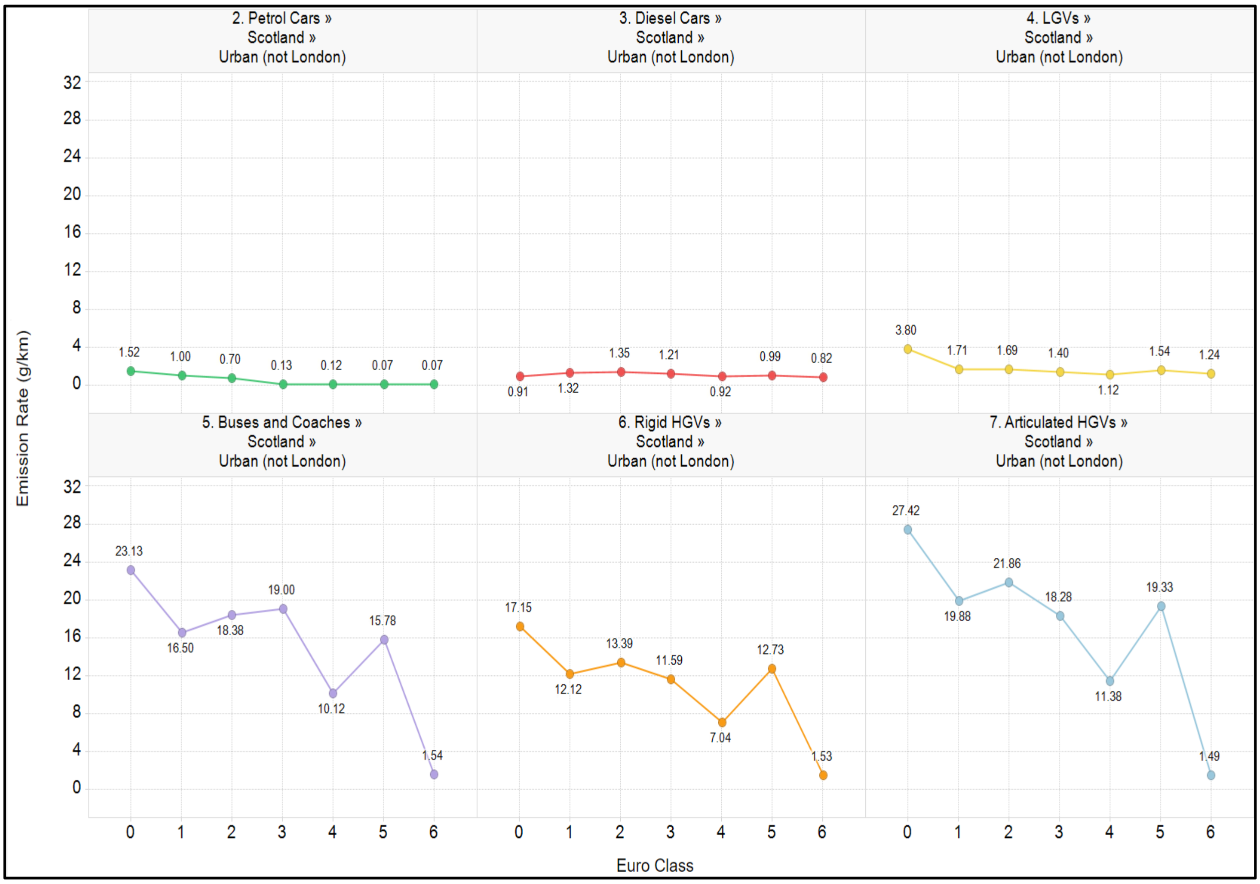

Figure 42: NOx Emission Rate (g/km) For Various Vehicle Type Euro Classes At 10 km/hr (6.21 miles/hr). Source: EFTv8. Year: 2016. All Euro Classes Shown As Numbers.

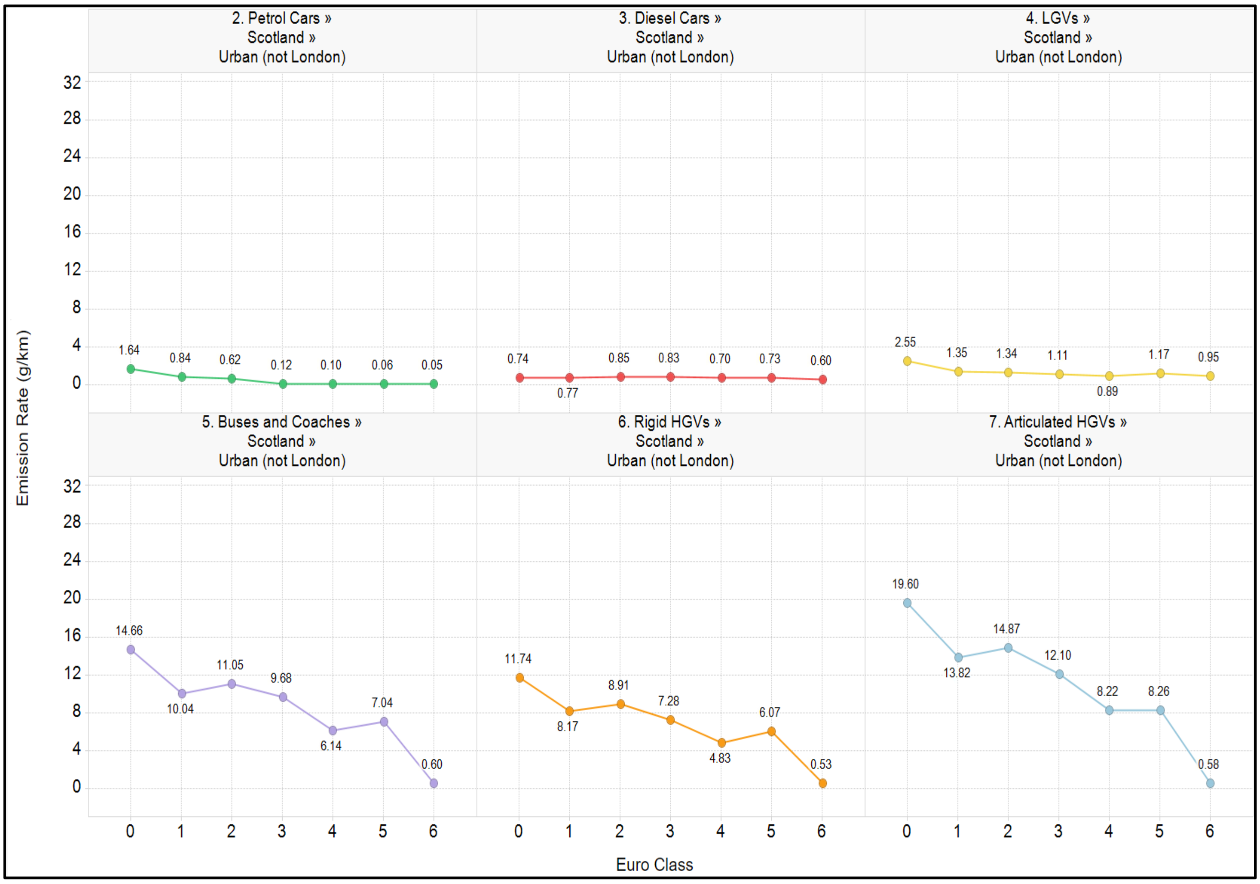

Figure 43: NOx Emission Rate (g/km) For Various Vehicle Type Euro Classes At 25 km/hr (15.53 miles/hr). Source: EFTv8. Year: 2016. All Euro Classes Shown As Numbers.

We have obtained these data from EFTv8 and they represent emissions in 2016. 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 2016 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 2016. 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 41. This represents a considerable investment in all vehicles.
- Traffic must be very similar to that in 2016.
- Urban Background remains similar to 2016 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 Edinburgh 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 Central AQMA would appear to be the highest priority.
- Tackling Bus, Diesel Car and LGV emissions in the Central 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 Central 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 Central AQMA 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 2016 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 2016 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 Central 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 Edinburgh 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 Central AQMA to verify high NO2 concentrations and monitor the effectiveness of any measures to improve air quality.

- A repeat traffic survey in 2019 is recommended to check fleet predictions and update the Traffic and Air Quality modelling.

- 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 2017 and 2018 PDT and Automatic Monitoring data, and other years as they become available.
    - Updating the model using 2019 traffic data and fleet information.
    - A more detailed analysis and modelling of all Edinburgh AQMAs.

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