APPENDIX A4

Cardiff Air Quality Management
Castle Street Scheme

March 2023

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Cardiff Air Quality Management Castle Street Scheme

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Executive summary

A Clean Air Feasibility Study was undertaken on behalf of Cardiff Council between 2018 and 2019. Arising from this several schemes were implemented in the city to improve air quality. Following on from schemes and network changes undertaken during the global pandemic, the Council are considering alterations to the road network in the vicinity of the original air quality schemes (in particular on Castle Street) and are therefore required by Welsh Government to undertake further modelling to understand the likely impact on pollutant concentrations.

Using traffic count data collected by the Council, Mott MacDonald has developed an updated 2022 base year cordon model of the city in PTV Visum software using the wider South East Wales Transport Model (SEWTM) as a basis. Since the scheme options distinguish between taxis and general traffic, and by taxi engine type, the model's car demand segments were disaggregated to general car, taxi compliant engine and taxi non-compliant engine (compliance with reference to EURO standards) before calibrating traffic flows to count data collected by the Council in 2022. The DfT's National Trip End Model (NTEM) has been used to grow highway demand to 2024 as part of a Do-Minimum (DM) forecast, incorporating schemes which will be implemented by the Council in the intervening period. The Castle Street scheme options have been coded into these networks to develop Do-Something (DS) forecasts.

Outputs from the 2022 base year model have been supplied to Ricardo Energy and Environment to facilitate the development of an updated air dispersion model. Subsequently, 2024 DM and DS outputs have been provided so the air dispersion model can be used to understand likely concentrations of pollutants in a forecast scenario, and the impact of the proposed Castle Street scheme options on these concentrations.

An economic assessment of the schemes has been undertaken using the DfT's Transport User Benefit Analysis (TUBA) software.

This report has been prepared to detail the modelling undertaken in the cordon model and the results of the scheme testing. The remainder of this report is structured as follows:

- Section 1 outlines the process undertaken to develop the base year (2022) cordon model;
- Section 2 details the forecasting process used to develop the 2024 forecasts;
- Section 3 provides a brief overview of the modelling results; and
- Section 4 provides details of the economic assessment using TUBA.

1 Base Year Cordon Model Development

The SEWTM model used as a basis for this study has a base year of 2015. Owing to significant changes to travel patterns due to the global COVID pandemic and recent alterations to the Cardiff highway network, it was necessary to develop a cordon model of the city so that travel patterns could be modelled sufficiently accurately for the calibration of the updated air dispersion model. This section outlines the development and calibration of the 2022 base year cordon model.

1.1 Coding Recent Highway Network Updates

A series of schemes were coded into the SEWTM highway networks to bring the model up to date in the vicinity of the Castle Street scheme. These were:

- Purple cycleway, reassigning road space from general traffic to cyclists along Tyndall Street;
- Gold cycleway, reassigning road space from general traffic to cyclists along Newport Road, Boulevard de Nantes, Castle Street and Wellington Street;
- City Centre East scheme incorporating bus gate on Station Terrace;
- Westgate Street bus and taxi gate;
- Closure of Tudor Street eastbound owing to roadworks during the period of count data collection; and
- Extensive updates to signal timings throughout the city, using observed data for 3rd March 2022 supplied by the council.

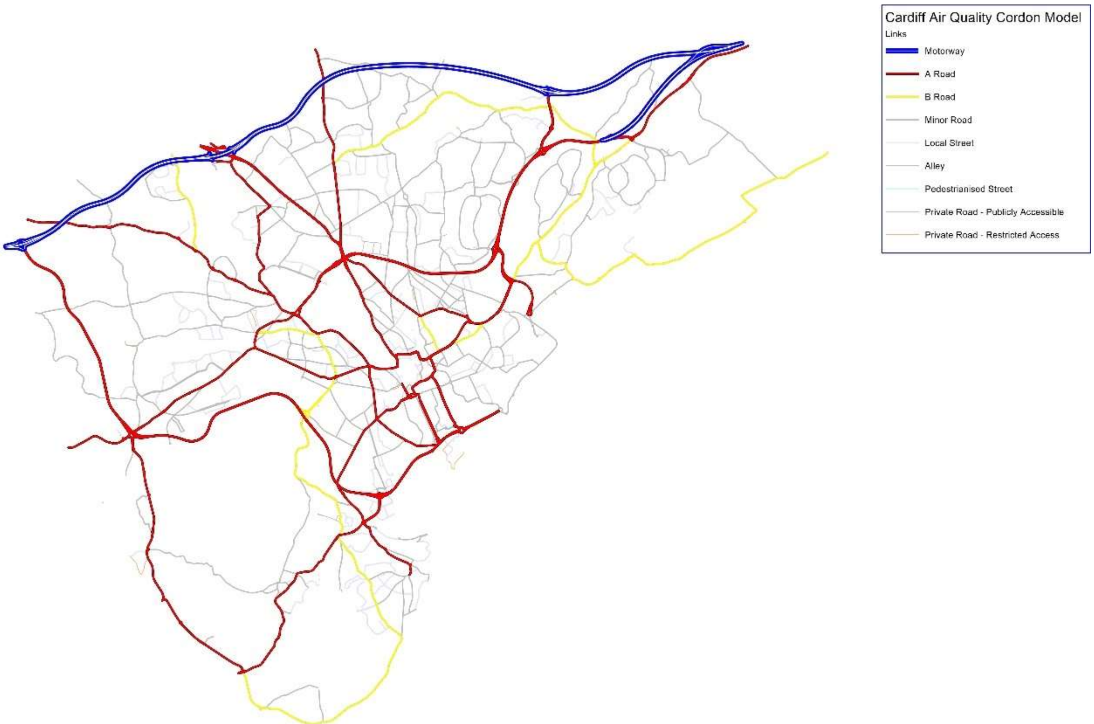
1.2 Variable Demand Model Run to Generate Baseline Demand

Demand and highway model parameters were generated for 2022 using the May 22 release of the TAG databook. Exogenous factors for changes (2015-22) in external link speeds, goods vehicles and external-external trips were generated using the DfT's Road Traffic Forecast (RTF) 2018. Population and employment inputs for 2022 were generated by interpolating values for 2015 and 2026 model years, whilst respecting development site profiling data, where such information was available. The Variable Demand Model (VDM) was then run to generate baseline 2022 demand matrices which could more easily be adjusted to match the count data provided by the Council.

1.3 Cordoning Process

Following the generation of the 2022 baseline demand the model was cordoned using Visum's inbuilt subnetwork generator to improve the manageability of the subsequent tasks. The cordon area is shown below in Figure 1.1

Figure 1.1: Cordon Model Area



1.4 Application of Splits to Car Demand Matrices

The SEWTM demand matrices for cars are split into three demand segments, representing the following trip purposes:

- Employer's business;
- Commute; and
- Other.

The Castle Street scheme options ban general traffic from Castle Street, allowing passage for only the following vehicles (as well as buses):

- Option 1 – taxis; and
- Option 2 – electric taxis.

Therefore, it was necessary to subdivide each of the car demand segments into the following categories:

- Electric-only taxi (not including hybrids);
- Other taxi; and
- Other vehicles.

ANPR data collected by the Council during on 3rd March 2022 was considered as a source for splitting the model into taxi/non-taxi in a geographically disaggregate manner. However, it was found that this data only identified Hackney Carriages in the taxi data, which was not in line with the distinctions being made in terms of the scheme. Further, manually classified count data collected during the period 2nd March-14th March 2022 was found to significantly underestimate the proportion of taxis compared to previous data used in the 2018-19 study. It is assumed that this is due to enumerators not being able to accurately identify such vehicles. Since these data sources were found to be unsuitable, an assumption of 9% of vehicles being taxis was applied, based on ANPR data collected during the previous study, which matched registration plates to the Council's data base of licensed taxis directly. Taxis were split into electric only and other types using information supplied by Ricardo Energy and Environment based on their analysis of the taxi database – 2.3% of taxis were modelled as electric only. The model's demand matrices were split consistently, with no distinction made between different trip purposes or origin-destination pairs, in the absence of suitable information to facilitate this. It should be noted, however, that in the assigned model the proportion of taxis on links is higher in the vicinity of the scheme than elsewhere, owing to existing taxi-only restrictions included in the model (Westgate Street and Eastside Scheme) as described in 2.1. Noting the issues with these sources, this approximately reflects the patterns in the 2022 ANPR and manual count data, if not the actual proportions. The same 2022 Value of Time (VoT) and Vehicle Operating Cost (VOC) parameters were applied to the split matrices as used for the parent classes. Following the split of the assignment matrices, the highway networks were reassigned.

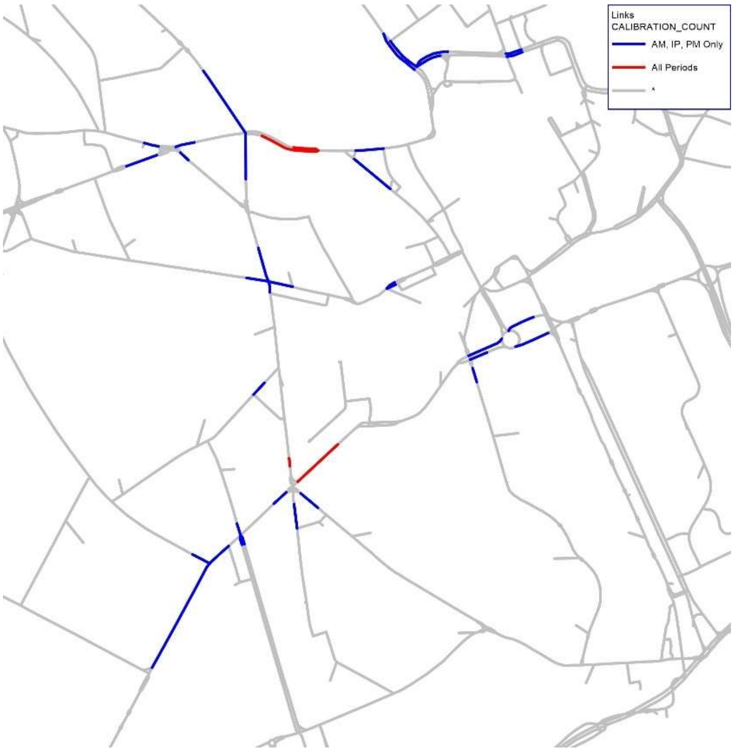
1.5 Adjustment of Traffic Flows to Count Data

A significant amount of count data was collected by Cardiff Council in the city centre in March 2022, covering:

- ANPR counts (as described above);
- Two-week Automatic Traffic counts (ATCs) (collected 28th February-20th March 2022);
- Single day (12 hour) manually classified link counts (as described above); and
- Single day (12 hour) manually classified turning counts (collected on 3rd March 2022).

Various movements were covered more than once in the dataset, for example some ATC locations also had a single day manually classified count, and some manually classified link counts occurred on junctions with individual arms that also had a single day count. A subset of the data was used to calibrate the model, with preference given to longer term ATCs over manually classified counts, and manually classified turning counts amalgamated to link counts where appropriate (turning movements were not specifically calibrated). The data was processed to modelled time periods and comparisons made between observed and modelled car and total flows. The location of the links with calibration counts is shown below in Figure 1.2.

Figure 1.2: Model Link Counts Used in Calibration Process



The adjustment process was complicated by the increased number of demand segments used in the assignments. The dataset also represents a much denser set of counts than would usually be applied to a strategic model, with significant variations owing to a high proportion of single day counts, therefore significant effort was required in getting the matrix estimation process to run. As a result, a lower proportion of passing links was considered acceptable than would usually be applied. In some cases, a lower overall pass rate was accepted to improve the fit to counts on Castle Street and Westgate Street. Comparisons were made on the basis of the GEH criterion only, for cars and all vehicles. The proportion of counts with a GEH statistic of less than 5, post matrix-estimation, is shown below in Table 1-1.

Table 1-1: Link Flow Comparison Following Matrix Estimation

		Cars		**All Vehicles**	
Time Period	Total Sites	Number GEH < 5	Proportion GEH <5	Number GEH < 5	Proportion GEH <5
AM	60	52	86.7%	50	83.3%
IP	60	50	83.3%	49	81.7%
PM	60	43	71.7%	44	73.3%
OP	6	6	100.0%	6	100.0%

Due to the importance of matching flows accurately for the air dispersion model, and the layout of the counts not allowing parallel screenlines to be formed, no counts were kept back for independent validation. TAG guidance usually specifies that matrix estimation should only be carried out on an unadjusted prior matrix, however given the need to adjust a cordon matrix which had been forecast from the model's base year of 2015, this was not possible in this instance.

Following the adjustment of the flows to the count data, base year link flows and speeds were supplied to Ricardo Energy and Environment to facilitate development and calibration of the base year air dispersion model.

2 Do-Minimum Forecast

The DfT's National Trip End Model (NTEM) was used to apply growth to the base year model to develop a 2024 DM forecast. That process is described in this section.

2.1 Coding Do-Minimum Schemes

The following schemes were coded into the highway networks:

- Extension of the westbound bus lane on Cowbridge Road East to within 60m of the Cowbridge Road East/Cathedral Road junction; and
- Updates to the signal timings at the above junction.

2.2 Highway Assignment Parameters

Highway assignment parameters (VoT and VOC) were generated using the same (May '22) version of the TAG databook as for the base model.

2.3 Forecast Demand Changes

Origin/destination trip end information was extracted from NTEM 8 as follows:

- NTEM 8 core scenario only;
- Car driver only;
- Covering trips with an origin/destination in the Cardiff Local Authority;
- By trip purpose (15 NTEM trip purposes);
- Data for 2022 and 2024; and
- By time period (NTEM definitions).

Trip end forecasts for the 15 NTEM purposes were amalgamated to the highway assignment model's three trip purposes. It was assumed that:

- Calculated growth factors were suitable for application to all matrices of a given purpose (taxi electric, taxi non-electric and other cars); and
- Factors for the NTEM time periods could be applied directly to the equivalent model time periods (though the time period definitions are not identical).

Separate origin and destination trip growth factors were calculated, as well as an origin/destination average, as shown below in Table 2-1.

Table 2-1: Applied Car Growth Rates 2022-24

		AM			IP			PM			OP	
Purpose	Origin	Dest	O/D	Origin	Dest	O/D	Origin	Dest	O/D	Origin	Dest	O/D
Commute	2.3%	1.8%	2.0%	1.9%	2.0%	2.0%	1.8%	2.3%	2.0%	1.6%	1.7%	1.7%
Business	2.3%	1.9%	2.1%	1.9%	1.9%	1.9%	1.9%	2.2%	2.0%	1.9%	2.2%	2.1%
Other	2.4%	2.0%	2.2%	2.3%	2.3%	2.3%	2.1%	2.2%	2.2%	2.1%	2.2%	2.2%

The factors were applied as follows:

- Trips with an origin within the cordon and a destination at the cordon boundary – origin factor;

- Trips with an origin at the cordon boundary and a destination within the cordon – destination factor; and
- Other trips – average origin/destination factor.

Growth for goods vehicles was generating using RTF 2018 and applied at a whole matrix level as shown below in Table 2-2.

Table 2-2: Goods Vehicle Growth

Vehicle Type	LGV	HGV
Growth 2022-24	1.6%	-0.2%

The networks were subsequently reassigned, and the outputs provided to Ricardo Energy and Environment as the 2024 DM for an initial air quality assessment.

2.4 Do-Something Scheme Coding

The two do-something schemes were subsequently coded into the networks:

- Option 1 – Castle Street closed to general traffic, taxis (and buses) allowed only; and
- Option 2 – Castle Street closed to general traffic, fully electric taxis (and buses) allowed only.

Signal timings were also updated at the following junctions, based on initial outputs from a microsimulation model of the area developed by AECOM:

- Boulevard des Nantes / North Road junction; and
- Castle Street / Westgate Street Junction.

The networks were subsequently reassigned, and the outputs provided to Ricardo Energy and Environment as the 2024 DS for an initial air quality assessment.

2.5 Signal Updates

Cordon matrices for the microsim model were then extracted from the initial DM and DS forecasts and supplied to AECOM, who then provided updated signal timings for the following junctions, which were coded into the model:

- Tudor Street / Clare Road;
- Cowbridge Road East / Cathedral Road;
- Castle Street / Westgate Street; and
- North Road / Boulevard de Nantes.

Concurrently, Mott MacDonald were made aware of recent changes implemented to the layout of the Tudor Street/Clare Road junction, which were also coded into both the DM and the DS.

Both the DM and DS models were then reassigned, and flow/speed outputs provided to Ricardo Energy and Environment to undertake a full air quality assessment using the final networks.

3 Model Results

This section briefly outlines the impact of the Castle Street scheme options.

3.1 Option 1 Flow Difference Plots

The forecast changes in traffic flow, flow differences, (compared to the DM) for Option 1 for the AM peak are shown below in Figure 3.1 and Figure 3.2. As would be expected there is a significant reduction in Castle Street in both directions, extending northwards along North Road. The decrease in traffic is more significant east of Westgate Street, since this is the section which the closure is specifically applied to. East of Westgate Street there is a reduction in flow of around 800 vehicles in each direction, west of Westgate Street the reduction is approximately 500 vehicles per direction. The model forecasts only a slight change in flow on Westgate Street, since in both scenarios there is already a bus and taxi gate in operation. As this is a fixed trip assignment test, there are corresponding decreases in flow on alternative routes. In particular, the largest increases are along the A4232 and A4234, and along the A48. These routes are now facilitating the east-west movements across the city centre rather than Castle Street.

Figure 3.1: Castle Street Option 1, Flow Difference vs DM, AM Peak View 1

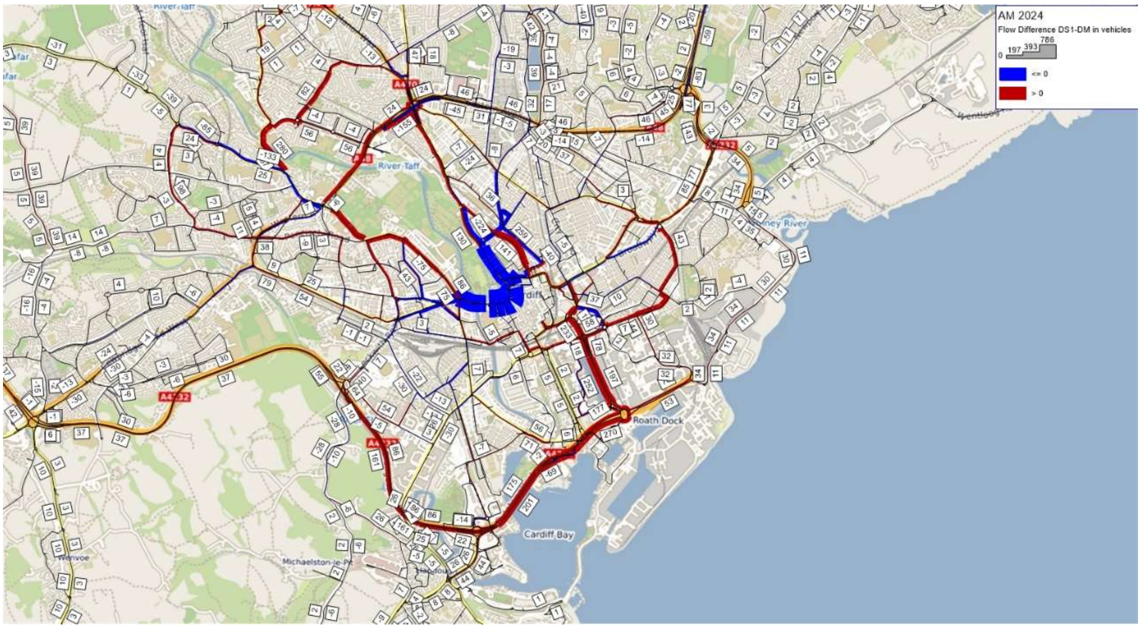
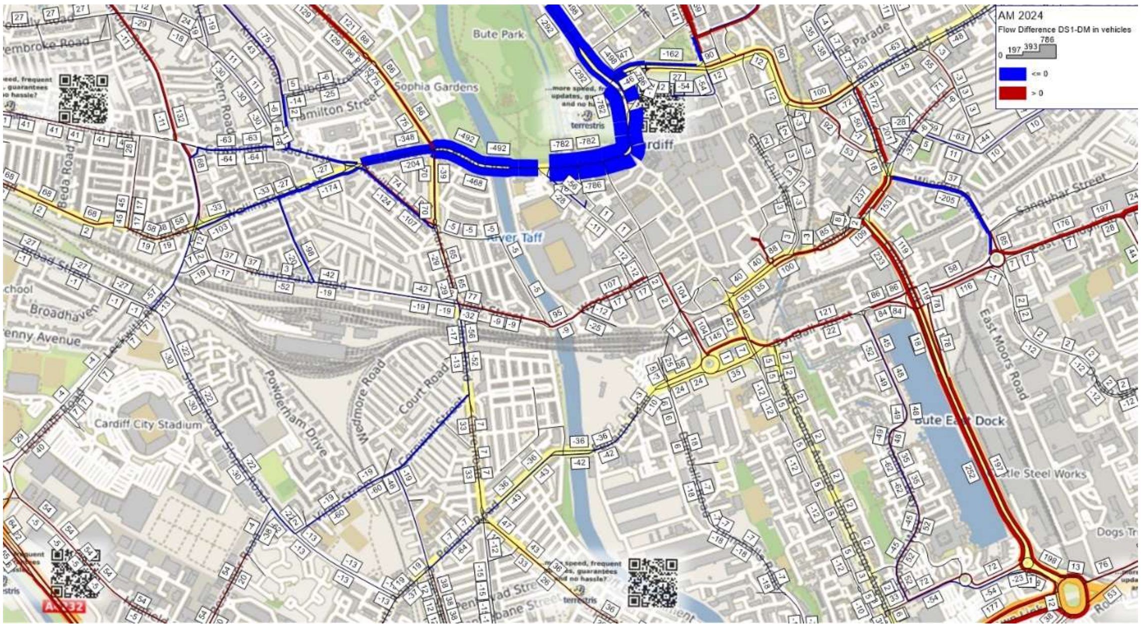


Figure 3.2: Castle Street Option 1, Flow Difference vs DM, AM Peak View 2



The flow differences (compared to the DM) for Option 1 for the PM peak are shown below in Figure 3.3 and Figure 3.4. Similar patterns to the AM peak are reflected in the PM peak, with traffic flow reductions on Castle Street being offset by increases on the A4232, A4234 and A48. The flow reduction on Castle Street is again greater on the section east of Westgate Street than the section to the west, though the eastbound decrease is more pronounced compared to westbound; in the AM peak the flow reduction is closely matched across directions. The flow reduction eastbound is approximately 600 vehicles west of Westgate Street and approximately 1,000 vehicles east of Westgate Street. Eastbound, these figures are approximately 250 and 550 vehicles, respectively.

Figure 3.3: Castle Street Option 1, Flow Difference vs DM, PM Peak View 1

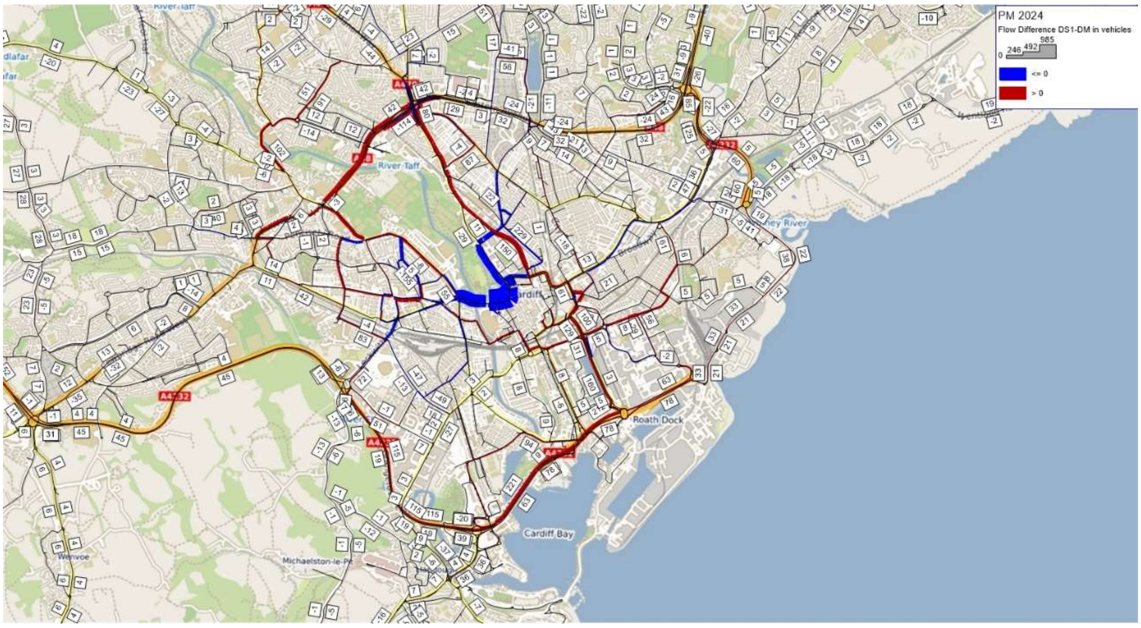
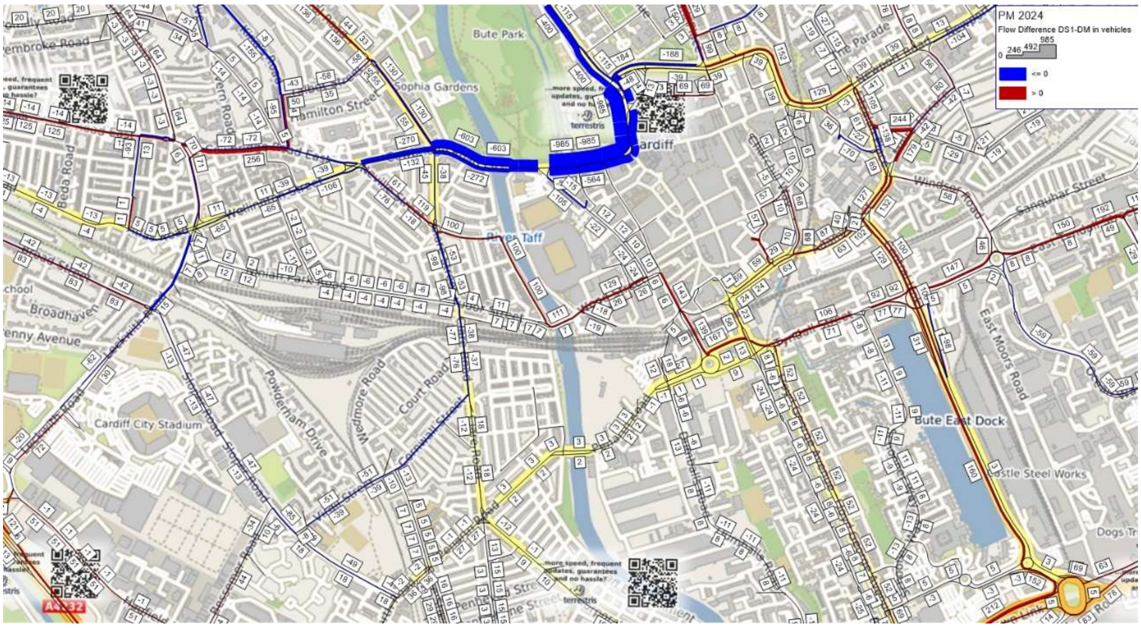


Figure 3.4: Castle Street Option 1, Flow Difference vs DM, PM Peak View 2



3.2 Option 2 Flow Difference Plots

Flow difference plots (compared to the DM) for Option 2 for the AM peak are shown below in Figure 3.5 and Figure 3.6. The patterns shown are almost identical to those for Option 1. This is to be expected, since there is only a marginal difference between the schemes, with non-electric taxis (representing just less than 9% of the car demand) now being banned from Castle Street in addition to non-taxi cars. West of Westgate Street there are around 550 fewer vehicles eastbound and around 500 fewer vehicles westbound (for Option 1 this was approximately 500 vehicles in each direction). East of Westgate Street flows reduce by around 850 vehicles in each direction, compared to the value of 800 for Option 1.

Figure 3.5: Castle Street Option 2, Flow Difference vs DM, AM Peak View 1

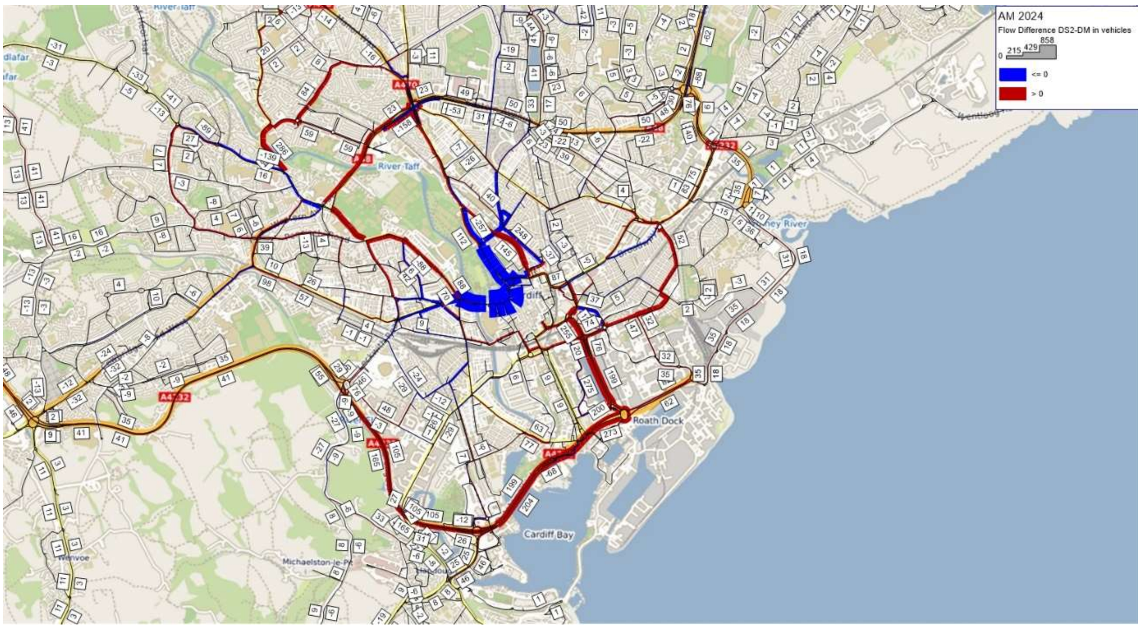


Figure 3.6: Castle Street Option 2, Flow Difference vs DM, AM Peak View 2

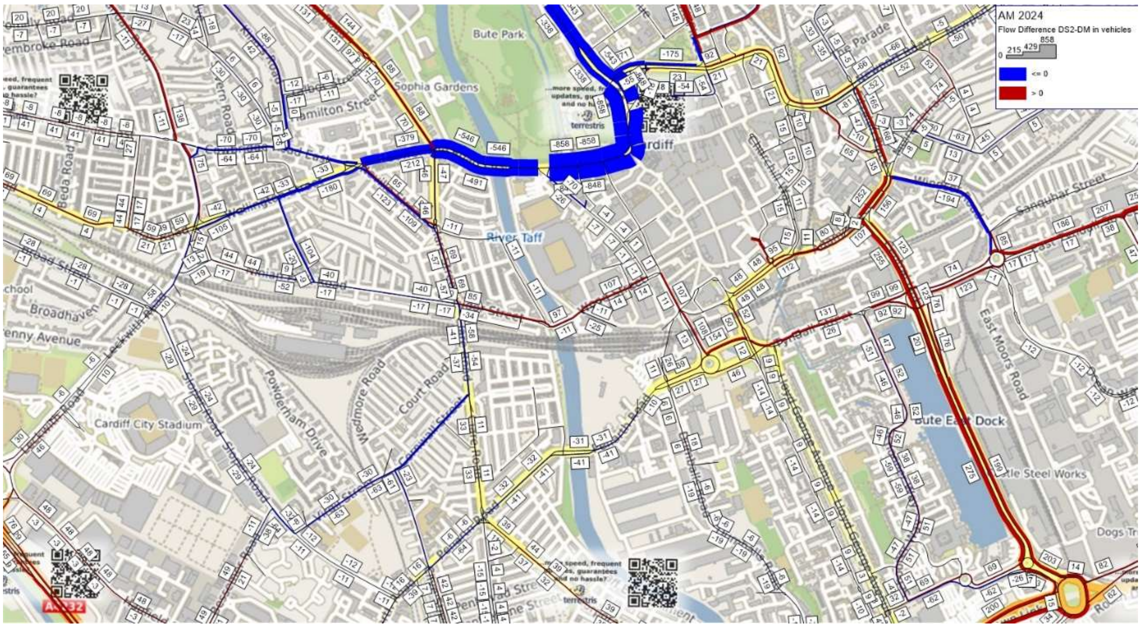


Figure 3.7 and Figure 3.8 below illustrate the flow differences arising from Castle Street Option 2 in the PM peak. Similar patterns are seen again when compared with the changes brought about by Option 2, with small increases in the size of flow reductions on Castle Street and nearby links, commensurate with the further changes in Option 2.

Figure 3.7: Castle Street Option 2, Flow Difference vs DM, PM Peak View 1

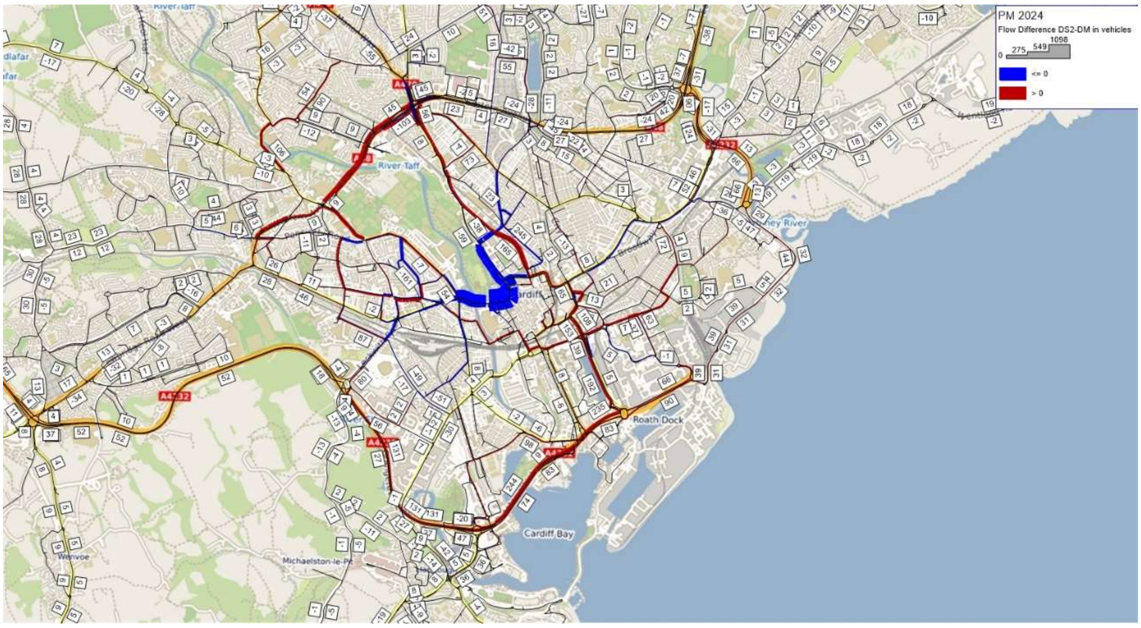
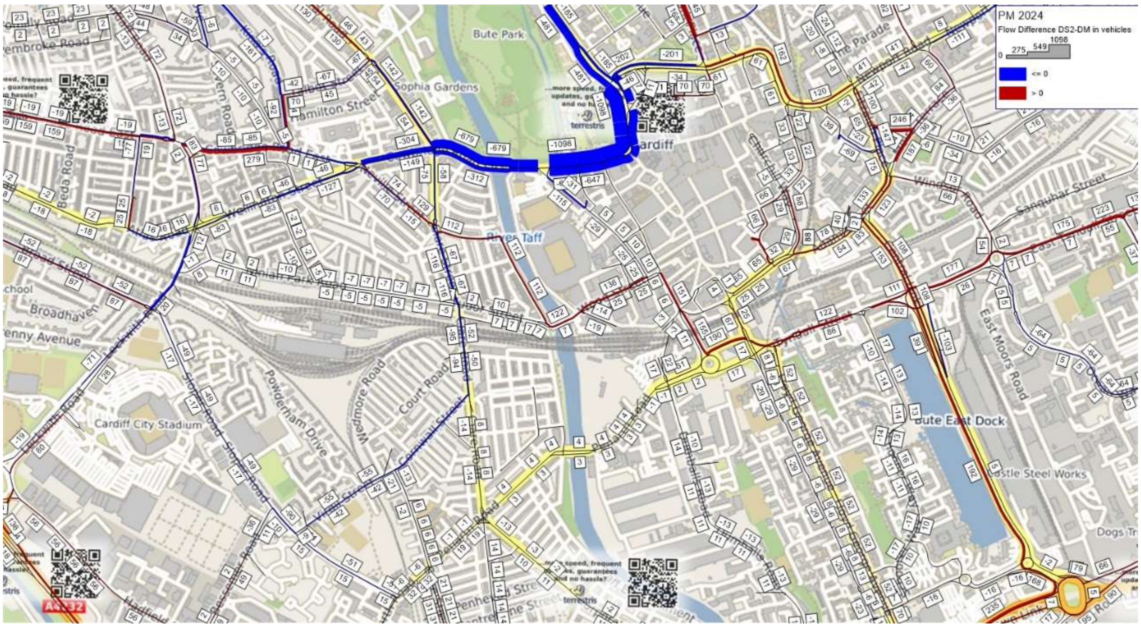


Figure 3.8: Castle Street Option 2, Flow Difference vs DM, PM Peak View 2



3.3 Flows on Key Links

Table 3-1 below illustrates the forecast changes in traffic flow on Castle Street and other key links for Option 1, corresponding to the flow differences show in Figure 3.1 - Figure 3.4. The most significant changes, both in percentage and absolute terms, are the decreases in flow on Castle Street east of Westgate Street. Whilst greater changes are forecast on other links in absolute terms, the second most affected location with respect to percentage change is Cowbridge Road East. At a 24-hour level there are increases on Cathedral Road, though there are decreases for some directions and time periods. Table 3-2 displays the same information for Option 2, with similar patterns observed.

Table 3-1: Key Link Flow Changes DM vs DS1

Link	Direction	DM Flow (Demand)			DS1 Flow (Demand)			Change (Absolute)			Change (%)		
		AM	PM	AAWT	AM	PM	AAWT	AM	PM	AAWT	AM	PM	AAWT
Castle St (east of Westgate St)	EB	870	1110	9770	90	120	1050	-780	-990	-8720	-90%	-89%	-89%
	WB	860	660	9630	70	90	1070	-790	-560	-8560	-92%	-86%	-89%
Castle St (west of Westgate St)	EB	910	880	9060	420	280	4640	-490	-600	-4420	-54%	-68%	-49%
	WB	640	530	8680	170	260	4250	-470	-270	-4430	-73%	-51%	-51%
Westgate St (north of bus gate)	NB	170	340	4810	140	230	3980	-30	-110	-830	-16%	-31%	-17%
	SB	430	230	5030	380	210	4370	-60	-20	-660	-13%	-7%	-13%
Boulevard De Nantes	EB	770	400	6990	520	220	4190	-250	-180	-2800	-32%	-46%	-40%
	WB	320	630	6620	270	580	4850	-50	-50	-1770	-14%	-8%	-27%
North Road (north of Blvd de Nantes)	NB	610	1070	8990	320	670	5350	-290	-400	-3640	-48%	-37%	-40%
	SB	1040	390	9220	540	280	4710	-500	-120	-4520	-48%	-29%	-49%
Cathedral Road (north of Castle St)	NB	430	400	5710	500	460	6730	80	60	1020	18%	14%	18%
	SB	520	540	5240	600	410	6070	90	-130	840	17%	-24%	16%
Cowbridge Rd E (west of Cathedral Rd)	EB	440	340	3860	90	70	1190	-350	-270	-2660	-80%	-80%	-69%
	WB	270	190	3290	70	60	1130	-200	-130	-2160	-76%	-68%	-66%

Table 3-2: Key Link Flow Changes DM vs DS2

Link	Direction	DM Flow (Demand)			DS2 Flow (Demand)			Change (Absolute)			Change (%)		
		AM	PM	AAWT	AM	PM	AAWT	AM	PM	AAWT	AM	PM	AAWT
Castle St (east of Westgate St)	EB	870	1110	9770	10	10	130	-860	-1100	-9640	-99%	-99%	-99%
	WB	860	660	9630	10	10	170	-850	-650	-9470	-99%	-99%	-98%
Castle St (west of Westgate St)	EB	910	880	9060	370	200	4180	-550	-680	-4880	-60%	-77%	-54%
	WB	640	530	8680	150	220	3920	-490	-310	-4760	-77%	-58%	-55%
Westgate St (north of bus gate)	NB	170	340	4810	140	220	3850	-30	-110	-960	-15%	-34%	-20%
	SB	430	230	5030	360	200	4130	-70	-30	-900	-16%	-14%	-18%
Boulevard De Nantes	EB	770	400	6990	490	200	3940	-270	-200	-3050	-35%	-50%	-44%
	WB	320	630	6620	260	580	4740	-60	-50	-1880	-17%	-7%	-28%
North Road (north of Blvd de Nantes)	NB	610	1070	8990	270	590	4820	-340	-480	-4170	-56%	-45%	-46%
	SB	1040	390	9220	500	210	4070	-540	-190	-5160	-52%	-47%	-56%
Cathedral Road (north of Castle St)	NB	430	400	5710	500	450	6750	70	50	1040	16%	14%	18%
	SB	520	540	5240	600	400	6110	90	-140	870	17%	-26%	17%
Cowbridge Rd E (west of Cathedral Rd)	EB	440	340	3860	60	40	940	-380	-300	-2920	-87%	-90%	-76%
	WB	270	190	3290	60	40	990	-210	-150	-2290	-79%	-77%	-70%

4 Economic Assessment Using TUBA

An economic assessment of the schemes has been undertaking using the fixed trip assignments with DfT's TUBA software. This section outlines the process and results for this analysis, based on a single year assessment.

4.1 Software and Economic File Versions

The economic assessment was undertaken using v1.9.17 of the TUBA software (the most up to date available). The economics inputs were based on the standard v1.9.19.0 release of the economics file, derived from the May '22 version of the TAG databook (designed to work with v1.9.17 of the software). Modifications were made to the economics file to combine the OGV1 and OGV2 goods vehicle classes into a single HGV class. Since the economic assessments were run, an updated version of the economics file has become available.

4.2 Other Parameters

The following assumptions were made as part of this assessment:

- First year: 2024;
- Horizon year: 2024;
- Modelled year: 2024; and
- Current year: 2023.

Given that a single forecast year has been modelled, TUBA requires both the first year and horizon year to be the same as the modelled year. The (dis)benefits discussed in this section are therefore only applicable to the single modelled year and would need to be profiled to cover the full appraisal period. This would require, amongst other things, an understanding of the changes to the proportion of taxis which are fully electric.

Annualisation factors have been applied representing the SEWTM hour to time-period factors multiplied by the usual number of weekdays in a year (253) – (dis)benefits covered in this section therefore only account for weekdays. These factors are:

- AM peak: 556;
- Inter-peak: 1518;
- PM peak: 601; and
- Off peak: 3289.

4.3 Treatment of Taxis and Non-Taxis

For ease of running the TUBAs, the two sets of taxi demand segments (electric and non-non-electric, by purpose) have been run through separate TUBAs assuming the same parameters as general cars. Parameters may differ between taxis and general cars in reality (and also between electric and non-electric taxis, particularly with respect to greenhouse gas emissions), however this approach is considered to be proportionate. Further, a full set of parameters specific to these types of vehicles is not presently available. General cars have been assessed using the same TUBA run as for HGVs and LGVs.

4.4 TUBA Results

4.4.1 Disbenefit Totals

The total disbenefits of the two scheme options across all time periods and user classes are shown below in Table 4-1. These values represent single year disbenefits and are (as standard) presented in 2010 prices, discounted to 2010. Modelling has been undertaken on a highway-basis only, therefore PT fare benefits are not shown in this table. For a frame of reference, the single year (2021) disbenefit for the CASAP package of schemes submitted during the final business case for the previous study was -£3.2m across all benefit types.

Table 4-1: Castle Street Scheme TUBA Results by Benefit Type, 2024 Values in 2010 Prices, Discounted to 2010

Scenario	Time benefit	Fuel VOC benefit	Non-fuel VOC benefit	Change in indirect tax revenue	Green House Gases	Total
DS1	-£6,949,000	-£1,223,000	-£858,000	£680,000	-£550,000	**-£8,900,000**
DS2	-£7,813,000	-£1,322,000	-£924,000	£735,000	-£594,000	**-£9,918,000**

As would be expected, the largest component of the disbenefit arises from user time in both scenarios. The disbenefit arises as travellers must take more circuitous routes as travel via Castle Street is now disallowed for most user classes. The disbenefit for Option 2 is greater than for Option 1 since in this scenario non-electric taxis, as well as non-taxi cars, LGVs and HGVs are subject to the restrictions. The additional user time disbenefit is in line with expectations, given the proportion of cars which are non-electric taxis.

There are VOC disbenefits in both options, owing to the increased network vehicle-km. Correspondingly, there are disbenefits in terms of greenhouse gas emissions, and benefits in terms of indirect tax revenue.

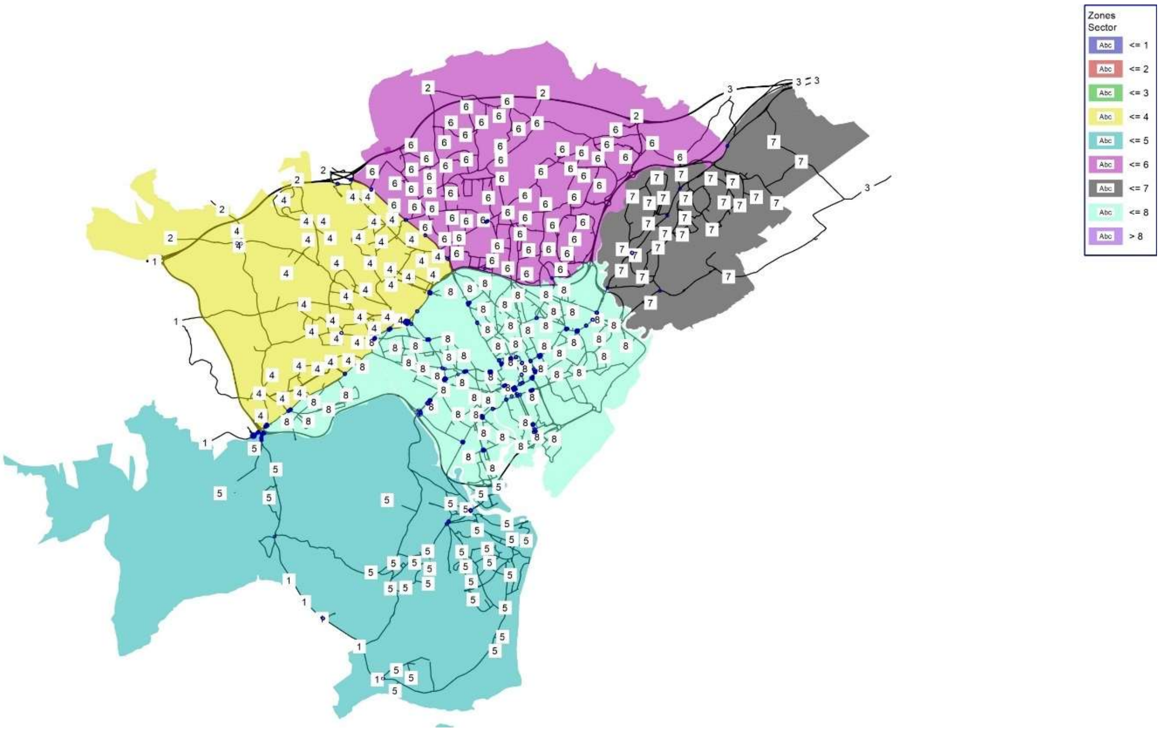
Were the Castle Street options assessed using a variable demand model run, it is likely that the disbenefits presented above in Table 4-1 would be lower. Likewise, the model operates on fixed timings for signals, which have not been altered for the DS scenarios except for a small area in the vicinity of the scheme; as there are significant traffic flow changes over a much larger area, disbenefits could be alleviated by optimising signal timings, as might naturally be expected to occur where traffic signals are demand actuated.

4.4.2 Sectorised Results

A sector system has been defined as follows, and as shown below in Figure 4.1:

- Sector 1: External West;
- Sector 2: External North;
- Sector 3: External East;
- Sector 4: Internal North West;
- Sector 5: Internal SW Of A4232;
- Sector 6: Internal North;
- Sector 7: Internal East: and
- Sector 8: Internal Central.

Figure 4.1: Sector Definitions



For the purposes of brevity, only sectorised values for time benefit and across all time periods and demand segments are shown in this report. A spreadsheet has been supplied containing pivot tables to enable the user to interrogate these results in greater detail.

4.4.2.1 Option 1 Sectorized Results

Table 4-2 below shows the sectorised time disbenefits for Option 1. Sector 8, where Castle Street is situated, shows the most significant disbenefits, with around a third of the total time disbenefit deriving from intra-sector trips within this area. Approximately 80% of the total time disbenefit arises for movements with at least one trip end in this sector. Whilst disbenefits are significant, this illustrates that they are predominantly limited to an area within the vicinity of the scheme itself. Other than sector 8, the most significant disbenefits are between Sector 4 (internal North West) and Sector 6 (internal North). These arise because of reassignment to the A48 and other parallel routes, which are used heavily to facilitate movements between these two sectors.

There are small levels of benefits between some sectors, arising from second order effects of reassignment, for example between sectors 5 and 2. These are small, around 1% of the total disbenefit.

Table 4-2: Sectorised Time Disbenefits - Option 1

	1	2	3	4	5	6	7	8	Grand Total
1	-17,487	-36,021	-73,397	-13,541	-9,128	-78,780	-24,707	-63,720	-316,782
2	-15,108	74	-10,225	-23,659	-9,627	-13,745	-3,008	-71,459	-146,756
3	-29,301	341	4	-44,896	-23,862	6,413	802	-217,760	-308,260
4	-5,032	-10,108	-95,662	-96,452	-3,018	-260,802	-19,060	-281,411	-771,545
5	-36,573	36,045	-56,673	-19,220	-12,970	-73,863	-40,348	-91,426	-295,030
6	-24,822	9,197	14,102	-129,997	-28,804	11,288	9,707	-337,796	-477,125

	1	2	3	4	5	6	7	8	Grand Total
7	-11,748	-497	-16	-17,705	-33,031	-9,219	-3,873	-100,922	-177,012
8	-174,973	-198,600	-355,196	-434,780	-87,580	-702,729	-149,679	-2,352,932	-4,456,469
Grand Total	-315,044	-199,570	-577,064	-780,250	-208,020	-1,121,438	-230,166	-3,517,426	**-6,948,980**

4.4.2.2 Option 2 Sectorised Results

Table 4-3 below shows the sectorised time disbenefits for Option 2. The sectorised time disbenefits for Option 2 replicate those for Option 1; again, around a third of the disbenefit arises for trips entirely within Sector 8, with around 80% of the disbenefit occurring for movements with at least one trip end in this sector. Otherwise, the largest disbenefits again occur between sectors 4 and 6. Again, the positive benefit totals are around 1% of the total disbenefit.

Table 4-3: Sectorised Time Disbenefits - Option 2

	1	2	3	4	5	6	7	8	Grand Total
1	-20726	-42110	-84398	-15743	-12635	-89194	-28725	-73006	-366538
2	-17503	75	-11740	-26702	4177	-13459	-3856	-88914	-157924
3	-34754	1053	4	-49335	-29436	6960	583	-237542	-342466
4	-6552	-11362	-105840	-109099	-4955	-279701	-21515	-319005	-858028
5	-41399	31404	-63065	-21555	-13824	-85482	-44602	-99093	-337614
6	-31339	10862	16333	-143967	-37076	13654	9321	-410218	-572430
7	-14041	-53	-142	-19146	-38593	-10023	-4250	-117018	-203265
8	-198591	-225377	-392128	-484970	-98997	-780831	-169961	-2624134	-4974989
Grand Total	-364906	-235507	-640976	-870517	-231338	-1238075	-263004	-3968930	-7813253

CARDIFF CASTLE STREET UPDATED AQ ASSESSMENT REPORT

Report for: Cardiff City Council

Ref. PO 4501784228

Ricardo ref. ED16675 Issue: 3 20/02/23

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Cardiff City Council

Customer reference:
PO 4501784228

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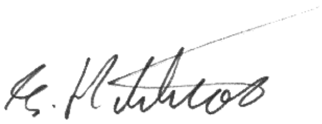

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EXECUTIVE SUMMARY

Ricardo Energy and Environment have undertaken an air pollutant dispersion study at the request by Cardiff City Council to support their understanding of the potential impacts on air quality by a proposed alteration to the current road network scheme for Cardiff Castle Street. Cardiff City Council have requested that only the impacts of the proposed changes on annual averaged concentrations of Nitrogen Dioxide (NO_2) were considered.

Cardiff City Council have requested that two scenarios were modelled for the year 2024 as part of this study:

- Do minimum – No alterations are made to the current Castle Street road scheme
- Do something - Restricting the use of Castle Street to bus and taxis services only

A third model which predicted concentrations across Cardiff for the year 2022 was also run. This model was used to assess the model's performance at locations where real concentrations were captured by the local NO_2 monitoring network.

Additionally, Cardiff City Council are considering a third scenario where access to the Castle Street is restricted to the use of electric buses and taxis only. This scenario was only modelled in an indicative way and not with a full dispersion model run.

This report details the approach undertaken to complete this assessment and the results from the air dispersion modelling.

The results from this study found that:

- The 2022 baseline scenario indicates that there were no exceedances of the NO_2 annual average concentration above the 40µg/m^3 target threshold. There were six locations likely to have been above the 90% compliance threshold i.e. above 36 µg/m^3, and one of these PCM links is on Castle Street. It is noted that only small stretches of these road links were above these thresholds whilst the majority of PCM receptors along these road links are expected to be below 36 µg/m^3.
- The 2024 do minimum model suggests that the maximum concentration on all road links will be below 36 µg/m^3, including on Castle Street.
- The 2024 do something model suggests that the maximum concentration on all road links will be below 36 µg/m^3.

The results from the study therefore show that:

- Annual average NO_2 across Cardiff will be reduced naturally should the assumptions made in the do minimum scenario occur. This will bring the highest NO_2 concentration at PCM receptors to below 36 µg/m^3.
- The 2024 do something model suggests that implementing further action targeting the reduction of annual averaged NO_2 concentration along Castle Street would further reduce concentrations on Castle Street.

CONTENTS

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1. INTRODUCTION

City of Cardiff Council (CCC) has previously carried out a Nitrogen Dioxide (NO_2) Feasibility Study directed by Welsh Government for non-compliance with the NO_2 limit values. The study assessed a number of options to improve air quality and a preferred package, the Clean Air Strategy Action Plan (CASAP), was agreed with Welsh Government to be taken forward. CASAP measures included the removal of one vehicle lane on Castle Street and a replacement cycle way, along with other traffic management measures in the centre, zero emission buses, retrofit existing buses, taxi licensing scheme, and a cycle superhighway.

During lockdown Castle Street was fully closed resulting in improvements in air quality but has since re-opened and is currently operating in line with the CASAP scheme agreed with WG. CCC have requested Ricardo to provide an updated assessment of the current Castle Street scheme with the latest available traffic and air quality data and compare this with an alternative which would see Castle Street closed to all traffic except taxis and buses. This report provides the draft results of this analysis covering:

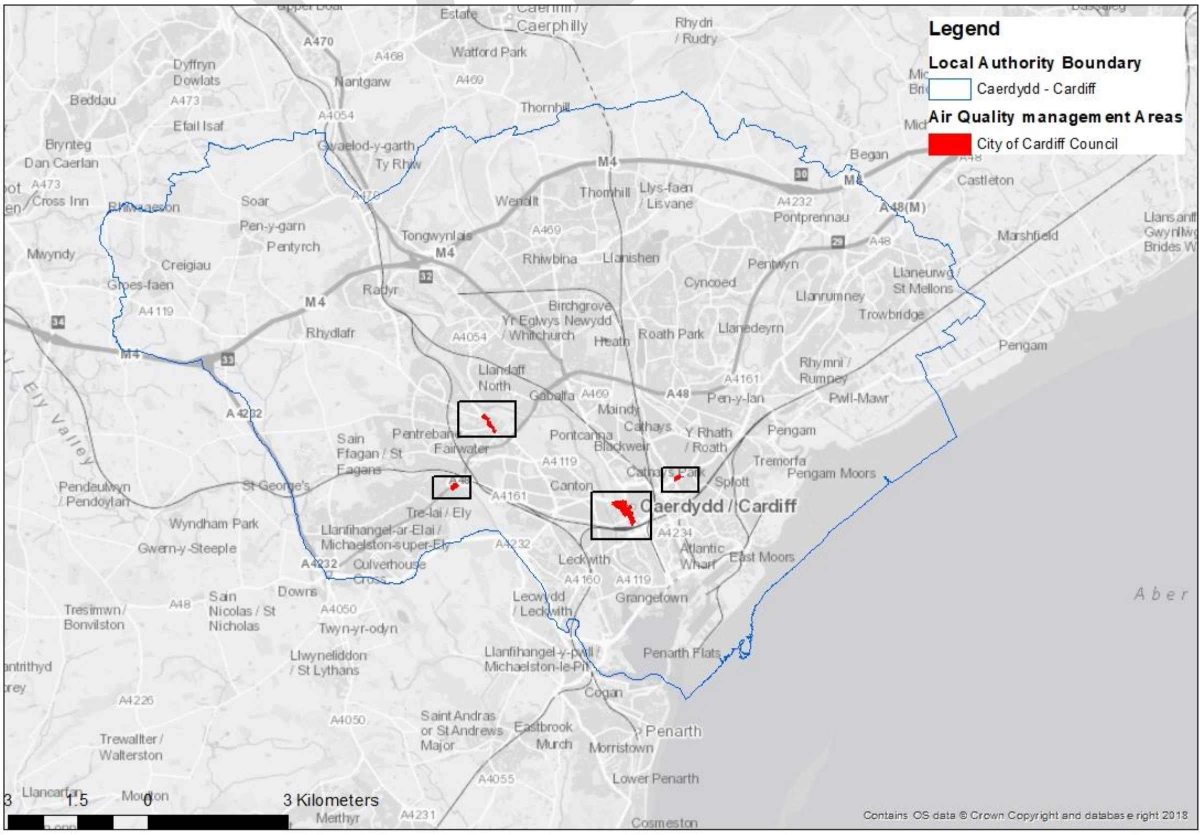
- An updated 2022 base year assessment with the current CASAP scheme in place
- A future 2024 forecast year with the current CASAP scheme in place (the do minimum scenario, DM)
- A future 2024 forecast year with the bus and taxi only scheme option in place (the do something scenario, DS)

An enhancement of the bus and taxi scheme, where only electric buses and taxis are given access, was also consider but has only been assessed in an indicative way as set out in the results.

1.1 BACKGROUND

Cardiff like many other urban areas, has elevated levels of NO_2 due mainly to road transport emissions. As such CCC has designated four Air Quality Management Areas (AQMA) across the city where concentrations of NO_2 breach Government, health-based air quality objectives as shown in Figure 1-1.

Figure 1-1 Cardiff Air Quality Management Areas (AQMA)



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AQMAs cover the city centre, Ely bridge, Stephenson Court, and Llandaff. Cardiff have been proactive in managing air quality prior to the NO_2 feasibility study and proposed measures to improve air quality in these areas, and more widely across the city in the Form of a Clean Air Strategy. Cardiff have also bid for funding for Ultra low emission buses/zero emission buses which will introduce electric buses within Cardiff's AQMAs, and those areas identified within the Welsh Government Interim Supplemental Plan (WGSP), such as the city centre AQMA, Stephenson Court AQMA and the A470 corridor.

Subsequent work by Department for Environment Food and Rural Affairs (Defra) updated its air quality plan using more recent information on the expected real-world emission performance of vehicles. This latest analysis is suggesting that emissions from vehicles will be higher than previously estimated and so breaches of the air quality limits are likely to persist for longer, and over a wider area.

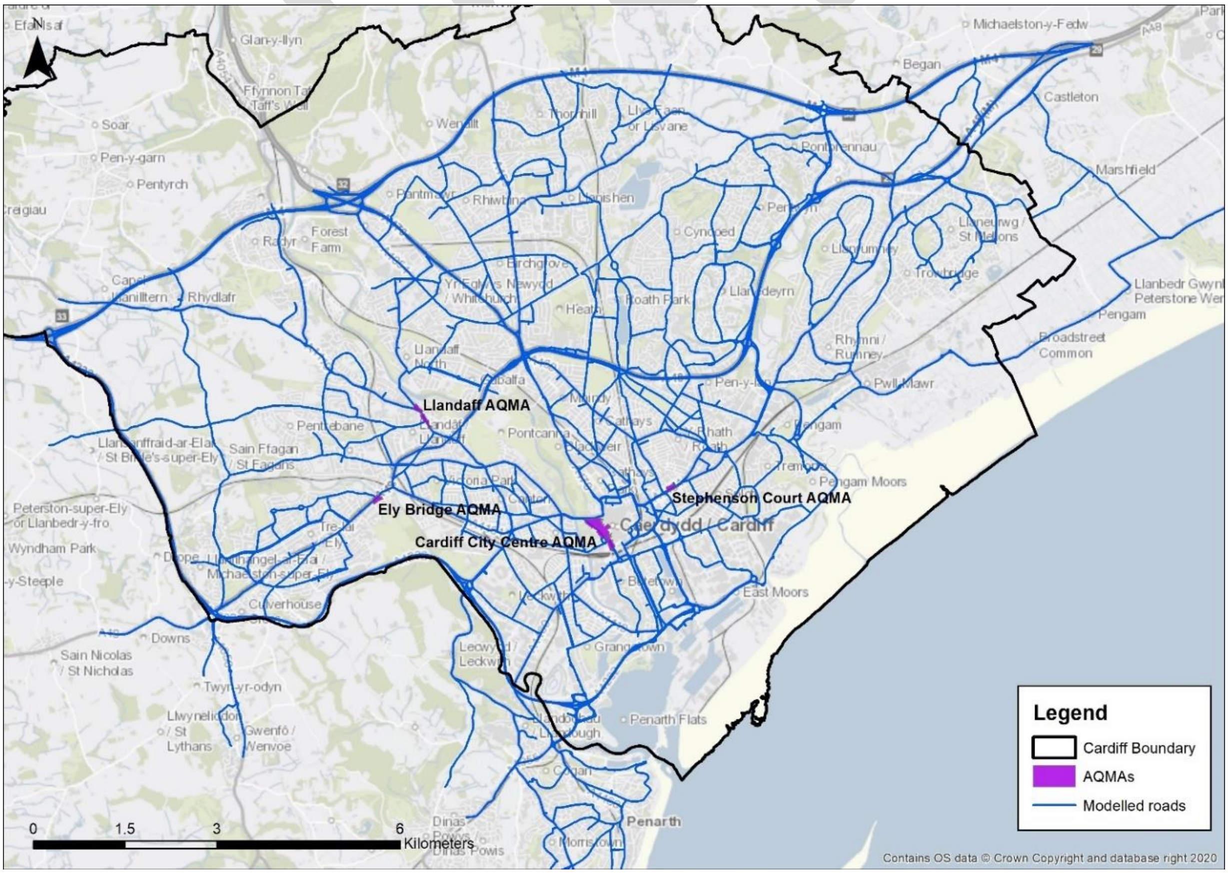
The latest study has carried out a fully updated assessment of air quality in and around Cardiff in relation to European limit values for NO_2 using the latest data on emission factors and traffic activity. This assessment has been used to establish the current extent of any air quality compliance with the existing CASAP scheme, and how this would compare with the bus and taxi only option going forward. This study will focus in particular on Castle Street area where previous exceedance issues were identified.

1.2 MODELLING DOMAIN AND YEARS

Modelling measure options and associated air quality impacts requires a model domain that covers the scheme options, relevant AQMAs and potential diversion routes. Therefore, the model domain shown in Figure 1-2 has been used to cover the following:

- All the AQMAs in Cardiff including the main areas of concern from the national modelling assessment along the A470 and A48;
- The wider transport network out to and including the M4 which will cover all the likely key diversion routes to avoid Castle Street;

Figure 1-2 Model domain



Two key model years are used in the modelling work: a 2022 base year and a 2024 future year (Table 1-1). The base year is taken as 2022 as this is the base year for the most recently validated transport model covering the area. To compliment this, the 2022 air quality data has been used to validate the air quality model.

Table 1-1 Model years

Scenario	Measure
2022	**Base year** – using latest available data on air quality and traffic.
2024	**Future year** – latest date when scheme is due to be in place.

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2. MODEL AND RECEPTOR LOCATION SELECTION

2.1 DISPERSION MODEL

We have used the RapidAir modelling system for the study. This is Ricardo Energy & Environment's proprietary modelling system developed for urban air pollution assessment and the model that was used in other Clean Air Zone feasibility studies such as Derby, London and Southampton.

The model is based on convolution of an emissions grid with dispersion kernels derived from the USEPA AERMOD[1] model. The physical parameterisation (release height, initial plume depth and area source configuration) closely follows guidance provided by the USEPA in their statutory road transport dispersion modelling guidance[2]. AERMOD provides the algorithms which govern the dispersion of the emissions and is an accepted international model for road traffic studies (it is one of only two mandated models in the US and is widely used overseas for this application). The combination of an internationally recognised model code and careful parameterisation matching international best practice makes RapidAir demonstrably fit for purpose for this study.

The USEPA have very strict guidelines on use of dispersion models and in fact the use of AERMOD is written into federal law in 'Appendix W' of the Guideline on Air Quality Models[3]. The RapidAir model uses AERMOD at its core and is evidently therefore based on sound principles given the pedigree of the core model.

The model produces high resolution concentration fields at the city scale (1 to 3m scale) so is ideal for spatially detailed compliance modelling. A validation study has been conducted in London using the same datasets as the 2011 Defra inter-comparison study[4]. Using the LAEI 2008 data and the measurements for the same time period the model performance is consistent (and across some metrics performs better) than other modelling solutions currently in use in the UK. The results of this study have been published in Environmental Modelling and Software[5].

2.1.1 Meteorology

Modelling was conducted using the 2022 annual surface meteorological dataset measured at Cardiff City Centre measurement station. The dataset was processed in house using our own meteorological data gathering and processing system. We use freely available overseas meteorological databases which hold the same observations as supplied by UK meteorological data vendors. Our RapidAir model also takes account of upper air data which is used to determine the strength of turbulent mixing in the lower atmosphere; this was obtained from the closest radiosonde site and process with the surface data in the USEPA AERMET model. We have utilised data filling where necessary following USEPA guidance which sets out the preferred hierarchy of routines to account for gaps (persistence, interpolation, substitution). AERMET processing was conducted following the USEPA guidance. To account for difference between the meteorological site and the dispersion site, surface parameters at the met site were included as recommended in the guidance and the urban option specified for the dispersion site.; land use parameters were accessed from the CORINE land cover datasets[6].

A uniform surface roughness value of 1.0 m was modelled to represent a typical city/urban environment.

2.1.2 Canyon modelling

The platform includes two very well-known street canyon algorithms with significant pedigree in the UK and overseas. The first replicates the functionality of the USEPA 'STREET' model. The code was developed by the Office of Mobile Source Air Pollution Control at the USEPA and published in a series of technical articles

[1] https://www3.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod

[2] https://www.epa.gov/state-and-local-transportation/project-level-conformity-and-hot-spot-analyses

[3] 40 CFR Part 51 Revision to the Guideline on Air Quality Models: Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and Other Revisions; Final Rule, Environmental Protection Agency, 2005

[4] https://uk-air.defra.gov.uk/research/air-quality-modelling?view=intercomparison

[5] Masey, Nicola, Scott Hamilton, and Iain J. Beverland. "Development and evaluation of the RapidAir® dispersion model, including the use of geospatial surrogates to represent street canyon effects." *Environmental Modelling & Software* (2018). DOI: https://doi.org/10.1016/j.envsoft.2018.05.014

[6] EEA (2018) https://www.eea.europa.eu/publications/COR0-landcover

aimed at operational dispersion modellers in the regulatory community[7,8]. The STREET model has been used for many years and has been adopted in dispersion modelling software such as AirViro. The USEPA canyon model algorithms are essentially the same as those recommended by the European Environment Agency for modelling canyons in compliance assessment[9].

The RapidAir model also includes the AEOLIUS model which was developed by the UK Met Office in the 1990s. The AEOLIUS model was originally developed as a nomogram procedure[10]. The scientific basis for the model is presented in a series of papers by the Met Office[11,12,13,14,15.] The model formulation shares a high level of commonality with the Operational Street Pollution Model[1617] (OSPM) which in turn forms the basis of the basic street canyon model included in the ADMS-Roads software. Therefore, the AEOLIUS based canyon suite in RapidAir aligns well with industry standards for modelling dispersion of air pollutants in street canyons.

Using available information on building heights and road widths, candidate locations for street canyons were identified. These locations were then checked using Google Street View to confirm the presence of a street canyon. For roads assigned as street canyons, the required information for the AEOLIUS street canyon model was populated – this includes building height, emissions and number of vehicles per hour. The canyon model is only turned on if the wind is blowing parallel across the canyon (± 5 degrees) i.e. the wind must be between 40 and 50 degrees from the orientation of the canyon. For each hour in the meteorological data (same as that described in 2.1.1) with wind direction matching the criteria to turn the street canyon on, the leeward, windward and parallel street canyon concentrations were calculated. To provide annual street canyon concentrations, the sum of the data contained within each of leeward, windward and parallel was calculated.

The results from the street canyon module were combined with the concentrations modelled in the dispersion step of RapidAir. The annual leeward and annual windward concentrations were added together, then this was added to the dispersion modelled road NO_x.

Figure 2-1 shows the locations of street canyons included in the modelling.

[7] Ingalls., M. M., 1981. Estimating mobile source pollutants in microscale exposure situations. US Environmental Protection Agency. EPA-460/3-81-021

[8] USEPA Office of Air Quality Planning and Standards., 1978. Guidelines for air quality maintenance planning and analysis, Volume 9: Evaluating indirect sources. EPA-450/4-78-001

[9] http://www.eea.europa.eu/publications/TEC11a/page014.html

[10] Buckland AT and Middleton DR, 1999, Nomograms for calculating pollution within street canyons, Atmospheric Environment, 33, 1017-1036.

[11] Middleton DR, 1998, Dispersion Modelling: A Guide for Local Authorities (Met Office Turbulence and Diffusion Note no 241: ISBN 0 86180 348 5), (The Meteorological Office, Bracknell, Berks).

[12] Buckland AT, 1998, Validation of a street canyon model in two cities, Environmental Monitoring and Assessment, 52, 255-267.

[13] Middleton DR, 1998, A new box model to forecast urban air quality, Environmental Monitoring and Assessment, 52, 315-335.

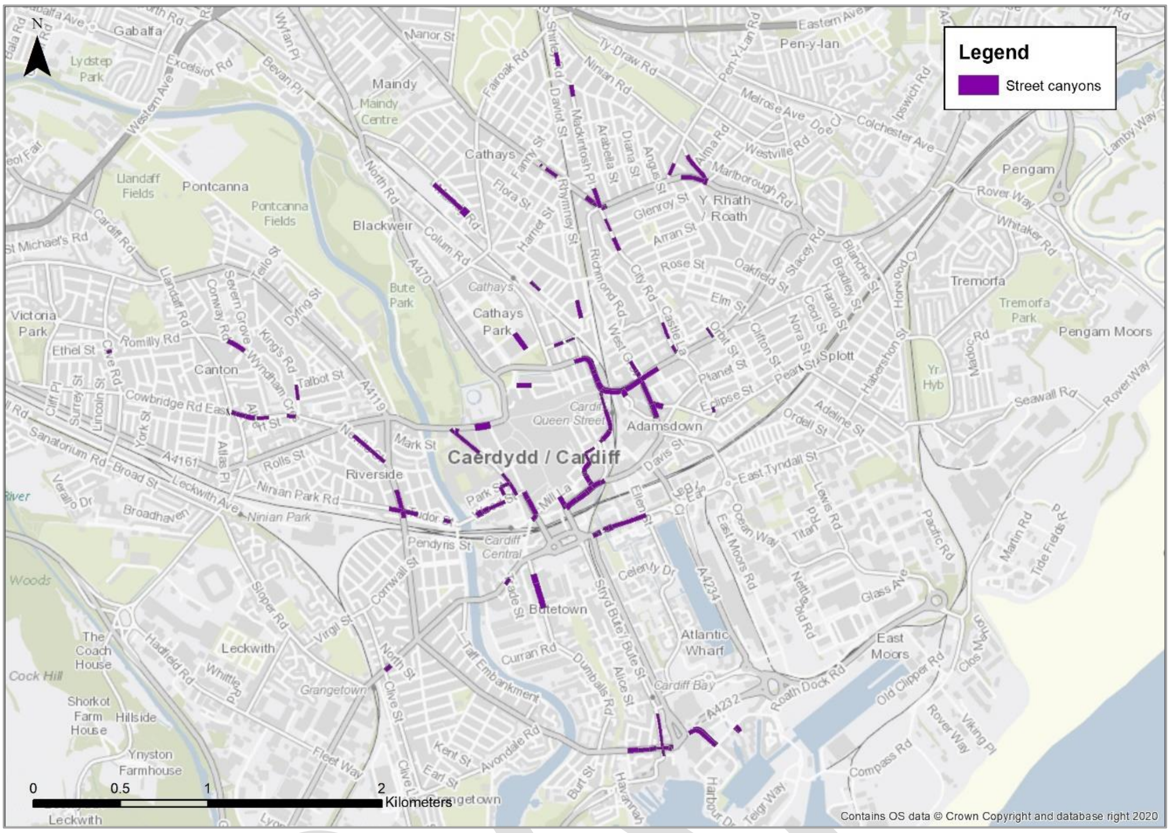
[14] Manning AJ, Nicholson KJ, Middleton DR and Rafferty SC, 1999, Field study of wind and traffic to test a street canyon pollution model, Environmental Monitoring and Assessment, 60(2), 283-313.

[15] Middleton DR, 1999, Development of AEOLIUS for street canyon screening, Clean Air, 29(6), 155-161, (Nat. Soc for Clean Air, Brighton, UK).

[16] Hertel O and Berkowicz R, 1989, Modelling pollution from traffic in a street canyon: evaluation of data and model development (Report DMU LUFT A129), (National Environmental Research Institute, Roskilde, Denmark).

[17] Berkowicz R, Hertel O, Larsen SE, Sørensen NN and Nielsen M, 1997, Modelling traffic pollution in streets, (Ministry of Environment and Energy, National Environmental Research Institute, Roskilde, Denmark).

Figure 2-1 Location of street canyons modelled



2.1.3 Gradient, tunnels and flyovers

Gradient effects have been included for relevant road links during emissions calculations. LIDAR Composite Digital Terrain Model (DTM) and Digital Surface Model (DSM) datasets at 1m resolution are available over the proposed model domain[18]. Link gradients across the model domain can be calculated using GIS spatial analysis of LIDAR datasets.

Figure 2-2 shows the roads where gradient effects were included during emissions calculations.

[18] http://lle.gov.wales/GridProducts#data=LidarCompositeDataset

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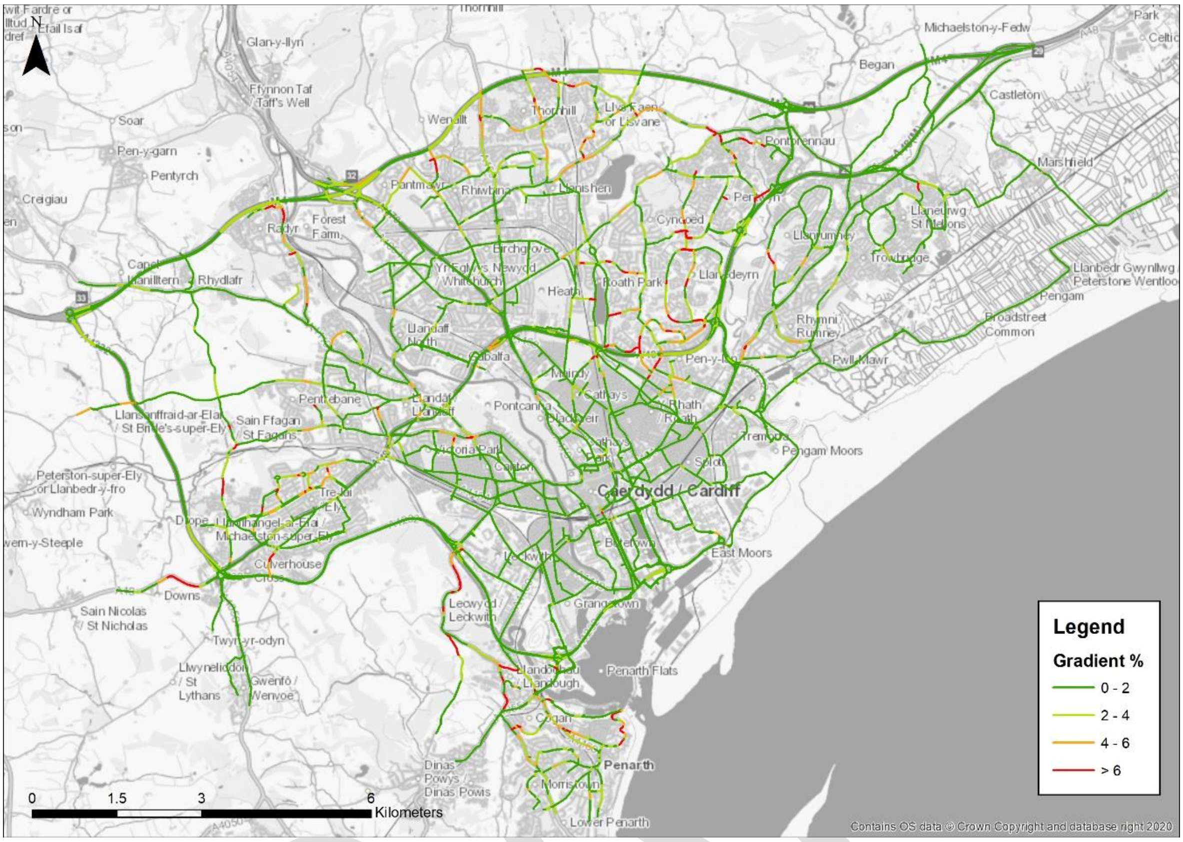
Figure 2-2 Gradient effects (absolute value of gradient percent)



No modelling of tunnels or flyovers was included as the RapidAir kernel approach applies the same source height across the model domain. All roads provided by the traffic modellers within CCC boundary were modelled at ground level, this includes both flyovers and tunnels. For example, the A4232, Cardiff Bay Link Road, flyover and tunnel have been included. If modelling of flyovers was considered to be beneficial for this assessment, we could have modelled road link at a higher elevation using a dispersion kernel created with a different source height in AERMOD. It was not however considered beneficial to do this for this assessment.

2.2 RECEPTOR LOCATIONS

As RapidAir produces concentration grids (in raster format), modelled NO_2 concentrations can be extracted at receptor locations anywhere on the 1m resolution model output grid. For comparison with PCM model results, annual mean concentrations at a distance of 4m from the kerb have been extracted from the RapidAir data and presented as a separate model output file. This will allow the selected locations to be assessed according to the Air Quality Directive (AQD) requirements Annex III A, B, and C3.

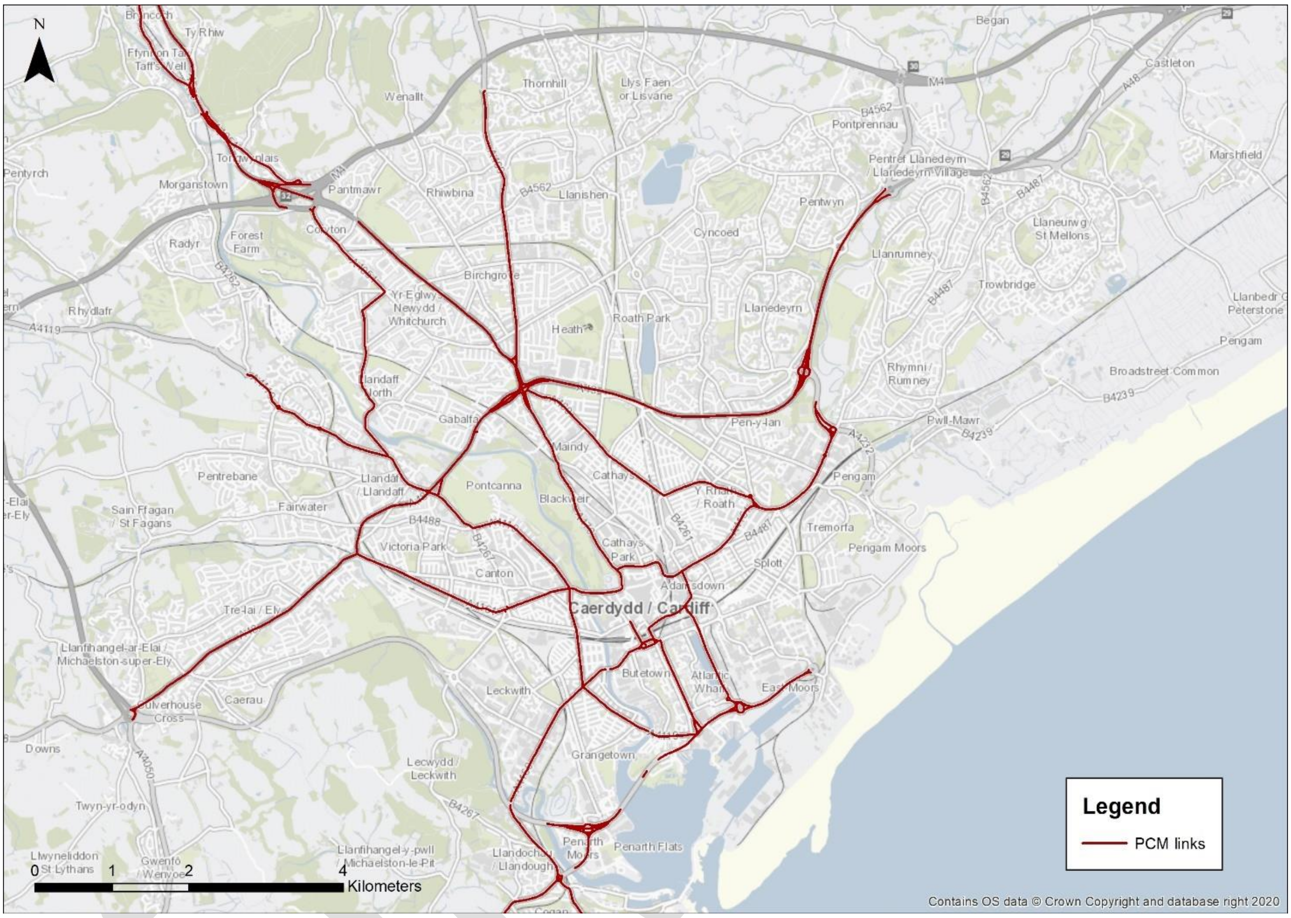
To aid interpretation of the outcomes of the study when considering compliance with the air quality directive (AQD), annual mean concentrations at the roadside exceedance locations identified in the PCM model were extracted from the RapidAir dispersion model results and presented as a separate model output file. Roadside receptor locations in the PCM model are at a distance of 4m from the kerb and at 2m height. A subset of the OS Mastermap GIS dataset provided spatially accurate polygons representing the road carriageway, receptor locations were then placed at 10m intervals along relevant road links using a 4m buffer around the carriageway polygons. For Cardiff's modelling exercise concentrations were sampled at 4m from the kerbside and at a height of 1.5 metres.

Annex III of the AQD specifies that microscale sampling should be at least 25 m from the edge of major junctions. When reporting model results relevant to compliance with the AQD, locations up to 25m from the edge of major junctions in the model domain have also been excluded.

Geospatial analysis permitted point allocation to the closest Census IDs used within the PCM model. The maximum estimated concentration at discrete receptors representative of Census IDs were used for this localised dispersion modelling study. Consequently, the worst-case modelled concentrations are being used in comparison with those from the PCM model.

Figure 2-3 shows the PCM links in Cardiff. PCM receptors generated along these links for the previous modelling work were updated with the latest Census IDs from the PCM 2018 baseline.[19]

Figure 2-3 PCM links



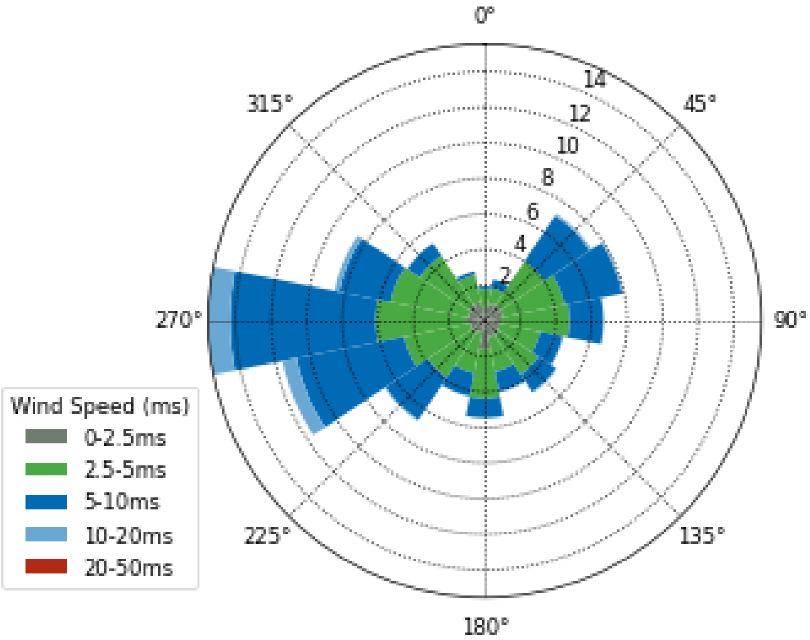
[19] https://uk-air.defra.gov.uk/library/no2ten/2020-no2-pm-projections-from-2018-data

3. BASE YEAR MODELLING

3.1 BASE YEAR AND METEOROLOGICAL DATASET

A baseline year of 2022 has been used as the foundation of this study. The air dispersion model uses the 2022 annual surface meteorological dataset measured at Cardiff City Centre. The model uses an open overseas meteorological databases which hold the same observations as supplied by UK meteorological data vendors. The RapidAir model also takes account of upper air data which is used to determine the strength of turbulent mixing in the lower atmosphere; we have derived this from the closest radiosonde site and process with the surface data in the USEPA AERMET model. Where necessary we have utilised data filling following USEPA guidance which sets out the preferred hierarchy of routines to account for gaps (persistence, interpolation, substitution). A wind rose for the 2022 Cardiff City Centre met dataset is presented in Figure 3-1.

Figure 3-1 Windrose



3.2 ROAD TRAFFIC MODELLING

3.2.1 Average daily vehicle flow and speeds

Baseline and future year annual average daily traffic (AADT) link flows for each model link were calculated using 2022 traffic surveys from the South East Wales Transport Model (SEWTM) that covers the areas of Cardiff, Newport, Caerphilly and east of Swansea. Traffic flows were provided for the following vehicle types; cars, taxis, light goods vehicles (LGV), heavy goods vehicles (HGV). Bus flows were projected to 2022 from the previous modelling dataset using a conversion factor calculated from an analysis of bus timetable information.

Speeds were provided for four modelled periods: AM (peak hour 07:45-08:45), Inter-Peak (average of period 09:30-15:30), PM (peak hour 16:30-17:30) and Off-peak (average between 18:00-07:00). Ricardo calculated the AADT equivalent speeds with a weighted average. This involves summing the multiplication of each peak hour speed by the corresponding period traffic flow and dividing by AADT, see equation below.

$$AADT\ speed = \frac{(AM\ phs\ \times\ AM\ ptf) + (IP\ aps\ \times\ IP\ ptf) + (PM\ phs\ \times\ PM\ ptf) + (OP\ aps\ \times\ OP\ ptf)}{AADT}$$

Where: phs = peak hour speed
ptf = period traffic flow
aps = average period speed

In traffic modelling there is an area of detailed modelling (AODM) and rest of area (ROF), the former denotes areas where the traffic modellers have greater accuracy in traffic forecasts and the latter less accuracy. It has been confirmed all roads links included in the dispersion modelling exercise are within the AODM.

A standard diurnal profile calculated from DfT statistics TRA0307 was considered suitable for representing Cardiff's hourly traffic profile. This diurnal profile was used in RapidAir's dispersion model.

3.2.2 Vehicle fleet composition

The 4 core vehicle fleet types are; cars, LGVs, HGVs and buses. The subcategories of these vehicle types with emission rates are;

- Cars: are split into passenger/private, private hire taxis and hackney taxis;
- LGVs: there is no split for LGVs;
- HGVs: are split into articulated HGVs and rigid HGVs; and
- Buses: there is no split for buses.

These can be calculated using the latest COPERT 5.3 NOx emission functions.

The traffic model provided vehicle flows for four highway user classes which are: Car, LGV, HGV and Buses. HGVs were further broken down into rigid and articulated and cars were divided into private hire and Hackney taxis subcategories, this was undertaken using Automatic Number Plate Recognition (ANPR) data. ANPR locations were selected if they were in an area of key concern for air quality. This includes AQMAs and non-compliance links in the PCM model. One fleet mix was used across Cardiff.

The ANPR survey enables emission rates from road traffic to be represented in the greatest detail possible within COPERT 5.3, which includes:

1. Cars, split between Petrol and Diesel from pre-euro standards up to Euro 6 and alternative technologies such as electric and plug in hybrids;
2. Light Goods Vehicles (LGV) (<3.5 tonnes), split between Petrol and Diesel from pre-euro standards through to Euro 6; LGVs consist of Vans and People Carriers e.g. large passenger cars and mini-buses.
3. Rigid and Artic Heavy-Goods Vehicles (HGV), from pre-euro standards through to Euro 6.
4. Bus and Coach, from pre-euro standards through to EURO VI.
5. Motorcycles are an option within COPERT, however, the NAEI defaults for 2022 and 2024 have been used.

Emission calculations for each vehicle category will be based on vehicle fuel type and Euro classification. Information on the local fuel type mix and Euro standard distribution has been collected from the ANPR surveys conducted over 24 hours on 5th March 2022. The ANPR data were used to calculate the proportions of vehicle types, fuel splits, and Euro classification for the 2022 fleet used in the modelling. The fleet was projected forward to 2024 using NAEI projections for the future year modelling.

Representing Fleet Mixes with ANPR data

ANPR records were matched to the DVLA database. Each individual vehicle which has been captured and matched to the DVLA database has had a vehicle type assigned. Further detail provided includes the vehicle type associated with each vehicle captured e.g. car, LGV, HGV and bus. As mentioned above, there are euro standards for each of the vehicle types, as such these have been associated and used within the COPERT 5.3 emission calculations.

There were few vehicles classified as taxi in the 2022 ANPR dataset, and sub-types of PHV and Hackney were not available. The 2018 ANPR data from the previous modelling was used to determine the taxi fleet split as it was found to represent movement data reliably and included a PHV/Hackney split. It was projected forward to 2022 using 2022 taxi registration data provided by Cardiff County Council.

Figure 3-2 to Figure 3-8 present the Euro classification split for each vehicle type in 2022. For all vehicle types, the ANPR data show a slower fleet renewal in Cardiff than projected by the NAEI.

Figure 3-2 Car fuel type split

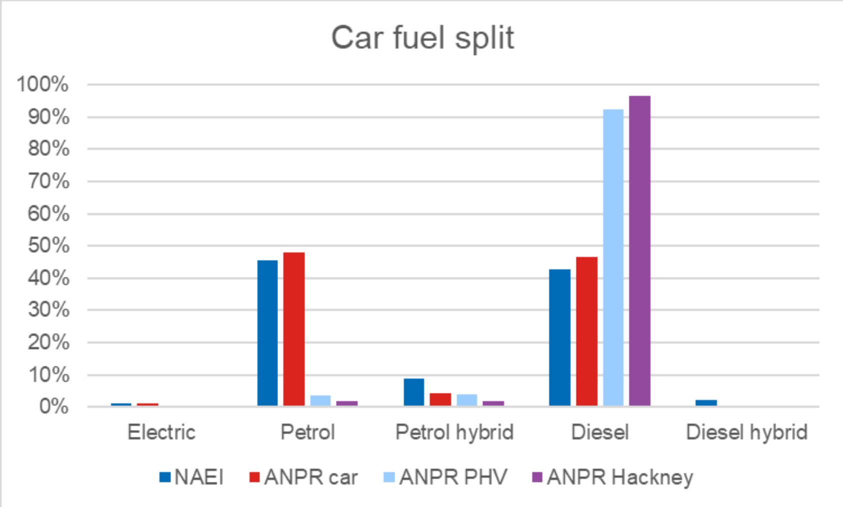


Figure 3-3 Diesel car Euro classification distribution

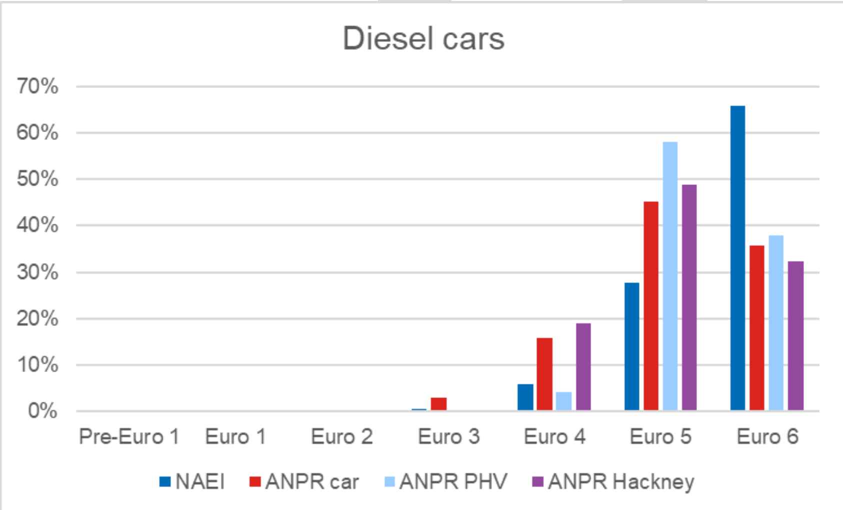


Figure 3-4 Petrol car Euro classification distribution

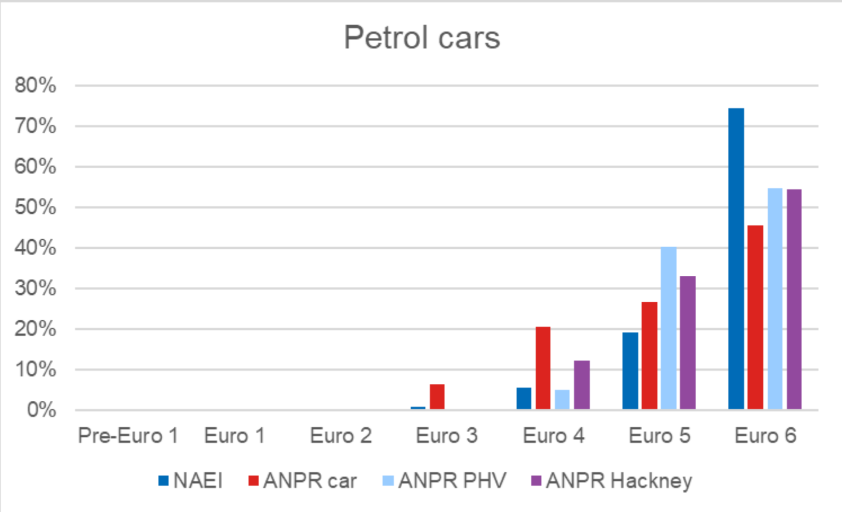


Figure 3-5 Diesel van Euro classification distribution

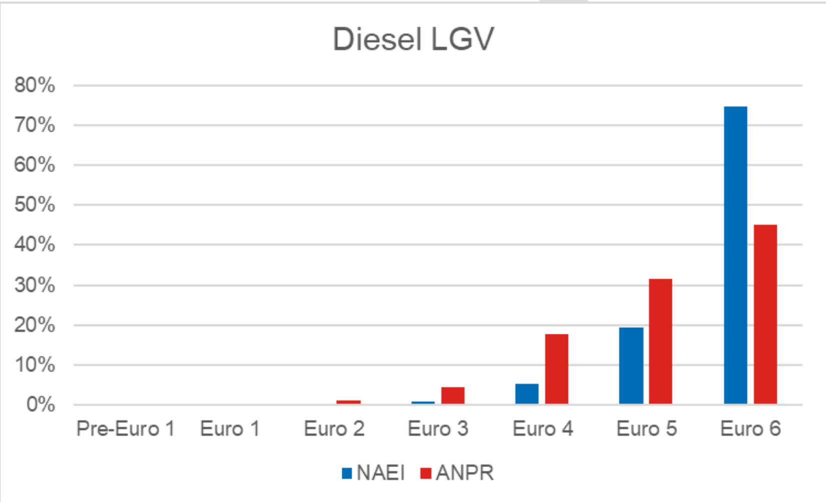


Figure 3-6 Rigid HGV Euro Classification distribution

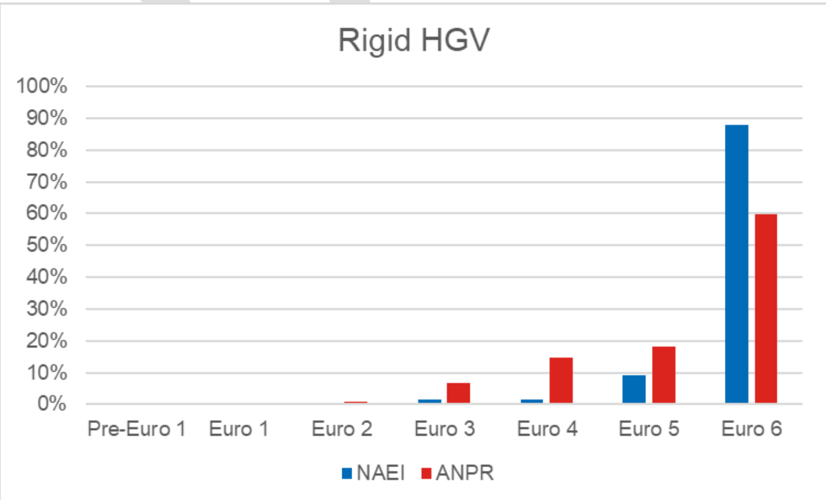


Figure 3-7 Artic HGV Euro Classification

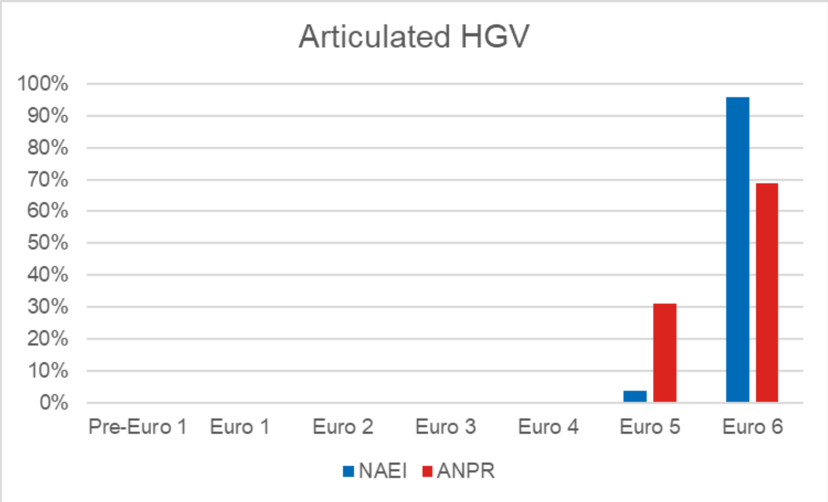
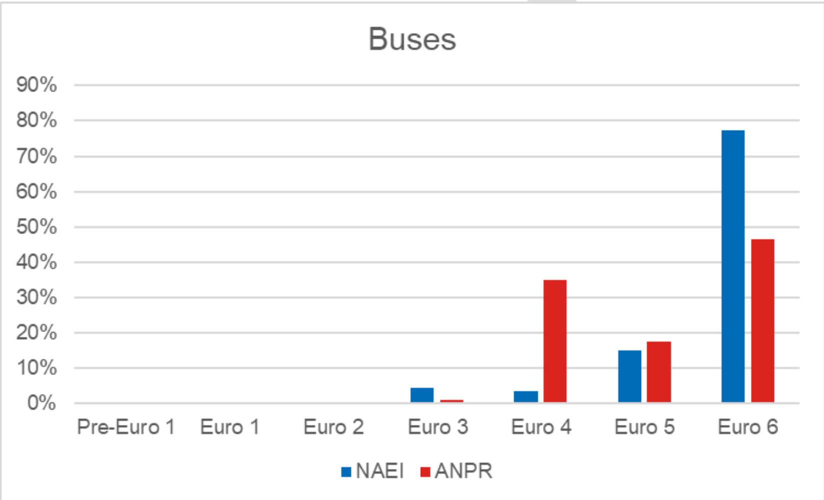


Figure 3-8 Bus Euro Classification



3.2.3 NOx/NO2 emissions assumptions

Link specific NOx emission factors have been calculated using the COPERT 5.3 emission functions for all vehicles up to and including Euro 6/VI. Emission rates have been calculated with our in-house emission calculation tool RapidEMS, which is fully consistent with COPERT 5.3 and links directly to our RapidAir dispersion modelling system.

JAQU recommend the use of data on primary NO_2 emissions (fNO_2) by vehicle type which is available via the NAEI website (based on 2014 NAEI) to provide a more detailed breakdown than the LAQM NOx to NO_2 convertor. This suggests a link specific f-NO_2 emissions estimate for use in the NO_2 modelling.

Based on this requirement, the RapidEMS road emissions calculation tool includes functionality to calculate NO_2 emission rates for each road link. Link specific fNO_2 fractions can then be calculated for each link by dividing NO_2 by total road NOx emission rate. Calculating link specific NO_2 emission rates also facilitate dispersion modelling of both road NOx and NO_2 across the entire model domain to produce separate concentration rasters, which can then be combined with background concentrations to calculate NO_2 concentrations in each grid cell.

The recently updated version (v8.1) of the LAQM NOx to NO_2 conversion spreadsheet has been used to convert road NOx, fNO_2 and background NOx into NO_2 concentrations where results at discrete receptor locations are required. This currently includes all NO_2 monitoring site locations and receptors placed at 4m from the PCM road links.

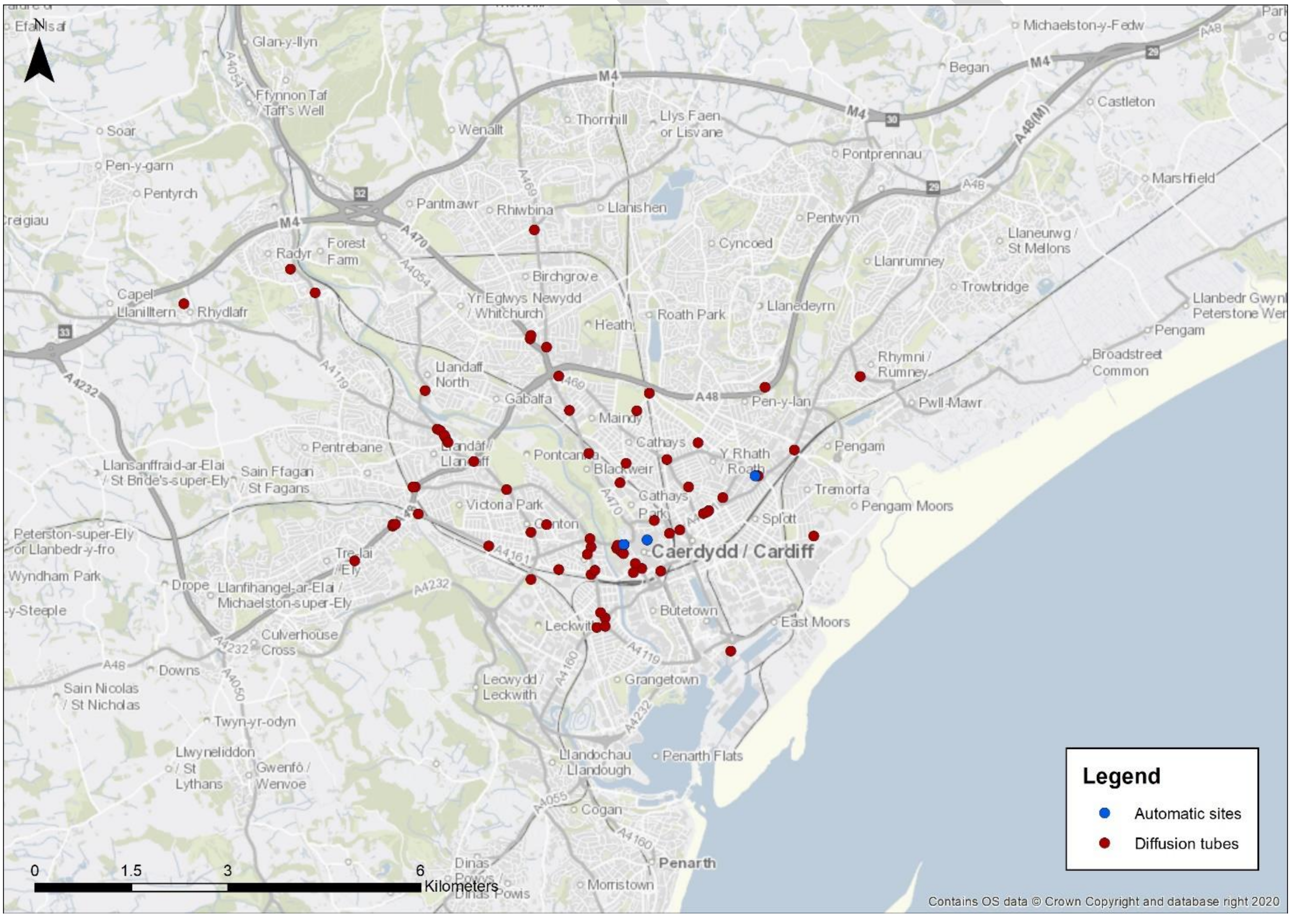
3.3 NON-ROAD TRANSPORT MODELLING AND BACKGROUND CONCENTRATIONS

The latest Defra NOx background maps with a 2018 baseline were downloaded for 2022 and 2024. [20] The 1km resolution LAQM background maps were used to provide estimates for all sources with the exception of motorway, primary and trunk roads contribution. To avoid double counting of modelled road transport sources motorway, primary and trunk roads contributions were discounted from Defra's background maps.

3.4 MEASUREMENT DATA FOR MODEL CALIBRATION

CCC's 2022 automatic and diffusion tube annual mean NO_2 measurements from roadside sites were considered for model verification. Further information on model verification has been presented within Appendix 1. Information on monitoring data QA/QC, diffusion tube bias adjustment factors etc. will be as presented in the CCC's 2023 LAQM Annual Progress Report. Diffusion tube data from the full year of 2022 was provided by CCC. Figure 3-9 displays the monitoring locations used in verification.

Figure 3-9 Monitoring locations



4. PROJECTED FUTURE YEAR SCENARIO MODELLING

4.1 ROAD TRANSPORT FUTURE YEAR BASELINE

The assessment year for all future scenarios is 2024. The basic projections used for the future year baseline scenario are:

- AADT flows for future baseline year were provided from the SEWTM. Further information on how these traffic flows were derived and how local growth in traffic is calculated is presented in 'Transport Modelling Methodology Report'.
- Projected fleet split (vehicle type): All future year scenarios will have the four-core vehicle category fleet splits provided from the traffic model in the same breakdown as provided for the 2022 base year. The further split of HGVs into artic and rigid, and cars into private hire and hackneys will use the same ratios as derived for the 2022 baseline.
- Projected fuel type and Euro class distribution: a local fuel type and Euro class distribution has been projected forward from the local ANPR results to provide Euro class distributions for each of the future modelling years. This projection has been carried out in line with the draft methodology provided by JAQU. This has been done by deriving future scaling factors from the national NAEI data, applying these to the local ANPR results and then normalising to 100%. This gives an evolution of the local fleet that is slightly behind the national fleet. This can be seen in Figure 3-2 to Figure 3-8, which shows that the average Euro classes across all ANPR sites have a slower uptake of Euro VI than NAEI.

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5. RESULTS

5.1 PCM RESULTS

An evaluation was undertaken to compare how concentrations of NO_2 from the three modelled scenarios compare to the outputs of PCM modelling undertaken for 2022 and 2024. Table 5-1 displays the maximum NO_2 value predicted at receptors at each given road link (Census ID). It is important to note that the PCM model forecasts values for 2022 and 2024 from a 2018 base year whilst the model used in this study has been validated against annual NO_2 measurements collected during 2022 and has been based upon fleet data captured by the city's ANPR network.

Table 5-1 Maximum NO_2 concentrations on PCM links

CensusID	Previous ID	Road name	PCM Baseline		Local Baseline		2024 measures
			2022	2024	2022	2024 DM	2024 DS
802000522	312000	A48/ Cowbridge Rd West	20.2	17.9	*30.4*	*24.9*	*24.8*
802000638	317670	A4119/ Clare Rd	16.8	15.2	*35.8*	*22.6*	*22.8*
802000642	319033	A4160/ Fitzalan Place	25.6	23.3	*37.2*	*28.4*	*29.6*
802010527	315040	A48/ Western Avenue	23.3	20.8	*29.4*	*25.9*	*27.1*
802010629	314860	A4054/ Station Rd, Llandaff	13.2	11.8	*21.0*	*18.6*	*19.4*
802010655	315350	A4119/ Cardiff Rd	21.4	19.1	*27.1*	*23.9*	*25.0*
802010659	318000	A4160/ Penarth Rd	22.3	20.4	*29.0*	*25.2*	*25.0*
802010660	320730	A4161/ Newport Rd	28.7	25.7	*34.7*	*29.1*	*29.3*
802010661	317140	A4161/ Wellington St	18.2	16.5	*20.7*	*18.0*	*17.5*
802020527	320000	A48/ Eastern Avenue	35.1	31.2	*39.2*	*33.4*	*33.3*
802020548	317940	A470/ North Rd	22.0	19.6	*26.2*	*23.5*	*20.2*
802030659	314920	A4119/ Llantrisant Rd	19.2	17.1	*21.4*	*19.0*	*19.4*
802030660	318000	A4119/ Corporation Rd	15.6	14.2	*38.0*	*31.1*	*32.2*
802030665	318000	A4161/ Castle St	28.2	25.3	*38.1*	*33.9*	*26.4*
802040549	316998	A470/ North Rd	29.1	25.7	*29.5*	*25.7*	*26.3*
802040582	318000	A469/ Whitchurch Rd	21.7	19.4	*32.9*	*28.9*	*28.8*
802040655	317430	A4160/ Penarth Rd	18.7	16.8	*20.6*	*18.9*	*18.9*
802040656	319475	A4161/ Newport Rd	24.8	22.5	*30.9*	*27.2*	*27.4*
802050527	316017	A48/ Western Avenue	31.9	28.4	*34.8*	*31.0*	*32.8*
802050541	315785	A470/ Manor Way	25.1	22.4	*37.2*	*32.4*	*32.4*

CensusID	Previous ID	Road name	PCM Baseline		Local Baseline		2024 measures
			2022	2024	2022	2024 DM	2024 DS
802050580	316835	A469/ Caerphilly Rd	19.9	17.8	*28.8*	*26.1*	*25.7*
802050647	317550	A4119/ Lower Cathedral Rd	21.7	19.6	*28.8*	*27.2*	*26.7*
802050651	316145	A4119/ Cathedral Rd	20.5	18.3	*28.6*	*24.9*	*28.0*
802050657	314950	A4161/ Lansdowne Rd	20.6	18.3	*21.8*	*19.4*	*19.4*
802050660	318220	A4161/ Kingsway	27.7	24.8	*28.2*	*25.3*	*19.8*
802070055	318590	A4161/ Boulevard de Nantes	25.8	23.3	*39.0*	*34.0*	*34.1*
802074101	317500	A4232/ Grangetown Link	36.1	32.0	*27.2*	*22.1*	*22.4*
802077018	318580	A470/ Bute St	22.2	20.2	*26.4*	*23.4*	*24.3*
802080726	318210	A470/ St Mary St	20.9	18.5	*30.3*	*30.4*	*31.2*
802080896	319000	A470/ Lloyd George Avenue	19.8	18.8	*28.8*	*23.8*	*24.1*
802088061	318315	A4232/ Cardiff Bay Link Rd	32.5	28.9	*32.7*	*27.4*	*27.8*
802099671	316659	A469/ Thornhill Rd	18.8	16.8	*25.4*	*23.0*	*22.9*
802099955	318680	A4160/ Bute Terrace	24.7	22.3	*35.4*	*32.3*	*33.5*
802099956	319420	A4234/ Central Link	34.0	30.7	*29.8*	*26.4*	*27.5*
802099960	317740	A4055/ Cogan Spur	24.8	22.1	*27.4*	*23.3*	*23.3*
801050524	320725	A48/ Eastern Avenue	39.1	34.5	*32.9*	*27.5*	*27.3*

Table 5-1 shows that:

- The modelling predicts that annual averaged NO_2 concentrations differ from those predicted by the PCM model using a 2018 baseline. One potential explanation might be that the PCM model was based upon a fleet composition where a higher number of older vehicles were assumed to be replaced by a new vehicle. A likely impact of the pandemic and cost of living crisis is older vehicles may not have been replaced as quickly as expected.
- The modelled maximum annual average NO_2 concentration predicted in 2022 and 2024 (do minimum) by the model used in this study is predicted to be higher than the maximum values predicted by the PCM model.
- The 2022 baseline model does not indicate exceedances of the NO_2 annual average 40 µg/m^3 threshold limit on any PCM links. The maximum concentration on the link representing Castle Street (census ID 802030665) was 38.1 µg/m^3. As the model is known to over-predict concentrations in this location (see Appendix 1), exceedances on Castle Street are not likely.
- The 2024 do minimum model predicts that annual average NO_2 concentrations are likely to reduce on most PCM road links, and there are no exceedances of the NO_2 annual average 40 µg/m^3 threshold limit. On Castle Street the maximum NO_2 concentration reduces to 33.9 µg/m^3.
- The 2024 do something model also predicts that annual averaged NO_2 concentrations are likely to fall compared to both the 2022 baseline and 2024 do minimum scenario on Castle Street, where the peak

concentration is expected to be 26.4 µg/m³. There are no exceedances of the NO_2 annual average 40 µg/m³ threshold limit.

- Differences in NO_2 concentrations between the 2024 do minimum and 2024 do something are smaller at most locations than between the 2022 baseline and 2024 do minimum. In some locations, the maximum concentrations of the 2024 do something are slightly higher than the maximum 2024 do minimum; this is expected to be caused by traffic from vehicles other than buses and taxis that are diverted from Castle Street to surrounding roads. However, the diverted traffic is not predicted to cause exceedances of the NO_2 annual average 40 µg/m³ limit, even when model uncertainty is considered.

Figure 5-1 to Figure 5-4 shows how the data shown in Table 5-1 corresponds to PCM receptors and the associated road network across the study domain.

Figure 5-1: Maximum predicted NO_2 assigned to corresponding road links (2022 baseline)

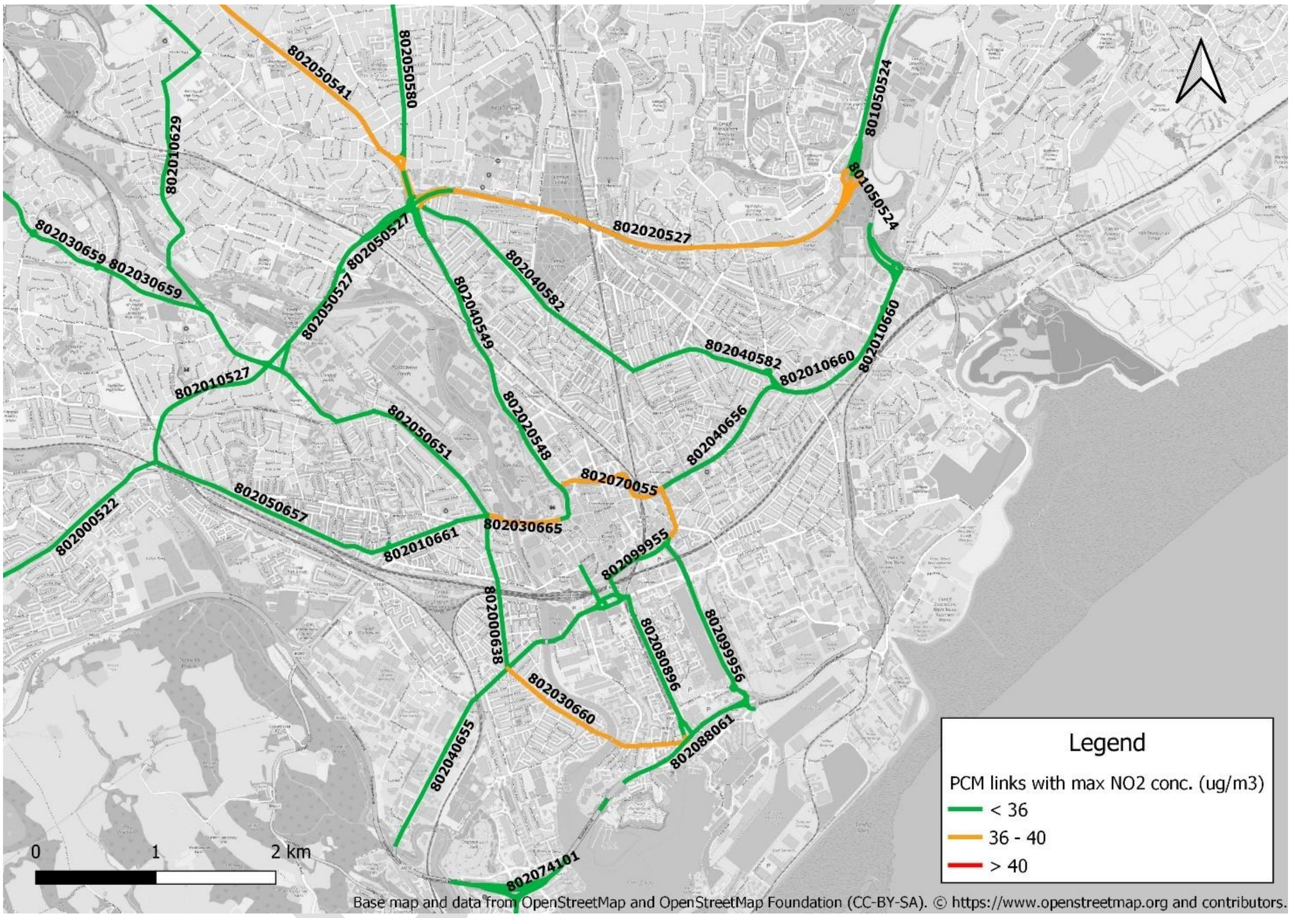

Figure 5-1 shows a mapped projection of the data shown in Table 5-1, where the entirety of the PCM road link has been assigned the maximum 2022 baseline NO_2 value, sampled along that section of road link.

Figure 5-2: PCM receptors with NO_2 concentrations above desired thresholds (2022 baseline)

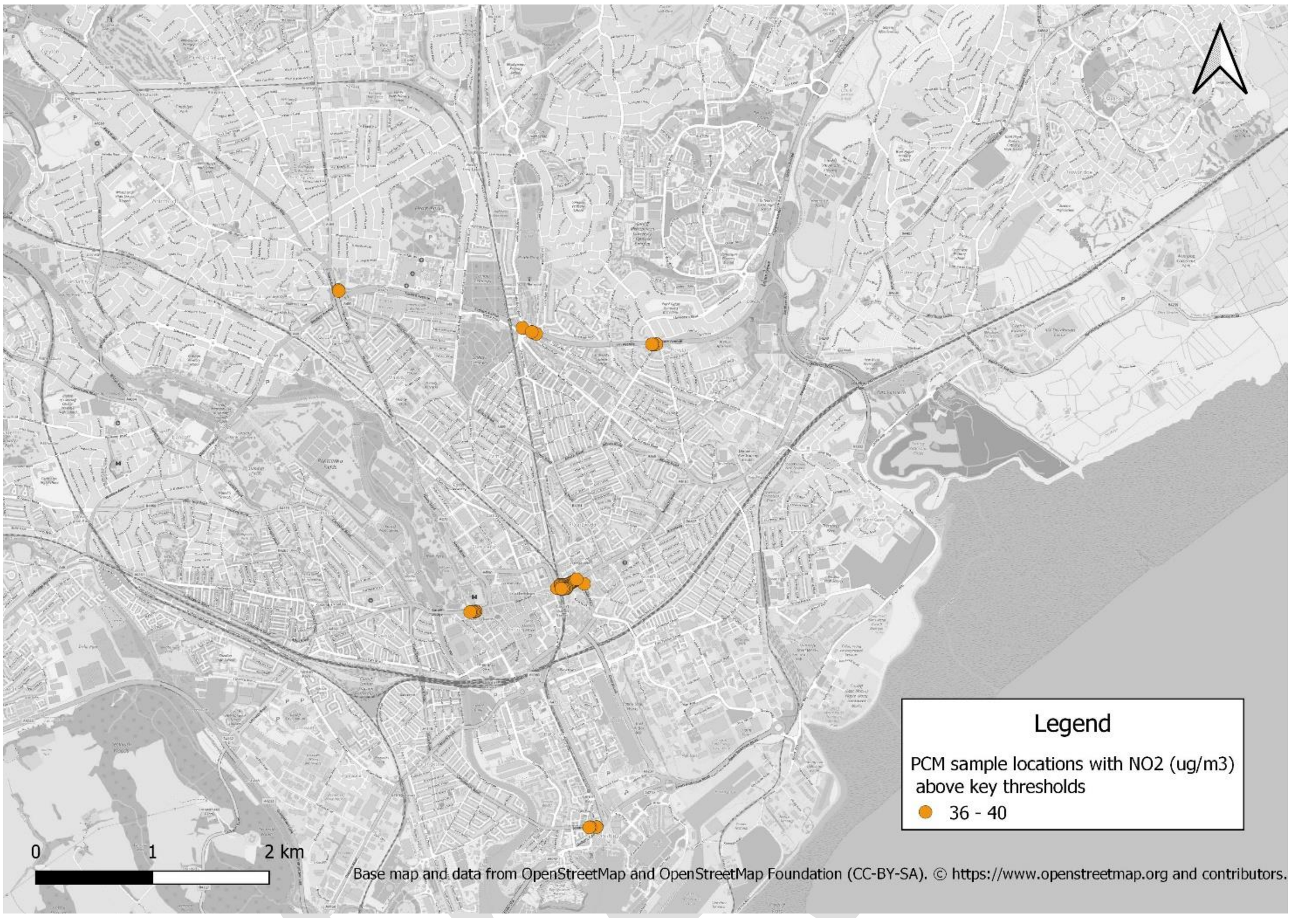

Figure 5-2 displays the same values as shown in Figure 5-1 with the section of road link replaced by the locations where predicted NO_2 concentration exceeded the 36 µg/m^3 threshold. The table shows that although long stretches of road links were shown to be above targeted thresholds in Figure 5-1, the number of locations this exceedance occurred was very localised.

Figure 5-3: Maximum predicted NO_2 assigned to corresponding road links (2024 DM)

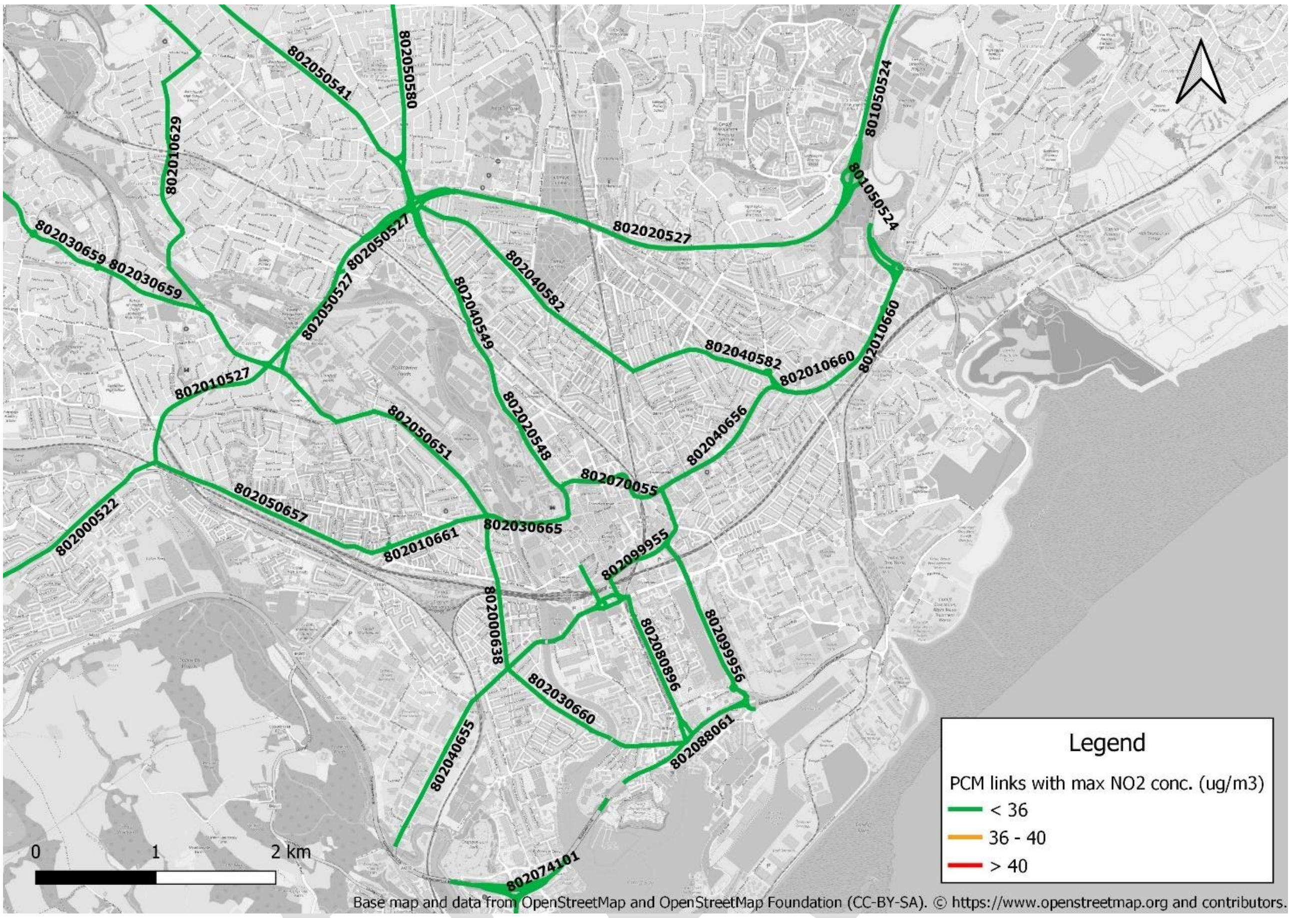

Figure 5-3 shows a mapped projection of the data shown in Table 5-1, where the entirety of the PCM road link has been assigned the maximum 2024 do minimum NO_2 value, sampled along that section of road link. The figure shows that all PCM links are expected to fall below 36 $\mu g/m^3$ including along Castle Street.

Figure 5-4: Maximum predicted NO_2 assigned to corresponding road links (2024 DS)

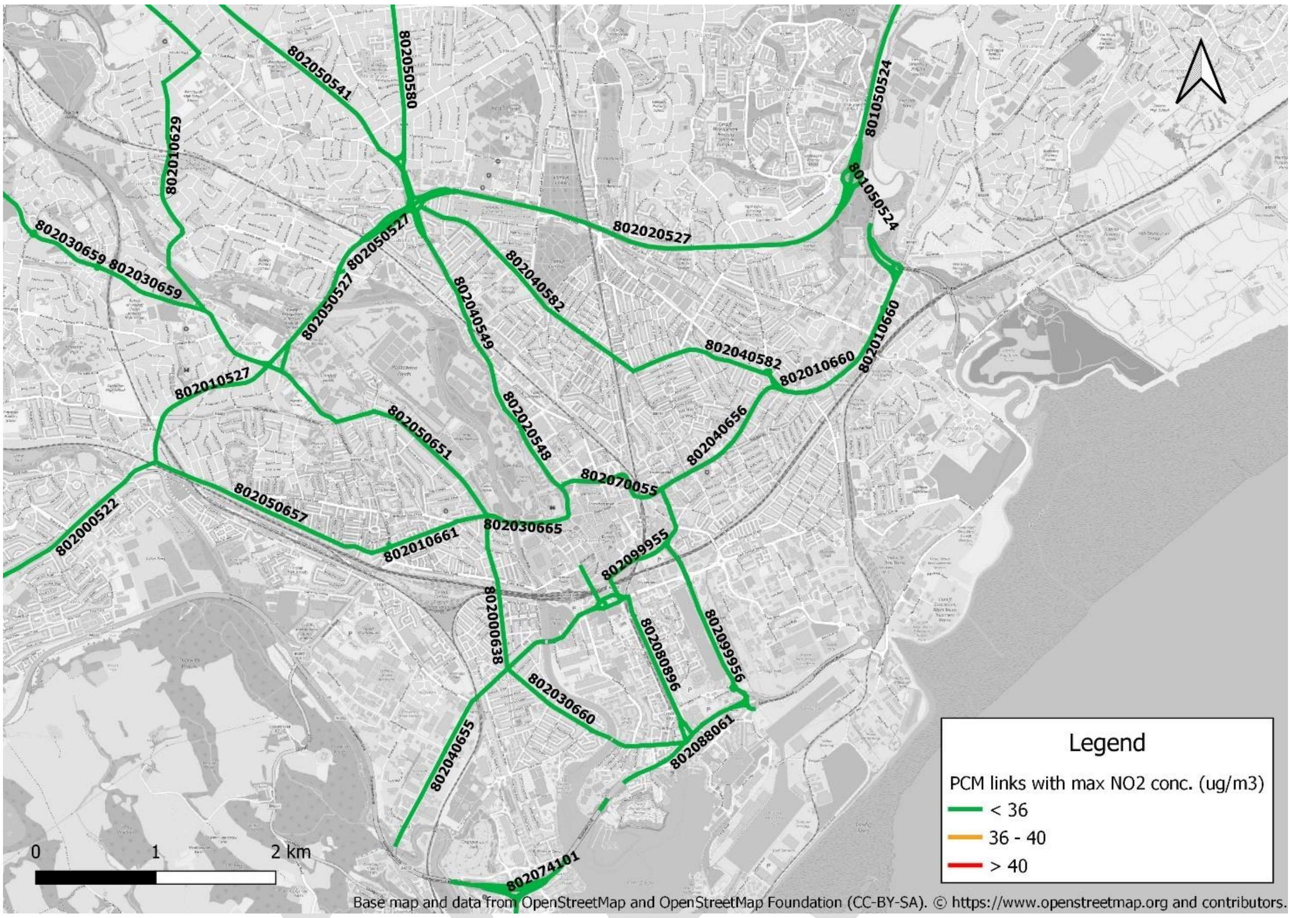

Figure 5-4 shows a mapped projection of the data shown in Table 5-1, where the entirety of the PCM road link has been assigned the maximum 2024 do something NO_2 value. This shows that all PCM receptors along these road links are predicted to be below the 36 µg/m^3 threshold.

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6. SUMMARY

This report has detailed the results from the dispersion modelling undertaken to understand the potential impacts of alterations to the use of the road network in Cardiff Castle Street.

The results given in section 5 show that:

- The 2022 baseline scenario indicates that there were no exceedances of the NO_2 annual average concentration above the 40µg/m^3 target threshold. There were six locations likely to have been above the 90% compliance threshold of 36 µg/m^3, and one of these PCM links is on Castle Street. It is noted that only small stretches of these road links were above these thresholds whilst the majority of PCM receptors along these road links are expected to be below 36 µg/m^3.
- The 2024 do minimum model suggests that the maximum concentration on all road links will be below 36 µg/m^3, including on Castle Street.
- The 2024 do something model suggests that the maximum concentration on all road links will be below 36 µg/m^3.

The results from the study therefore show that:

- Annual averaged NO_2 across Cardiff will be reduced naturally should the assumptions made in the do minimum scenario occur. This will bring the highest NO_2 concentration at PCM receptors to below 36 µg/m^3.
- The 2024 do something model suggests that implementing action targeting the reduction of annual averaged NO_2 concentration along Castle Street would further reduce concentrations on Castle Street.

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APPENDICES

APPENDIX 1 MODEL VERIFICATION

Verification of the model involves comparison of the modelled results with any local monitoring data at relevant locations; this helps to identify how the model is performing and if any adjustments should be applied. The verification process involves checking and refining the model input data to try and reduce uncertainties and produce model outputs that are in better agreement with the monitoring results. This can be followed by adjustment of the modelled results if required. The LAQM.TG(22) guidance recommends making the adjustment to the road contribution of the pollutant only and not the background concentration these are combined with.

The approach outlined in the LAQM.TG(22) guidance has been used in this case. All roadside diffusion tube NO_2 measurement sites in Cardiff have been used for model verification. A single road NOx adjustment factor was derived and used to calculate:

Citywide modelling results at receptor points adjacent to relevant PCM road links.

Citywide 1 m resolution NO_2 annual mean concentration rasters providing a continuous representation of the spatial variation in modelled concentrations.

It is appropriate to verify the performance of the RapidAir model in terms of primary pollutant emissions of nitrogen oxides (NOx = NO + NO_2). To verify the model, the predicted annual mean Road NOx concentrations were compared with concentrations measured at the various monitoring sites during 2022. The model output of Road NOx (the total NOx originating from road traffic) was compared with measured Road NOx, where the measured Road NOx contribution is calculated as the difference between the total NOx and the background NOx value. Total measured NOx for each diffusion tube was calculated from the measured NO_2 concentration using the latest version of the Defra NOx/NO2 calculator (v8.1).

The initial comparison of the modelled vs measured Road NOx identified that the model was under-predicting the Road NOx contribution at most locations. Refinements were subsequently made to the model inputs to improve model performance where possible.

The gradient of the best fit line for the modelled Road NOx contribution vs. measured Road NOx contribution was then determined using linear regression and used as a domain wide Road NOx adjustment factor. This factor was then applied to the modelled Road NOx concentration at each discretely modelled receptor point to provide adjusted modelled Road NOx concentrations. A linear regression plot comparing modelled and monitored Road NOx concentrations before and after adjustment is presented in Figure 6-1.

The total annual mean NO_2 concentrations were then determined using the NOx/NO_2 calculator to combine background and adjusted road contribution concentrations.

Some clear outliers were apparent during the model verification process, whereby we were unable to refine the model inputs sufficiently to achieve acceptable model performance at these locations. These sites were excluded from the model verification. The reasons why acceptable model performance could not be achieved at these sites include:

- Sites located next to a large car park, bus stop, petrol station, or taxi rank that has not been explicitly modelled due to unknown activity data.

The RapidAir canyon allocator identified Westgate Street as a canyon, however including a canyon in this location leads to very scattered data in the model verification and the sites located in this canyon do not follow the general trends shown by the remainder of the monitoring locations. Consequently, the canyon in Westgate was manually removed which resulted in the relationship between measured and modelled concentrations at sites in this street following similar trends to the other verification sites and reduced the error in the model predictions.

To present a conservative approach to adjusting future year predictions of road NOx concentrations, a primary NOx adjustment factor (PAdj) of **2.4294** based on model verification using all of the 2022 NO_2 measurements was applied to all modelled Road NOx data prior to calculating an NO_2 annual mean.

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A polynomial regression factor was derived from combining the primary NOx adjustment factor with concentrations taken from set sampling locations from the total NO_x and primary road NO_2 raster's outputted from the air dispersion model and the background NOx concentrations given for in the Defra background concentration maps at the same location.

A plot comparing modelled and monitored NO_2 concentrations before and after adjustment during 2022 is presented in Figure 6-2.

Figure 6-1 Comparison of modelled Road NOx Vs Measured Road NOx before and after adjustment

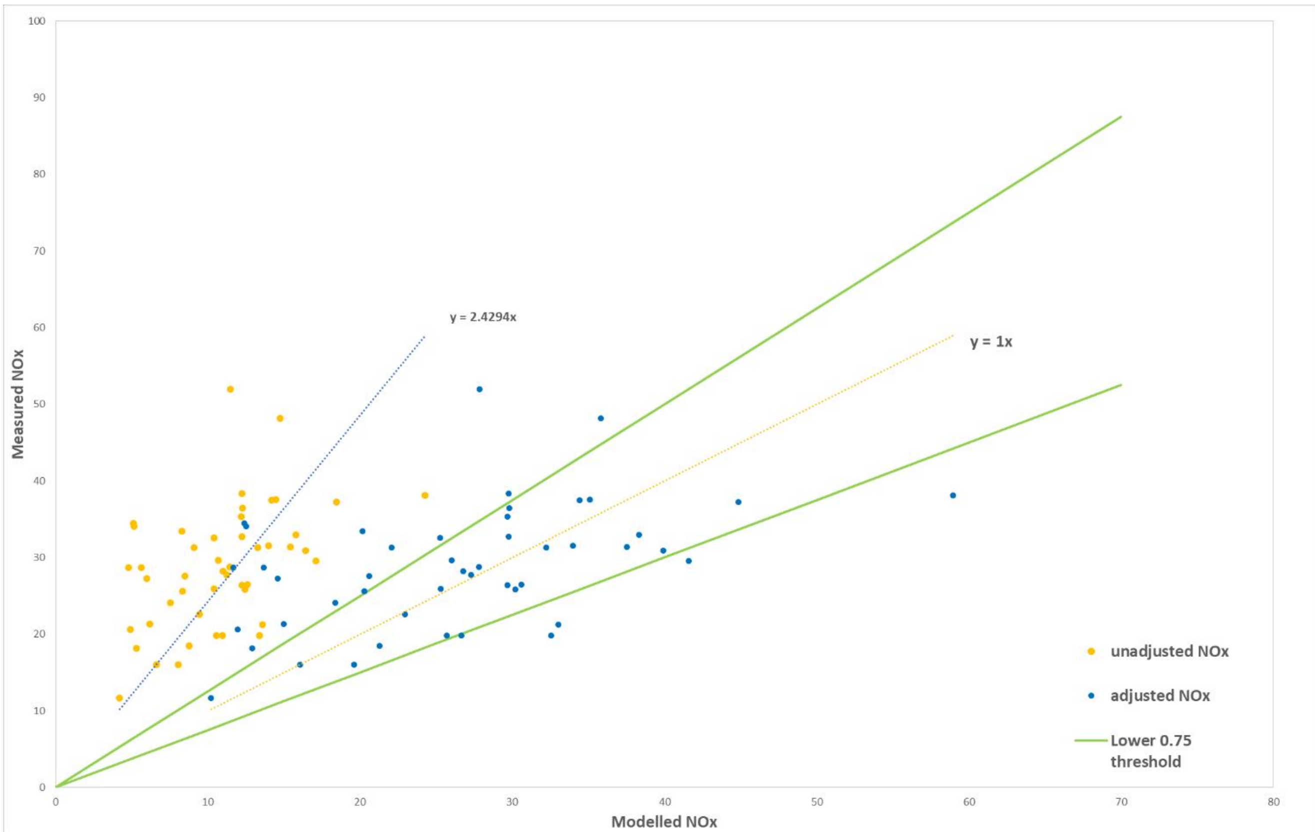
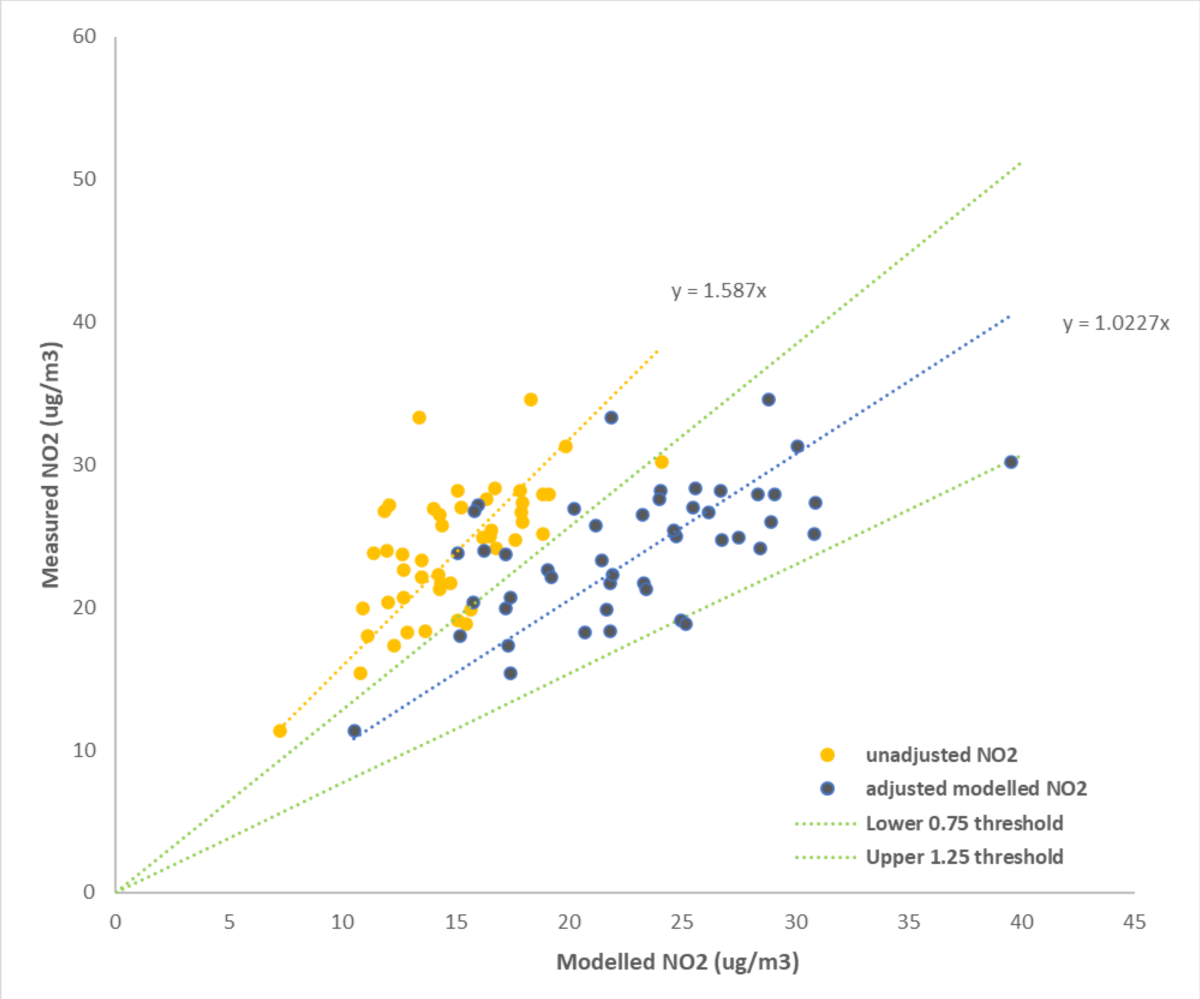


Figure 6-2 Modelled vs. measured NO_2 annual mean 2022 before and after adjustment



Model performance

To evaluate the model performance and uncertainty, the Root Mean Square Error (RMSE) for the observed vs predicted NO_2 annual mean concentrations was calculated, as detailed in Technical Guidance LAQM.TG(122). This guidance indicates that an RMSE of up to 4 µg/m³ is ideal, and an RMSE of up to 10 µg/m³ is acceptable. The calculated RMSE is presented in Table 6-1. In this case the RMSE was calculated at 4.7 µg/m³ which is close to the ideal range suggested by the guidance.

Using a single adjustment factor for a city-wide model causes under-prediction in some areas and over-prediction in others. In particular, the model is over-predicting the NO_2 concentration on Castle Street (DT 186), although the modelled concentration is not predicted to exceed the 40 µg/m³ annual mean objective.

Table 6-1 Comparison of measured and modelled concentrations at measurement locations in 2022, and the model root mean square error

NO_2 monitoring site	Site name	Measured NO_2 annual mean concentration 2022 (µg/m³)	Modelled NO_2 annual mean concentration 2022 (µg/m³)
16	167 Ninian Park Road	23.8	15.1
81	Stephenson Court	26.7	26.2
86	19 Fairoak Road	28.2	24.1
96	Manor Way Junction	24.9	27.5

NO_2 monitoring site	Site name	Measured NO_2 annual mean concentration 2022 (µg/m^3)	Modelled NO_2 annual mean concentration 2022 (µg/m^3)
98	Western Avenue (premises)	21.7	23.3
99	Cardiff Road Llandaff	26.5	23.3
259	WELLFIELD ROAD (NEW 2022)	25.7	21.2
260	St Marys Catholic School CANTON (NEW 2022)	20.3	15.8
261	Rhydalfar Drive NEW 2022	11.3	10.5
106	30 Caerphilly Road	24.1	28.5
112	17 Sloper Road	22.6	19.1
115	21 Llandaff Road	27.1	16.0
117	25 Cowbridge Road West	33.3	21.9
126	Westgate Street Flats	25.0	24.8
128	117 Tudor Street	26.9	20.3
143	Windsor House	25.4	24.7
144	Marlborough House	27.6	24.0
147	211 Penarth Road	24.0	16.3
148	161 Clare Road	23.7	17.2
149	10 Corporation Road	26.7	15.9
156	2a/4 Colum Road	21.7	21.8
157	47 Birchgrove Road	19.1	25.0
158	64/ 66 Cathays Terrace	22.1	19.2
159	IMO facade replacement	28.4	25.6
168	570 Cowbridge Road East	23.3	21.5
179	Altolusso, Bute Terrace	31.3	30.1
184	Hophouse, St Mary Street	27.9	29.1
186	Dempseys Public House, Castle Street	30.2	39.6
187	Angel Hotel	34.6	28.9
188	Westgate Street (45 Apartments)	28.2	26.7
191	7 Mackintosh Place	25.1	30.9
194	115 Cowbridge Road West	19.9	17.2
195	244 Newport Road	24.7	26.7
196	2 Pencisely Road	22.3	22.0
198	Next Building to Stephenson Court	27.9	28.4
199	157 Newport Road	19.9	21.7
200	350 Whitchurch Road	27.3	30.9

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NO_2 monitoring site	Site name	Measured NO_2 annual mean concentration 2022 (μg/m^3)	Modelled NO_2 annual mean concentration 2022 (μg/m^3)
202	22 Clare Street	26.0	29.0
203	10 Fairoak Road	17.3	17.4
204	53 Neville Street	20.7	17.4
207	42 Waungron Road	18.3	21.8
208	2 Llantrisant Road	21.2	23.4
209	178 North Road	18.8	25.2
210	485 Caerphilly Road	18.0	15.2
214	Mitre Place	27.0	25.5
224	110 Cardiff Road	18.3	20.7
251	Heol Isaf, Radyr	15.4	17.4
Correlation coefficient			**0.6**
RMSE (all sites)			**4.7**
Fractional bias			**0.05**

DRAFT

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