DONCASTER COUNCIL REAL WORLD DRIVING EMISSIONS STUDY 2022

Report for: Doncaster Council

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1. INTRODUCTION

Vehicle emissions are considered to be the primary source of pollution at both of the Air Quality Monitoring Areas (AQMAs) declared by Doncaster Council. In order to support the development and implementation of effective Air Quality Action Plans (AQAPs) to reduce concentrations of NO (and NO_2) in these locations. Ricardo Energy & Environment conducted measurement campaigns of real-world driving emissions within one of these AQMAs: on the A635 in Hickleton and Marr, in both directions. The resulting high-quality location-specific and up-to-date measurements provide sufficient evidence to inform current and future action plans, abatement measures and policy.

This report presents an analysis of the real-world emissions measurements made during measurement campaigns conducted in Doncaster. Section 1 gives an introduction to the measurement campaigns and remote sensing. Section 2 of the report summarises the fleet composition derived from the vehicle emissions data collected during the measurement campaign by location. Section 3 of the report presents read-world emissions of NO and PM from the vehicle emissions remote sensing measurements of cars, vans and buses. Section 4 presents NO emission factors for cars and Section 5 shows how real-world emission factors can be combined with local fleet data to provide source apportionment for specific roads. Section 6 presents an analysis of hybrid vehicles measured in Doncaster.

1.1 MEASUREMENT CAMPAIGNS

Ricardo deployed remote sensing instrumentation in Doncaster over a period of 10 days during March and May 2022. Measurements were made at two locations in Doncaster:

- Doncaster Road, A635 Eastbound, directly after the junction with Lidget Lane (B6411) at the bottom of the hill into the village of Hickleton
- Doncaster Road, A635 Westbound, approximately 30 m before the speed limit increases from 30 mph to the national speed limit.

These locations are indicated on the map in Figure 1. Table 1 presents summary information about the two sites. Site descriptions and photos are included below. Over 26,000 vehicle measurements were made over the course of the measurement campaigns, including over 16,000 cars, 6,100 LGVs, 2,500 HGVs and 52 buses.

Not every attempted measurement provides useful data for two main reasons:

1. Not every emission measurement necessarily has vehicle technical information associated with it because the number plate may not have been readable (e.g. if the plate was partially obscured or could not be read by the ANPR software), or a readable plate may not match to a vehicle (e.g. vehicles with a non-UK registration plate);
2. Not every emissions measurement is valid, for example vehicles may be too close together for distinct measurements to be made.

Table 1 Summary of site information.

Site Name	Latitude, Longitude	Gradient of Road	Average Temperature (°C)	Average Humidity	Average Speed (km/h)	Average Acceleration (km/h s)
A635 Eastbound, Doncaster	53.54198, -1.277691	2.5	18.63	32.23	34.88	1.35
A635 Westbound, Doncaster	53.54118, -1.277961	-0.5	17.03	50.08	40.32	0.63

Figure 1 Locations of remote sensing campaigns in Doncaster.

1.1.1 A635 Eastbound

Measurements were taken eastbound on Doncaster Road (A635) in Hickleton village, directly after the junction with Lidget Lane (B6411). The OPUS instrument set-up is shown in Figure 2. The speed limit for this road is 30 mph, however vehicles were mainly accelerating as this section of Doncaster Road is at the bottom of a hill heading into the village. Generally around 490 vehicles were measured per hour, with a high valid measurement success rate overall (>90%) due to the incline of the road and subsequent acceleration of vehicles.

This measurement site is located inside one of Doncaster Council's Air Quality Management Areas (AQMAs)[1] for nitrogen dioxide (NO_2).

Figure 2 Photograph of the OPUS instrument set-up on the A635 Eastbound.

1.1.2 A635 Westbound

Measurements were taken westbound on Doncaster Road (A635), measuring vehicles leaving Hickleton village. The OPUS instrument set-up is shown in Figure 3, where the speed limit was 30 mph. Approximately 30 m after the site, the speed limit increases to the national speed limit, thus some vehicles were accelerating. Generally around 370 vehicles were measured per hour, with a valid measurement success rate of just over 51% due to the slight decline of the road.

This measurement site is located inside one of Doncaster Council's Air Quality Management Areas (AQMAs)[1] for nitrogen dioxide (NO_2).

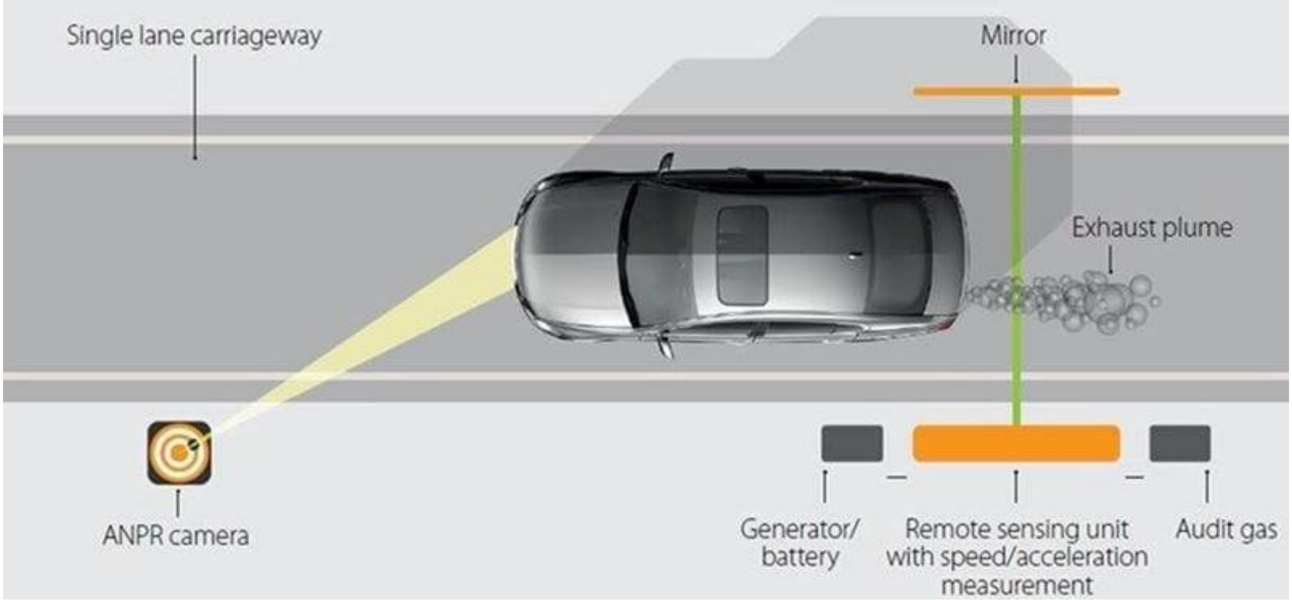
Figure 3 Photograph of the OPUS instrument set-up on the A635 Westbound.

1.2 VEHICLE EMISSIONS REMOTE SENSING METHODOLOGY

Vehicle emissions were measured using the Opus RSD5000 remote sensing instrument. The instrument measures tail-pipe emissions from passing vehicles under real-world driving conditions and is capable of measuring emissions of nitric oxide (NO), nitrogen dioxide (NO_2), particulate matter (PM), ammonia (NH_3), carbon monoxide (CO) and hydrocarbons. Emissions are measured as ratios to CO_2 and the analysis routine uses combustion equations to calculate fuel-specific emissions in units of grams of pollutant per kilogram of fuel (g/kg fuel). Distance specific emissions can be estimated from fuel-specific emissions by estimating the amount of fuel burnt per kilometre travelled (kg/km). The majority of the vehicle emissions presented in this report are in units of g/kg fuel.

In conjunction with the vehicle emissions measurements, a camera records number plates of passing vehicles, and a pair of light gates record the vehicle speed and acceleration. Figure 4 shows a typical measurement set-up. The number plate of each vehicle is matched to a set of vehicle details derived from DVLA and SMMT databases, including, where available, vehicle type (i.e. car, van, bus, heavy goods vehicle (HGV)), fuel type, Euro standard, engine size, vehicle weight, date of registration, and the odometer reading at last MOT.

Figure 4 Real-world vehicle emissions testing set-up.



The RSD5000 is always calibrated internally prior to each data collection session, in a process that only takes a few minutes. During the session, the RSD5000 is audited each hour, to verify the system is performing within specifications and does not need re-alignment and/or re-calibration. This process involves measurements of gases of known concentrations through the RSD5000. As data is collected, exhaust plume verification software reviews each measurement in real-time to ensure it is of adequate strength, that the exhaust plume decayed in a manner consistent with warm loaded-mode vehicle operations, and that the prevailing background levels are stable and can be accurately determined. Each session's dataset is compiled every day and put together into a database later.

1.2.1 Benefits of real world driving emissions data

Remote sensing data has many applications and can be beneficial to a Local Authority (LA):

- Remote sensing measurements are local to an area, therefore the emissions are representative of the actual vehicle fleet in the local area. Vehicle information such as vehicle type, age, mileage, makes and models are gained.
- Real-world emissions factors can be developed which will be representative of the driving conditions on the road.
- These real-world emissions factors can be used in local dispersion modelling and to inform predictions of air quality.
- Understanding local emissions sources can help LAs take targeted action to improve air quality, such as implementing Low Emission or Clean Air Zones.
- With extended monitoring campaigns, remote sensing can go beyond current inventory approaches, for example looking at the impact of temperature and vehicle mileage on emissions.

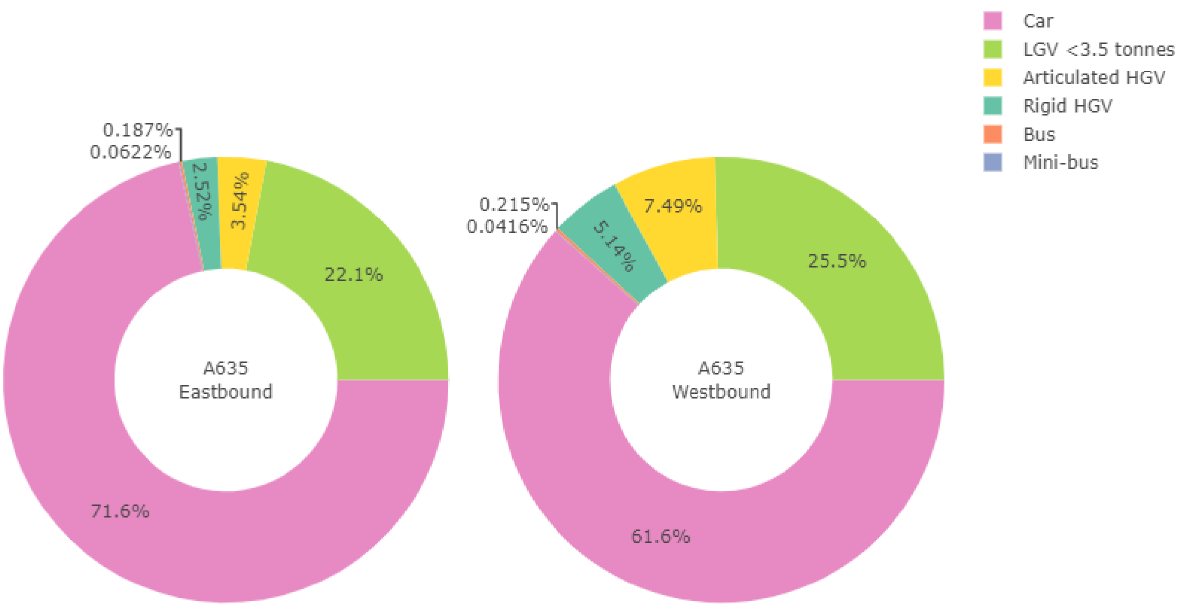
2. FLEET COMPOSITION

The composition of the fleet surveyed during the Doncaster vehicle emissions remote sensing campaign is presented in this section. The fleet at each measurement location is presented separately and includes all passing vehicles.

2.1 FLEET BY VEHICLE TYPE

The pie charts in Figure 5 show the proportion of cars, buses, LGVs and HGVs sampled at each of the measurement sites in Doncaster. The fleet composition is similar at each location with cars and then LGVs forming the main components of the fleet. Cars contribute a greater proportion of the fleet at A635 Eastbound (71.6%) than A635 Westbound (61.1%). Consequently, the total proportion of LGVs, HGVs and buses in the local fleet is greater at A635 Westbound (38.4%) than at A635 Eastbound (28.4%). The individual proportion of LGVs, HGVs and buses are greater at A635 Westbound (25.5%, 12.6% and 0.22%, respectively). Overall, the fleet composition in Doncaster is similar to the NAEI fleet projections for 2022, where 78.0% of the vehicles in rural areas outside of London are cars, and 16.2% are LGVs [2]. Differences are expected between locations.

Figure 5 Fleet composition by measurement location and vehicle type.



2.2 CAR AND LGV FLEET BY FUEL TYPE

Vehicle emissions show a strong dependence on fuel type used by the vehicle, so it is important to understand the proportion of cars and LGVs that use petrol, diesel, or alternative fuel types such as electric. Figure 6 and Figure 7 show the car and LGV fleet, respectively, by fuel type at each measurement location, derived from the vehicle emissions remote sensing campaign.

Figure 6 shows that diesel cars made up the largest proportion of the fleet recorded at both measurement locations, contributing just over 55% at both sites. Alternative fuels made up a small proportion of the total car fleet with electric cars contributing 1.19% and 1.32%, and petrol hybrid (petrol/electric) cars contributing 4.06% and 4.71% A635 Eastbound and A635 Westbound, respectively. The NAEI fleet projections for 2022 estimate that 55.2% of a rural car fleet (outside of London) are petrol vehicles (including full hybrid and plug-in hybrid cars), 43.8% are diesel cars (including hybrids) and 1.03% are pure electric cars. The Doncaster car fleet aligns well with the NAEI projections.

Figure 6 Cars by fuel type at the two measurement locations in the monitoring campaign.

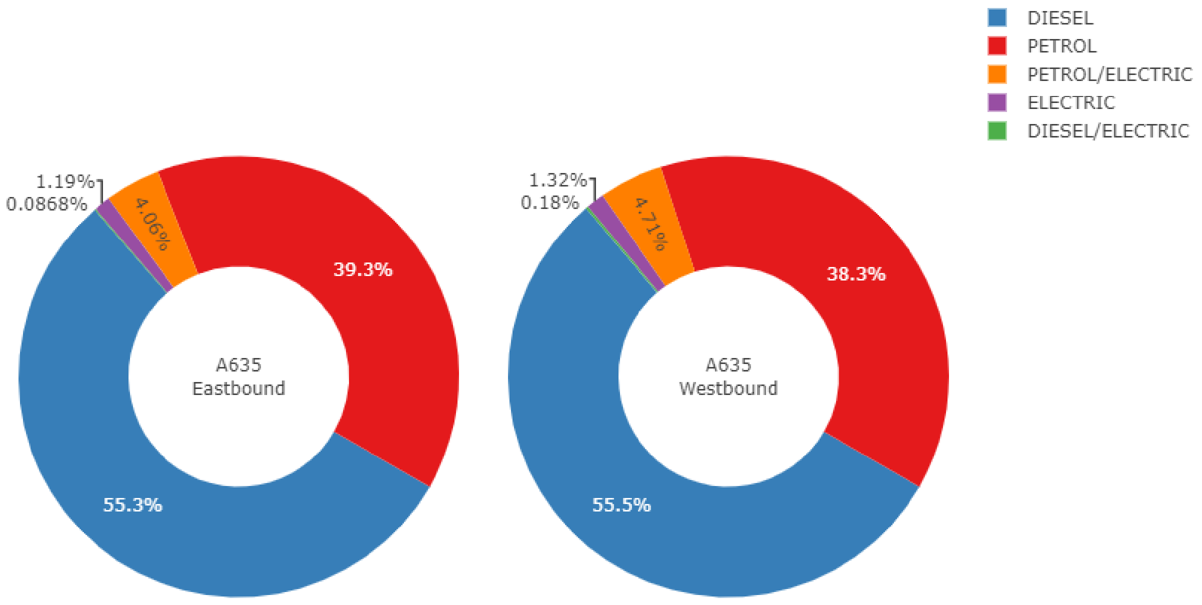
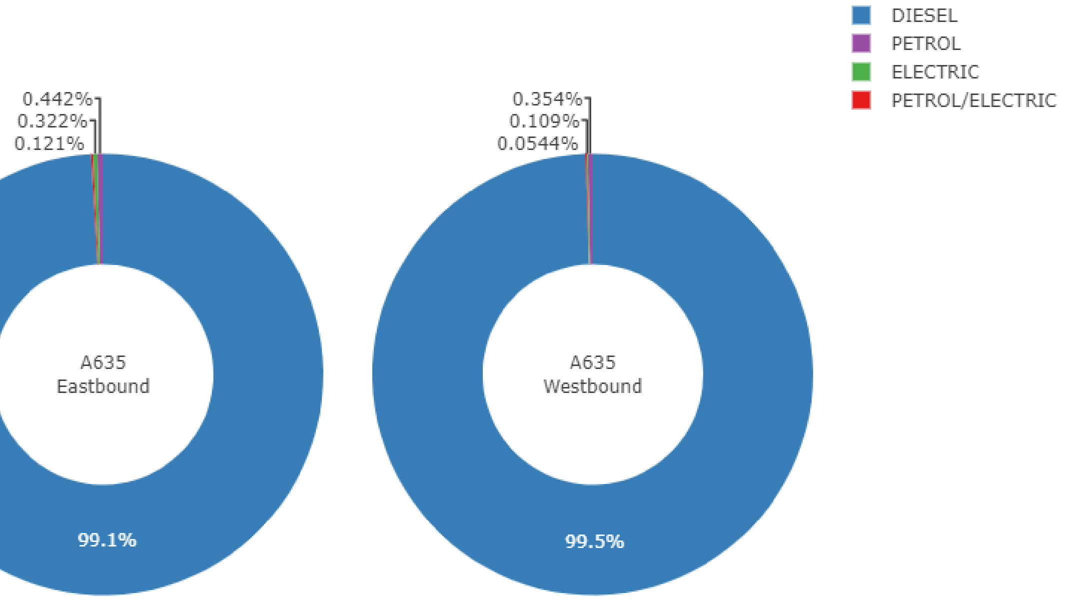


Figure 7 shows that diesel LGVs made up the largest proportion of the fleet recorded at both measurement locations, contributing over 99% at both locations. The NAEI fleet projections for 2022 estimate that 98.4% of a rural LGV fleet (outside of London) are diesel vehicles, 1.2% are petrol and 0.4% are pure electric. The Doncaster LGV fleet composition agrees well with the NAEI projections in terms of the proportion of diesel LGVs, but has a lower proportion of pure electric LGVs, with 0.32% and 0.11% at A635 Eastbound and A635 Westbound, respectively.

Figure 7 LGVs by fuel type at the two measurement locations in the monitoring campaign

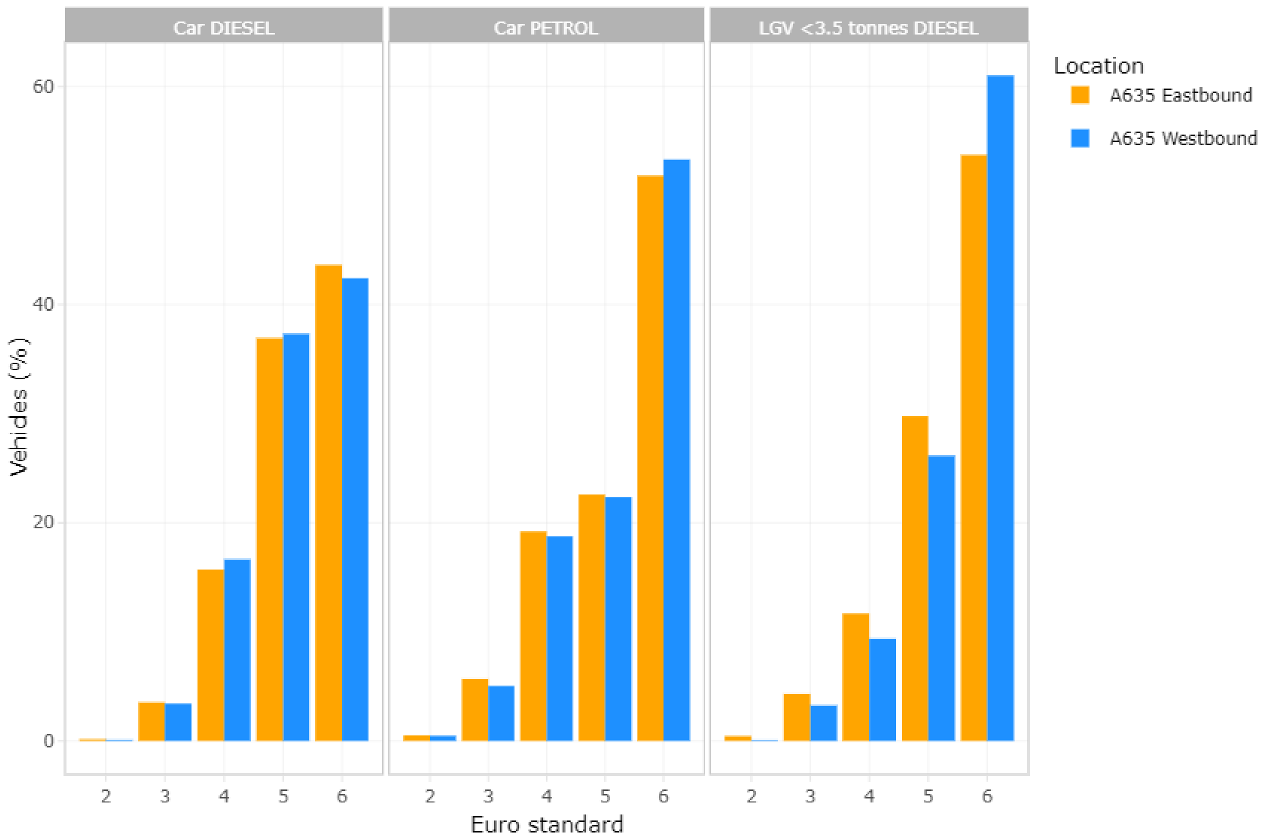


2.3 CAR AND LGV FLEET BY FUEL TYPE AND EURO STANDARD

The age of the fleet is a significant factor when considering vehicle emissions. European legislation sets out emissions limits that new vehicles must meet under test conditions. These "Euro standards" are periodically updated to increase the stringency of emissions limits. Figure 8 shows the car and LGV fleet by fuel type and Euro standard for each measurement site. Note that petrol LGVs have been excluded from this analysis due to low vehicle counts. The highest proportion of vehicles in each category (at both measurement locations) are Euro 6 vehicles, which is the latest Euro standard (and has the most stringent emissions limits). The number of vehicles increases with Euro standard in each vehicle type and fuel category, at both A635 Eastbound and A635 Westbound.

The NAEI fleet projections for 2022 (outside London) suggest a greater proportion of Euro 6 vehicles and a lower proportion of Euro 5 vehicles in each of the categories, than the proportions shown in Figure 8. The NAEI predicts that 76.0% of petrol cars are of Euro 6 standard and 18.0% are Euro 5. For diesel cars, 66.6% are Euro 6 and 27.1% are Euro 5. For diesel LGVs, 74.7% are Euro 6 and 19.2% are Euro 5. In each category, a small proportion of Euro 4, Euro 3 and Euro 2 (diesel LGV only) vehicles are expected.

Figure 8 Car and LGV fleet by fuel type and Euro standard. Petrol LGVs have been excluded due to low vehicle counts.



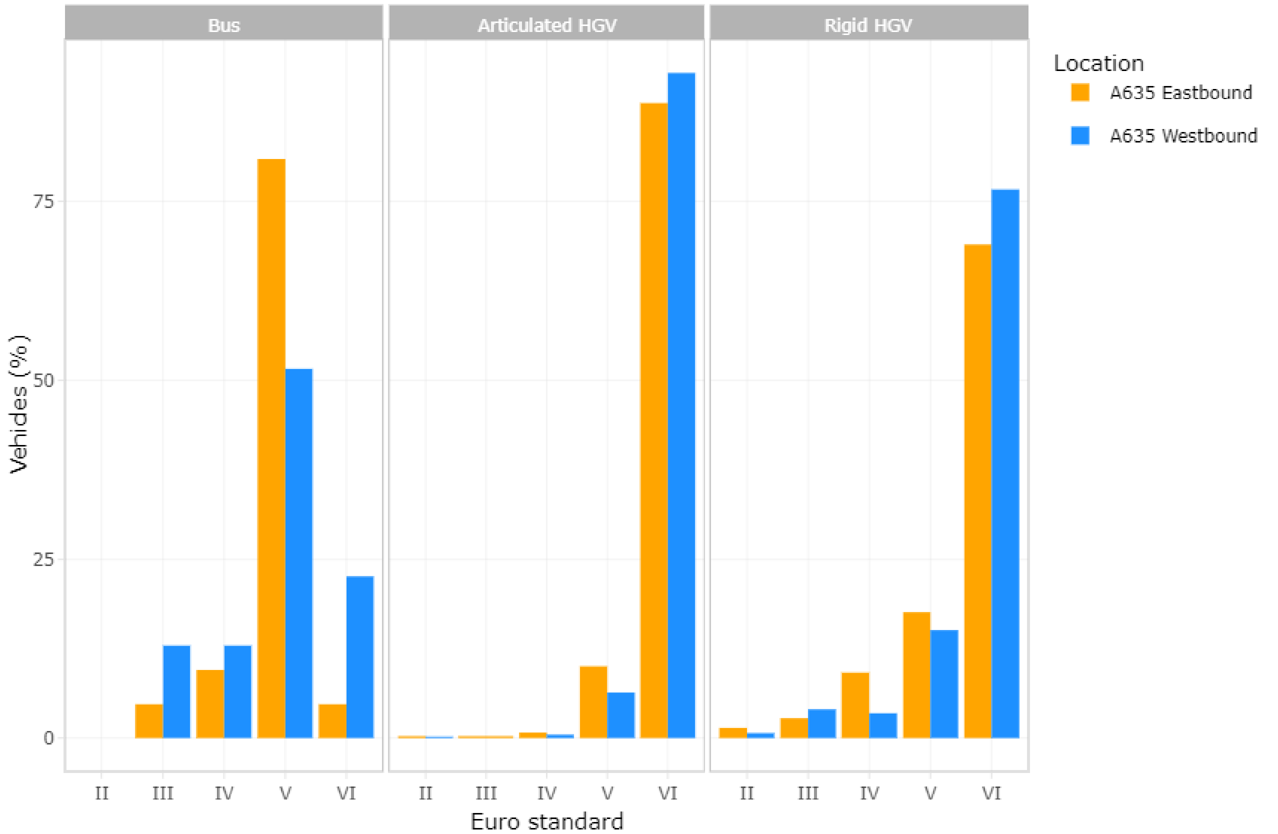
2.4 BUS AND HGV FLEET BY FUEL TYPE AND EURO STANDARD

The age of the fleet is a significant factor when considering vehicle emissions. European legislation sets out emissions limits that new vehicles must meet under test conditions. These "Euro standards" are periodically updated to increase the stringency of emissions limits. Figure 9 shows the bus and HGV fleet (including rigid and articulated HGVs) by Euro standard for each measurement site.

The highest proportion of both rigid and articulated HGVs (rHGV and aHGV, respectively) at both measurement locations are Euro VI vehicles. This is the latest Euro standard (and has the most stringent emissions limits), Conversely, the highest proportion of buses at both locations are Euro V vehicles. It may be that some of these vehicles have been retrofitted to emulate Euro VI emission limits, however this information is not available from the remote sensing data set. Generally the number of vehicles increases with Euro standard in each vehicle type category, at both the A635 Eastbound and the A635 Westbound.

The NAEI fleet projections for 2022 (outside London) suggest a lower proportion of Euro VI vehicles and a greater proportion of Euro V vehicles in each of the categories, than the proportions shown in Figure 9. The NAEI predicts that 76.8% of buses are of Euro VI standard and 15.6% are Euro V. For rHGVs, 87.9% are Euro VI and 9.1% are Euro V. For aHGVs, 95.8% are Euro VI and 3.8% are Euro V. In each category, a smaller proportion of Euro IV, Euro III and Euro II (HGVs only) vehicles are expected.

Figure 9 Bus and HGV fleet by Euro standard.



3. REAL-WORLD EMISSIONS OF NO_X AND PM FROM REMOTE SENSING

This section summarises the valid real-world emissions of NO_x and particulate matter (PM) from the cars, vans, buses and HGVs recorded during the measurement campaigns.

3.1 NO_X EMISSIONS BY EURO STANDARD – CARS AND VANS

3.1.1 A635 Eastbound

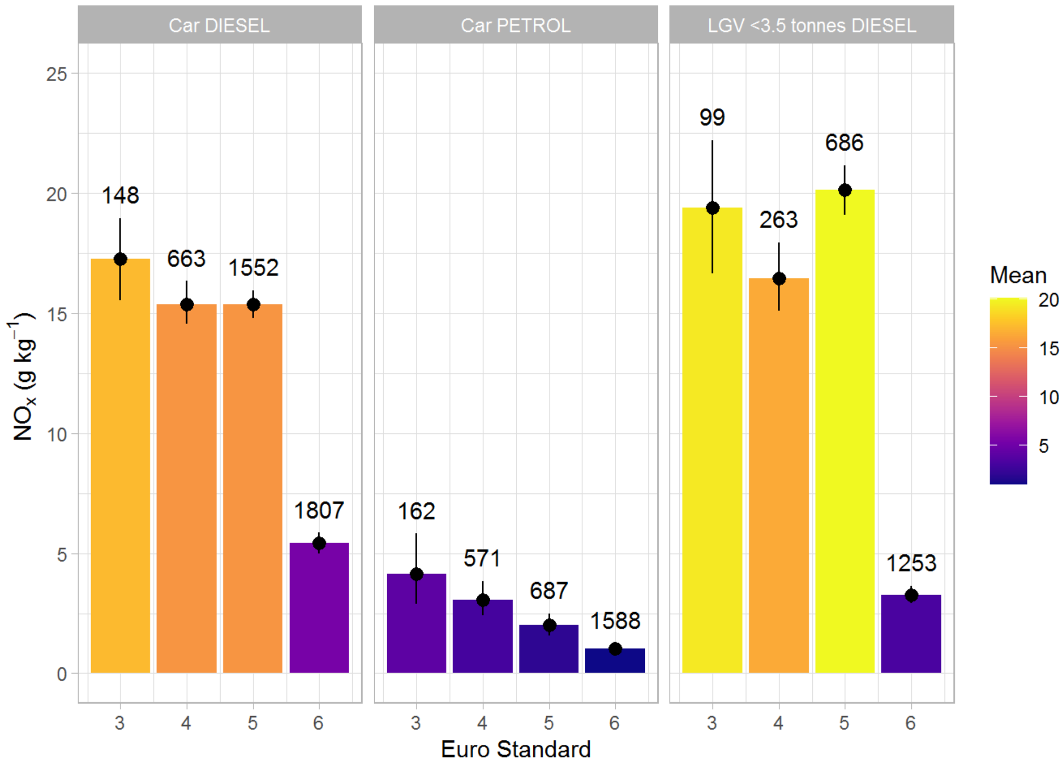
Figure 10 shows the mean NO_x emissions from cars and vans by fuel type, split by Euro standard, recorded on the A635 Eastbound. The error bars show the 95% confidence interval in the mean and the number shown at the top of each bar is the number of vehicles measured. Data points for which 25 or fewer valid vehicle emissions measurements were recorded have been excluded from the plot. This is because too much uncertainty is introduced where too few valid vehicle measurements are available to make the calculation. However, due to the small number of measurements, these groups of vehicles are likely to contribute little to the overall emissions of the fleet. Such contributions to the overall NO_x emissions at A635 Eastbound, separated by vehicle type, fuel type and Euro standard, are presented in the source apportionment analysis (Section 5).

Some key observations from Figure 10 are:

- NO_x emissions are higher from diesel cars than from petrol cars of the same Euro standard.
- NO_x emissions from petrol cars are low across all Euro standards measured (Euro 3 to Euro 6).
- Euro 6 diesel cars have the lowest NO_x emissions across all Euro standards measured for diesel cars, but still emit more NO_x than petrol cars of Euro 4 standard or higher (Euro 4, Euro 5 and Euro 6).

  NO_x emissions from diesel LGVs show an increase between Euro 4 and Euro 5 vehicles, however also show a large decrease from Euro 5 to Euro 6.

Figure 10 Emissions of NO_x from cars and vans by fuel type and Euro standard, measured on the A635 Eastbound. The uncertainty intervals shown are the 95% confidence intervals in the mean and the number shown at the top of each bar is the number of vehicles measured.



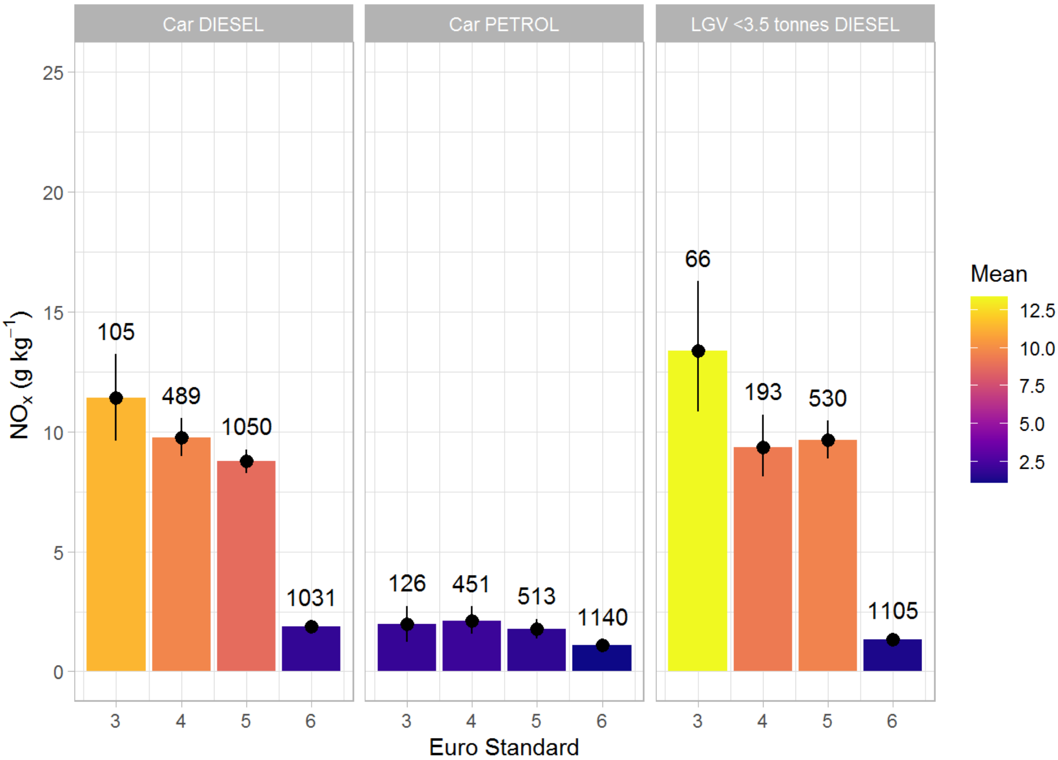
3.1.2 A635 Westbound

Figure 11 shows the mean NO_x emissions from cars and vans by fuel type, split by Euro standard, recorded on the A635 Westbound. The error bars show the 95% confidence interval in the mean and the number shown at the top of each bar is the number of vehicles measured. Data points for which 25 or fewer valid vehicle emissions measurements were recorded have been excluded from the plot. This is because too much uncertainty is introduced where too few valid vehicle measurements are available to make the calculation. Contributions of vehicles, separated by vehicle type, fuel type and Euro standard, to the overall NO_x emissions at A635 Westbound are presented in the source apportionment analysis (Section 5).

Some key observations from Figure 11 are:

- NO_x emissions are higher from diesel cars than from petrol cars of the same Euro standard.
- NO_x emissions from petrol cars are low across all Euro standards.
- Euro 6 diesel cars have the lowest NO_x emissions across all Euro standards for diesel cars.
- NO_x emissions from diesel LGVs show no significant difference between Euro 4 and Euro 5 vehicles, however also show a large decrease from Euro 5 to Euro 6.
- Absolute emissions measurements for comparable vehicle Euro standards are lower at A635 Westbound than A635 Eastbound. This could be attributed to the difference in site characteristics, such as the gradient of the road. The A635 Eastbound site has a steeper gradient, which means that vehicles captured will be driving under higher load conditions than when driving slightly downhill at the A635 Westbound site.

Figure 11 Emissions of NO_x from cars and vans by fuel type and Euro standard, measured on the A635 Westbound. The uncertainty intervals shown are the 95% confidence intervals in the mean and the number shown at the top of each bar is the number of vehicles measured.



3.2 NO_X EMISSIONS BY EURO STANDARD – BUSES

Figure 12 shows the mean NO_x emissions from diesel buses, split by Euro standard and site location. The error bars show the 95% confidence interval in the mean and the number shown at the top of each bar is the number of vehicles measured. Data points for which fewer than 5 valid vehicle emissions measurements were recorded have been excluded from the plot (see Table 2 for all vehicle counts). Note that the vehicle category used in this analysis could include buses and/or coaches.

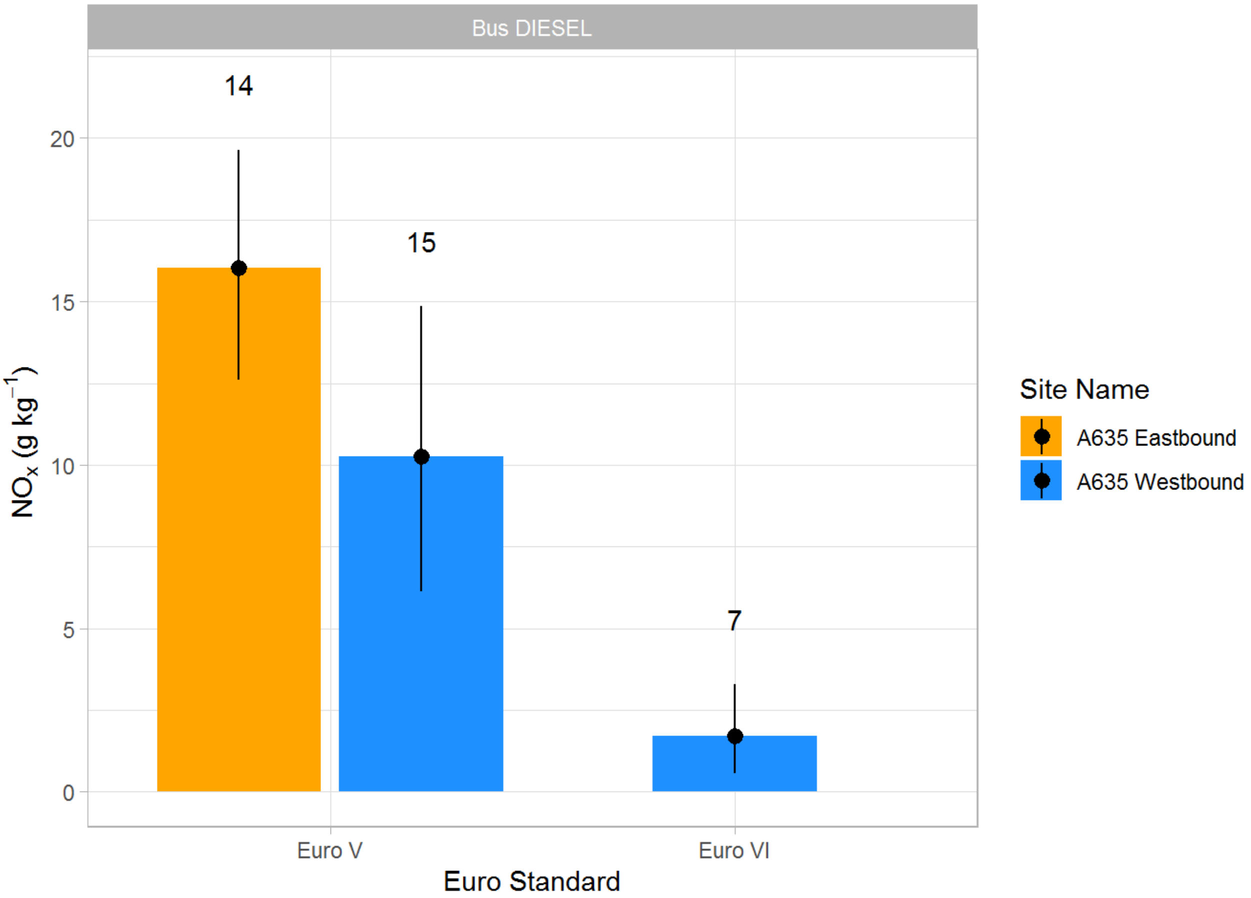
Table 2 Summary of NO_x valid bus measurements at each measurement location.

Site name	Euro standard	Fuel type	NO_x Valid	Total	% Valid	Unique vehicles
A635 Eastbound	Euro III	DIESEL	0	1	0.0	1
A635 Eastbound	Euro IV	DIESEL	1	2	50.0	2
A635 Eastbound	Euro V	DIESEL	14	17	82.4	4
A635 Eastbound	Euro VI	DIESEL	1	1	100.0	1
A635 Westbound	Euro III	DIESEL	4	4	100.0	1
A635 Westbound	Euro IV	DIESEL	4	4	100.0	3
A635 Westbound	Euro V	DIESEL	15	16	93.8	6
A635 Westbound	Euro VI	DIESEL	7	7	100.0	5

The contribution of buses (of each Euro standard) to the overall NO_x emissions at each site are presented in the source apportionment analysis (Section 5). Some key observations from Figure 12 are:

- Only 52 measurements of 23 buses were captured during the campaign in Doncaster. These were predominantly Euro V vehicles.
- There is a decrease in NO_x emissions between Euro V and Euro VI diesel buses observed at A635 Westbound.
- Comparable numbers of valid bus measurements were captured at the A635 Eastbound and A635 Westbound sites.
- Emissions of NO_x from Euro V buses at A635 Westbound were greater than at A635 Eastbound on average, although the error bars overlap. A mixture of single and double deck buses were observed at both sites. Single deck vehicles have a lighter load than double deck vehicles and because of this, the SCR technology in the after-treatment system behaves differently. The limited number of bus measurements at both sites result in a large amount of uncertainty.

Figure 12 Emissions of NO_x from buses by Euro standard and site location. The uncertainty intervals shown are the 95% confidence intervals in the mean and the number shown at the top of each bar is the number of vehicles measured.



3.3 NO_X EMISSIONS BY EURO STANDARD – HGVS

Figure 13 shows the mean NO_x emissions from diesel HGVs, split by Euro standard and site location. The error bars show the 95% confidence interval in the mean and the number shown at the top of each bar is the number of vehicles measured. Data points for which fewer than 10 valid vehicle emissions measurements were recorded have been excluded from the plot (see Table 3 for all vehicle counts).

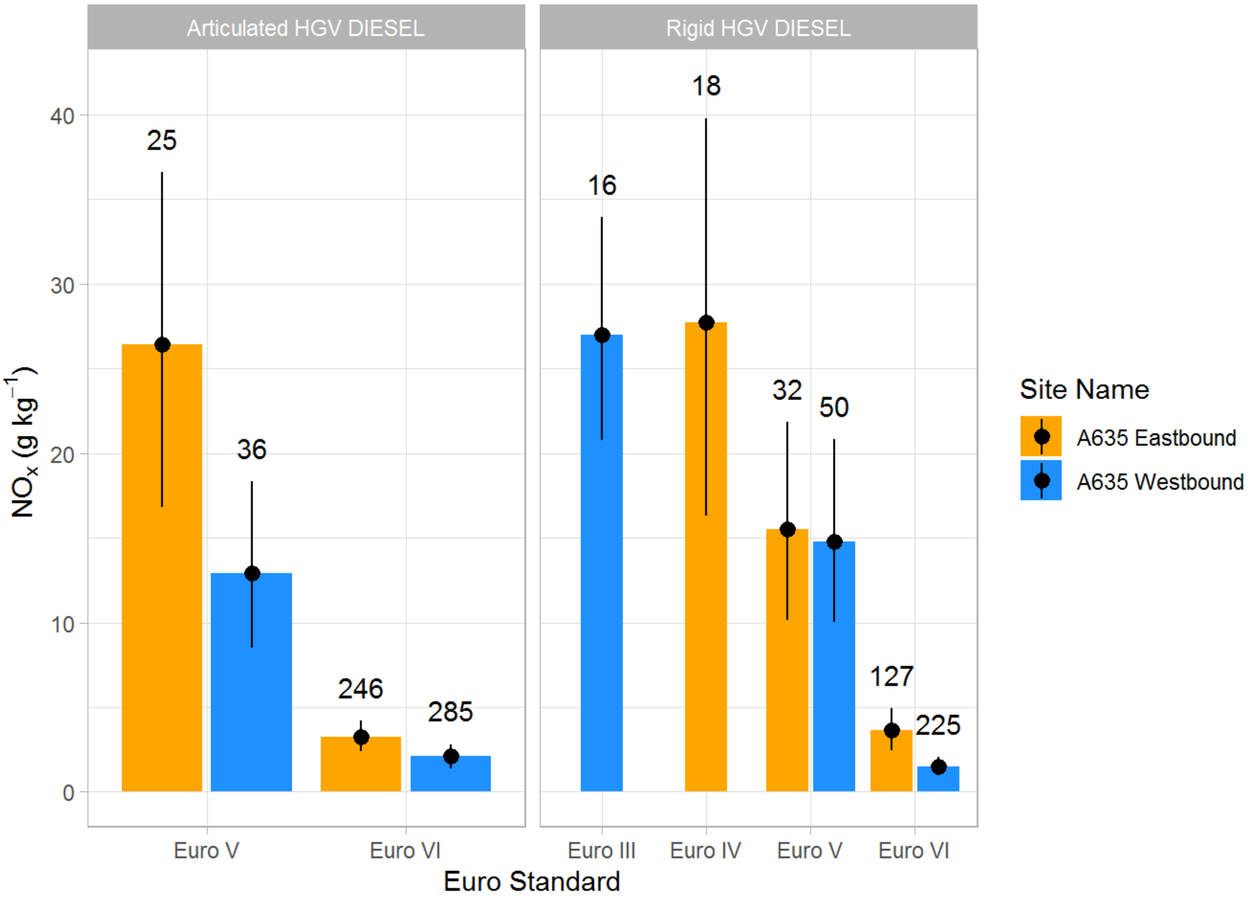
Table 3 Summary of NO_x valid rigid and articulated HGV measurements at each measurement location.

Site name	Euro standard	Fuel type	HGV type	NO_x Valid	Total	% Valid
A635 Eastbound	Euro III	DIESEL	ARTIC	1	1	100.0
A635 Eastbound	Euro III	DIESEL	RIGID	1	8	12.5
A635 Eastbound	Euro IV	DIESEL	ARTIC	1	3	33.3
A635 Eastbound	Euro IV	DIESEL	RIGID	18	26	69.2
A635 Eastbound	Euro V	DIESEL	ARTIC	25	40	62.5
A635 Eastbound	Euro V	DIESEL	RIGID	32	50	64.0
A635 Eastbound	Euro VI	DIESEL	ARTIC	246	350	70.3
A635 Eastbound	Euro VI	DIESEL	RIGID	127	196	64.8
A635 Westbound	Euro III	DIESEL	RIGID	16	30	53.3
A635 Westbound	Euro IV	DIESEL	ARTIC	3	5	60.0
A635 Westbound	Euro IV	DIESEL	RIGID	9	26	34.6
A635 Westbound	Euro V	DIESEL	ARTIC	36	69	52.2
A635 Westbound	Euro V	DIESEL	RIGID	50	111	45.0
A635 Westbound	Euro VI	DIESEL	ARTIC	285	1000	28.5
A635 Westbound	Euro VI	DIESEL	RIGID	225	568	39.6

The contribution of HGVs (of each Euro standard) to the overall NO_x emissions at each site are presented in the source apportionment analysis (Section 5). Some key observations from Figure 13 are:

- There is a decrease in NO_x emissions with increasing Euro standards, in both articulated and rigid HGVs (aHGV and rHGV, respectively) at both measurement locations.
- Uncertainty in NO_x emissions is large for HGVs of all Euro standards at both sites.
- There is a large decrease in NO_x emissions between Euro V and Euro VI rHGVs and aHGVs ar the A635 Eastbound and the A635 Westbound.
- NO_x emissions from Euro VI aHGVs are similar to Euro VI rHGVs at both measurement sites (error bars overlap).

Figure 13 Emissions of NO_x from rigid and articulated HGVs (aHGV and rHGV, respectively) by Euro standard and site location. The uncertainty intervals shown are the 95% confidence intervals in the mean and the number shown at the top of each bar is the number of vehicles measured.



3.4 PM EMISSIONS BY EURO STANDARD – CARS AND VANS

The following sections summarise the real-world emissions of particulate matter (PM) from the diesel cars, vans and buses recorded during the measurement campaigns. Remote sensing provides an indicative measure of PM from vehicle exhaust that is based on a measurement of opacity. This section focuses on diesel vehicles because the ultraviolet (UV) channel (around 230 nm) used in the remote sensing instrument, has been shown to provide a measure of diesel smoke emissions (i.e. emissions dominated by black carbon). Smoke emissions like these are negligible for petrol vehicles, and as such the same analysis cannot be conducted. Negative emissions can arise as a result of the background subtraction procedure used within the remote sensing instrument software and are indicative of measurement noise.

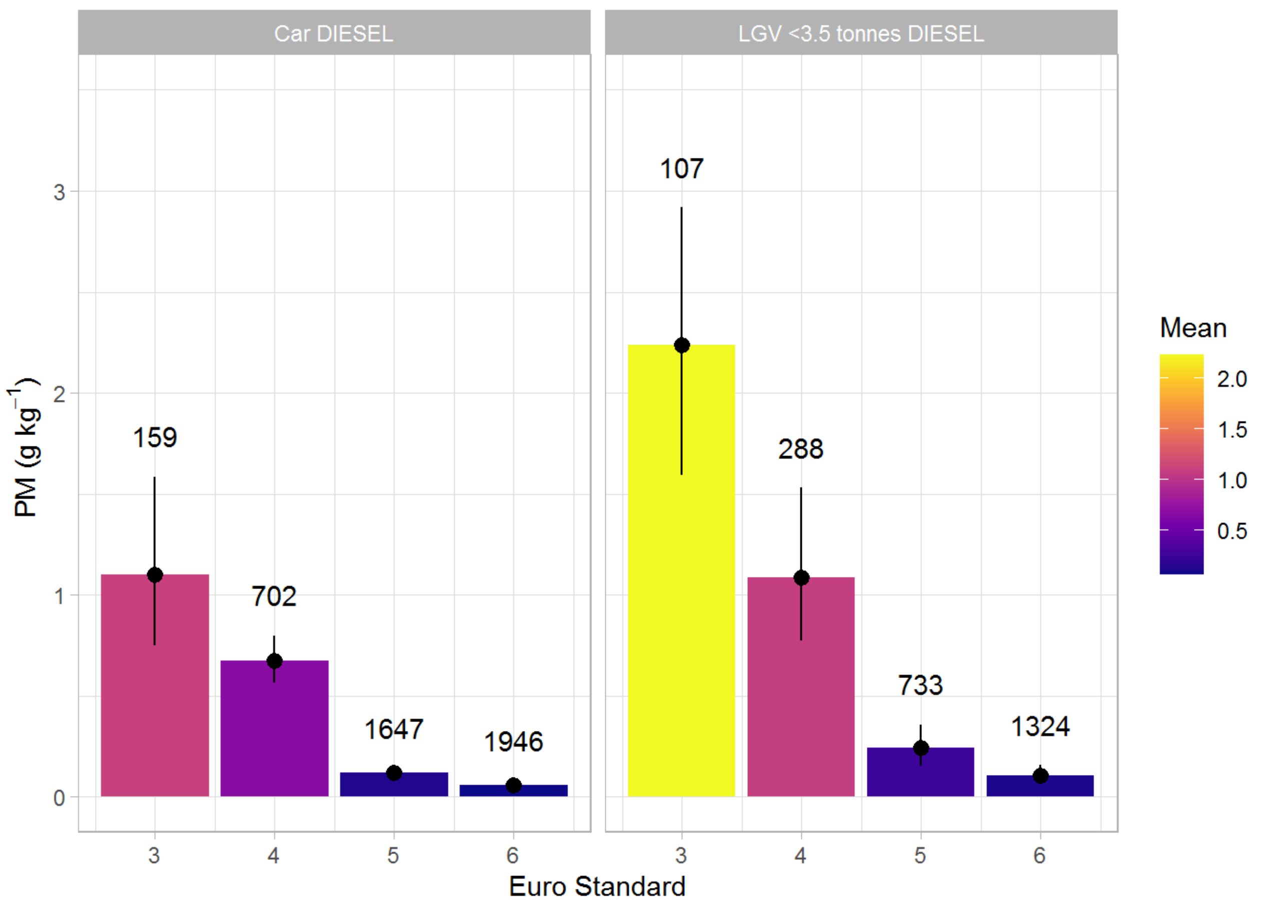
3.4.1 A635 Eastbound

Figure 14 shows the mean PM emissions from diesel cars and vans split by Euro standard, recorded on the A635 Eastbound. The error bars show the 95% confidence interval in the mean and the number shown at the top of each bar is the number of vehicles measured. Data points for which 10 or fewer valid vehicle emissions measurements were recorded have been excluded from the plot.

Some key observations from Figure 14 are:

- In general, emissions of PM decrease as Euro standard increases.
- Emissions of PM dropped from Euro 3 to Euro 4, aligning with the introduction of diesel particulate filters (DPF), which physically trap the PM, introduced in late Euro 4 vehicles.
- Euro 5 and Euro 6 diesel vehicles also use DPFs; as a result emissions of PM are low for Euro 5 and Euro 6 diesel cars and diesel LGVs.

Figure 14 Emissions of PM from diesel cars and vans by Euro standard, measured on the A635 Eastbound. The uncertainty intervals shown are the 95% confidence intervals in the mean and the number shown at the bottom of each bar is the number of vehicles measured.



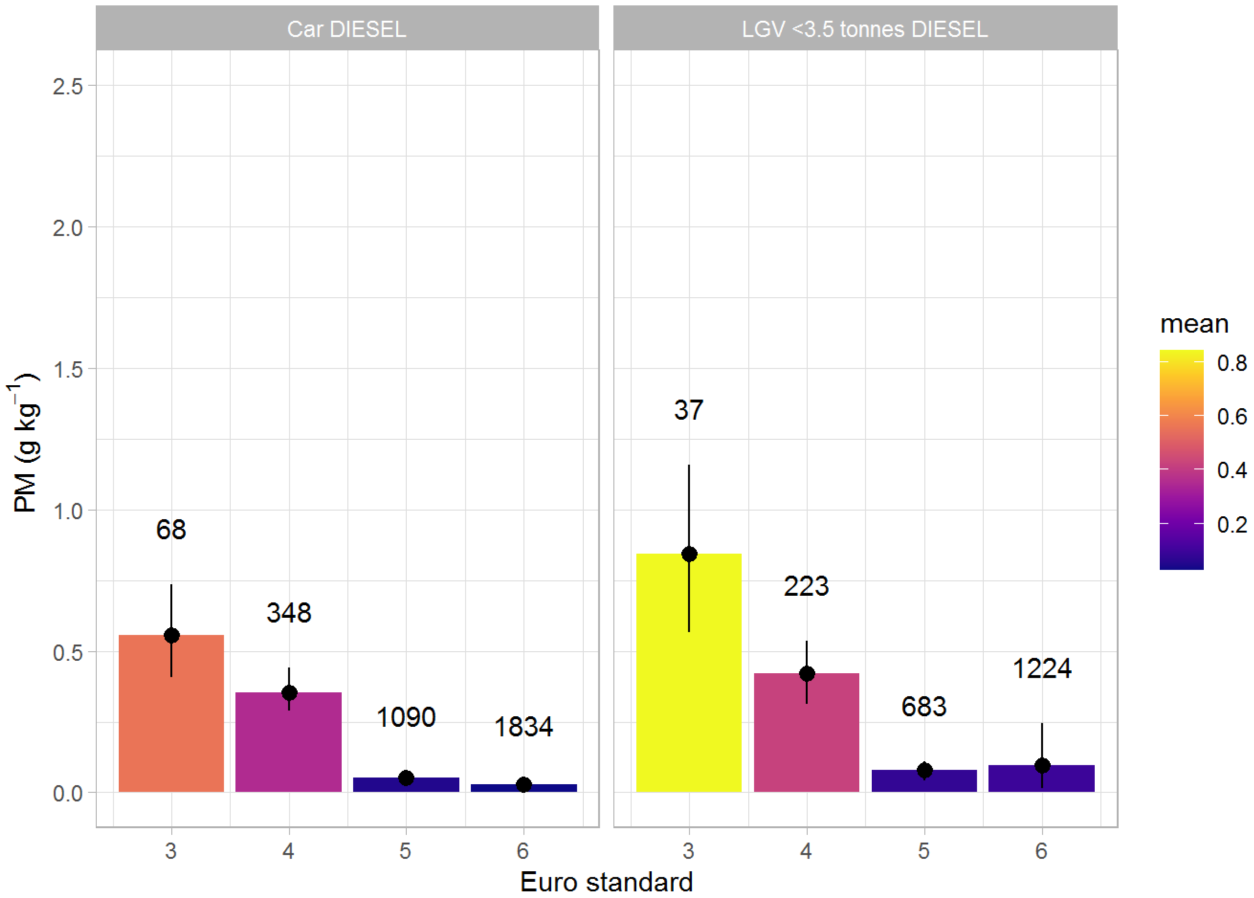
3.4.2 A635 Westbound

Figure 15 shows the mean PM emissions from diesel cars and vans split by Euro standard, recorded on the A635 Westbound. The error bars show the 95% confidence interval in the mean and the number shown at the top of each bar is the number of vehicles measured. Data points for which 10 or fewer valid vehicle emissions measurements were recorded have been excluded from the plot.

Some key observations from Figure 15 are:

- In general, emissions of PM decrease as Euro standard increases.
- Emissions of PM dropped from Euro 3 to Euro 4, aligning with the introduction of diesel particulate filters (DPF), which physically trap the PM, introduced in late Euro 4 vehicles.
- Euro 5 and Euro 6 diesel vehicles also use DPFs; as a result emissions of PM are low for Euro 5 and Euro 6 diesel cars and diesel LGVs.

Figure 15 Emissions of PM from diesel cars and vans by Euro standard, measured on the A635 Westbound. The uncertainty intervals shown are the 95% confidence intervals in the mean and the number shown at the bottom of each bar is the number of vehicles measured.



3.5 PM EMISSIONS BY EURO STANDARD - BUSES

Figure 16 shows the mean PM emissions from diesel buses, split by Euro standard and site location. The error bars show the 95% confidence interval in the mean and the number shown at the bottom of each bar is the number of vehicles measured. Data points for which fewer than 10 valid vehicle emissions measurements were recorded have been excluded from the plot (see Table 4 for vehicle counts). Note that the vehicle category used in this analysis could include buses and/or coaches.

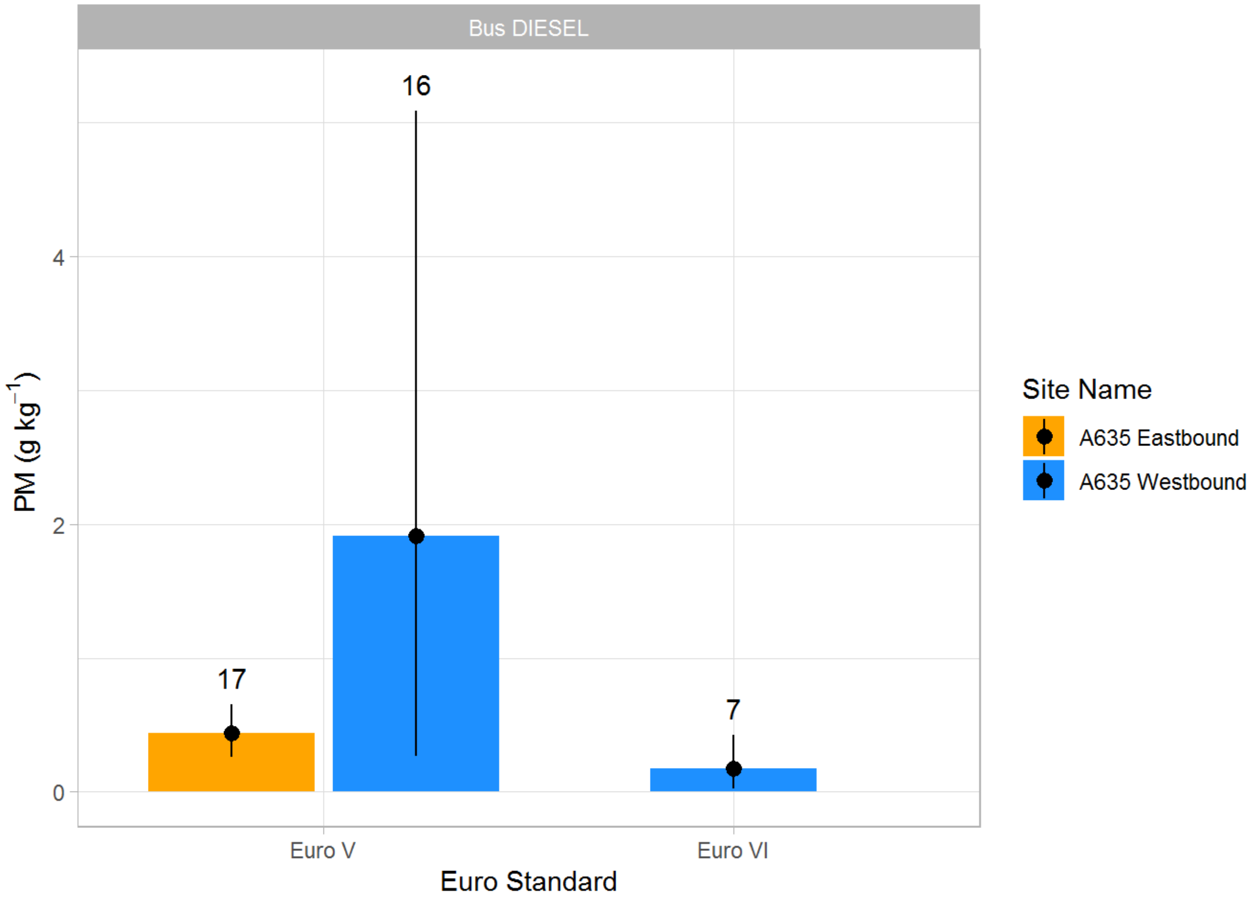
Table 4 Summary of PM valid bus measurements at each measurement location.

Site name	Euro standard	Fuel type	PM Valid	Total	% Valid	Unique vehicles
A635 Eastbound	Euro III	DIESEL	1	1	100	1
A635 Eastbound	Euro IV	DIESEL	2	2	100	2
A635 Eastbound	Euro V	DIESEL	17	17	100	4
A635 Eastbound	Euro VI	DIESEL	1	1	100	1
A635 Westbound	Euro III	DIESEL	4	4	100	1
A635 Westbound	Euro IV	DIESEL	4	4	100	3
A635 Westbound	Euro V	DIESEL	16	16	100	6
A635 Westbound	Euro VI	DIESEL	7	7	100	5

Some key observations from Figure 16 are:

- Only 52 measurements of 23 buses were captured during the campaign in Doncaster. These were predominantly Euro V vehicles.
- Comparable numbers of valid bus measurements were captured at the A635 Eastbound and A635 Westbound sites.
- Emissions of PM from Euro V buses are greater at the A635 Westbound than at the A635 Eastbound, with significantly larger error bars that do overlap. The statistics presented for the A635 Westbound are weighted by one particularly large PM emissions measurement at the site (approximately 25 g kg^{-1}). Other measurements of the same bus (5 at the A635 Eastbound and 4 at the A635 Westbound) show that this is not representative of this vehicles normal working operations. The median emissions measured from all Euro V buses at both measurement locations are similar (0.24 g kg^{-1} at the A635 Eastbound and 0.27 g kg^{-1} at the A635 Westbound), which demonstrates that bus emissions of PM at both sites are mostly comparable.
- There is a decrease in PM emissions between Euro V and Euro VI diesel buses observed at A635 Westbound.

Figure 16 Emissions of PM from buses by Euro standard and site location. The uncertainty intervals shown are the 95% confidence intervals in the mean and the number shown at the bottom of each bar is the number of vehicles measured.



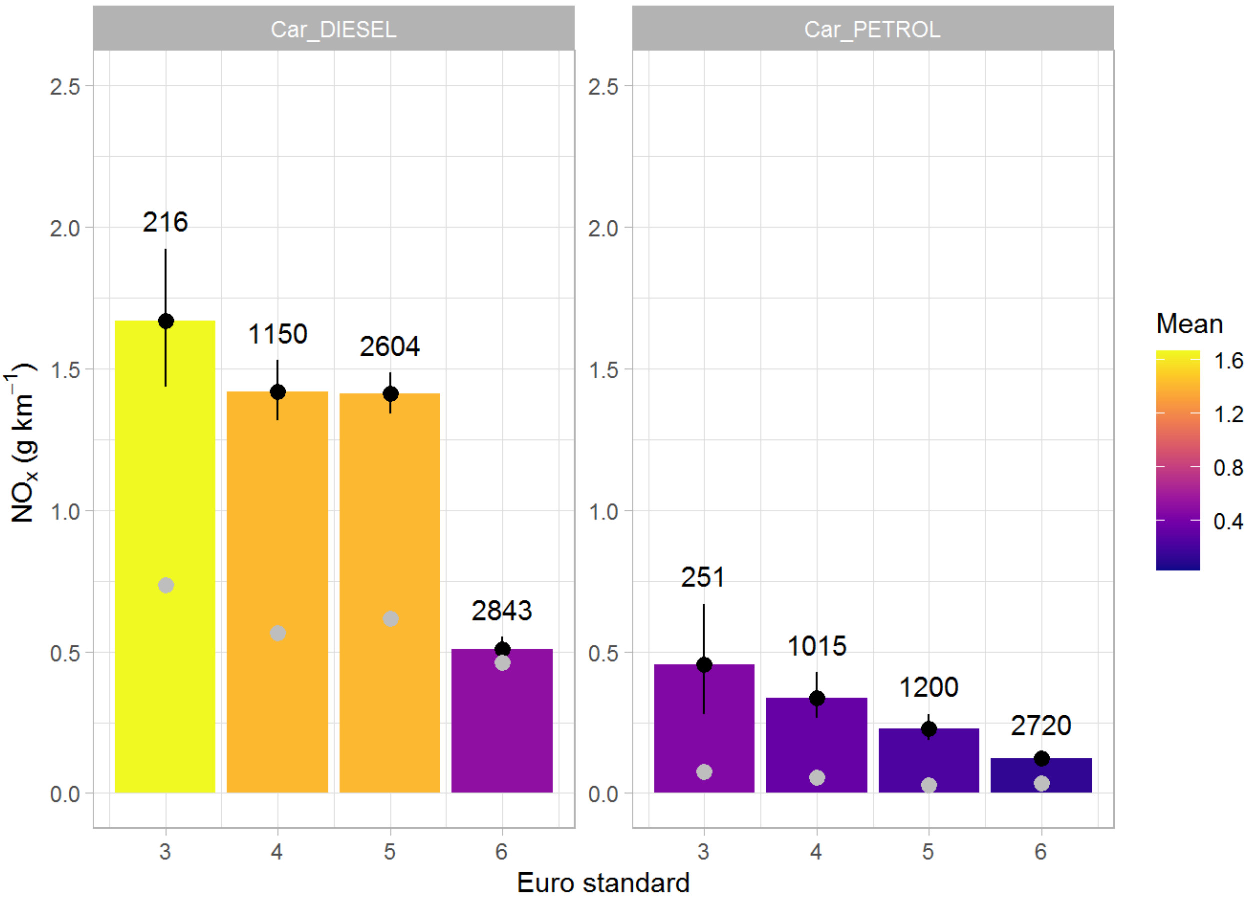
4. NO_X EMISSION FACTORS

Mean NO_x emissions for different vehicle types can be derived from the large number of vehicle measurements made during the measurement campaign grouped by selected vehicle characteristics. Figure 17 presents the NO_x emission factors for petrol and diesel cars by Euro standard. The black points and coloured bars present the data derived from the Doncaster measurement campaign. The error bars show the 95% confidence interval in the mean and the number shown at the top of each bar is the number of vehicles measured. Data points for which fewer than 10 valid vehicle emissions measurements were recorded have been excluded from the plot. The grey points show emission factors derived from COPERT 5.4 for comparison. The COPERT emission factors were extracted for each vehicle at the actual speed of the vehicle at the point of measurement and the COPERT emission factor presented is an average of the COPERT emissions factors for all vehicles in a category. Note that remote sensing measurements tend to be captured when a vehicle is under higher load conditions than average driving, which can lead to overestimates in mean emissions [3]. Some key observations from Figure 17 are:

- NO_x emission factors for petrol cars have reduced steadily with the introduction of higher Euro standards from Euro 3 to Euro 6.
- NO_x emission factors for petrol cars have reduced steadily with the introduction of higher Euro standards from Euro 3 to Euro 6.
- NO_x emission factors for diesel cars show a decrease between Euro 5 and Euro 6 vehicles, contributed by the significant reduction in EU emission standards for Euro 6 diesel vehicles [4].
- The real-world NO_x emission factors are higher than the COPERT emission factors.

- The difference between real-world and COPERT NO_x emission factors is greater for Euro 3, Euro 4 and Euro 5 cars, than for Euro 6.
- The difference between Euro 5 and Euro 6 emission factors for diesel cars is bigger for the real-world emission factors, than for the COPERT emissions factors. This means that as fleets evolve towards having more Euro 6 vehicles, emissions projections based on the real-world emission factors would reduce quicker than using the COPERT factors.

Figure 17 NO_x emissions for diesel and petrol cars by Euro standard. The black points and bars show the real-world emission factors derived from the vehicle emissions remote sensing data and the grey points show the corresponding emission factors derived from COPERT.



5. NO_X SOURCE APPORTIONMENT

By combining the Doncaster real-world vehicle emission factors derived during this study (Section 4) with the fleet composition for a particular road or area (Section 2), it is possible to apportion the overall vehicle tail-pipe emissions to different vehicle categories. Source apportionment is particularly useful because it provides a quantification of the most important vehicles to control.

Figure 18 and Figure 19, shown in the tabs below, show the apportionment of emissions from cars, LGVs, buses, rigid HGVs (rHGV) and articulated HGVs (aHGV), to vehicles by fuel type and Euro standard based on the fleet composition recorded at each measurement location during the vehicle emissions remote sensing campaign. Vehicle classes for which the emission factors are particularly uncertain because there were fewer than 10 valid emissions measurements have been excluded from the source apportionment plots. In general, these vehicles would be expected to contribute a small proportion of the total NO_x emissions as only a small number of these vehicles were seen on the road during the measurement campaigns.

The same analysis cannot be completed for PM, as a result of the measurement method. This is because the remote sensing measurements of PM are based on opacity, which provides an indication of the black carbon emissions from a vehicle but cannot distinguish between particles of different sizes and compositions. As a result, the real-world driving emissions measurements are not directly comparable to PM emissions from vehicle certification tests and inventory emission factors, and therefore the PM source apportionment cannot be calculated.

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Figure 18 Apportionment of emissions to cars, vans, buses, rigid HGVs and articulated HGVs by fuel type and Euro standard based on real-world emission factors and fleet composition on the A635 Eastbound, measured during the vehicle emissions remote sensing field campaign.

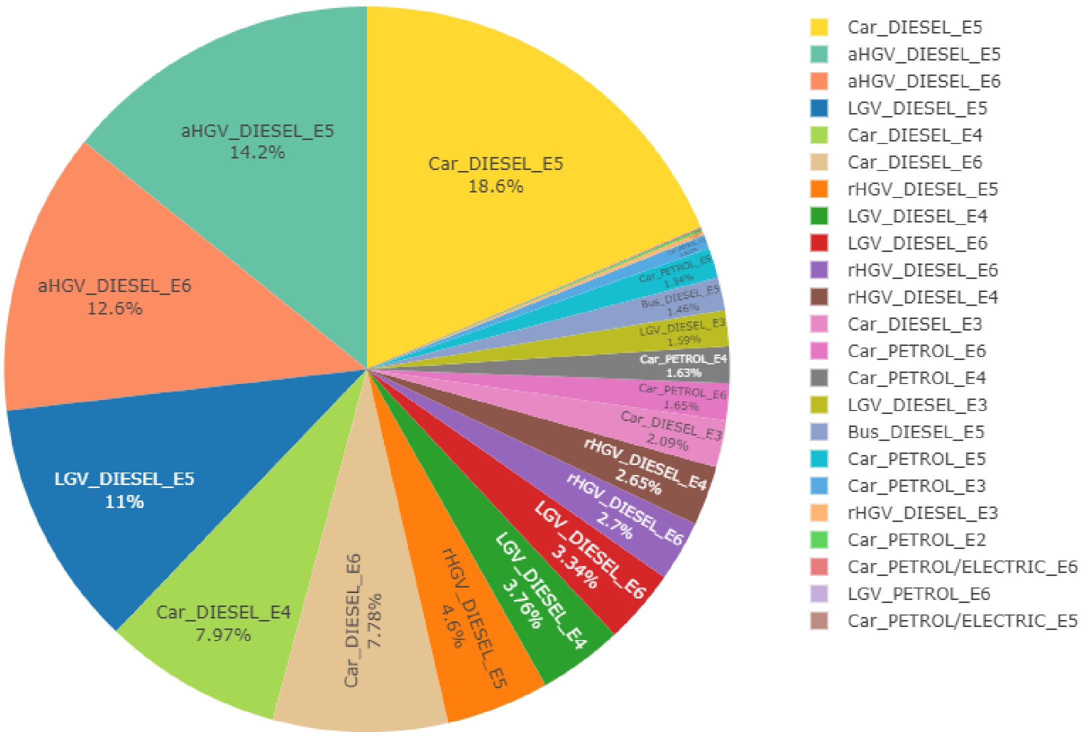
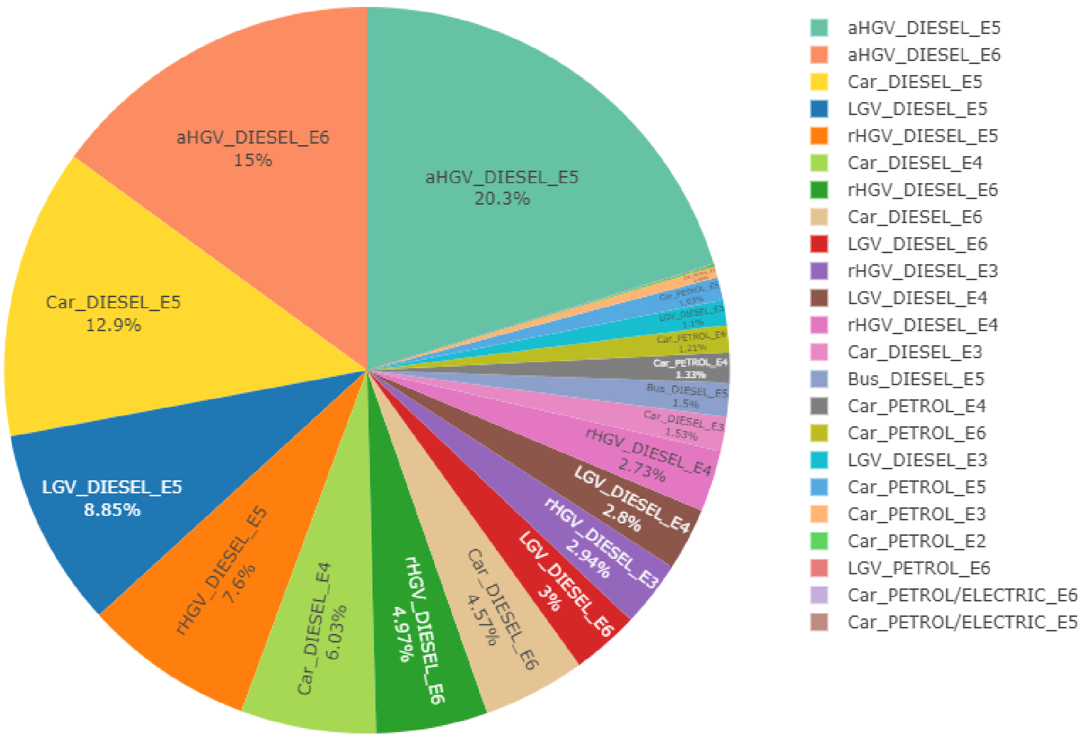


Figure 19 Apportionment of emissions to cars, vans, buses, rigid HGVs and articulated HGVs by fuel type and Euro standard based on real-world emission factors and fleet composition on the A635 Westbound, measured during the vehicle emissions remote sensing field campaign.



5.1 COMPARISON OF SOURCE APPORTIONMENT AT EACH MEASUREMENT SITE

Euro 5 diesel cars as well as Euro V and VI articulated HGVs (aHGVs) are the top three emissions sources at both measurement lcoations in Doncaster. Of these three, Euro 5 diesel cars are highest at the A635 Eastbound site (18.6%) followed by the Euro V and VI aHGVs (14.2% and 12.6%, respectively). Conversely, aHGVs are highest at the A635 Westbound site (20.3% and 15%, respectively), compared to Euro 5 diesel cars (12.9%). Emissions on Doncaster Road in both directions are dominated by diesel vehicles. This is because diesel vehicles have larger NO_x emission factors than petrol vehicles. The emission factors presented for Euro V aHGVs, as well as all rigid HGVs (rHGVs) and buses are uncertain; which will have an impact on the uncertainties in the proportion of NO_x attributed to these vehicle classes. It should be noted that the camera placement for number plate recognition, may not be optimised for the capture of HGVs. The source apportionment plots presented above can be used to calculate what the reduction in emissions would be by implementing a range of measures, for example a Low Emission or Clean Air Zone.

6. HYBRID VEHICLES

This section provides information about the hybrid vehicles measured during the campaign in Doncaster, as they will become an increasingly important component of the vehicle fleet over time. Following Ricardo's blog on hybrid vehicles, this section aims to determine the amount of time hybrid vehicles spend using batteries under real driving conditions.

Electric vehicles and petrol hybrid vehicles operating in battery mode have zero exhaust emissions. This means that the remote sensing instrument will 'fail' to measure any pollutants in the vehicle's exhaust plume. In the blog mentioned above, Ricardo investigated whether this measurement failure could in fact provide an insight into the behaviour of hybrid vehicles.

Table 5 shows a summary of the number of petrol hybrid and pure electric cars seen during the measurement campaigns, at both measurement sites. The number of pure electric, electric hybrid and plug-in hybrid vehicles sold in the UK continues to increase, with over 110,000 new cars registered in March [5] and April 2022 [6].

The remote sensing measurements in Doncaster, carried out in March and May 2022, captured 23 pure electric and 37 electric hybrid vehicles with a registration date during or after March 2022, demonstrating that there are brand new hybrid vehicles in the Doncaster vehicle fleet. The UK Government have committed to phase out the sale of new petrol and diesel cars by 2030 [7]. Hybrid vehicles will be phased out in 2035, after conventional petrol and diesel cars, and will therefore become increasingly important over time.

Table 5 Summary of hybrid and electric cars seen during the measurement campaigns.

Fuel type	Hybrid type	Number of vehicles
Electric	Pure Electric	213
Petrol Hybrid	Hybrid Electric	437
Petrol Hybrid	Plug-in Hybrid	305
Petrol Hybrid	Range Extender	4

Using a measure of whether the remote sensing CO_2 measurement was successful (i.e. there were tail-pipe emissions) or not, it is possible to calculate the percentage of vehicles which were operating in battery mode. Where an opus measurement of a hybrid vehicle fails, we can attribute this to the vehicle operating on the battery (i.e., there are no tailpipe emissions to measure), rather than the regular combustion engine which would produce detectable tailpipe emissions. Overall, failed CO_2 plume measurements are seen for 60.4% of hybrid electric vehicles, and as such this percentage is assumed to be operating in battery mode (compared to 39.6% of vehicles operating on the combustion engine) at the time of measurement. Similarly, 64.3% of plug-in hybrids and 100% of range-extended electric vehicles were measured while operating on their battery. The calculation method was verified using the pure electric vehicles seen during this study.

7. REFERENCES

[1] UK-Air, “Doncaster Metropolitan Borough Council AQMA No. 7 (Hickleton and Marr on the A635),” 2022. [Online]. Available: https://uk-air.defra.gov.uk/aqma/details?aqma_ref=3379.

[2] National Atmospheric Emissions Inventory (NAEI), “Vehicle fleet composition projections (Base 2019r),” [Online]. Available: https://naei.beis.gov.uk/resources/rtp_fleet_projection_NAEI_2017_Base2019r_v1_1.xlsx. [Accessed 18 03 2022].

[3] J. Davidson, R. A. Rose, N. J. Farren, R. L. Wagner, T. P. Murrells and D. C. Carslaw, “Verification of a National Emission Inventory and Influence of On-road Vehicle Manufacturer-Level Emissions,” *Environ. Sci. Technol.,* vol. 55, pp. 4452-4461, 2021.

[4] AA, “Euro Emission Standards: Limits to improve air quality and health,” 11 Decemeber 2017. [Online]. Available: https://www.theaa.com/driving-advice/fuels-environment/euro-emissions-standards. [Accessed 01 04 2022].

[5] SMMT, “New car market feels supply chain squeeze during critical ‘new numberplate’ month,” 05 04 2022. [Online]. Available: https://www.smmt.co.uk/2022/04/new-car-market-feels-supply-chain-squeeze-during-critical-new-numberplate-month/.

[6] SMMT, “April new car market declines -15.8% as supply constraints see 2022 outlook downgraded,” 05 05 2022. [Online]. Available: https://www.smmt.co.uk/2022/05/april-new-car-market-declines-15-8-as-supply-constraints-see-2022-outlook-downgraded/.

[7] gov.uk, “Government takes historic step towards net-zero with end of sale of new petrol and diesel cars by 2030,” 18 11 2020. [Online]. Available: https://www.gov.uk/government/news/government-takes-historic-step-towards-net-zero-with-end-of-sale-of-new-petrol-and-diesel-cars-by-2030. [Accessed 18 03 2022].

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