Scottish Environment Protection Agency
Buidheann Dìon Àrainneachd na h-Alba

CLEANER AIR FOR SCOTLAND – NATIONAL MODELLING FRAMEWORK

Low Emission Zone Glasgow Evidence Report

September 2021

Scope of Report

Air Quality modelling for Glasgow has been ongoing, supporting the Scottish Government Cleaner Air for Scotland strategy (CAFS). This report follows on from the previous SEPA report 'Glasgow Emissions Analysis Report' (SEPA, 2021) which focused on calculated tail-pipe emissions of Nitrogen Oxides (NO_x). This work represents the final stages of the National Modelling Framework (NMF), providing modelled NO_2 concentrations to support the final phase of Glasgow City Council's (GCC) Low Emission Zone (LEZ) to extend to all vehicles. Traffic modelling has been carried out by SYSTRA to predict changes in vehicle flows and fleet compositions, which was then used to calculate pollutant emissions and air quality concentrations. This report presents the results of air quality modelling work to examine the changes on emissions and concentrations associated with the implementation of the proposed LEZ. Calculated changes in Particulate Matter (PM_{10}) emissions are also presented.

Main Points to Note

- Earlier modelling identified that the highest concentrations of annual-average NO_2 occurred in the City Centre where vehicle emissions are dominated by buses. Diesel car emissions dominate other key routes around the city.
- SEPA's emissions report identified that key bus routes within the LEZ boundary will experience the largest reductions in NO_x emissions by an average of over 70%. There is an overall decrease across all roads inside the LEZ of 53%.
- Air quality model results indicate that nearly all current NO_2 exceedances inside the LEZ will be removed. Some isolated exceedances may remain around junctions on key bus routes.
- Traffic model outputs indicated some displacement of non-compliant vehicles, with a small number of roads to the east of Saltmarket and High Street experiencing an increase in car flow of up to 1200 cars per day. This corresponds to a localised increase in NO_x emissions of up to 34%.
- Predicted changes to air quality concentrations east of Saltmarket and High Street remain dominated by improvements in the bus fleet outside, as well as inside, the LEZ. Predicted concentrations of NO_2 remain low in this area, not exceeding 30µgm^{-3}.

- Air quality model results are based on the age of the Glasgow fleet in 2020 and are therefore precautionary, given that further fleet improvements are expected before full LEZ implementation.
- The LEZ is expected to lead to substantial reductions in tailpipe emissions of PM_{10}, most notably on bus routes inside the LEZ.

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 Consultant
DfT	Department for Transport
DEFRA	Department for Environment Food & Rural Affairs
DVLA	Driver and Vehicle Licensing Agency
EFTv10.1	Emissions Factors Toolkit v10.1
EMIT	CERC Emissions Tool
GCC	Glasgow City Council
HGV	Heavy Goods Vehicle
JTC	Junction Turn Counts
LAQM	Local Air Quality Management
LEZ	Low Emission Zone
LGV	Light Goods Vehicle
NAEI	National Atmospheric Emissions Inventory
NLEF	National Low Emission Framework
NMF	National Modelling Framework
PDT	Passive Diffusion Tube
SEPA	Scottish Environment Protection Agency
SG	Scottish Government
TS	Transport Scotland

List of Chemical Abbreviations

NO_2	Nitrogen Dioxide
NO_x	Nitrogen Oxides
PM_{10}	Particulate Matter less than 10µm in diameter

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Introduction

Background

As part of the National Modelling Framework (NMF) and National low Emission Framework (NLEF) process within the Cleaner Air for Scotland (CAFS) strategy, an air quality model was built using good quality data and performance validated against air quality monitoring data. The principals and methodology underpinning the model development is set out in the SEPA Aberdeen Pilot Project (SEPA, 2017). Further iterations of the modelling methodology specific to Glasgow can be found in the Glasgow AQ Evidence Report (SEPA, 2019). A consistent approach to air quality model development has been taken across all four cities implementing Low Emission Zones (LEZs).

Following on from the initial air quality modelling and evidence presented to Glasgow City Council and SYSTRA (SEPA, 2019) during the early stages of the LEZ development, the next step was to model LEZ scenarios. As part of this, further traffic surveys were carried out to identify if there were any significant changes in traffic flows and to detect improvements in the fleet composition due to fleet turnover. GCC commissioned SYSTRA consultants to carry out traffic modelling and predict changes to traffic flows in response to the introduction of the all-vehicle LEZ. Traffic model data was used to run the Air Quality models to assess potential changes in pollutant concentrations.

SEPA Cyberattack

On Christmas Eve 2020, SEPA was subject to a serious and complex criminal cyber-attack that significantly impacted our internal systems and our Air Quality modelling capabilities.

As part of our recovery plan, SEPA implemented a phased rollout programme to restore critical services, re-establish critical communication systems to continue providing our priority regulatory, monitoring, flood forecasting and warning services. Our priority regulatory work programme included the delivery of our NMF obligations to assist in the final assessments of the LEZ options for each city.

Due to SEPAs inability to carry out Air Quality modelling, an alternative approach to allow for local authorities to report to committee in Spring 2021 was discussed at the LEZ Leadership Group meeting held on the 3rd of February 2021. The following steps were recommended by Scottish Government and SEPA on a way forward:

- Continuation of traffic modelling to define potential LEZ options or a preferred LEZ option for each city.

- SEPA to carry out emissions analysis on the traffic model outputs using the established NMF methodology, assessing the impact of the LEZ by comparing traffic and emissions between the reference/base case and LEZ options.

- SEPA to continue detailed AQ modelling during the consultation phase over the summer of 2021 to support the local authorities in finalising the preferred LEZ scheme for Ministerial approval.

Since July 2021, SEPA's air modelling capacity has been restored, however the original modelling data for Glasgow was not recoverable. This has resulted in a significant delay to work plans as some modelling parameters had to be regenerated.

National Modelling Framework

Modelling work presented here continues to follow the NMF approach and methods outlined in previous reports (SEPA, 2017) ensuring a consistent approach in air quality modelling. These include:

- The use of ADMS-Urban and EMIT as used in previous NMF work.

- Processing traffic model outputs in the same way that detailed data from traffic data collection surveys was processed earlier in the NMF process.

- Running the air quality models of each city using identical methods and default model settings as used previously.

- Using the same sources of data for input into the model, such as road layout, road width and building heights.

- Using appropriate meteorological and background emission data obtained from a common source.

- Combining 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.

The model continues to be assessed against measurement data to ensure the model is performing well, which includes updating emission calculations based on Automatic Number Plate Recognition (ANPR) data to account for fleet turnover and localised bus fleet data.

It's important to note that some differences in methodology between the cities have arisen due to different approaches in traffic modelling for each city. GCC, along with Aberdeen and Dundee, commissioned SYSTRA to carry out traffic modelling using Paramics (a microsimulation traffic model), whilst City of Edinburgh Council commissioned Jacobs to carry out traffic modelling using the VISUM model (a strategic traffic model). There are some differences in how the traffic data is processed into Annual Average Daily Traffic (AADT) as required by the air quality modelling. However, from that point the traffic data is treated in the same way when calculating emissions and processing within ADMS.

The ADMS-Urban software has been updated recently. The main difference compared to the previous version is an update to the way ADMS-Urban deals with canyons, which may lead to some differences between ADMS-Urban model versions. However, the new version of ADMS-Urban (version 5) has been used to re-model Glasgow.

Modelling Methodology

Traffic Model

The 2017 Glasgow City Centre Paramics Model (SYSTRA, 2018) was used to develop a Reference Case model (SYSTRA, 2019). This Reference Case Model for Glasgow includes infrastructure changes identified by GCC to be in place by the end of 2022 and assumes that there is no background growth or changes in wider travel patterns. It was used as a basis to develop two LEZ options (SYSTRA, 2020):

- 2022 LEZ Option 1 covering the city centre bound by the M8 and including Broomielaw and High Street.
- 2022 LEZ Option 2 covering the city centre bound by the M8 but excluding Broomielaw and High Street.

Each of the LEZ options were tested in the traffic model for two different vehicle fleet assumptions that represented different levels of fleet compliance. These were based on National Atmospheric Emission Inventory fleet datasets for 2020 and 2023.

Following discussion with GCC it was decided that LEZ Option 1 with a 2020 fleet would be taken forward for emission analysis and air-quality modelling. The 2020 fleet assumption is a more precautionary approach because it assumes greater levels of vehicle non-compliance than the 2023 fleet. There are also uncertainties associated with projecting future trends in fleet composition, which have been further amplified by recovery from the COVID pandemic. The extent of LEZ Option 1 is shown in Figure 1.

In this report the 2022 LEZ Option 1 with 2020 fleet is compared against the 2022 Reference case with 2020 fleet.

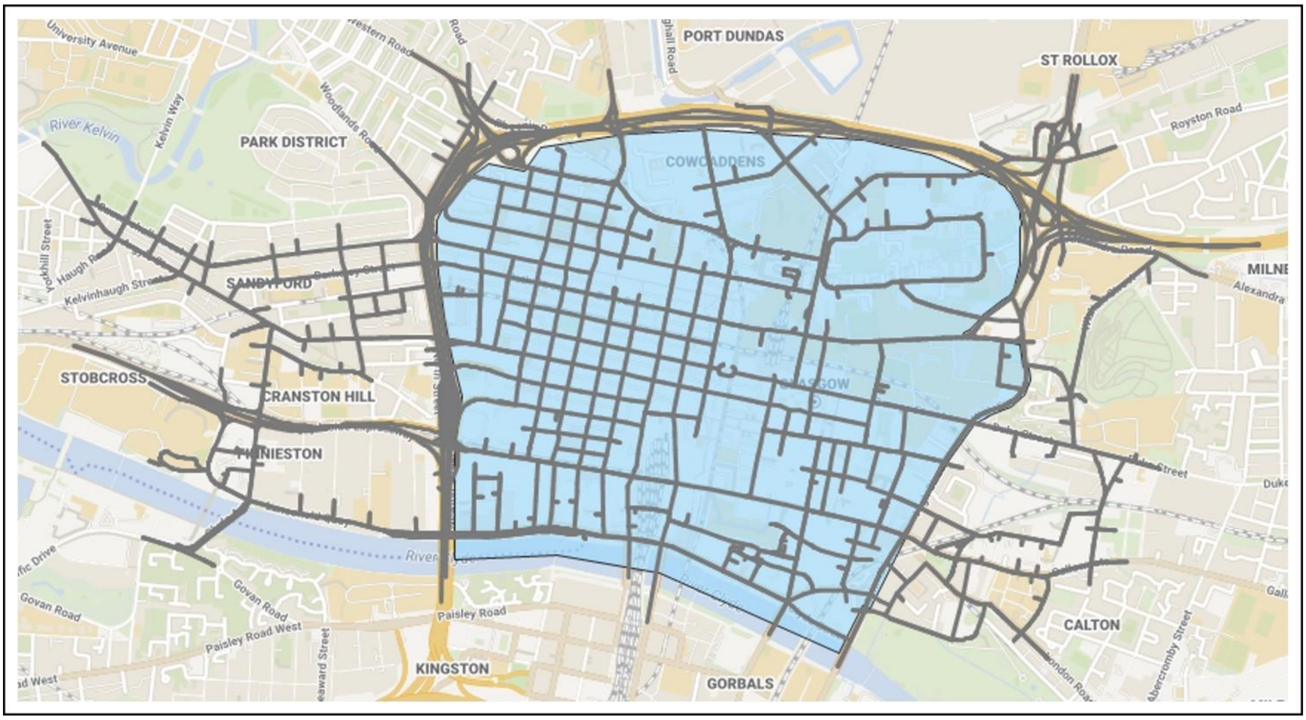

Figure 1: Extent of the traffic model road network and the LEZ covering the area of Glasgow City Centre bound by the M8, the River Clyde and Saltmarket.

For the Reference Case the traffic model has 7 vehicle types represented; Car, Light Goods Vehicle (LGV), Medium Goods Vehicle (MGV), Heavy Goods Vehicle (HGV), Bus, Coach and Taxi that include both compliant and non-compliant vehicles. The MGV category in the Paramics model is split across the 3 Rigid-HGV classes and the HGV category is split across the 3 Artic-HGV classes.

For the LEZ scenario the 3 vehicle categories; Car, LGV and HGV were further split to provide Compliant and Non-Compliant sub-categories giving 11 vehicle types. Traffic entering, leaving, or travelling within either LEZ is ‘Compliant’. Traffic which is ‘Non-Compliant’ is forced to divert around the LEZ. This may result in ‘Compliant’ traffic taking advantage of quieter roads within the LEZ and changing their route accordingly. Only the displacement of Cars, LGV's and HGV's are considered in the LEZ scenarios. It is assumed bus routes will remain unchanged and vehicles will become compliant. Following discussions with GCC and TS it was assumed that all taxis in the LEZ option are compliant.

The regulations for petrol cars are different from all other vehicles. This is because NO_x emissions from petrol vehicles are much lower than diesel vehicles. The LEZ rules for different categories are shown in Table 1.

Table 1: LEZ rules.

Vehicle category	Compliant	Non-Compliant
Cars (Petrol)	Euro 4, 5, 6	Euro 3 or earlier
All Vehicles (except Cars (Petrol))	Euro 6, Electric	Euro 5 or earlier

Fleet Composition

The LEZ rules outlined in Table 1 were used in conjunction with data on fleet composition to split cars, LGVs and HGVs into Compliant and Non-compliant categories. The percentage of vehicles in each of these categories are summarised in Table 2.

Table 2: Compliant and non-compliant percentages used in traffic modelling. Due to rounding the figures may not exactly sum to 100%.

Vehicle Type	Compliance	Fuel Type	Percentage by Vehicle Class (%)
Cars	Compliant	Petrol	50
		Diesel	29
	Non-Compliant	Petrol	1
		Diesel	19
LGV's	Compliant	Petrol	2
		Diesel	62
	Non-Compliant	Petrol	0
		Diesel	35
HGV's	Compliant	Petrol	0
		Diesel	96
	Non-Compliant	Petrol	0
		Diesel	4

The fleet composition for the traffic and air-quality models is mostly based on NAEI 'National Fleet' assumptions, which describe a Scottish Urban fleet in the year 2020. This is because a comparison of ANPR data collected in 2018 compared very closely to the 2018 National Fleet assumptions, including the split of petrol and diesel vehicles and the distribution of EURO classes across different vehicles. However, the proportion of buses across different EURO classes was adjusted in line with detailed data collected from bus operators.

This bus data was collated into an online data tool shared with Glasgow bus operators and was used by SEPA to identify the main bus routes across the city (Figure 2), with a particular emphasis on bus dominated streets within the LEZ boundary. The bus data provided a more accurate EURO class bus operating fleet within the city centre rather than a simple fleet category.

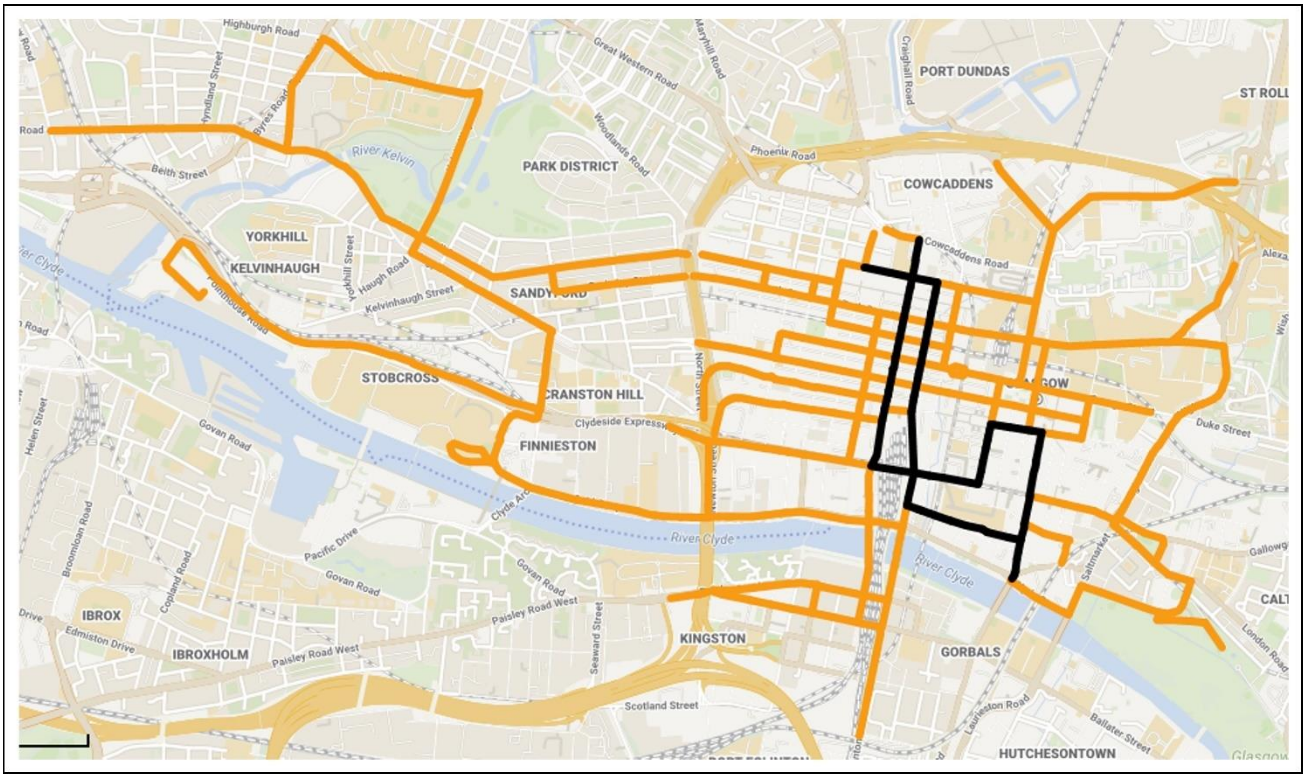

Figure 2: All bus routes (shown in orange) across Glasgow city centre taken from the SEPA Bus Operator tool (pre-Covid 2017). An example bus route through the city centre is highlighted in black.

In the Reference Case the proportion of bus journeys being made by the lowest-emitting Euro VI buses was 40.9% based on 2019 bus fleet data available in the Glasgow Bus Operator tool (Table 3 and Figure 2). The mix of EURO classes from the Bus Operator tool was used to represent all roads in the city centre, however, it should be noted that there is some fleet variation across the network. In the LEZ scenario the proportion of bus journeys being made by Euro VI buses was increased to 100%.

Table 3: Percentage of Bus Euro Class taken from the Bus Operators fleet and the SEPA Bus Operators Tool (2019).

Bus Class	Percentage of Bus Fleet
Euro II	0%
Euro III	28.4%
Euro IV	10.3%
Euro V	20.4%
Euro VI	40.9%

Development of Air Quality Model

The road network in the traffic model consists of approx. 2700 links (Figure 1) and is much more detailed than the network in the air quality model consisting of approx. 255 links (Figure 3). The original air quality model extended further west than the traffic model but did not include as many roads to the east of the city centre. In the emission analysis report (SEPA, 2021) the roads to the east of High Street were noted to experience additional traffic due to displacement around the edge of the LEZ. The air-quality model was therefore extended to include this area of the city.

Traffic model links across the LEZ area were mapped and associated with the appropriate links in the air-quality model. In most cases multiple traffic model links were associated with one air quality model link. In these instances, the maximum flow for each vehicle type in each direction along the traffic model links were summed to provide a two-way flow. This is a precautionary approach. Similarly, the average of the average speeds for each vehicle type in each direction in the traffic model links were assigned to the appropriate link in the air quality model.

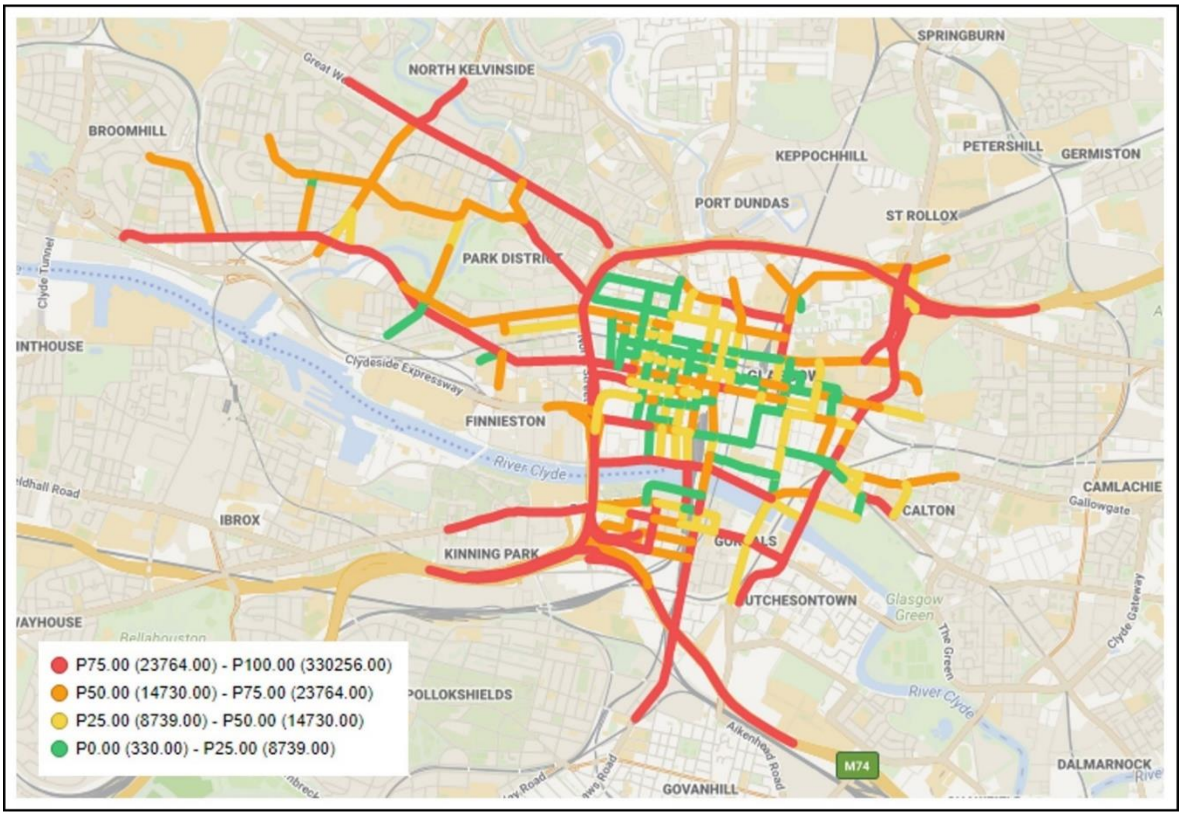

Figure 3: The extent of the original air quality model. Roads are coloured by traffic flow based on 2017 traffic observations.

Figure 4 shows the revised air-quality model network which has been extended to the east of High Street. It does not include areas to the west of the M8 as these roads were shown not to experience an overall increase in emissions (SEPA, 2021). The roads in Figure 4 are coloured by total daily traffic flow in the Reference case of the traffic model.

The contribution of NOx originating on the M8 motorway to roadside receptors across the city centre is mostly less than 5% (SEPA, 2020). Given the complexity of the trunk road network in the traffic model it was decided that their emissions would be based on observed traffic from the original air-quality model.

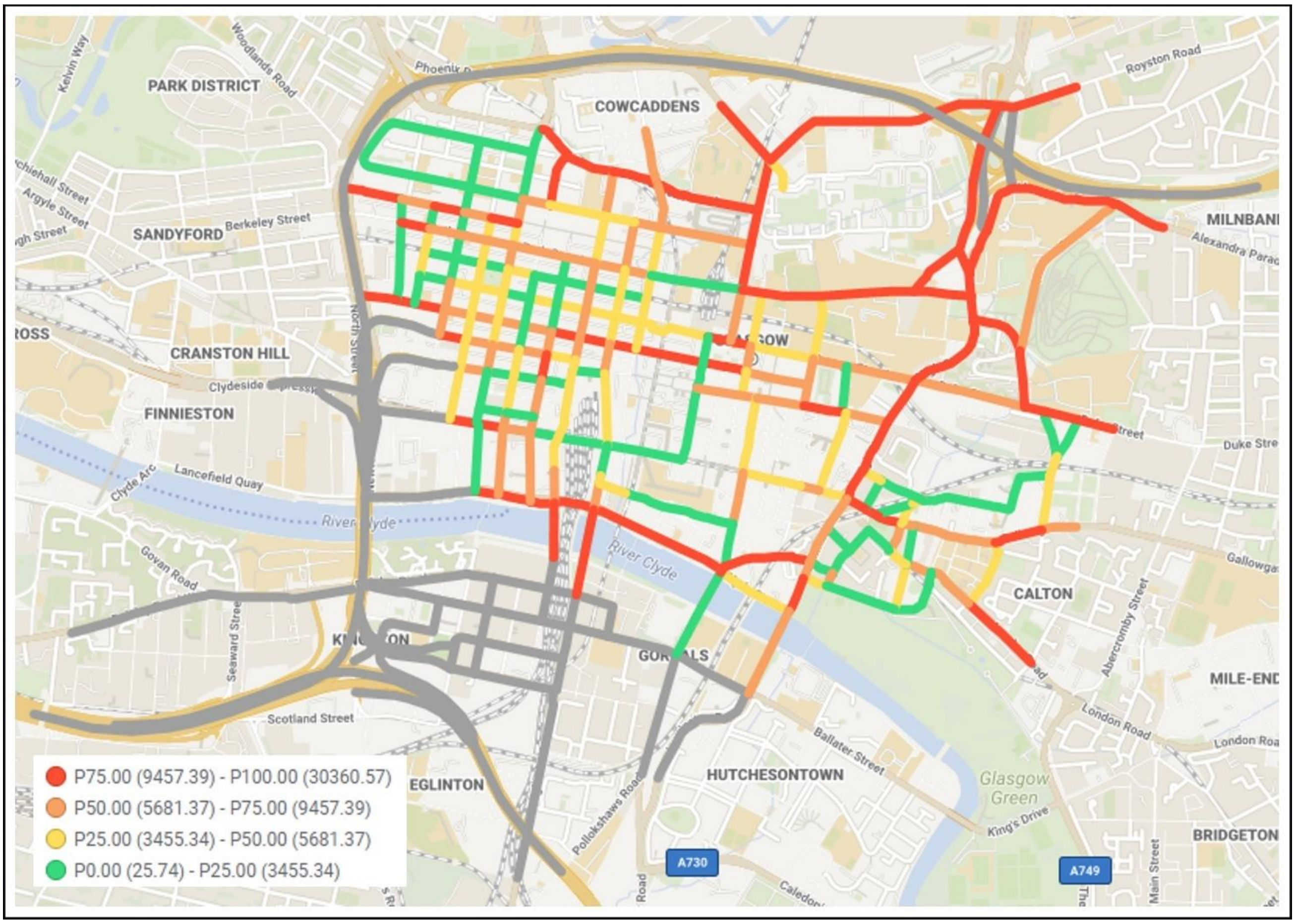

Figure 4: The extent of the revised air quality model which was extended east of High Street. Roads are coloured by traffic flow based on Reference case traffic model data.

Figure 5 shows combined extent of the revised air quality model in blue, overlaying the traffic model network in grey.

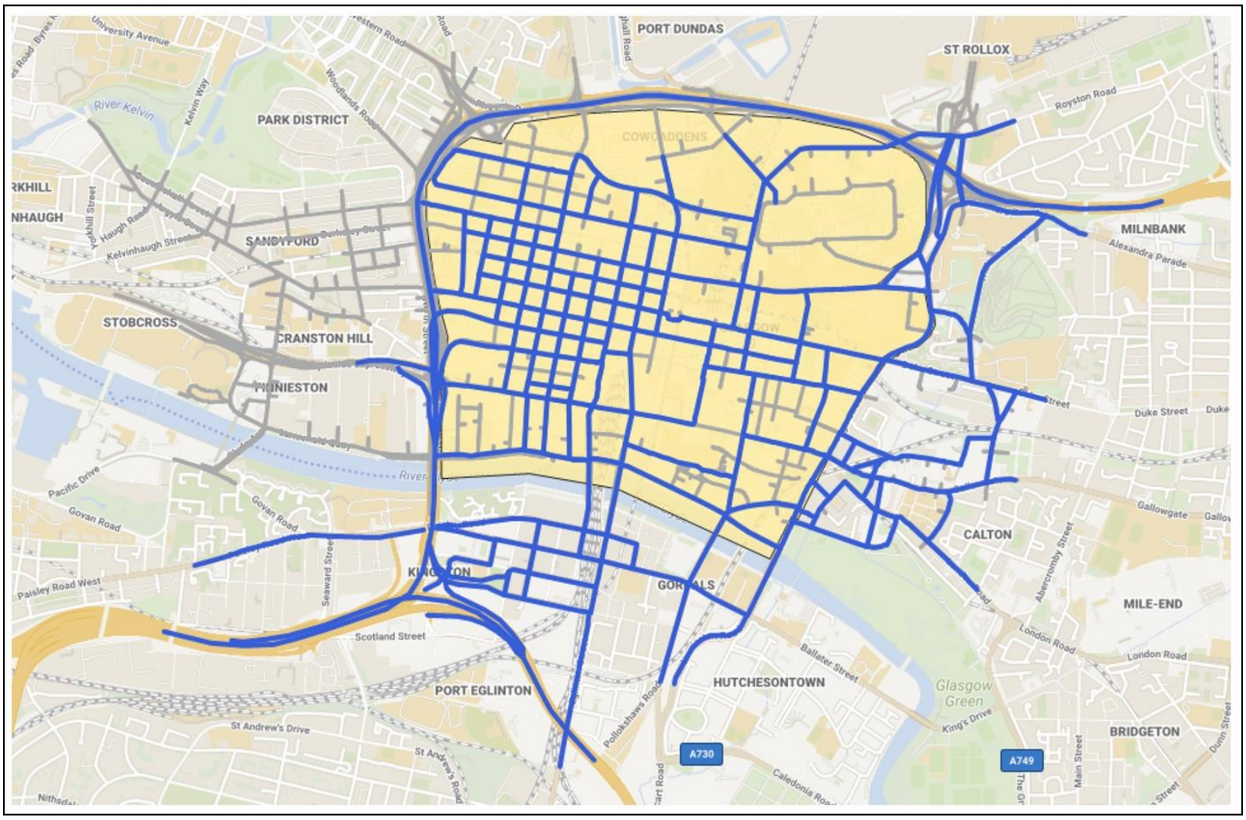

Figure 5: Glasgow Paramics model network in grey, with the revised ADMS road network overlaid in blue.

Traffic Flow

Traffic and air quality models must be underpinned by good quality traffic data to ensure traffic flows and the distribution of vehicle types are represented as accurately as possible (SEPA, 2017). Detailed traffic data surveys were carried out in 2017 and again in 2019 with additional Junction Turn Count (JTC) sites to support the development of the traffic model. In both the Reference Case and LEZ scenario the traffic flows are based on those observed in 2019.

The traffic data surveys included ANPR survey data, which provide information linking vehicle number plates to information on the DVLA database such as vehicle type, weight, engine size and fuel type. The DVLA also provide estimated Euro class, based on the age of the vehicle.

Calculating Emission Inputs for Air Quality Modelling

The Emission Factor Toolkit version 10.1 (EFT10.1) emission factors within the CERC database tool EMIT have been used to calculate emission rates in this analysis which was the most up to date available at the time.

Vehicle categories from the Paramics model were converted into 11-vehicle classes required by EMIT:

- Motorcycle, Car, LGV, Bus/Coach, RHGV-2ax, RHGV-3ax, RHGV-4ax, AHGV-34ax, AHGV-5ax, AHGV-6ax and Taxi.

The goods vehicles were split in line with the proportions identified in the 2017 Junction Turn Count data and counts for buses and coaches were added together. The taxi flows taken from the Paramics model are included in the taxi category in EMIT as black cabs (which assumes emissions are similar to LGV's). This includes some private hire vehicles, which results in a small overestimate in emissions in the Reference Case. This is a precautionary approach. In the LEZ scenario all taxis are assumed to be compliant

To calculate emission rates, 24-hour traffic flows (known as Annual Average Daily Traffic, or AADT) are required, which is not provided by the traffic model. In previous modelling work, traffic flows were calculated using 12-hour and 24-hour JTC data. The junctions that had 24-hour data were already AADT flows. Where data was collected over a 12-hour period, these values were factored up to AADT using conversion factors derived from the 24-hour JTC data, with different factors used for each traffic category.

Each scenario was run over 3 time periods within the traffic model, with the flows for each period summed to provide a 12-hour flow:

- AM: 07:00 – 10:00
- Interpeak: 10:00 -16:00
- PM: 16:00-19:00

Finally, the 2017 fleet composition tables and traffic flow data were used in the CERC EMIT database tool to generate NO_x, NO_2 and PM_{10} emission rates for each road link. These emission rates were analysed to provide information on emission rate changes for each road and were also ready to import into ADMS-Urban to predict NO_x and NO_2 concentrations.

Air Quality Modelling Methodology

The Aberdeen Pilot Project Technical report (SEPA, 2017) outlines the air quality modelling methodology and this remains the same to maintain consistency with previous modelling unless outlined in more detail below, which is mainly focused on the use of traffic model data to examine the effect on introducing an LEZ.

The following AQ modelling parameters were used:

- Meteorology: 2019 data from Glasgow Bishopton Met Office weather station. In a rank of annual-average wind speeds, the year 2019 is similar to 2017, which was chosen as a precautionary approach to accounting for future dispersion (SEPA, 2019).
- Background data: 2019 data from Glasgow Waulkmillglen (Rural automatic monitor) and 2018 annual gridded emissions from the NAEI.
- Traffic Speed: Average traffic speeds calculated from traffic model output.
- Street Geometry (road widths and canyons): These features were re-calculated from Mastermap using the established NMF methodology (SEPA, 2017).

Results

Traffic Model Output

The aim of the traffic model is to predict traffic flow changes in response to the introduction of an LEZ, which is likely to displace non-compliant traffic around the LEZ boundary. The first stage in assessing the effect of these changes on emissions involved processing the Traffic Model outputs to make them compatible with the CERC emissions database tool (EMIT) using conversion factors derived from observed traffic data. Emission rates (g/km/s) were calculated for the vehicle flows along every road in the traffic model for the Reference Case and LEZ scenarios. Comparing emissions between these 2 scenarios enabled any changes due to the LEZ to be identified (SEPA, 2021). Initial findings suggest that implementation of the proposed LEZ (to include all vehicles) will reduce NO_x emissions on key bus routes inside the LEZ boundary by an average of 70% whilst there is an overall reduction of annual NO_x emissions across the LEZ of 53%. The proposed LEZ results in some displacement of non-compliant vehicles with an increase of up to 1200 cars per day on a small number of roads east of Saltmarket and High Street. This is linked to localised increases in NOx emissions on roads that currently have a low volume of traffic.

The flows along each road in the traffic model used in the emission analysis have been incorporated into the air quality model to predict changes in roadside concentrations due to the LEZ. The absolute differences between Reference and LEZ cases may in some cases be smaller than previously presented in the Glasgow LEZ Emissions Report (SEPA, 2021). This is a consequence of aggregating the traffic data, whereby the maximum Reference and LEZ flows from the Paramics model are used in ADMS. The air quality modelling results for the LEZ case still represent a worst-case scenario as these are based on maximum traffic flows.

Predicted changes to road emissions

Inside the LEZ

There is a large reduction in emissions inside the LEZ due to its implementation. Total NO_x emissions across the LEZ reduce by 53%, with higher rates of reduction on roads dominated by bus emissions. Along the length of Hope Street there is a 69% reduction in NO_x emissions and an 83% reduction along Union/Renfield Street.

These changes to emissions inside the LEZ are associated with only small changes in the numbers of vehicles. Figure 6 shows changes to total traffic following implementation of the LEZ, confirming that total daily traffic mostly varies by less than 100 vehicles per day inside the LEZ. There are larger changes outside to the LEZ which will be discussed in the next section. Emission changes are explored here for 3 city centre roads shown in Figure 7.

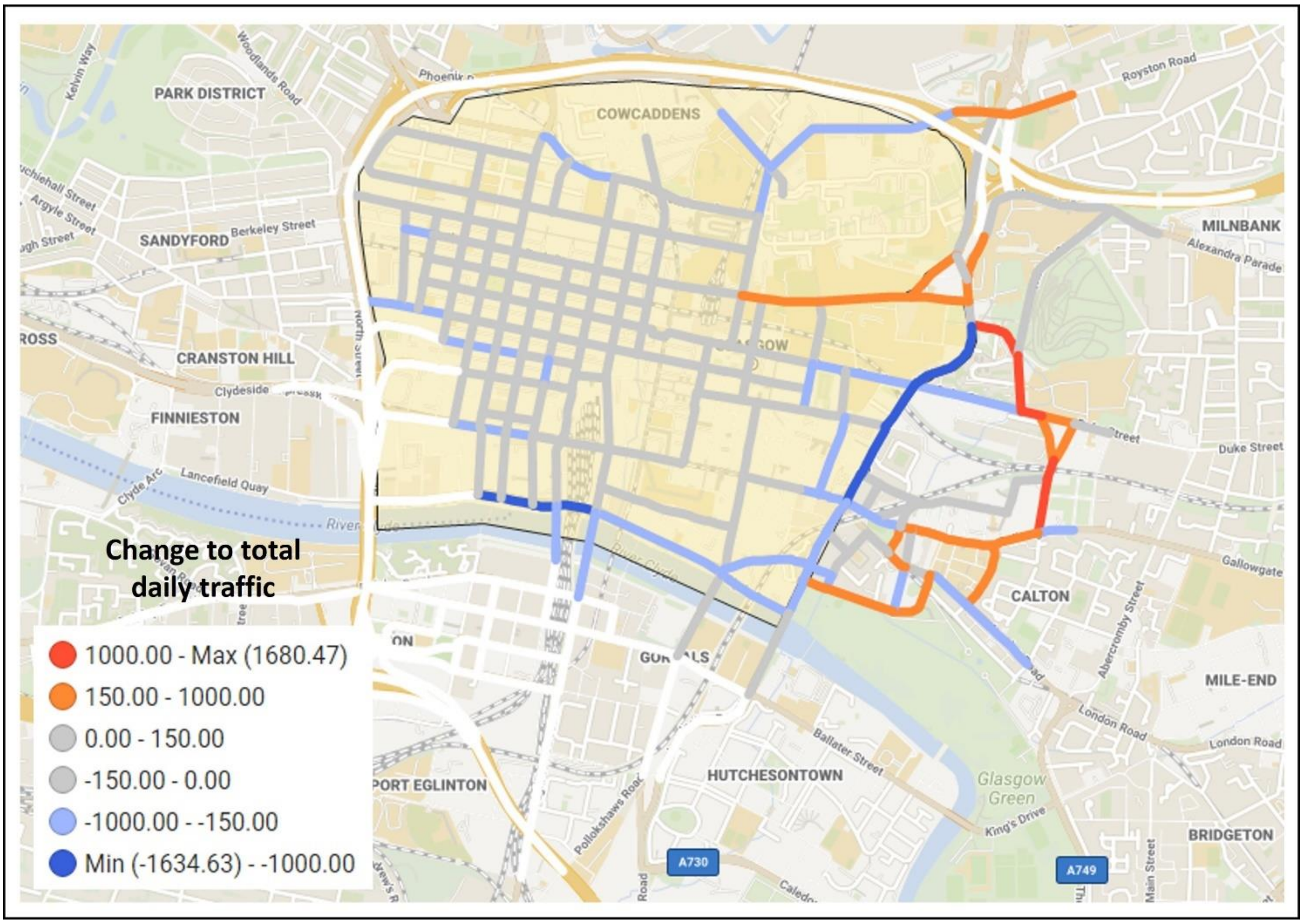

Figure 6: Predicted changes to total daily vehicles following implementation of the LEZ.

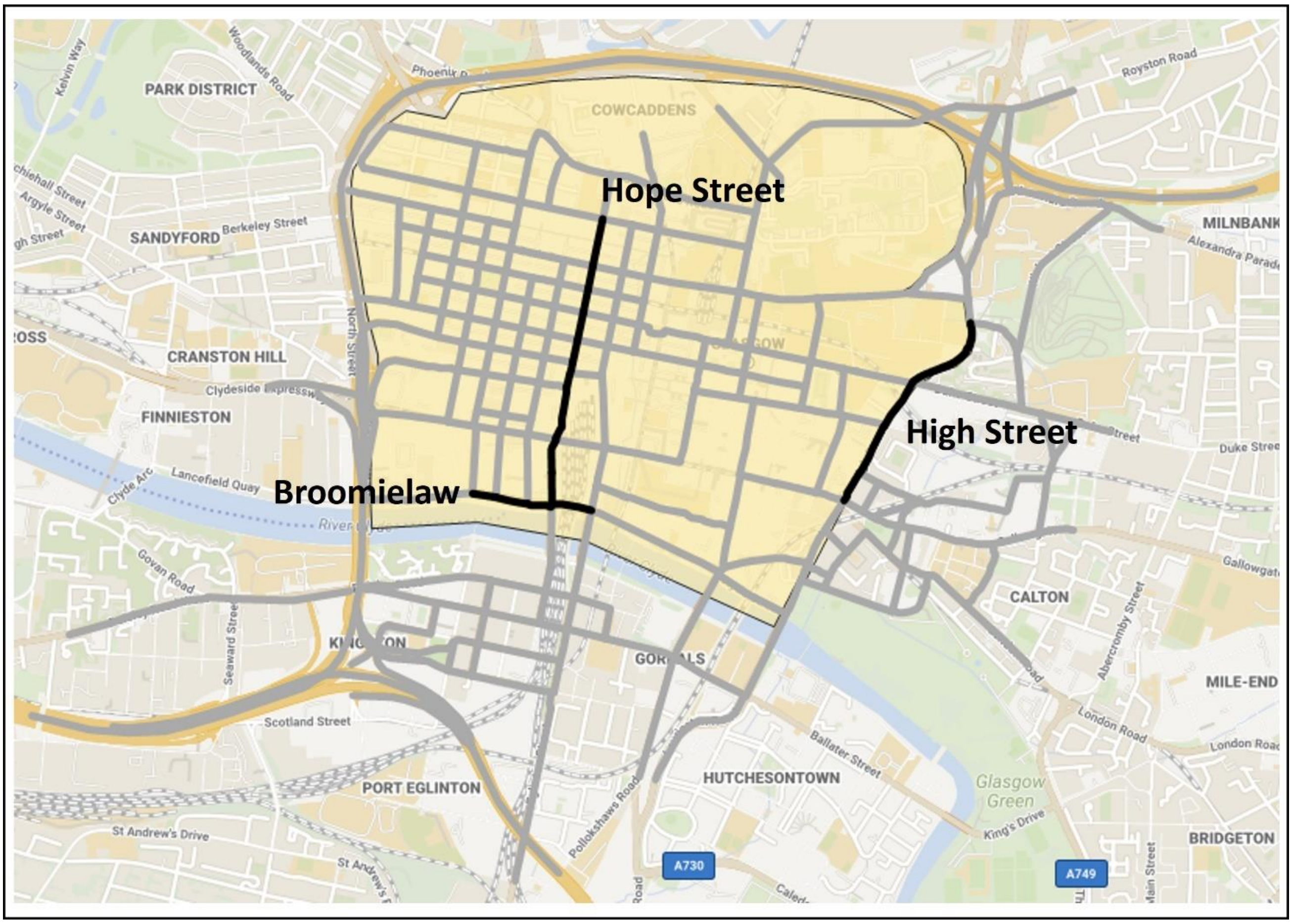

Figure 7: Location of 3 city centre roads referred to in the emissions analysis below.

In Figure 8, the roads inside the LEZ and east of High Street (coloured in Figure 4) are ranked by NO_x emission rate (g/km/s) for the Reference and LEZ cases, confirming a substantially lower range of emission rates in the LEZ case. The roads highlighted in black and shown in inset bar charts are sections of Hope Street also highlighted in the map in Figure 7.

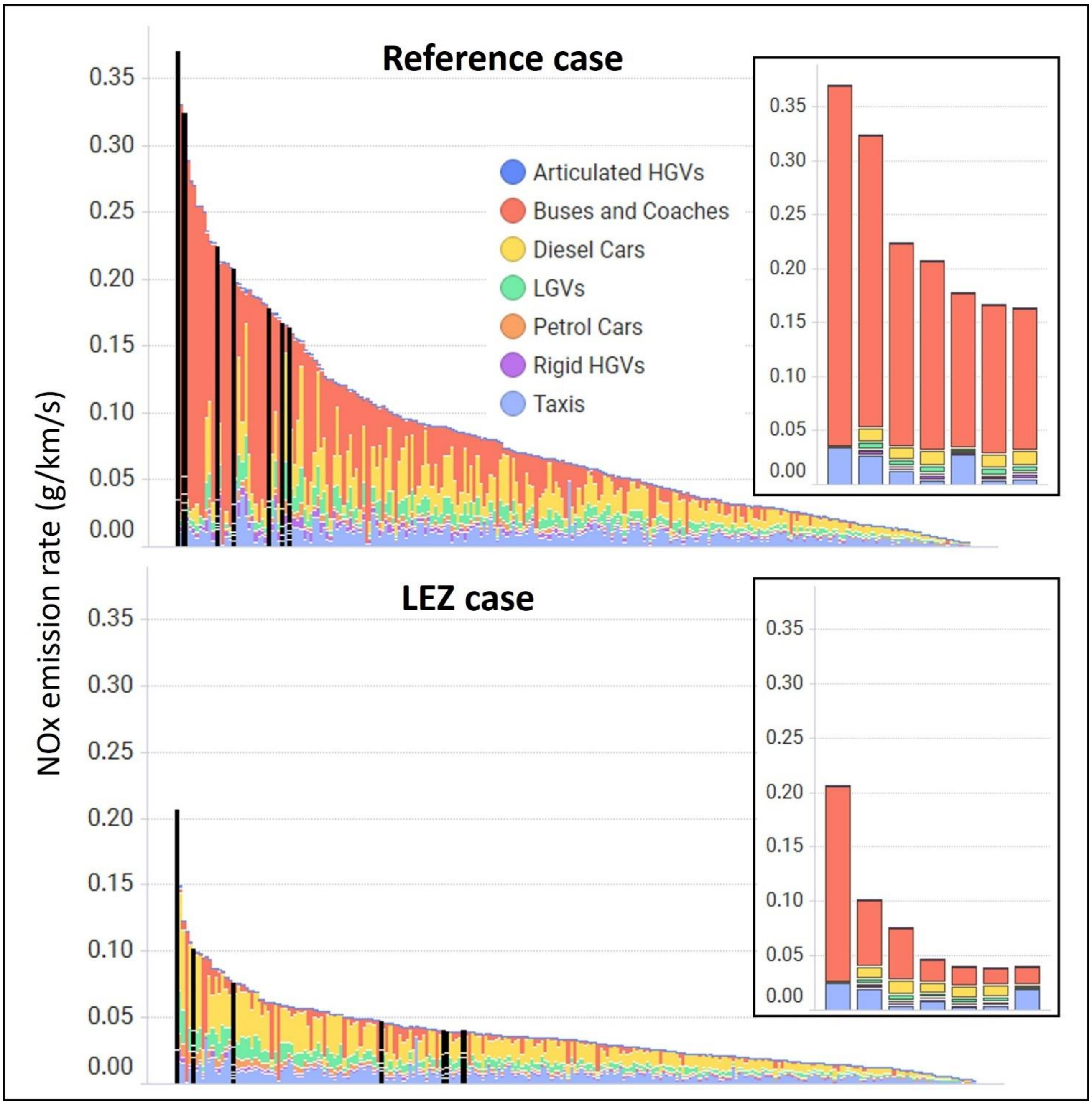

Figure 8: Ranked emission rates of NOx (g/km/s) for the Reference and LEZ cases. Hope Street is highlighted in black.

Some sections of Hope Street remain the highest emitters in the model, but there is a substantial reduction in total emissions. Buses remain the dominant source on the roads highlighted, but their contribution to total NO_x emissions falls from an average of 85% in the Reference case to 68% in the LEZ case.

Vehicle emissions on Broomielaw are dominated by diesel cars, and therefore the level of reduction in NO_x emissions is correspondingly lower than on Hope Street. On the section of Broomielaw highlighted in Figure 7 there is a total reduction in NO_x emissions of 36%.

In Figure 9, all roads in the network are ranked by NO_x emission rate (g/km/s) for the Reference and LEZ cases, with sections of Broomielaw highlighted in black. Broomielaw moves up in the ranking of NOx emission rates despite an overall decrease due to the LEZ. The NOx contribution from buses falls from an average of 11% to 2%, with the contribution from diesel cars increasing from 49% to 59%.

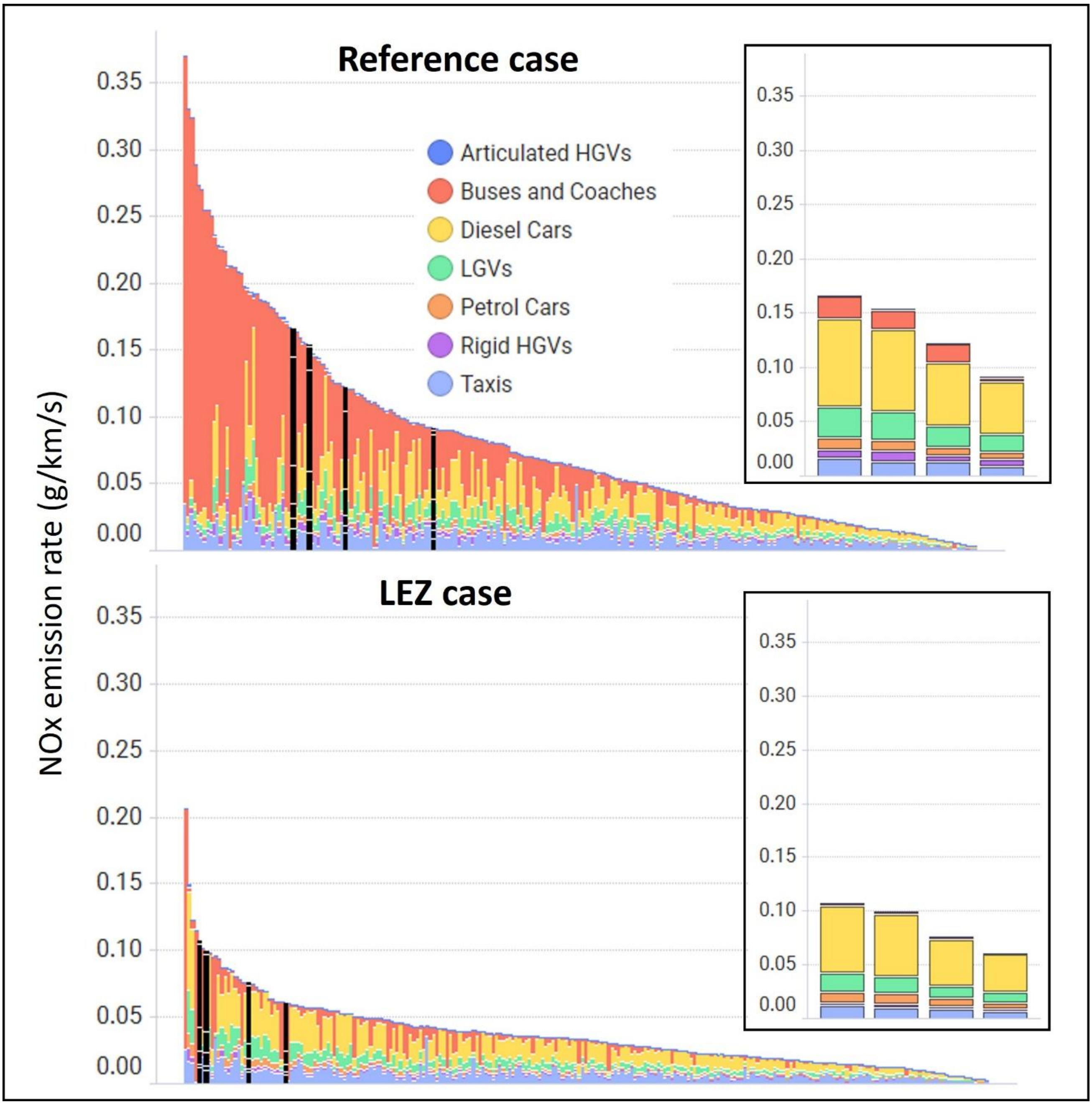

Figure 9: Ranked emission rates of NOx (g/km/s) for the Reference and LEZ cases. Broomielaw is highlighted in black.

There are similar changes to vehicle emissions on High Street, where emissions on the roads highlighted in black on Figure 7 reduce by 41%. Changes to emissions rates on High Street are highlighted in Figure 10. The average contribution to NO_x from buses decreases on this section of road from 13% to 2%, with the contribution from diesel cars increasing from 47% to 58%.

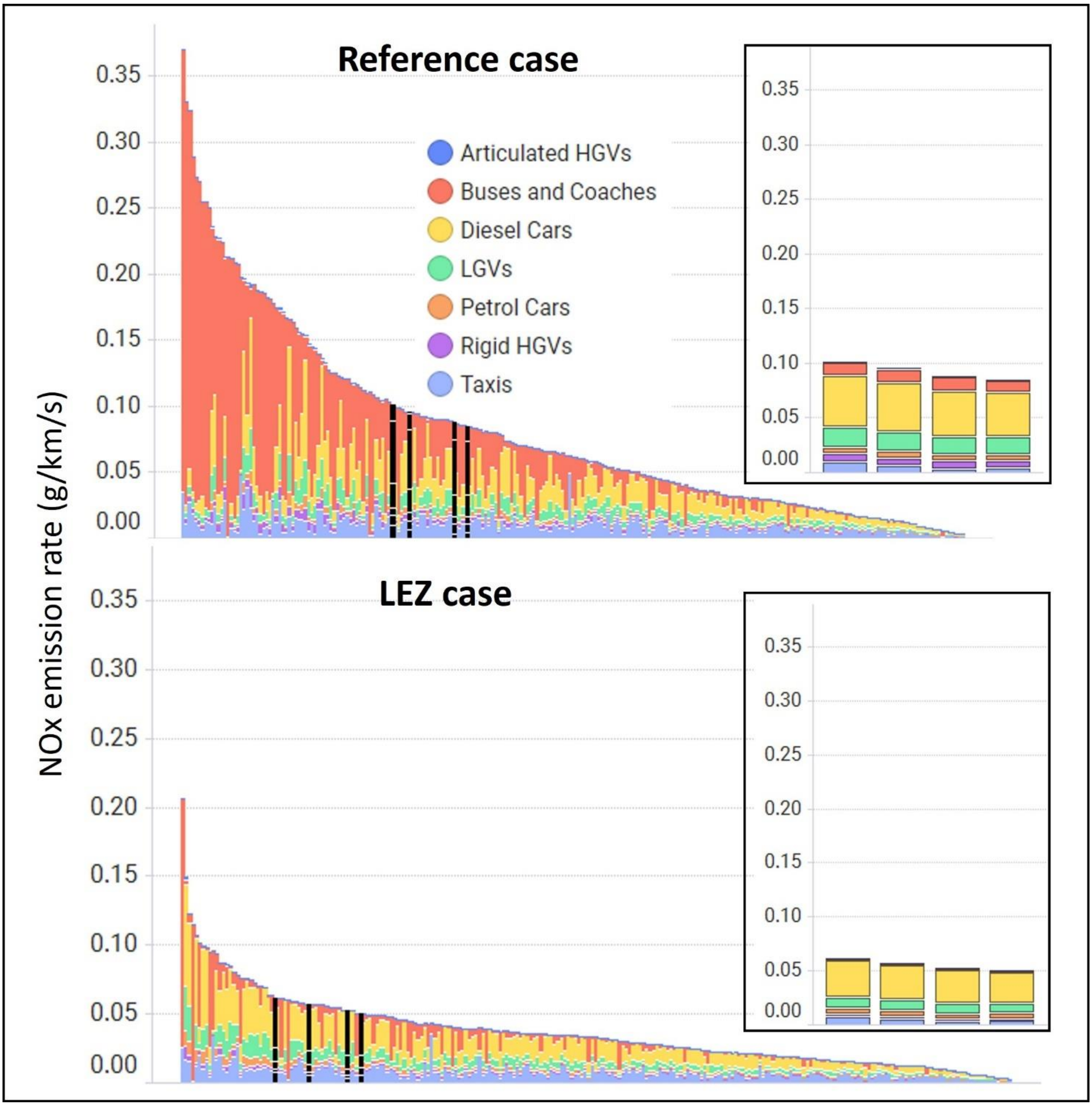

Figure 10: Ranked emission rates of NOx (g/km/s) for the Reference and LEZ cases. High Street is highlighted in black.

Outside the LEZ

Examples from inside the LEZ demonstrated the reduction in vehicle emissions across the LEZ, with the scale of reduction mostly reflecting the percentage contribution from buses to total NO_x.

Outside of the LEZ there is a localised increase in NO_x emissions on some roads to the east of High Street including Barrack St, Hunter St, John Knox St and Cathedral Square. Roads that experience an increase in emissions are highlighted red in Figure 11 with all other roads in blue experiencing a decrease due to the LEZ. The bar charts on Figure 11 show absolute and percentage changes in emission rate. This confirms that only a small number of roads experience an increase in emissions, and although the maximum percentage increase is 34% this is associated with very small absolute changes.

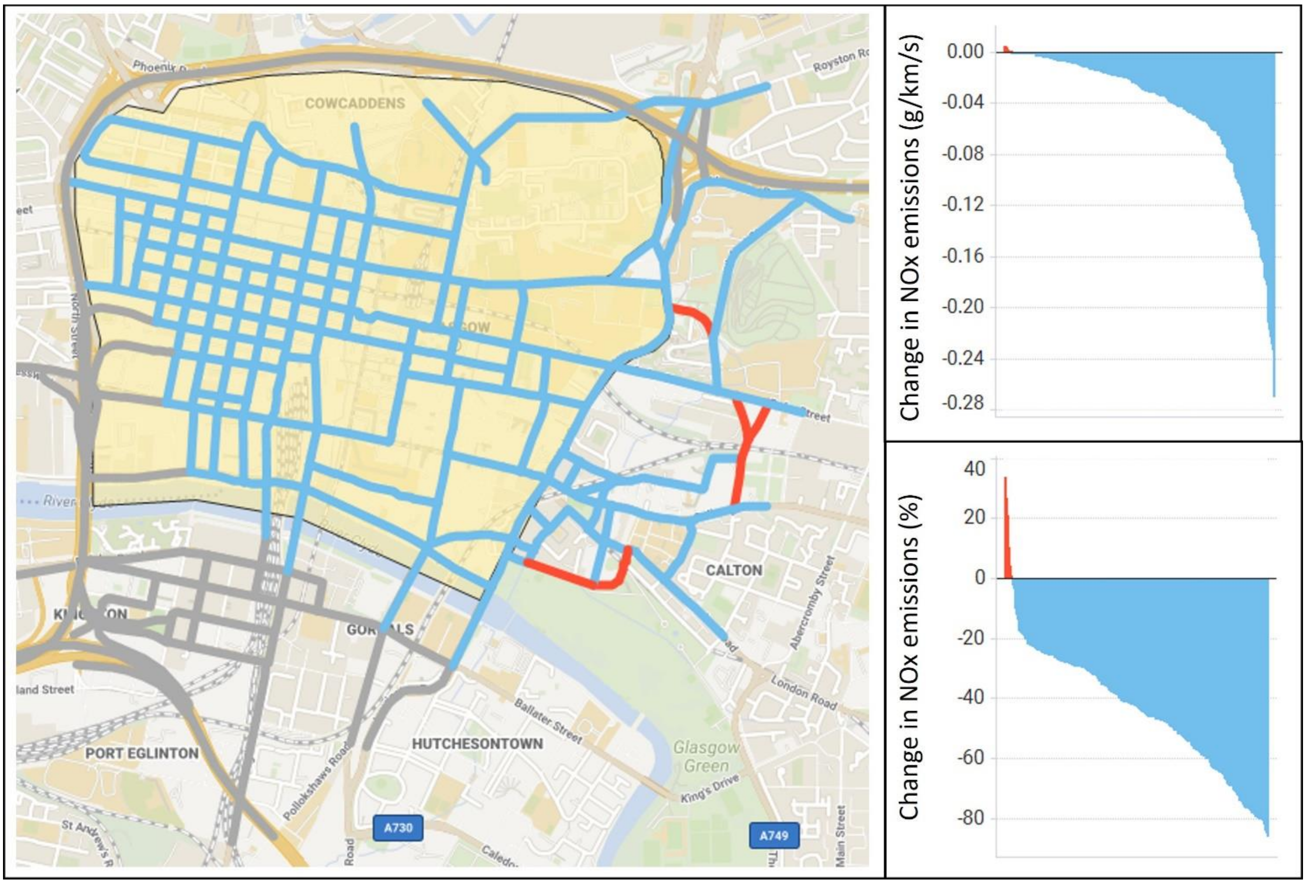

Figure 11: Changes to total NOx emissions due to implementation of the LEZ. All roads coloured blue experience a decrease in total emissions, and those coloured red experience an increase. Bar charts show absolute and percentage changes in emission rate.

The roads that experience an increase in NO_x emissions are linked to a displacement of traffic away from High Street around the edge of the LEZ. For example, John Knox St is predicted to experience an additional 1500 vehicles per day as a result of implementing the LEZ, corresponding to a new total daily traffic flow of ~12700 vehicles per day. Around 30% of the total daily flow is expected to be non-compliant, which predominately comprise cars and LGVs. These roads are investigated in more detail below.

Figure 12 focuses on the roads to the east of High Street that are predicted to experience an increase in traffic following LEZ implementation (highlighted in black).

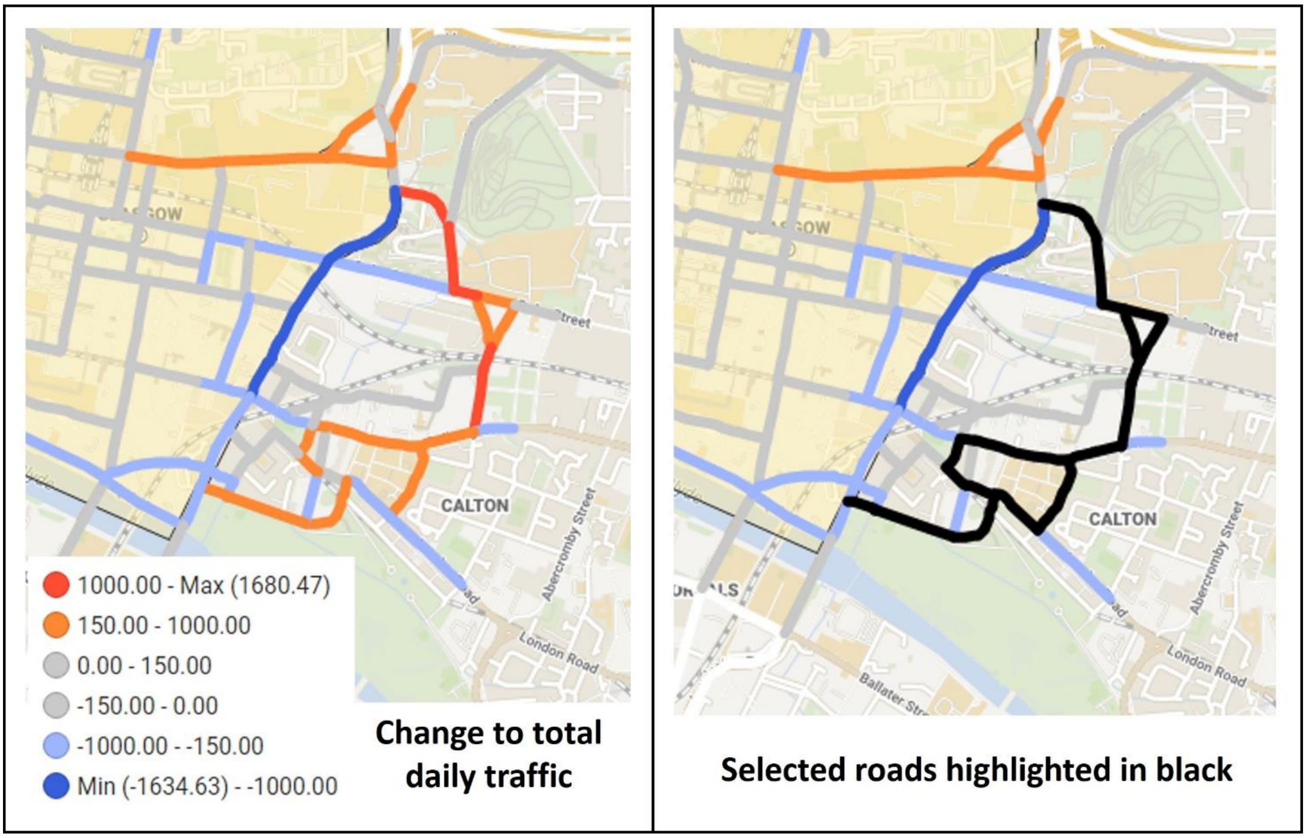

Figure 12: The model road network to the east of High Street. Roads are coloured by the predicted change in daily traffic. The roads highlighted in black are explored in more detail below.

Figure 13 shows ranked NO_x emission rates on the selected roads which are highlighted in Figure 12. This confirms that the most significant change on these roads is a reduction in the highest emission rates. Despite being outside of the LEZ this area of the city still benefits from cleaner buses that will enter the LEZ. Some of the emission rates in Figure 13 have increased between the Reference and

LEZ cases due to additional cars and LGVs. However, this applies to the roads that have the lowest emission rates and the level of increase is very small making it difficult to identify from these charts.

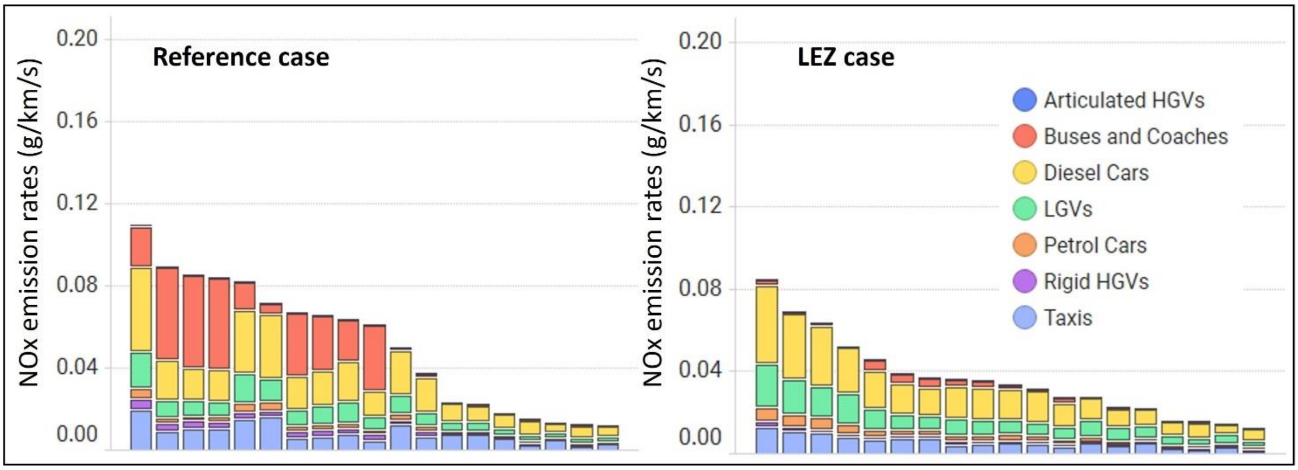

Figure 13: Ranked emission rates of NOx (g/km/s) for the roads highlighted in black in Figure 12 that see an increase in traffic flow following LEZ implementation, for the Reference and LEZ cases.

On these roads highlighted in Figure 12 and ranked in Figure 13 there is an additional contribution due to implementing the LEZ of 0.2 tonnes of NOx per year from cars and LGVs. However, there is a total decrease of 1.1 tonnes of NOx per year due to the cleaner bus fleet.

When all vehicle types are included, there is a total increase of 0.08 tonnes of NOx per year along this route, compared with a total decrease of 1.3 tonnes of NOx. In summary, there are localised increases in emissions due to traffic re-routing around the edge of the LEZ boundary. However, this change remains an order of magnitude smaller than the total emission saving due to stricter emission standards of the LEZ. This is reflected in the predictions of roadside NO_2 concentrations, as discussed in the following section.

Predicted changes in NO_2 concentration due to the LEZ

The air-quality model has been used to assess the impact on roadside NO_2 concentrations when implementing the LEZ for all vehicles. Figure 14 shows predicted annual mean NO_2 concentrations for the Reference case. These concentrations are predicted at the roadside and therefore concentrations at façade would be expected to be lower. In Figure 14 the highest concentrations correspond with major bus routes through the LEZ including Hope Street, Union/Renfield Street and St Vincent Street.

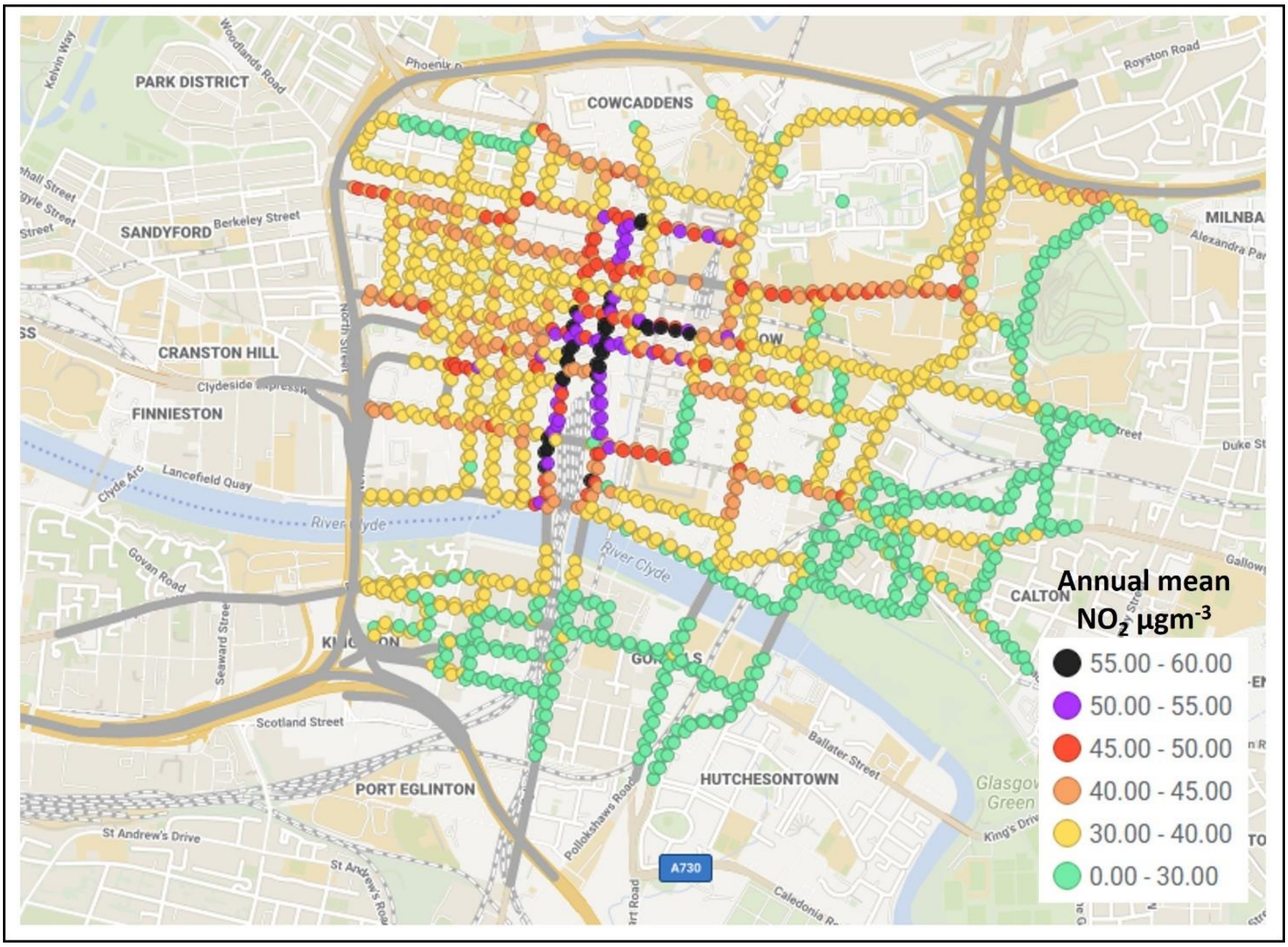

Figure 14: Predicted roadside concentrations of NO_2 for the Reference case.

Figure 15 also shows results from the Reference case, but model roadside points have been coloured to indicate where there were likely to be exceedances of the annual mean limit for NO_2 at the roadside, in 2020.

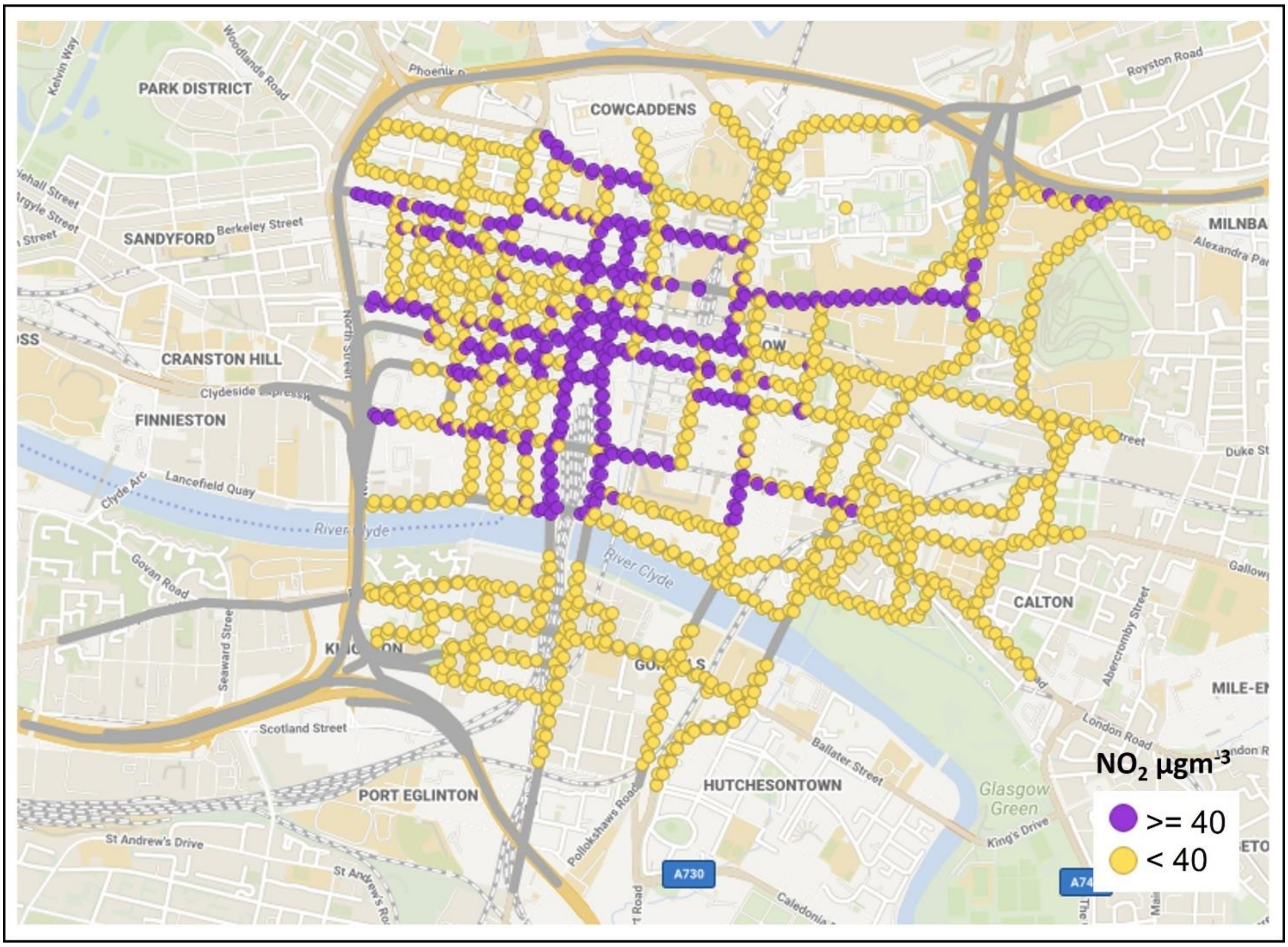

Figure 15: Predicted roadside exceedances of the NO_2 limit value for the Reference case. Markers coloured in purple are above the annual-average limit value of 40µgm^{-3}.

Figure 16 shows the predicted change in roadside NO_2 due to implementation of the LEZ. In line with changes to emissions described in the previous section, significant reductions to roadside NO_2 are focused along major bus routes inside the LEZ. There is a widespread reduction of between 15 and 20µgm^{-3}, with a peak reduction inside the LEZ of 30µgm^{-3}.

There are no areas outside of the LEZ where roadside concentrations of NO_2 are predicted to increase.

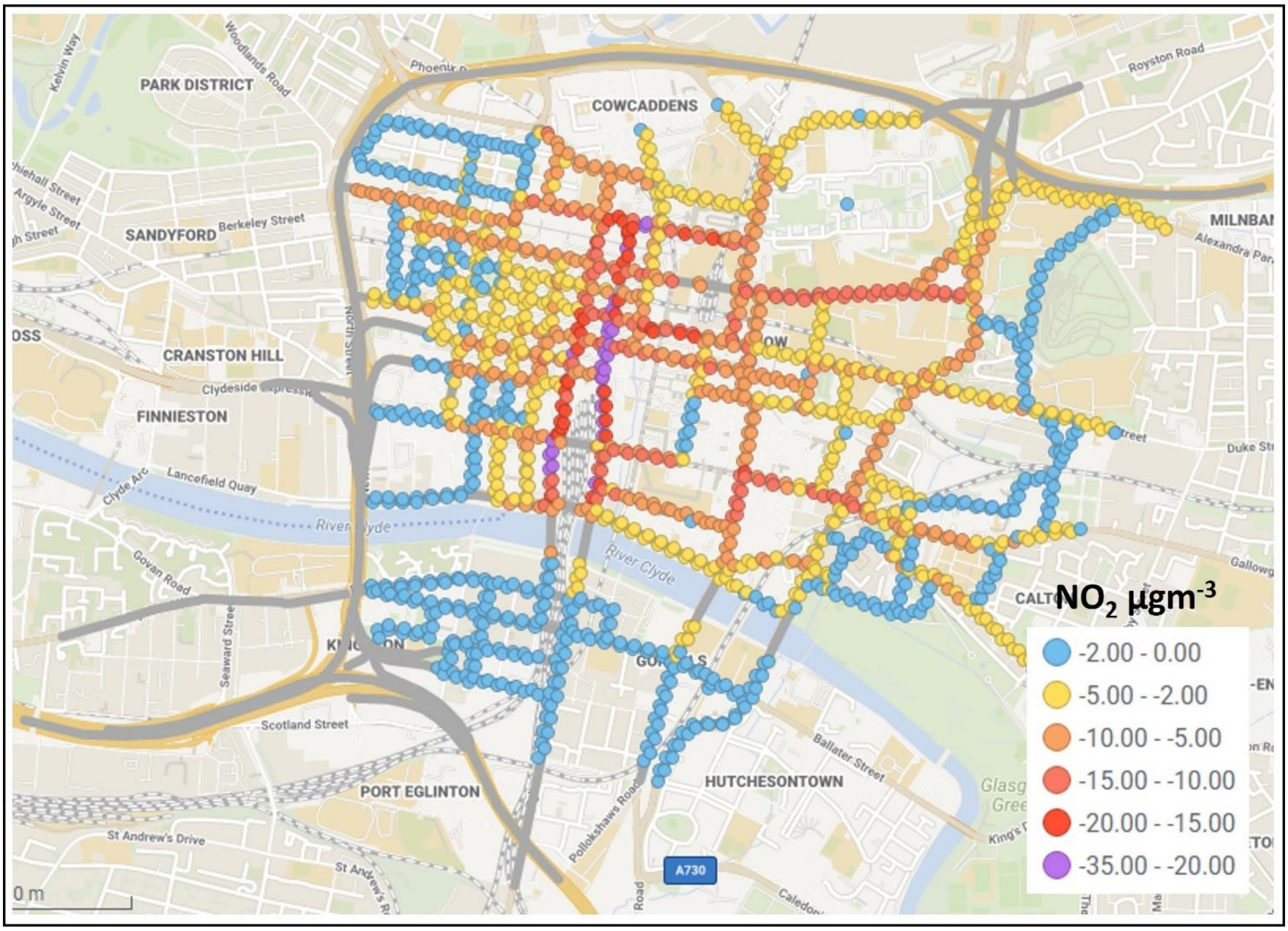

Figure 16: Predicted changes in annual-mean NO$_2$ due to implementation of the LEZ.

Figure 17 shows predicted NO$_2$ concentrations for the LEZ case and Figure 18 shows predicted exceedances. This confirms that following large reductions of NO$_2$ inside the LEZ almost all predicted exceedances are removed. Some isolated exceedances remain on key bus routes and near junctions. This is consistent with previous analyses that found that converting all vehicles to EURO 6/VI would remove most, but not all, city centre exceedances (SEPA, 2019).

These air-quality model results are based on the age of the Glasgow fleet in 2020 and are therefore precautionary, given that further fleet improvements are expected prior to implementing the LEZ for all vehicles.

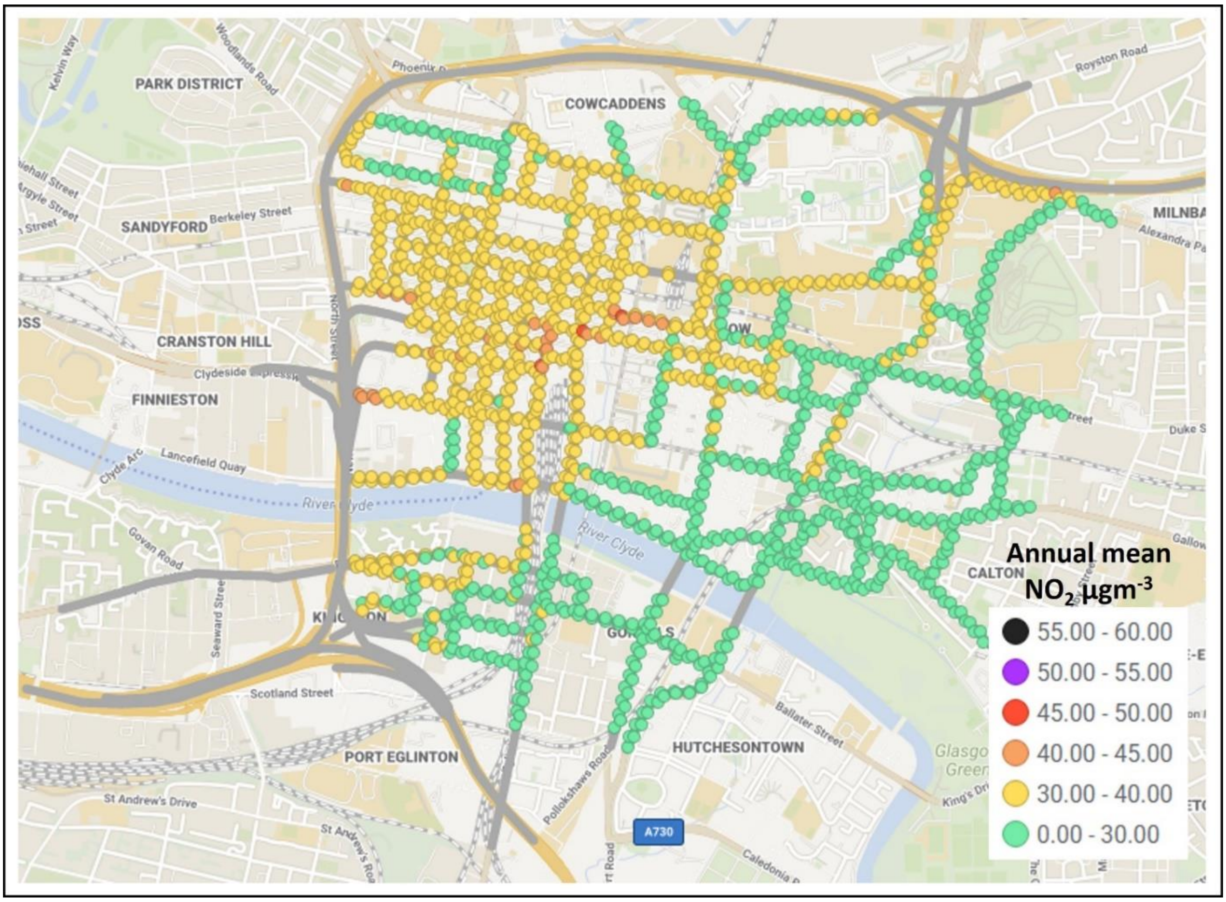

Figure 17: Predicted roadside concentrations of NO_2 for the LEZ case.

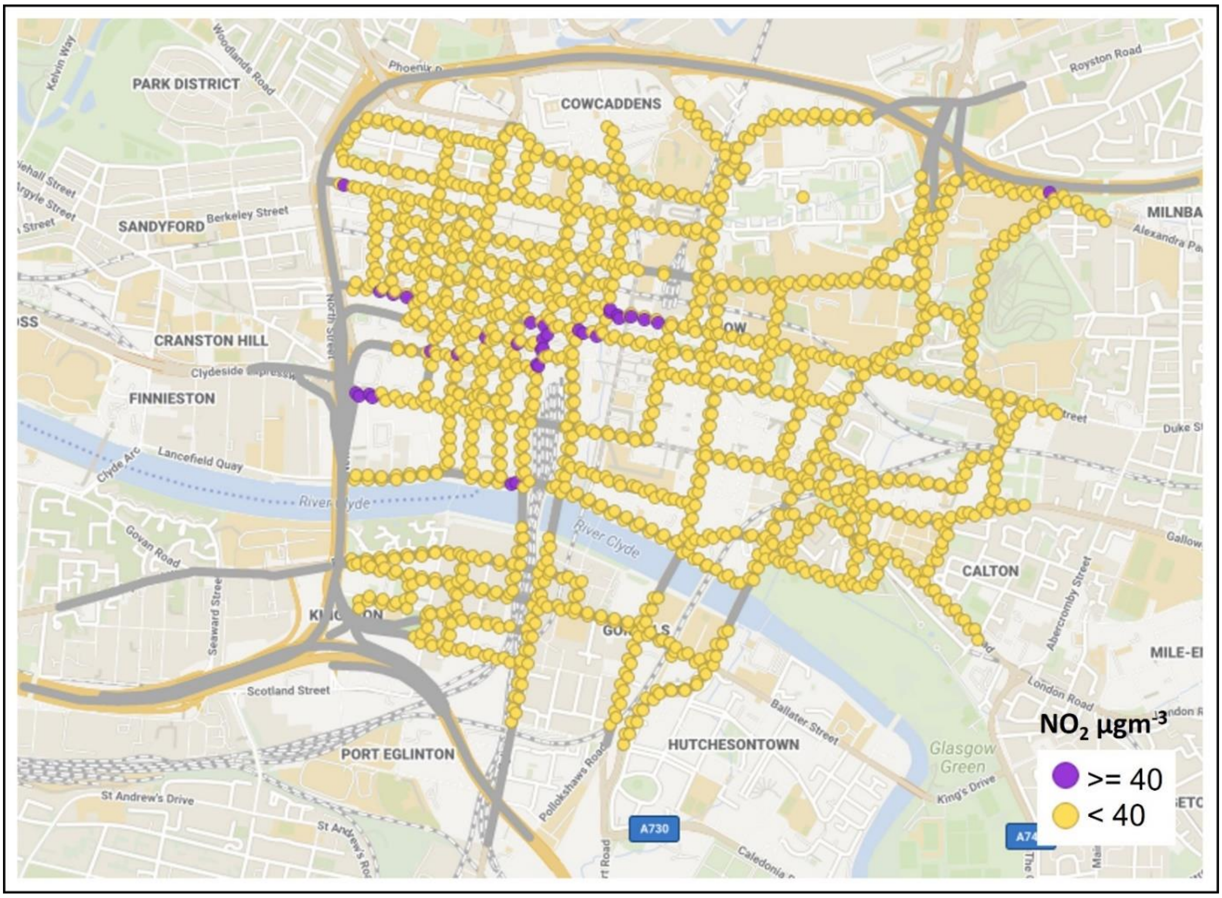

Figure 18: Predicted roadside exceedances of the NO_2 limit value for the LEZ case. Markers coloured in purple are above the annual-average limit value of 40µgm^{-3}.

As shown in the previous section on road emissions there are small sections of road to the east of High Street that experience an overall increase in emissions. However, these localised increases are very small when compared to the much larger decrease in emissions that occur on all surrounding roads.

Concentration data shows that roads which experience an increase in NO_x emissions do not experience an increase in roadside NO_x concentrations. This is because the signal of roadside NO_x concentrations is determined by changes to emissions on the immediate, as well as neighbouring, roads. In these instances, a small local increase has been outweighed by significantly larger decreases on surrounding roads.

Contribution to NO_X by vehicle type following LEZ implementation

The air-quality model has been used to show how the annual mean concentration of NO_x is made up by contributions from different vehicle types, following implementation of the LEZ.

Figure 19 shows roadside points that have been selected along Hope Street, as highlighted in black. The corresponding bar charts show the NO_x contribution from different vehicles. Buses still contribute the greatest proportion of NO_x although these are fully compliant. The next greatest contributor to total NO_x is compliant diesel cars.

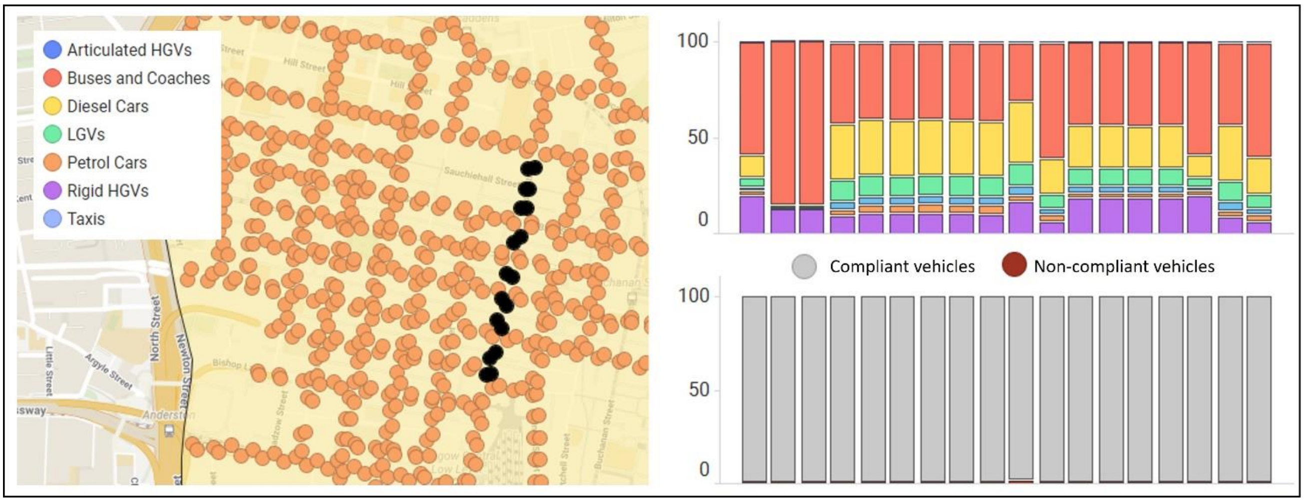

Figure 19: The contribution to modelled NOx concentrations from different vehicle types, at roadside points along Hope Street.

Barrack Street and Hunter Street are predicted to experience additional traffic that re-routes around the LEZ boundary. Figure 20 shows that around 45% of the total NO_x along this street is linked to non-compliant vehicles following LEZ implementation. Around 70% of total NO_x can be attributed to diesel cars and LGVs, with only a very small contribution from buses.

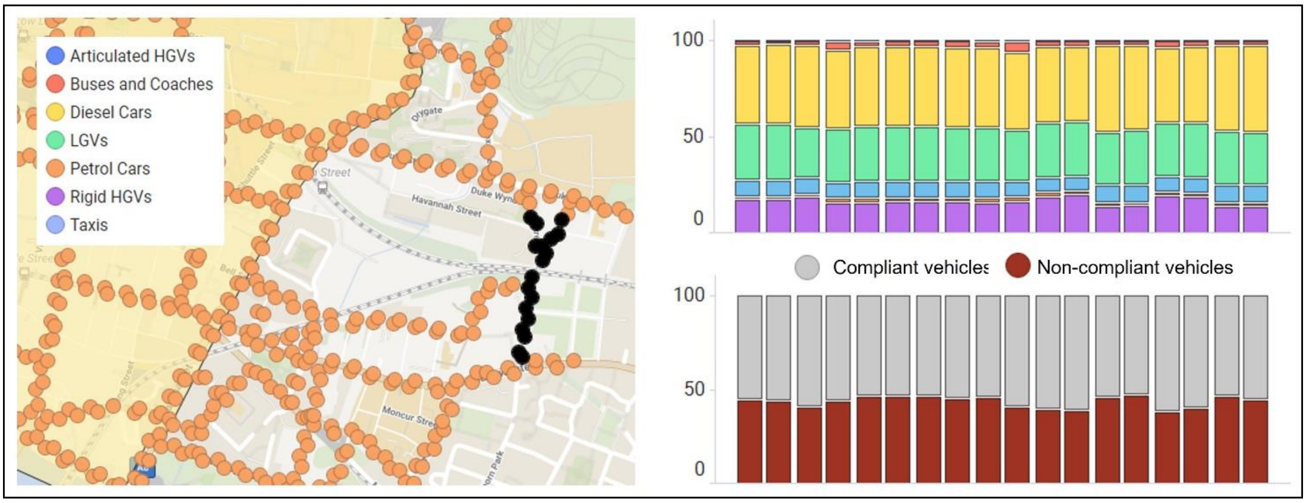

Figure 20: The contribution to modelled NOx concentrations from different vehicle types, at roadside points along Barrack Street / Hunter Street.

High Street is located close to the boundary of the LEZ and experiences a reduction in vehicle numbers and a reduction in roadside NO_2. NOx concentrations are therefore dominated by emissions from compliant diesel cars (Figure 21).

Figure 21: The contribution to modelled NOx concentrations from different vehicle types, at roadside points along High Street.

Predicted changes in PM_{10} emissions due to the LEZ

The predicted change in PM_{10} emissions due to implementing the LEZ have been explored by comparing calculations of vehicle tailpipe emissions between the Reference and LEZ cases. However, these emissions have not been used to predict concentrations of PM_{10}. Roadside concentrations of PM_{10} are dominated by non-tailpipe emissions, including brake and tyre-wear and re-suspension from the road surface. It is difficult to quantify the rates of these 'non-tailpipe' emissions and therefore model predictions of PM_{10} concentrations would be associated with high levels of uncertainty. The main aim of the LEZ was to accelerate compliance with AQ objectives, achieved by reducing vehicle tailpipe emissions. Therefore, as part of the assessment of the LEZ, the focus was on reducing primary emissions of PM10.

There are widespread large reductions in PM_{10} tailpipe emissions as a result of implementing the LEZ. The largest reductions occur inside the LEZ, as shown by the roads highlighted black in Figure 22. It should be noted that this scale of reduction is greater than would be expected to occur in PM_{10} concentration data, due to the contribution of non-tailpipe emissions, as discussed above.

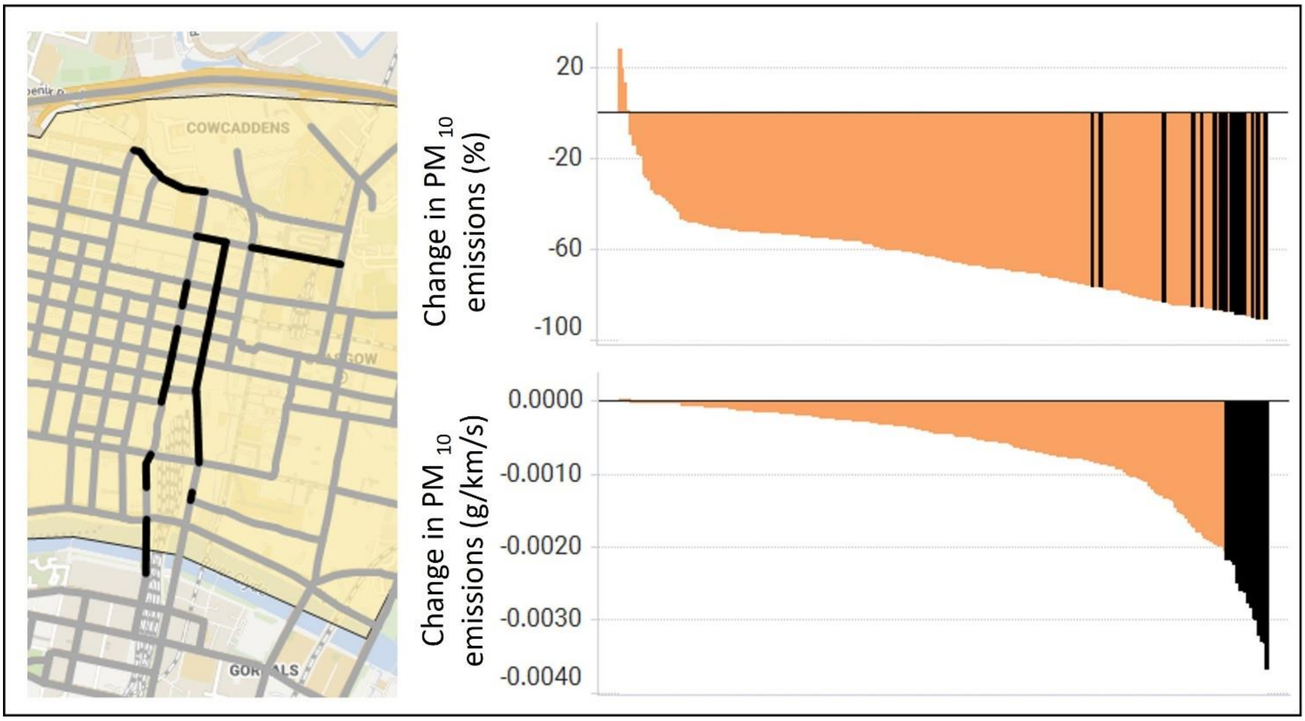

Figure 22: Ranked changed in PM_{10} emissions on all roads. The greatest reductions occur inside on key bus routes inside the LEZ as highlighted in black.

Figure 23 shows the change in PM_{10} emission rates (g/km/s) between Reference and LEZ cases by vehicle type. This confirms that the largest reductions in tailpipe PM_{10} are associated with roads dominated by bus emissions.

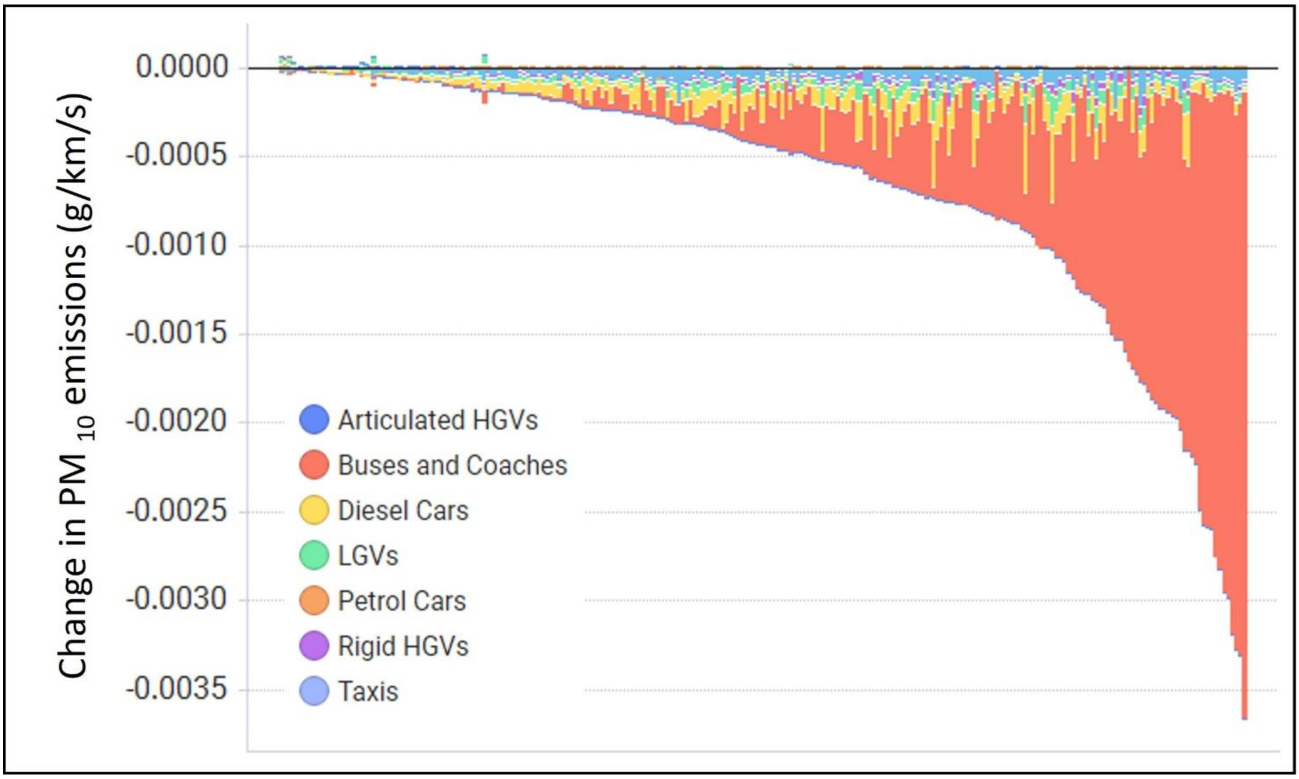

Figure 23: Ranked predicted change in PM_{10} emissions on all roads following implementation of the LEZ, by vehicle type.

There are very localised increases in tailpipe PM_{10} emissions on Barrack Street and Hunter Street, although these are associated with very small absolute changes (Figure 24).

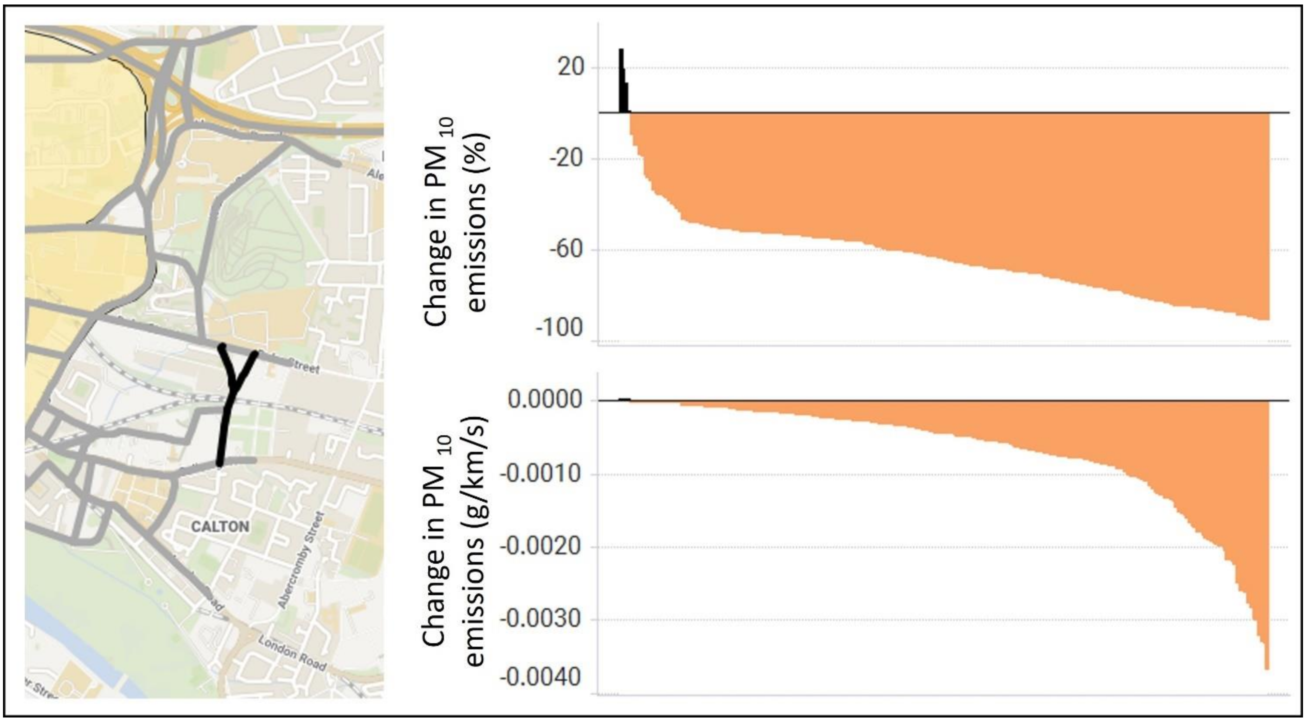

Figure 24: Ranked changes in PM_{10} emissions on all roads. Tailpipe emissions are predicted to increase on a small number of roads only, as highlighted in black.

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