Scenario development to inform air quality action planning in the London Borough of Ealing

Volume 1: Main Report

Version: December 12th 2014

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Glossary of Terms

Term	Meaning
DPF	Diesel Particulate Filter
EGR	Exhaust Gas Recirculation
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen (expressed as NO_2 equivalent values by mass unless otherwise stated)
RSD	Remote Sensing Detector
SCR	Selective catalytic reduction

Executive Summary

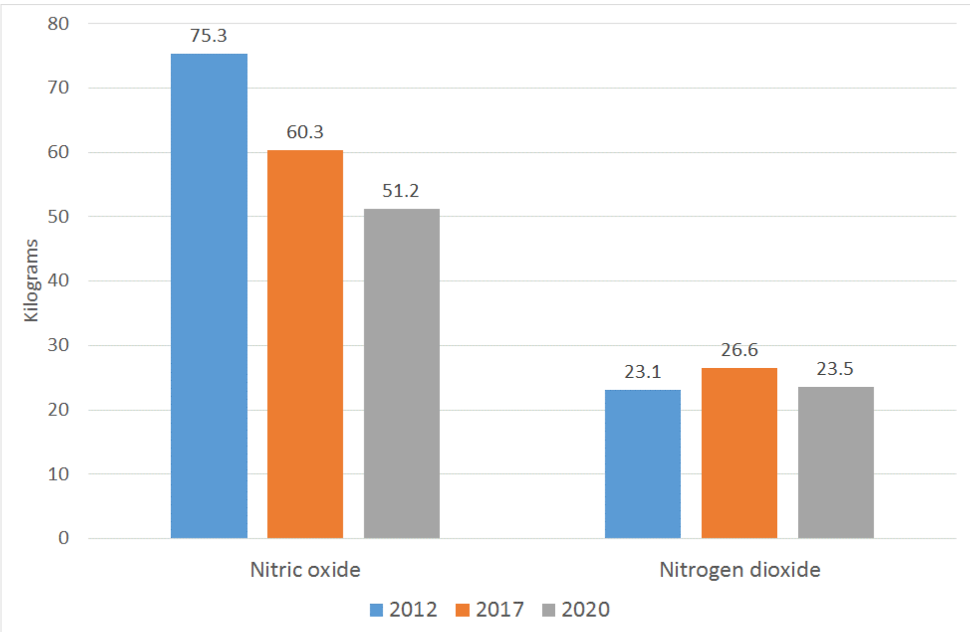
Overview

The development to date of local authority air quality action plans has been challenging because the 'a priori' efficacy of particular interventions has been difficult to quantify with any degree of confidence. One of the reasons for this is that insufficient empirical data has been available on the primary nitrogen dioxide (NO_2) emissions characteristics of the urban road vehicle fleet. The recent collection of NO_2 and NO emissions data in Ealing (and other locations in London) in 2012 using remote sensing techniques allows us to quantify with much greater confidence the likely impact and effectiveness of interventions relating to particular vehicle classes and modes of vehicle operation.

The aim of the project is to develop future year policy scenarios to inform the development of the Ealing air quality action plan. The remote sensing data collected in 2012 provide detailed insights into the NO_2 and NO emission characteristics of vehicle types, 'Euro' classes, and fuel technologies at 2012. In addition, the data allows us to describe the more detailed dynamic relationships between NO_2 and NO emissions, vehicle speed, and acceleration (and other factors that influence engine load such as vehicle mass and highway gradient). Case study locations within Ealing were selected in consultation with officers, the final selections representing a mix of Borough specific focus areas, and TfL focus areas. They include identified air quality 'hot spots', and encompass a range of road types and traffic conditions from intense urban operation to strategic routes.

Light duty vehicle emissions

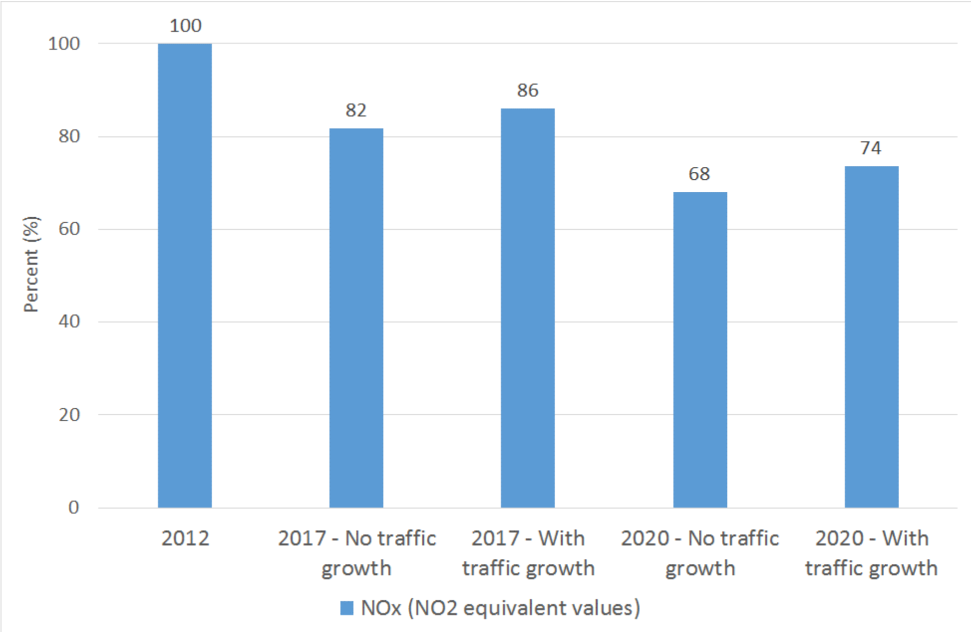
Emissions of nitric oxide and nitrogen dioxide from light duty vehicles (passenger cars, vans, and taxis) were quantified across the case study areas. Emission rates (grams of pollutant emitted per kilogram of fuel burned) were combined with estimates of fuel consumption, journey times, and traffic flow data to produce estimates of absolute mass emissions of pollutant in kilograms. Variability in light vehicle emissions due to traffic congestion and variability in journey time were quantified using data from probe vehicle surveys implemented in the case study areas in 2013.



Aggregate emissions of light vehicle NO and NO2 across case study areas

Reasonable assumptions regarding the evolution of the light vehicle fleet in terms of fuel type, engine capacity, and Euro standard were adopted.

A key issue is the assumed efficacy of the Euro 6 emissions standard. It was assumed initially that Euro 6 NO_x emissions would reduce pro rata in line with the reduction in NO_x type approval limit values from Euro 5 (180mg/km for diesel passenger cars) to Euro 6 (80mg/km for diesel passenger cars), i.e. a reduction of approximately 55%. Utilising these assumptions, it was calculated that light vehicle NO_x emissions (NO_2 equivalent values) summed over the case study areas would reduce by approximately 14% between 2012 and 2017, and by approximately 26% between 2012 and 2020.

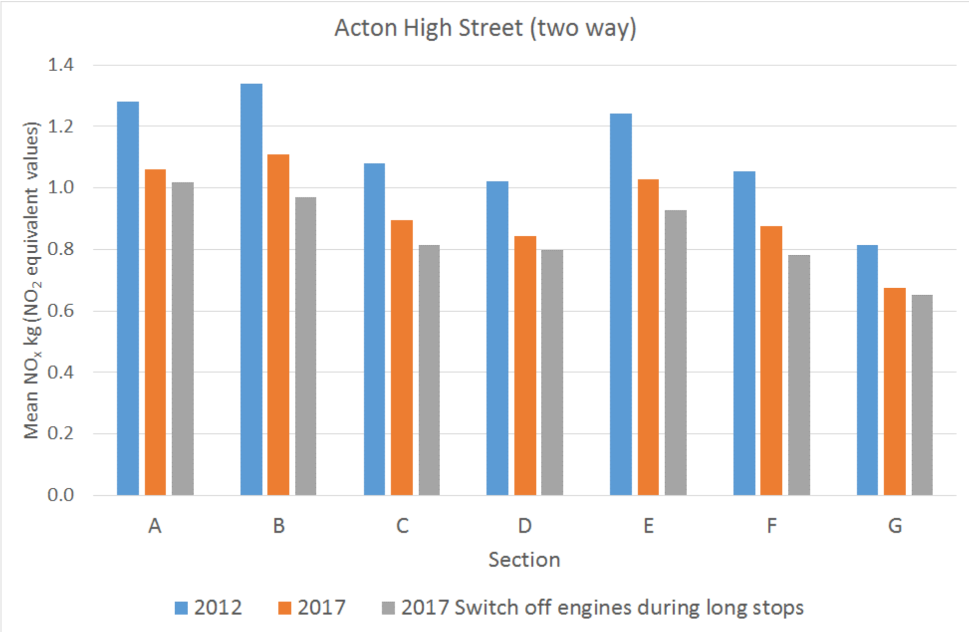


Light vehicle NOx emissions (NO2 equivalent values)

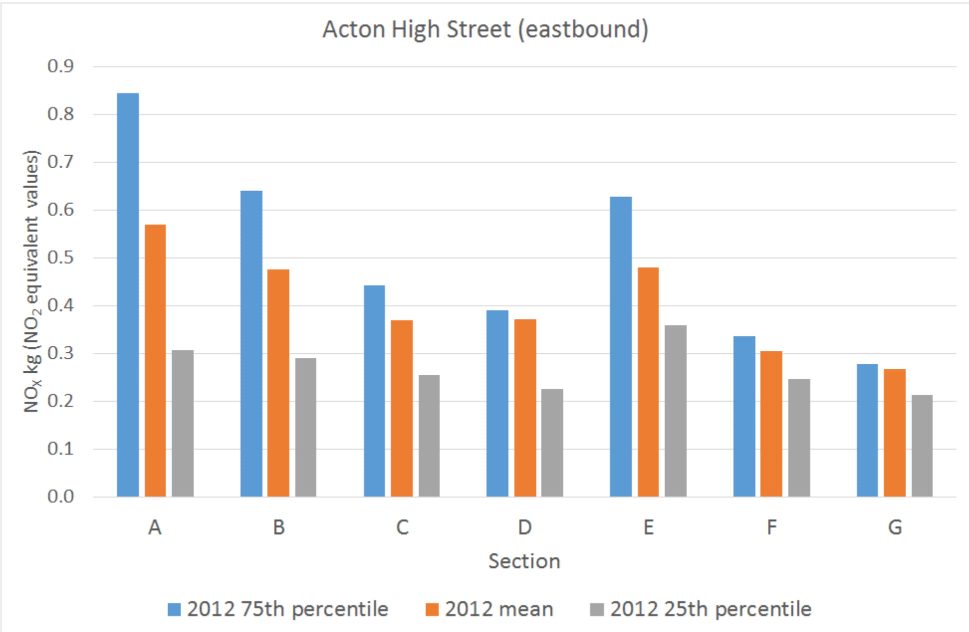
Significant spatial variability in NO_x emissions was quantified within the case study areas, with emissions 'hotspots' identified which are often related to congested areas and locations where queuing is common, for example on the approaches to signalised junctions and pedestrian crossings. The identification of such 'hotspots' provides a potential opportunity to manage such situations utilising behavioural or technological interventions. Related to this issue, dynamic variation (across repeated journeys) in journey times, stops, and delays was calculated to result in significant variability in NO_x emissions in these 'hotspot' locations. Examples of both spatial variability and dynamic variation in NO_x emissions are presented below for Acton High Street.

A number of possible light vehicle scenario interventions were tested at year 2017 to quantify potential reductions in NO_x emissions. A voluntary light vehicle scrappage scheme targeted at diesel cars and vans which are Euro 5 or older was calculated to reduce NO_x emissions by around 5% with a 10% take up, and by approximately 11% with a 20% take up, at 2017 relative to the 2017 base line.

A scenario to reduce the sales of new (Euro 6) diesel cars by 25% was calculated to result in only a marginal 1% reduction in overall light vehicle NO_x emissions in 2017. This demonstrates the magnitude of the 'legacy' challenge in managing emissions from vehicles which are already sold and operating on the network, and the time lag associated with any policy influencing new sales before the policy becomes meaningfully effective (given the current average age and turnover rate of the light vehicle fleet).



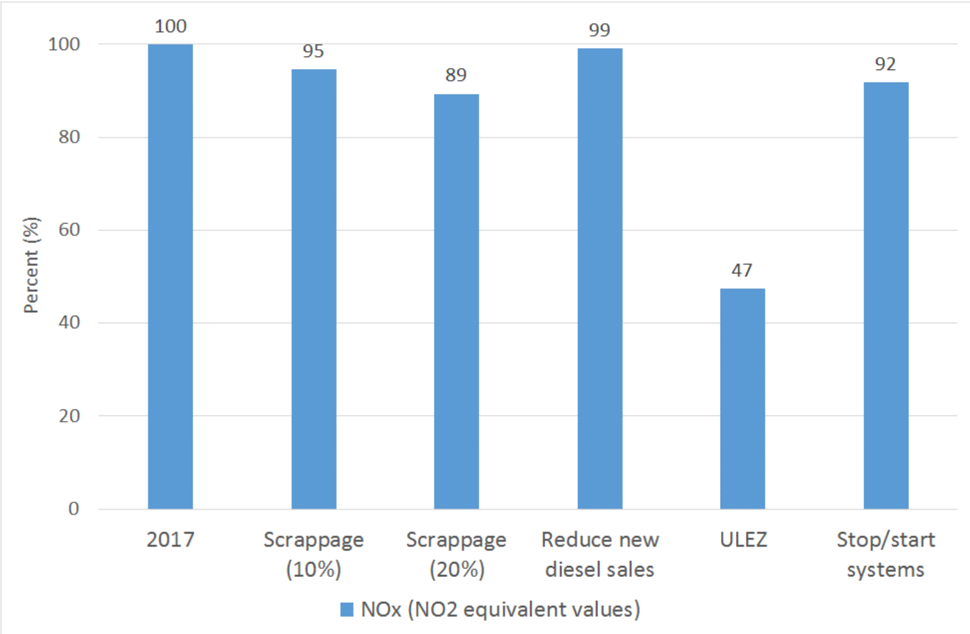
Acton High Street – Spatial variability of NOx emissions



Acton High Street (eastbound) – Dynamic variation in NOx emissions

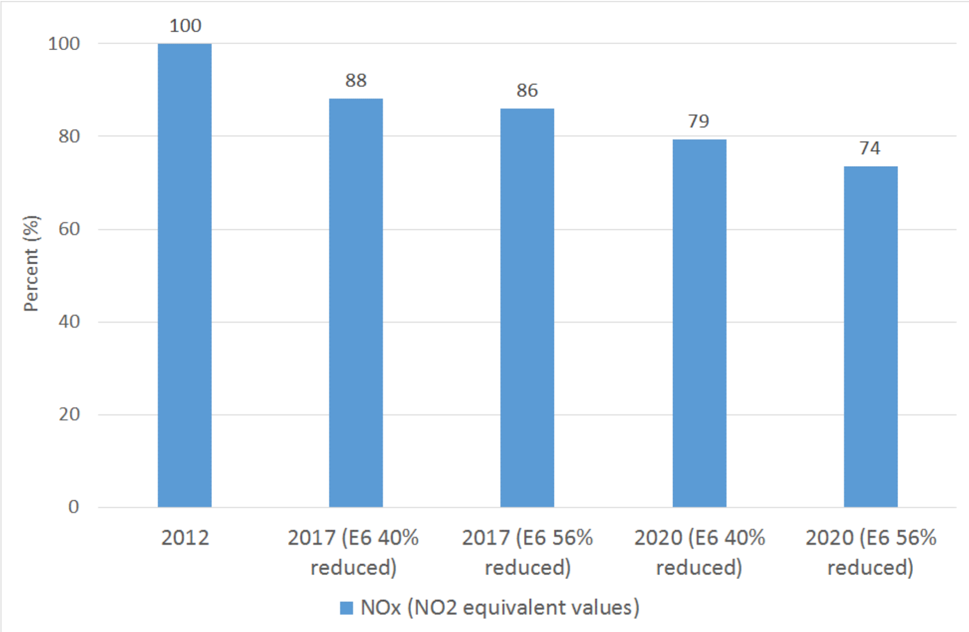
The probe vehicle surveys demonstrated that the proportion of total journey time spent stationary was very significant in some case study locations. A scenario which assumed that vehicle engines were switched off if the stop exceeded 10 seconds resulted in a reduction in NO_x emissions of approximately 8% overall. The particular benefit of this scenario is that much larger potential reductions in NO_x emissions were calculated for the 'hotspot' locations where most queuing behaviour occurs (a reduction of over 50% in one extreme location).

Finally, a more radical 'Ultra Low Emission Zone' scenario which adopted a Euro 6 standard for all diesel light vehicles, and a Euro 5/6 standard for all petrol light vehicles, resulted in a 53% reduction in total overall light vehicle NO_x emissions at 2017, relative to the 2017 baseline.



Scenario comparison of light vehicle NOx emissions at 2017

As noted above, one of the key initial assumptions in this analysis was that the introduction of the Euro 6 light vehicle emissions standard used for vehicle type approval will result in a pro rata (55%) reduction in NO_x emissions in 'real-world' vehicle operation, relative to Euro 5. Past experience suggests that this assumption is questionable. Therefore, a sensitivity test was carried out assuming that the Euro 6 standard delivered a 40% reduction in NO_x from light duty diesel vehicles, relative to Euro 5. With this amended assumption, it was calculated that light vehicle NO_x emissions (NO_2 equivalent values) summed over the case study areas would reduce by approximately 12% (previously 14%) between 2012 and 2017, and by approximately 21% (previously 26%) between 2012 and 2020.



Sensitivity test for Euro 6 diesel NOx reduction efficacy

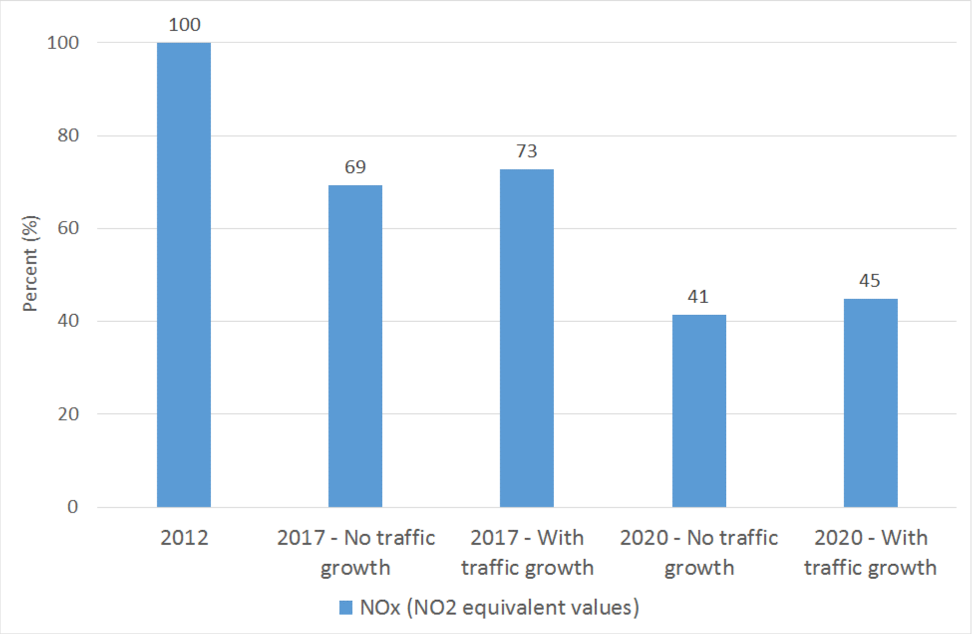
Heavy duty commercial vehicle emissions

Data derived from the 2012 remote sensing surveys for medium and heavy goods vehicles (N2 and N3 respectively) should be treated with some caution because the survey instrumentation would have difficulty collecting data from some heavy vehicle chassis configurations, and because sample sizes are relatively small (compared to light vehicles).

As with light vehicles, the assumed reduction in NO_x emissions from Euro VI vehicles relative to Euro V was based on the pro rata difference between the legislated type approval limit values. The Euro V NO_x emission limit value over the previous European Transient Cycle (ETC) is 2.0 g/kW.hr, whereas the Euro VI NO_x emission limit value over the World Harmonised Transient Cycle (WHTC) is 0.46 g/kW.hr, an assumed reduction of approximately 77%. A small additional adjustment was made to allow for the differences in the two drive cycles at Euro V and Euro VI.

A simplified approach to estimating absolute emissions is adopted for goods vehicles because the probe vehicle (speed and acceleration) data used for light vehicles is not necessarily representative of heavy duty commercial vehicles. The approach adopted utilised observed mean emission rates (g/kg of fuel burned), fuel consumption rates in units of kilograms per km, traffic volume (counts) by vehicle sub-type and time period, and distance travelled (km). Goods vehicle fuel consumption rates were derived from Department for Transport statistics.

The base 2017 scenario heavy duty goods vehicle total NO_x emissions over all case study areas combined are calculated to be approximately 27% lower than 2012; the base 2020 scenario NO_x emissions are calculated to be approximately 55% lower than 2012. In this context, NO_x is expressed in terms of NO_2 equivalent values (by mass). The relatively faster rate of reduction of goods vehicle NO_x emissions when compared to light vehicle emissions, with respect to time, is due to two factors; (a) the relatively larger assumed step change in NO_x emissions in the transition from Euro V to Euro VI for goods vehicles; and (b) the relatively faster rate of commercial vehicle fleet turnover (i.e. the goods vehicle fleet is younger than the passenger car fleet).



Goods vehicle NOx emissions (NO2 equivalent values)

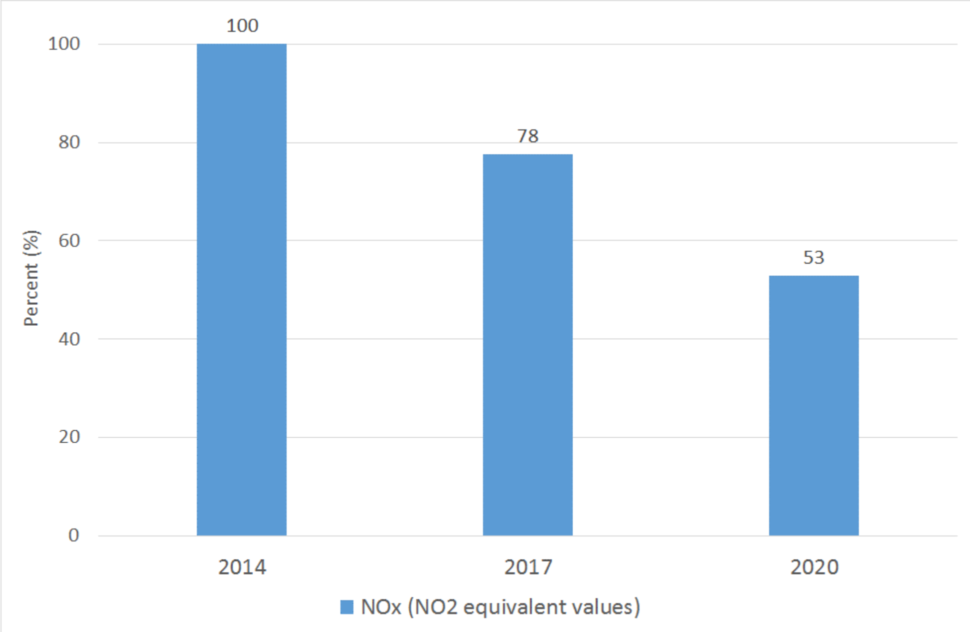
TfL bus emissions

The bus fleet is unique as it is the only element of the road vehicle fleet in the case study areas which is under direct public influence. Bus service contracts are negotiated between Transport for London and the various bus companies, specifying the types of vehicle technology to be utilised on particular services or groups of services. The characteristics of the bus fleet are therefore strongly influenced / determined by TfL policy.

Information on the bus vehicle engine and emissions control technology utilised in the existing bus fleet operating in the case study areas in Ealing in 2014 was obtained from TfL. Broad brush estimates of fuel consumption rates were also obtained from TfL.

As with heavy duty goods vehicles, sample rates for buses from the 2012 remote sensing surveys were relatively small compared to light vehicles, so results should be treated with some caution, particularly when disaggregated by type, emission standard, and after-treatment technology. Euro VI buses, and Euro III buses retro-fitted with selective catalytic reduction (SCR) technology, were not observed in the 2012 remote sensing surveys, so expected emissions performance of these bus types has been based on TfL test result data available in the public domain.

In defining the likely future characteristics of the TfL bus fleet operating in Ealing, reference has been made to existing TfL stated policy, for example that all TfL buses are planned to meet a minimum of Euro IV standard for particulate matter and NO_x by 2015. For the purpose of generating future year scenarios, the following additional scenario assumptions have been made regarding the future development of the TfL bus fleet in Ealing to 2017 and 2020:



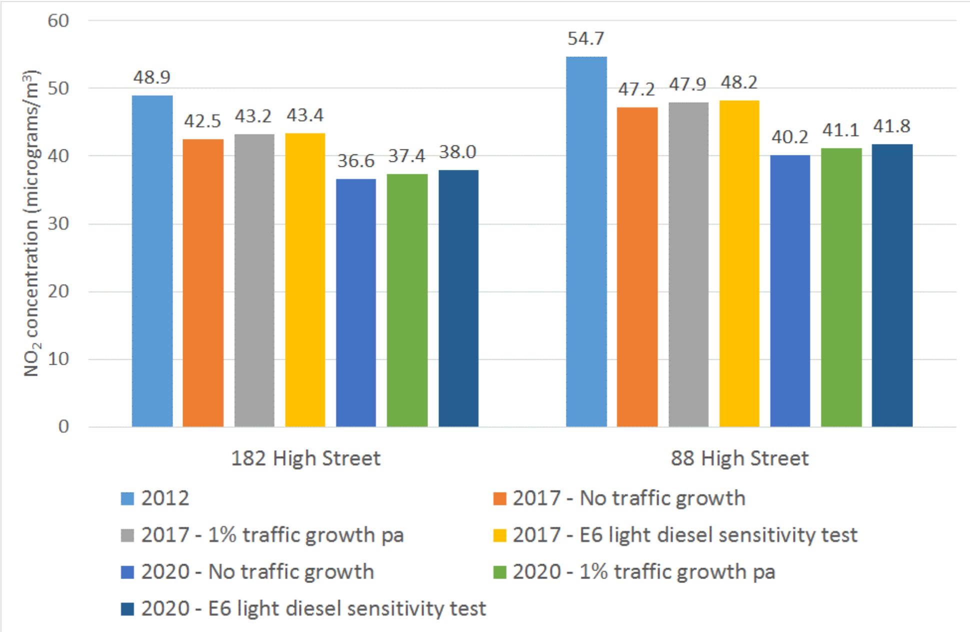
TfL bus NOx emissions (NO2 equivalent values)

- All TfL buses operating in Ealing will meet a minimum of Euro V standard for NO_x by 2020;
- There will be a 50% reduction in existing Euro IV buses between 2014 and 2017. These buses are assumed to be replaced by Euro V (50%), Euro VI (25%), and Euro VI hybrid (25%).
- There will be a 100% reduction in existing Euro IV buses between 2014 and 2020. These buses are assumed to be replaced by Euro V (50%), Euro VI (25%), and Euro VI hybrid (25%).
- Existing Euro III buses which have been retro-fitted with SCR emissions control technology are assumed to be retained to 2017, but will be replaced by 2020 with Euro VI (50%) and Euro VI hybrid (50%).

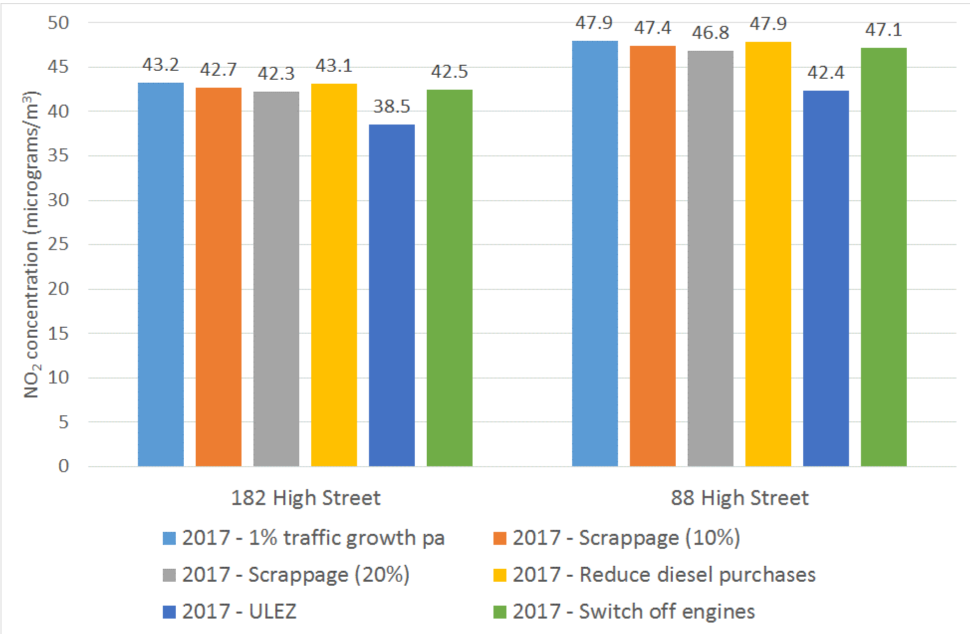
No growth in bus vehicle numbers / frequencies has been assumed in the future year scenarios. With the above assumptions, at 2017, total NO_x emissions from TfL buses operating in the Ealing case study areas are calculated to reduce by approximately 22% relative to 2014. At 2020, the reduction relative to 2014 is calculated to be approximately 47%.

Overall impact on local NO_2 concentrations

The annual average NO_2 concentrations in the case study areas, as measured using diffusion tubes in 2012 are utilised as a baseline. Year 2012 diffusion tube data are utilised because they are temporally consistent with the vehicle emissions data collected during the remote sensing surveys in 2012. According to the London Atmospheric Emissions Inventory (LAEI), 43.3% of NO_x emissions in Ealing are attributable to road transport, with 56.7% attributable to non road transport sources. If we assume that the changes in road transport emissions in Ealing from light vehicles, heavy vehicles, and buses, as a result of fleet evolution and the scenario interventions impact on this 43.3% value, we can calculate in a broad brush manner the likely change in overall NO_x emissions by case study area in 2017, and consequently, likely changes in air quality. Aggregating the calculated NO_x mass results for light vehicles, heavy vehicles, and buses permits us to estimate the likely impact on future year NO_2 concentrations, relative to the 2012 baseline, and to the 2017 scenario year. This provides an 'indication' of the likely changes in NO_2 concentrations in the case study areas in the future year scenarios. Examples of the calculated NO_2 concentrations for Acton High Street are presented below.



Acton High Street diffusion tube sites - Annual mean NO2 concentrations



Acton High Street – Light vehicle scenarios - Annual mean NO2 concentrations

Finally

Past experience suggests that there is significant uncertainty regarding the transferability of emission rates derived from laboratory based vehicle type approval tests to ‘real-world’ driving conditions. It would be wise to implement an appropriate and systematic monitoring regime so that ‘real-world’ emissions performance of the evolving vehicle fleet over the coming years can be monitored, to ensure that empirical data are consistent with assumed emission rates utilised in this (and other similar) analysis.

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1. Introduction

1.1 Project scope and objectives

The development to date of local authority air quality action plans has been challenging because the 'a priori' efficacy of particular interventions has been difficult to quantify with any degree of confidence. One of the reasons for this is that insufficient empirical data has been available on the primary nitrogen dioxide (NO_2) emissions characteristics of the urban road vehicle fleet. The recent collection of NO_2 and NO emissions data in Ealing (and other locations in London) in 2012 using remote sensing techniques allows us to quantify with much greater confidence the likely impact and effectiveness of interventions relating to particular vehicle classes and modes of vehicle operation (Carslaw and Rhys-Tyler, 2013a, b).

The aim of this project is to develop future year policy scenarios to inform the development of the Ealing air quality action plan. The scenario development is based on the extensive NO_2 and NO data sets collected using remote sensing instrumentation in the summer of 2012. These data provide detailed insights into the NO_2 and NO emission characteristics of vehicle types, 'Euro' classes, and fuel technologies at 2012. In addition, the data allows us to describe the more detailed dynamic relationships between NO_2 and NO emissions, vehicle speed, and acceleration (and other factors that influence engine load such as vehicle mass and highway gradient). The existence of such dynamic relationships has been identified by the author in previous research (Rhys-Tyler and Bell, 2012). The remote sensing data collected in 2012 is supplemented by similar data collected in Ealing in 2008 (Rhys-Tyler et al, 2011), particularly to inform the characterisation of the development of the light vehicle fleet in Ealing over time.

The project defines the relationship between light vehicle highway traffic and primary NO_2 and NO exhaust emissions on samples of the road network in Ealing (case study areas), across a range of road types in the Borough. The contribution of light vehicle traffic on these road types to emissions of primary NO_2 (and NO leading to the potential formation of secondary NO_2 through combination with O_3) is quantified, taking into account traffic volume, variation in fleet composition, and variation in traffic operating conditions during representative weekdays. Light vehicle speed and acceleration data has been collected on the sample of road network types in the case study areas through a reasonably extensive programme of instrumented (GPS equipped) probe vehicle surveys to collect speed, acceleration, and position data on the routes under consideration at a high level of temporal resolution (10Hz).

Vehicle dynamics and operating regimes of heavy goods vehicles, and in particular buses, will differ significantly from the general light vehicle fleet. TfL buses exhibit systematic stopping / starting behaviour at bus stops inherent to their operation. With respect to the relationships between vehicle dynamics and emissions, this project focuses on the light vehicle fleet. A simplified approach is adopted for heavy goods vehicles and buses, utilising mean emission rates (where available) by technology type / Euro standard, combined with estimates of fuel consumption rates and distance travelled in the case study areas. Due to the differing methodological approaches for light vehicles and heavy vehicles, the results for these two groups are reported separately.

These new data provide a geo-spatial picture of the extent and impact of traffic congestion on light vehicle dynamics on the road types under consideration, and the consequent impact on emissions of primary NO_2 and NO locally during typical daytime conditions over a 12 hour period. In principle, such an approach could be extended in future work to assess other time periods such as night-time, weekends, and seasonal variability.

The analysis provides the basis for a local mapping capability of primary NO_2 and NO emissions from road traffic in Ealing for the geographic areas under consideration, permitting officers to identify the most significant sources of pollution geo-spatially, and critically, the detailed breakdown of how vehicle type, 'Euro' class, fuel technology, and light vehicle dynamics each contribute to the total primary NO_2 and NO emitted.

The project investigates a limited number of illustrative scenarios to determine which package(s) of interventions may be required to reduce primary NO_2 and NO emissions to levels which will be consistent with legislated NO_2 air quality limit values. Scenario development includes technological, management, and behavioural interventions, with a qualitative assessment made of public and political acceptability. It is recognised that different types of intervention (technological, management, and behavioural) will have associated implementation challenges and varying timescales, depending on the type and extent of the proposed scenario intervention being considered.

Overall, the project helps us to identify the nature and extent of management, technological, and behavioural interventions required to achieve the desired reductions in road traffic related NO_2 and NO in Ealing.

1.2 Conceptual principles

The calculation of the absolute light vehicle emissions (i.e. grams or kilograms of NO_2 and NO) in this analysis depends on the quantification of four main factors:

- Emission rate
- Fuel consumption rate
- Elapsed time on network
- Traffic volume

The **emission rates** measured by the remote sensing instrumentation utilised in Ealing in 2012 are molar ratios of pollutant to carbon dioxide i.e. NO_2/CO_2 and NO/CO_2. Such ratios themselves do not tell us in absolute terms the quantity of nitrogen dioxide or nitric oxide emitted. However, these ratios can be converted into ratios of grams of pollutant per kilogram of fuel burned (g/kg) by carbon balance using the molecular weight of each species and the fuel's carbon mass fraction (Burgard et al, 2006). It should be noted that instantaneous emission rates can vary with changes in engine load, and this is the main parameter utilised in this analysis to characterise the dynamic relationship between emission rates and light vehicle dynamics.

The analysis of light vehicle emissions in this study utilises estimates of **fuel consumption** rates in units of grams per unit time (grams/second). Traditionally, fuel consumption rates are reported in terms of volume of fuel per unit distance (litres/100km) or distance per unit volume (miles per gallon). However, given that official fuel consumption values for light vehicles are calculated over a pre-defined test cycle of known distance and time, it is equally possible to present fuel consumption (for example over the legislated urban, inter-urban, or combined cycles) in units of litres per unit time. It is desirable to convert litres of fuel (volume) into kilograms of fuel (mass) because mass is independent of temperature. European regulations define fuel density for both petrol and diesel within prescribed temperature ranges for fuel consumption tests within vehicle type approval. Additionally, the use of fuel consumption values in terms of mass makes it relatively straightforward to estimate the mass of NO_2 and NO emitted utilising the observed NO_2/CO_2 and NO/CO_2 molar ratios from remote sensing, and combustion equations using carbon mass balance (Burgard et al, 2006; Rhys-Tyler and Bell, 2012).

To quantify and apportion light vehicle NO_2 and NO emissions on a particular section of highway network, it is necessary to quantify the **elapsed time on the network**, i.e. the time the individual vehicle spends on the section of road, consuming fuel at an assumed rate per second, and producing emissions at a given rate.

Finally, it is necessary to quantify the **traffic volume** (count) on the section of network in question, categorised by each sub-group of traffic for which observed emission rates are available. For example, in this analysis, passenger cars are sub-divided by fuel type (petrol/diesel), engine capacity (COPERT classifications), and Euro standard. Diesel vans (up to 3.5 tonnes gross weight) are categorised by Euro standard.

As noted above, a simplified approach is adopted for heavy vehicles (MGV's, HGV's and buses) utilising observed mean emission rates (NO_2/CO_2 and NO/CO_2 ratios) by vehicle type and Euro standard, fuel consumption rates in units of grams per km, traffic volume (counts) by vehicle sub-type and time period, and distance travelled (km).

2. Case study areas

2.1 Selection criteria

The case study locations were selected in consultation with officers at the London Borough of Ealing. The final selections represent a mix of Borough specific focus areas, and TfL focus areas. They include identified air quality 'hot spots', and encompass a range of road types and traffic conditions from intense urban operation to strategic routes. Five case study areas were identified:

- Acton High Street (from Steyne Road to Birkbeck Road)
- Horn Lane (from Steyne Road to the A40 Western Avenue)
- A40 Western Avenue (from Park Royal to Savoy Circus)
- Haven Green
- Western Road, Southall (from Brent Road to King Street)

The locations of these routes are illustrated in Figure 1 through Figure 10. Vertical alignment information has been derived from Ordnance Survey spot height measurements. Spot heights are captured by ground survey in urban areas, usually along the centre line of a road, to the nearest 0.1 meter. Vertical alignment information is necessary to calculate changes in highway gradient (positive and negative) throughout the case study areas, by direction of travel. Highway gradient (degrees) is an important input to the calculation of instantaneous engine load, used as one of the explanatory variables in the determination of NO_2 and NO emission rates across the range of light vehicle categories assessed in the analysis.

2.2 Acton High Street

The Acton High Street case study route (Figure 1) extends 0.712km from the junction with Steyne Road to the junction with Birkbeck Road. It has a 30mph speed limit, but often experiences significant congestion.

Table 1: Acton High Street – 12 hour weekday traffic flow (2012)

	Cars & taxis	Vans (N1)	Buses (M3)	MGV (N2)	HGV (N3)	Total
Eastbound	3734	724	538	222	89	5307
Westbound	3674	739	501	216	119	5249
Total	7408	1463	1039	438	208	10556

The roadside diffusion tube at 182 High Street recorded an annual mean NO_2 concentration of 48.9µg/m^3 in 2012, whilst the diffusion tubes at 88 High Street recorded a value of 54.7µg/m^3.

2.3 Horn Lane

The Horn Lane case study route (Figure 3) extends 1.448km from the junction with Steyne Road to the junction with the A40 Western Avenue. It has a 30mph speed limit, but the northbound section approaching the A40 can experience significant delays. The northbound section between Leamington Park and the A40 is a one way five lane approach, and carries traffic from the A40 westbound wishing to go north towards the A4000 Harlesden and Willesden Green, in addition to traffic from Horn Lane itself.

Table 2: Horn Lane – 12 hour weekday traffic flow (2012)

	Cars & taxis	Vans (N1)	Buses (M3)	MGV (N2)	HGV (N3)	Total
Northbound at A40	12060	3194	107	833	333	16527
Northbound	4186	934	107	289	76	5592
Southbound	4202	717	101	275	68	5363
Total	8388	1651	208	564	144	10955

The roadside diffusion tube at 156 Horn Lane recorded an annual mean NO_2 concentration of 40.7µg/m^3 in 2012, whilst the diffusion tubes at the Horn Lane AQMS (adjacent to 321 Horn Lane) recorded values of between 47.0 and 54.7µg/m^3.

2.4 A40 Western Avenue

The A40 Western Avenue case study route (Figure 5) extends 3.100km from Park Royal (adjacent to Park Royal underground station) to Savoy Circus (the junction with Old Oak Road). It has a 40mph speed limit, but the eastbound approach to the signalised junction at Savoy Circus can experience delays, especially for right turning traffic into Old Oak Road.

Table 3: A40 Western Avenue – 12 hour weekday traffic flow (2012)

	Cars & taxis	Vans (N1)	Buses (M3)	MGV (N2)	HGV (N3)	Total
Eastbound	19901	4914	115	1514	882	27211
Westbound	20683	6063	115	1430	1095	29271
Total	40584	10977	230	2944	1977	56712

N.B. Flows in Table 3 relate to the A40 west of Horn Lane. Traffic flow east of Horn Lane is higher.

The near road diffusion tube at Wendover Court recorded an annual mean NO_2 concentration of 56.0µg/m^3 in 2012, whilst the roadside diffusion tubes at the Western Avenue AQMS (adjacent to 326 Western Avenue) recorded values of between 73.8 and 75.1µg/m^3. The near road diffusion tube at 98 Western Avenue recorded an annual mean NO_2 concentration of 51.8µg/m^3 in 2012, whilst the roadside diffusion tube at 6 Western Avenue recorded a value of 70.8µg/m^3.

2.5 Haven Green

The Haven Green case study area (Figure 7) also includes a section of The Mall. The case study route extends in a clockwise direction 1.228km from the junction with Florence Road, clockwise around Haven Green, and back to the termination at Florence Road. It has a 30mph speed limit. Spring Bridge Road is one way northbound, and Haven Green adjacent to the entrance to Ealing Broadway Stations is one way southbound. The Haven Green case study area is notable for high concentrations of buses (due in part to the proximity of Ealing Broadway Station), and to a lesser extent taxis.

Table 4: Haven Green – 12 hour weekday traffic flow (2012)

	Cars & taxis	Vans (N1)	Buses (M3)	MGV (N2)	HGV (N3)	Total
The Mall (W/B)	4933	950	500	322	60	6765
Broadway (W/B)	8274	1408	911	433	63	11089
Spring Bridge Rd (N/B)	5432	766	556	207	16	6977
Haven Green (E/B)	7076	981	1000	221	8	9286
Haven Green (S/B)	5785	804	469	213	12	7283
The Mall (E/B)	5932	1101	505	326	54	7918

N.B. Flows reported in Table 4 are one way (clockwise) flows only.

The roadside diffusion tube at 8 Spring Bridge Road recorded an annual mean NO_2 concentration of 66.8µg/m^3 in 2012, whilst the kerbside diffusion tube at the junction of Spring Bridge Road and Gordon Road recorded 47.2µg/m^3. The roadside diffusion tube at 41-42 Haven Green recorded an annual mean NO_2 concentration of 52.1µg/m^3, whilst the near road diffusion tube at Haven Green Court recorded a value of 50.4µg/m^3.

2.6 Western Road, Southall

The Western Road, Southall case study route (Figure 9) extends 1.042km from the junction with Brent Road to the junction with King Street. It has a 30mph speed limit.

Table 5: Western Road, Southall – 12 hour weekday traffic flow (2012)

	Cars & taxis	Vans (N1)	Buses (M3)	MGV (N2)	HGV (N3)	Total
Eastbound	5592	1105	238	736	160	7831
Westbound	6291	1243	238	652	263	8687
Total	11883	2348	476	1388	423	16518

The roadside diffusion tube at 18 Western Road recorded an annual mean NO_2 concentration of 41.9µg/m^3 in 2012, whilst the near road diffusion tube at Featherstone Primary School recorded a value of 42.4µg/m^3.

Figure 1: Acton High Street case study area

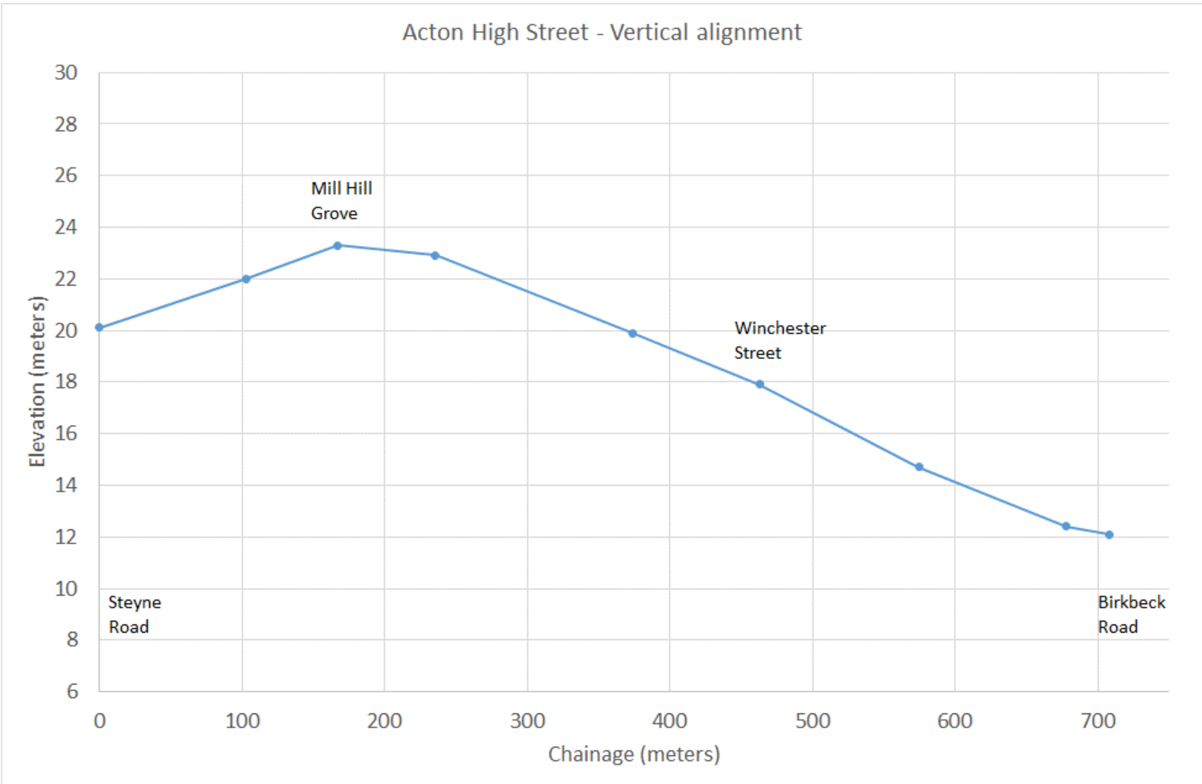

Figure 2: Acton High Street – Vertical alignment

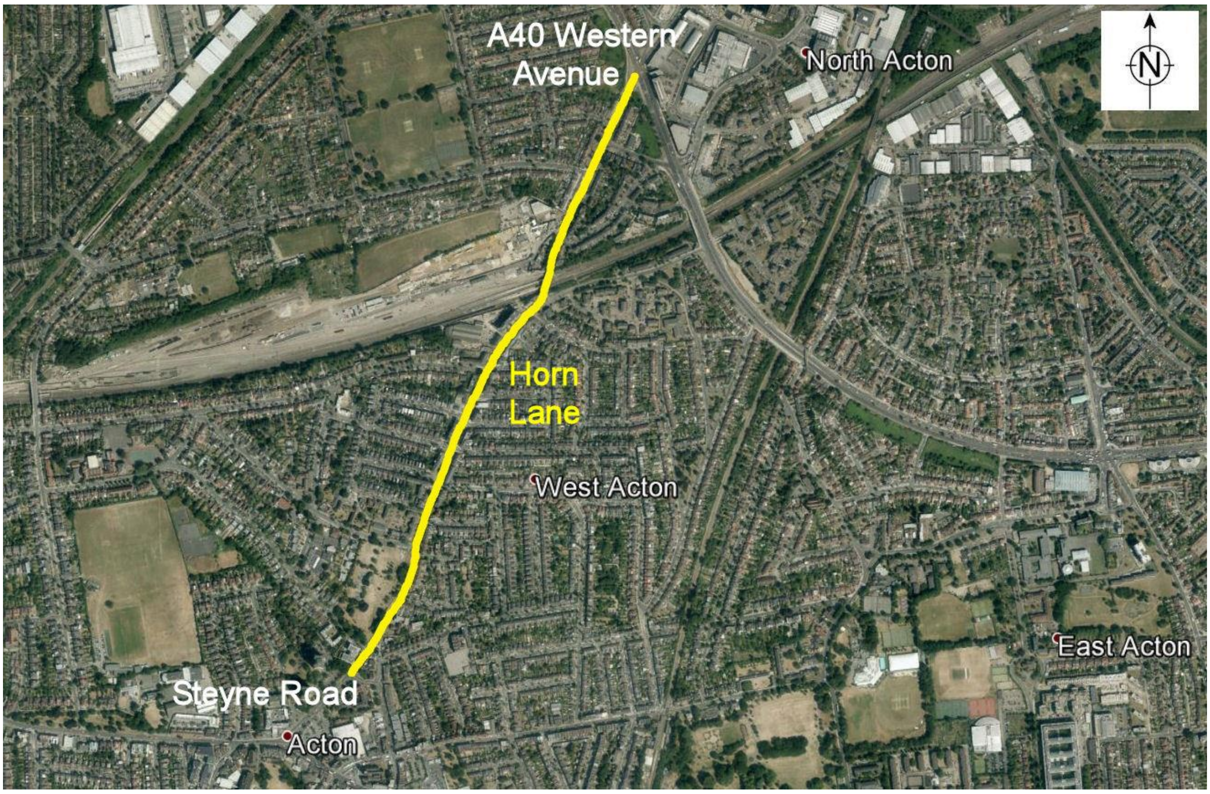

Figure 3: Horn Lane case study area

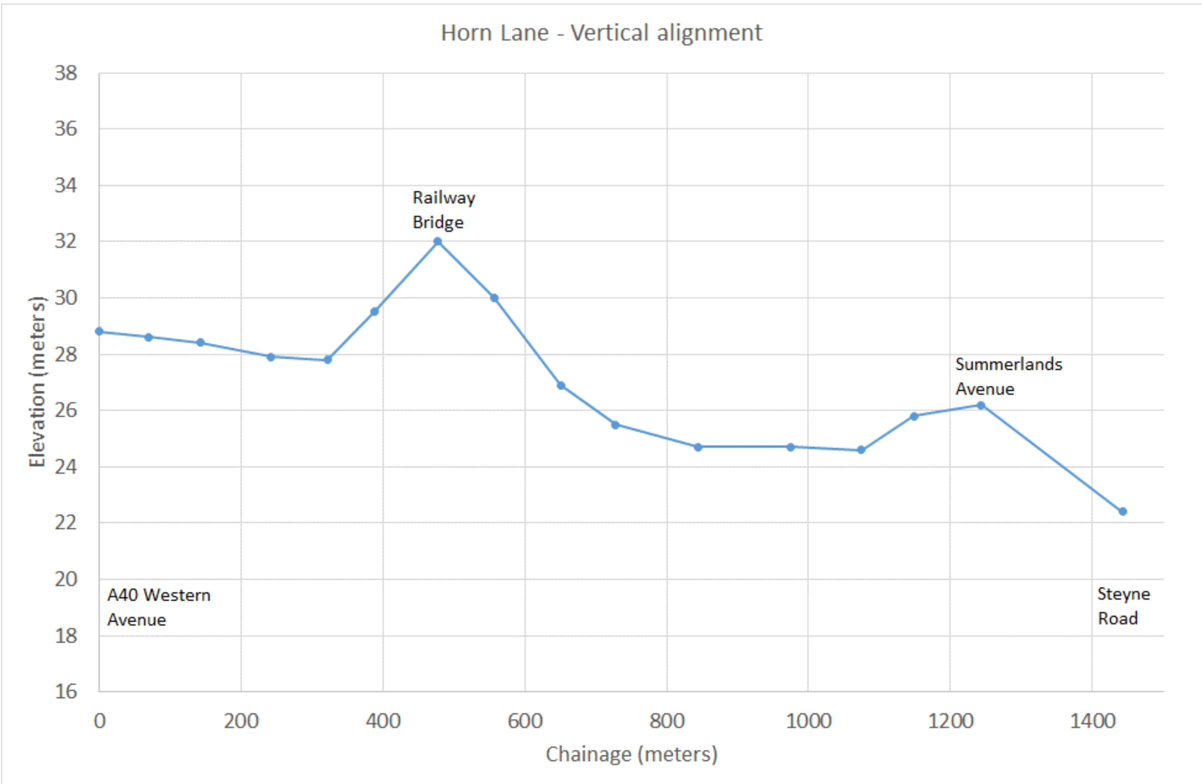

Figure 4: Horn Lane – Vertical alignment

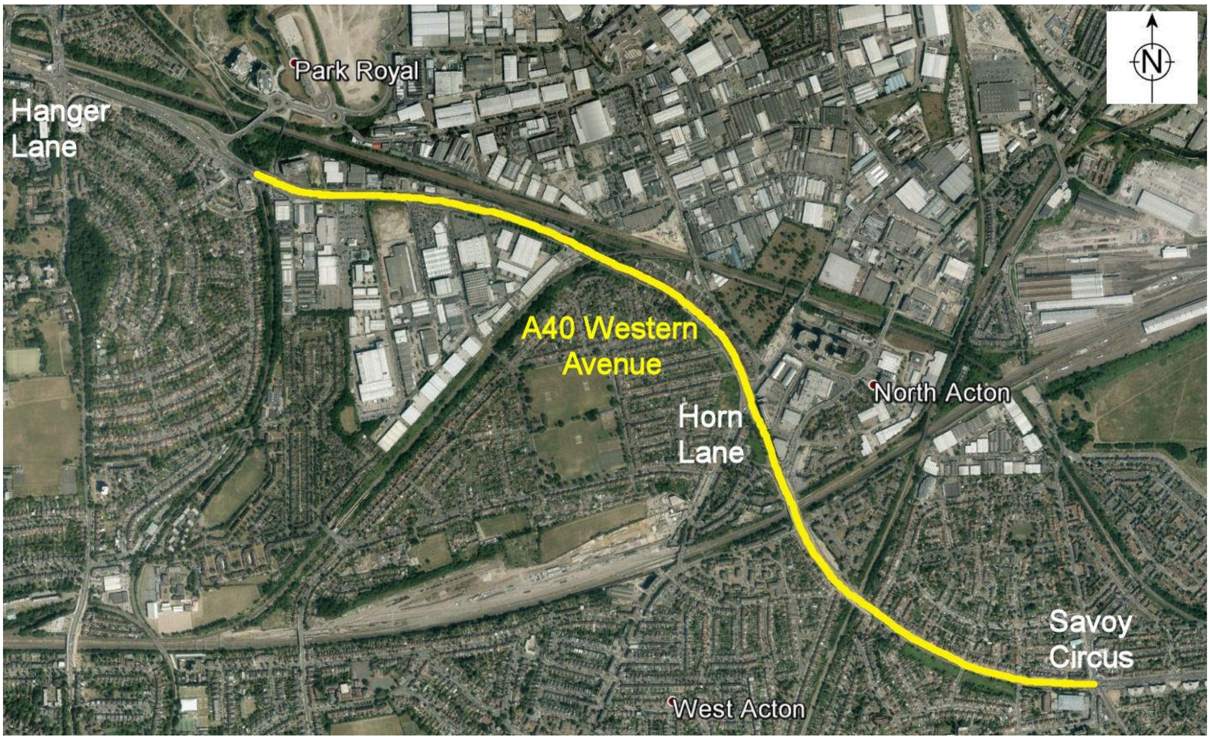

Figure 5: A40 Western Avenue case study area

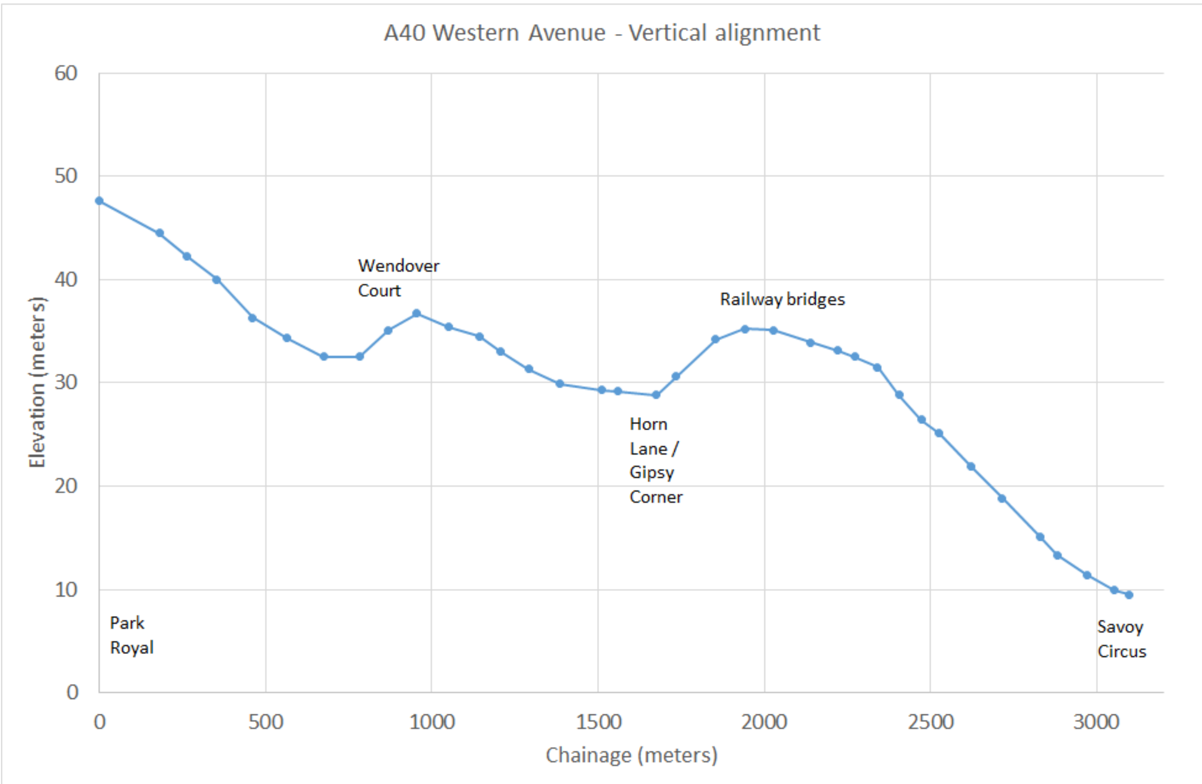

Figure 6: A40 Western Avenue – Vertical alignment

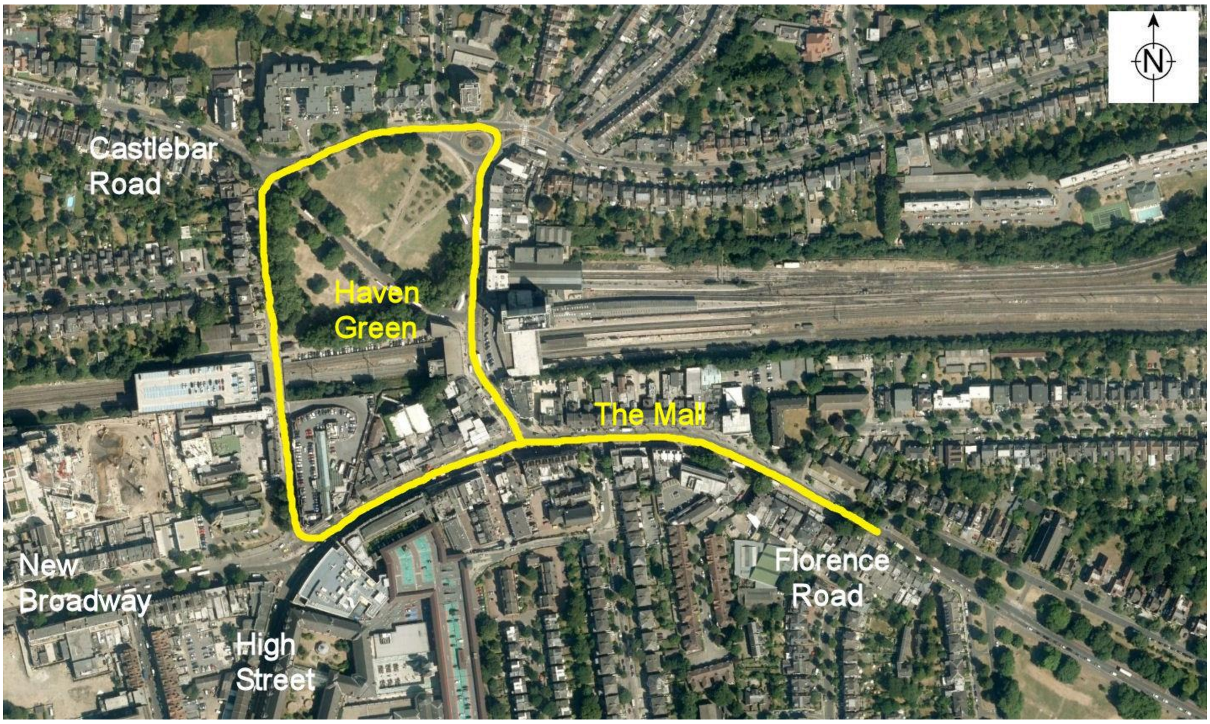

Figure 7: Haven Green case study area

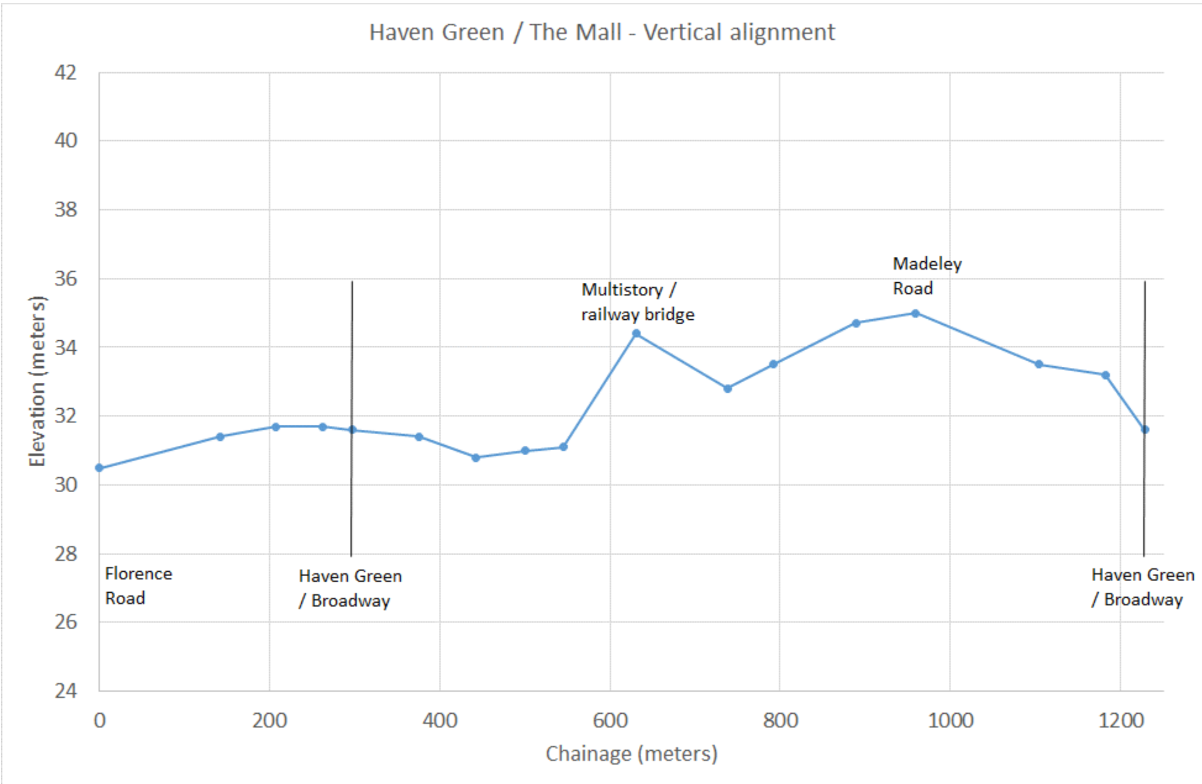

Figure 8: Haven Green – Vertical alignment

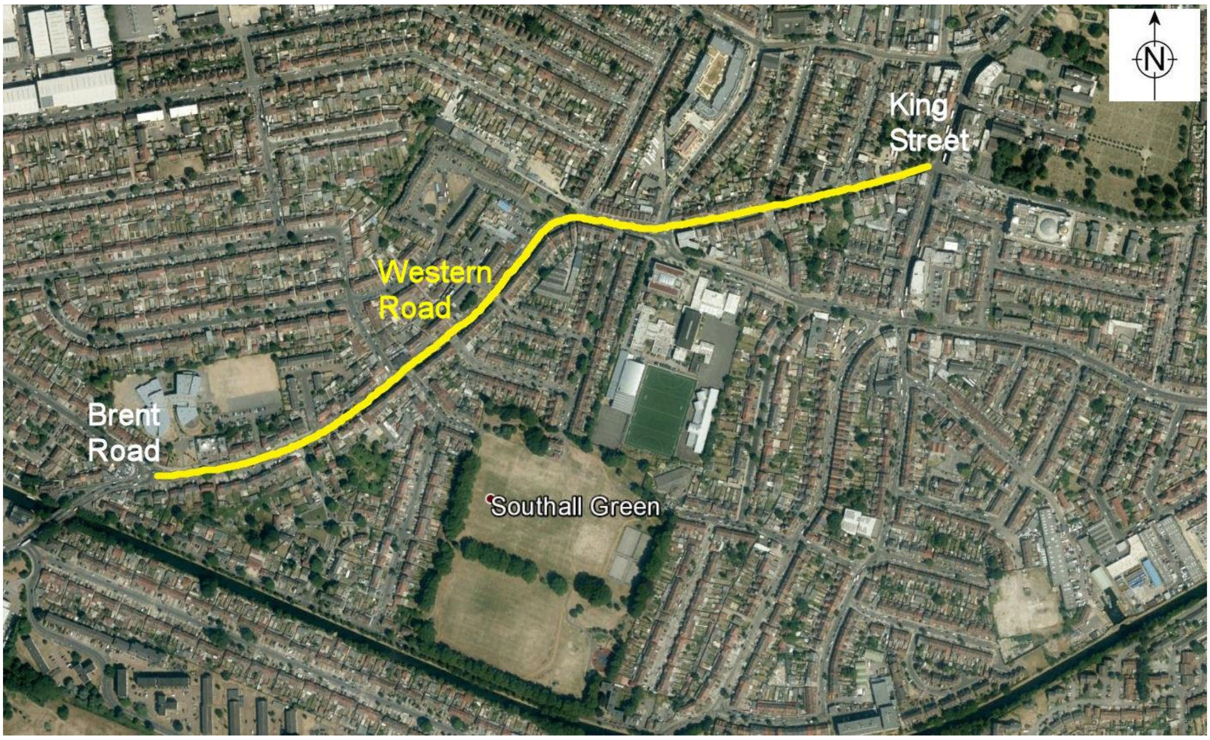

Figure 9: Western Road, Southall case study area

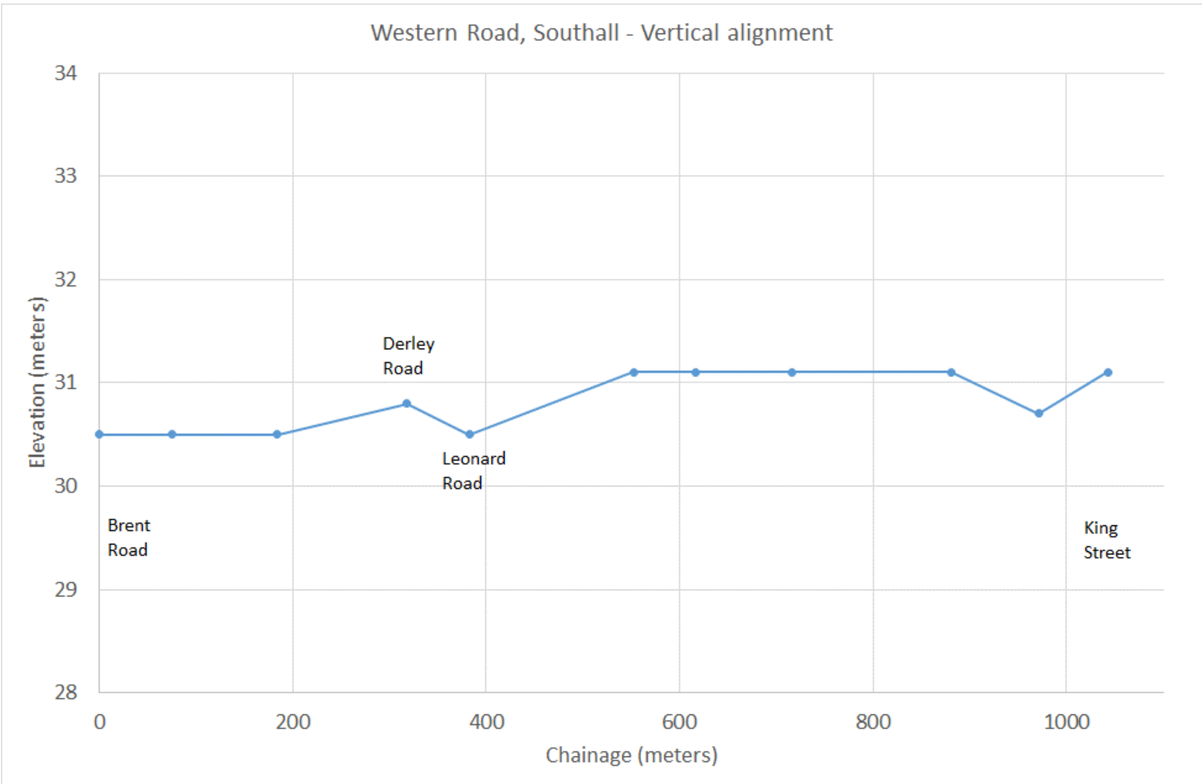

Figure 10: Western Road, Southall – Vertical alignment

3. Probe vehicle surveys

3.1 Overview

Data on the dynamics of light vehicle operation (speed, acceleration, deceleration, stops) within the case study areas were collected using a GPS equipped probe vehicle. This data collection served two main purposes:

- Spatial variation in vehicle dynamics was quantified i.e. how do vehicle speeds and delays vary geographically within case study areas (and how does it consequently impact on emissions spatially)?; and
- Variability in vehicle speeds and delays across multiple journeys was quantified i.e. how do vehicle speeds and delays vary due to random changes in traffic conditions, weather conditions, and non-random factors such as traffic signal aspects, and diurnal variation in traffic flow (and how does it consequently impact on variability in emission rates)?

Clearly, significant variation can be expected in vehicle speed and delays between individual journeys on a particular section of route at different times of day, depending on levels of congestion, traffic signal aspects for particular journeys, use of pedestrian crossings, traffic signal cycle times etc.

Probe vehicle surveys were carried out between October 3rd and October 18th 2013 inclusive, weekdays only, between 0900 and 1800 hours, using a passenger car (Ford Focus). Vehicle speed and position data were collected at a frequency of 10Hz using a commercial GPS data logger. Vehicle acceleration was determined as the first derivative of speed. A general objective was set of obtaining data from thirty runs in each direction in each case study location. This was achieved at all case study locations with the exception of Western Road, Southall where surveys were complicated by highway utility works (temporary traffic signals); twelve runs in each direction were obtained at Western Road. The sample size obtained across all case study areas was considered too small to permit meaningful disaggregation by time period; the data can therefore be considered to represent typical traffic conditions within weekday daytime conditions. For this reason, twelve hour (0700 – 1900) traffic count data have been utilised in the derivation of absolute NO_2 and NO exhaust emission estimates in this study.

3.2 Survey results

Volume 2 of this report (separate volume) presents the summary results of the probe vehicle surveys for all case study areas. At Acton High Street, Horn Lane, and Western Road, the case study routes are generally spatially disaggregated into 100 meter sections, measured along the road centreline. This allows spatial variation in vehicle speeds and delays to be determined. At the A40 Western Avenue, 200 meter sections are utilised because of the relatively large extent of the case study area. Haven Green is treated as a special case because of the mix of one way and two way highway links; for this reason, the locations of junctions / traffic signals are utilised as the spatial break points at Haven Green. The spatial sub-sections within each case study area are labelled ‘A’, ‘B’, ‘C’……n, for reporting purposes, as illustrated in Volume 2.

The probe vehicle survey summary results for Acton High Street (eastbound) are presented below as an example to illustrate the nature and range of information obtained from the surveys in the case study areas. Figure 11 and Figure 12 illustrate the spatial disaggregation of the Acton High Street case study area. Table 7 presents the eastbound journey times in seconds for each run through the case study area, and each sub-section. Table 8 presents the average speeds in kilometre per hour.

Table 9 presents the percentage of journey time spent stationary. Figure 13 illustrates the duration of stops in the form of a cumulative frequency distribution, whilst Figure 14 quantifies the proportion of stop duration where stops were longer than 10 seconds. Finally, Table 10 presents the percentage of travel time within the case study area at speeds greater than 20mph.

It can be seen in the case of Acton High Street (eastbound) that whilst average journey time was 164.6 seconds, the minimum journey time was 85.1 seconds, and the maximum 236.4 seconds. In terms of average speed through the case study area, the mean was 15kph, maximum 30kph, and minimum 11kph. It is notable that the highest average speed was achieved in section ‘H’ adjacent to Birkbeck Road, whilst the lowest average speeds were observed in sections ‘A’, ‘B’, and ‘E’ which are influenced by the proximity of junctions and pedestrian crossings. Sections ‘A’, ‘B’, and ‘E’ also have relatively high proportions of total journey time spent stationary (26% to 27%). A potential opportunity for air quality management is that 55% of the total time spent stationary (55% of 19%, i.e. 10% of total journey time) on Acton High Street (eastbound) was spent stationary in stops of greater than 10 seconds. If engines were systematically switched off during stops of longer duration, benefits in terms of reduced total emissions might be expected. Finally, it can be noted that, on average, only 5% of total journey time was spent at speeds greater than 20mph.

Table 6: Summary statistics from probe vehicle surveys

Location	Distance (km)	Mean journey time (seconds)	Mean speed (kph)	Mean % journey time spent stationary	% Journey time spent stationary >10 seconds	Percentage of journey time where speed >20mph
Acton High Street (E/B)	0.712	164.6	15	19%	10%	5%
Acton High Street (W/B)	0.712	289.1	9	35%	22%	1%
Horn Lane (N/B)	1.448	316.1	16	29%	25%	20%
Horn Lane (S/B)	1.283	185.5	24	13%	10%	34%
A40 (E/B) [b]	3.100	387.8	29	30%	27%	36% [a]
A40 (W/B)	3.100	296.9	37	8%	6%	40% [a]
The Mall (W/B)	0.297	90.2	12	35%	27%	11%
Haven Green Loop (clockwise)	0.931	230.3	14	32%	24%	7%
The Mall (E/B)	0.297	49.7	21	8%	1%	19%
Western Road (E/B) [c]	1.042	361.9	10	40%	33%	7%
Western Road (W/B) [c]	1.042	219.5	17	25%	18%	14%

[a] For A40 Western Avenue (speed limit 40mph), % greater than 30mph

[b] Note that results include right turning traffic at Savoy Circus. Delays will be greater than the straight ahead movement due to relatively less green time at the traffic signals.

[C] Results influenced by presence of temporary traffic signals in the vicinity of the junctions with Albert Road / Leonard Road (gas main repairs).

Table 6 presents a summary of aggregate statistics from all of the case study areas (details for individual runs and spatial sections are reported in Volume 2: Probe Vehicle Survey Results). It can be seen that for most of the case study areas, significant proportions of total observed journey time (between 8% and 40%) are spent stationary, often at traffic signals. Further, between 1% and 33% of total journey time is spent stationary for periods of greater than 10 seconds. Mean speeds for case study areas with 30mph (48kph) speed limits are observed to be in the range 9kph to 24kph.

Figure 11: Acton High Street – Sections A to E

Figure 12: Acton High Street – Sections D to H

Table 7: Acton High Street (eastbound) – Journey times

Acton High Street (eastbound)
Journey Time (seconds)

	Section								
Run	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Total**
1	24.0	14.6	30.7	13.1	33.0	13.4	13.1	1.7	**143.6**
2	16.8	53.9	18.3	17.1	31.7	15.4	16.4	2.7	**172.3**
3	20.0	41.0	19.4	24.8	31.8	22.9	18.6	1.2	**179.7**
4	12.9	46.5	12.5	26.5	12.2	13.8	12.1	1.4	**137.9**
5	46.7	23.3	15.3	20.7	30.4	17.6	12.1	1.3	**167.4**
6	28.5	37.2	20.9	62.0	18.1	34.1	14.8	1.4	**217.0**
7	25.9	26.5	17.3	13.6	15.4	22.6	43.1	1.9	**166.3**
8	13.7	37.4	11.0	22.9	12.6	23.2	32.3	1.6	**154.7**
9	26.6	15.7	18.8	20.0	25.7	14.1	17.3	1.7	**139.9**
10	51.4	13.8	11.6	38.9	26.5	19.2	11.5	1.2	**174.1**
11	10.8	11.5	13.5	13.9	11.9	11.5	10.7	1.3	**85.1**
12	63.7	21.8	14.2	14.9	37.8	16.7	10.7	1.3	**181.1**
13	73.6	21.6	18.5	11.7	38.7	19.6	17.4	2.2	**203.3**
14	11.2	30.0	21.8	22.1	25.9	29.0	14.6	1.6	**156.2**
15	28.0	17.5	38.1	32.8	26.1	15.2	14.0	1.6	**173.3**
16	19.3	18.3	39.8	13.9	42.0	16.7	15.1	1.4	**166.5**
17	13.4	38.4	13.6	13.4	34.7	22.6	12.6	1.3	**150.0**
18	18.9	43.4	11.7	10.7	36.9	14.5	15.5	1.8	**153.4**
19	21.1	36.1	15.2	20.7	36.7	12.4	11.2	1.1	**154.5**
20	29.0	36.3	15.9	17.3	33.8	17.3	12.2	1.3	**163.1**
21	22.8	30.9	29.6	10.9	11.0	15.4	16.6	2.2	**139.4**
22	77.1	35.7	30.5	21.7	39.6	18.1	12.3	1.4	**236.4**
23	10.0	11.7	36.1	21.0	28.6	17.9	13.1	1.3	**139.7**
24	49.4	42.4	17.6	10.7	11.4	14.4	12.5	1.4	**159.8**
25	39.5	18.4	22.5	13.2	38.2	17.3	11.9	1.2	**162.2**
26	54.5	13.4	42.0	11.3	20.8	12.4	12.0	1.2	**167.6**
27	10.6	11.6	16.5	72.3	34.6	13.6	12.7	1.3	**173.2**
28	58.0	15.9	26.5	12.0	37.5	12.9	18.8	2.0	**183.6**
29	69.2	30.7	17.4	30.9	27.1	19.4	11.6	1.3	**207.6**
30	32.3	20.7	14.0	11.0	20.7	16.2	12.6	1.2	**128.7**
Mean	**32.6**	**27.2**	**21.0**	**21.5**	**27.7**	**17.6**	**15.3**	**1.5**	**164.6**
Dist. (m)	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**12**	**712**

Table 8: Acton High Street (eastbound) – Average speeds

Acton High Street (eastbound)
Average speed (kph)

	Section								
Run	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Combined**
1	14	25	11	28	11	27	27	27	**18**
2	19	7	20	21	11	23	22	16	**15**
3	17	9	18	14	11	16	19	33	**14**
4	25	8	29	14	30	26	30	33	**18**
5	7	15	24	17	12	20	30	32	**15**
6	12	10	17	6	20	11	24	31	**12**
7	13	13	20	27	23	16	8	22	**15**
8	25	10	33	16	29	16	11	26	**17**
9	13	23	19	18	14	26	21	24	**18**
10	7	26	31	10	14	19	31	36	**15**
11	32	32	27	26	30	31	34	34	**30**
12	6	16	24	24	10	21	34	35	**14**
13	5	16	20	31	9	18	21	19	**13**
14	31	12	17	16	14	12	25	27	**16**
15	12	21	9	11	14	24	26	28	**15**
16	17	20	9	26	9	22	24	33	**15**
17	26	9	26	27	10	16	28	33	**17**
18	19	8	30	34	10	25	23	23	**17**
19	16	10	23	18	10	29	32	39	**17**
20	12	10	22	21	11	21	29	34	**16**
21	17	12	12	33	33	24	22	20	**19**
22	4	10	11	17	10	20	30	31	**11**
23	34	30	10	17	13	20	27	34	**18**
24	7	9	20	34	32	25	29	32	**16**
25	9	20	16	27	9	21	30	35	**16**
26	6	27	9	31	17	29	30	35	**15**
27	33	31	22	5	10	26	28	34	**15**
28	6	24	13	30	10	28	19	22	**14**
29	5	12	21	12	13	18	31	34	**12**
30	11	17	26	33	17	22	29	36	**20**
Combined	**10**	**13**	**17**	**17**	**13**	**20**	**24**	**29**	**15**

Table 9: Acton High Street (eastbound) – Time spent stationary

Acton High Street (eastbound)
Percentage (%) time spent stationary

	Section								
Run	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Combined**
1	15%	0%	48%	0%	34%	0%	0%	0%	**21%**
2	0%	31%	0%	0%	31%	0%	0%	0%	**15%**
3	0%	36%	0%	10%	31%	0%	0%	0%	**15%**
4	0%	52%	0%	9%	0%	0%	0%	0%	**19%**
5	35%	0%	0%	0%	13%	0%	0%	0%	**12%**
6	27%	27%	0%	28%	0%	16%	0%	0%	**19%**
7	17%	30%	0%	0%	0%	0%	36%	0%	**17%**
8	0%	53%	0%	7%	0%	0%	17%	0%	**18%**
9	9%	0%	0%	0%	0%	0%	0%	0%	**2%**
10	28%	0%	0%	16%	9%	0%	0%	0%	**13%**
11	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
12	30%	8%	0%	0%	52%	0%	0%	0%	**22%**
13	42%	9%	0%	0%	50%	2%	0%	0%	**26%**
14	0%	42%	0%	17%	8%	19%	0%	0%	**15%**
15	37%	0%	29%	34%	1%	0%	0%	0%	**19%**
16	15%	0%	48%	0%	46%	0%	0%	0%	**25%**
17	0%	49%	0%	0%	14%	0%	0%	0%	**16%**
18	0%	51%	0%	0%	52%	0%	0%	0%	**27%**
19	0%	24%	0%	0%	28%	0%	0%	0%	**12%**
20	5%	45%	0%	0%	41%	0%	0%	0%	**19%**
21	0%	34%	26%	0%	0%	0%	0%	0%	**13%**
22	46%	0%	9%	0%	46%	0%	0%	0%	**24%**
23	0%	0%	46%	0%	16%	0%	0%	0%	**15%**
24	15%	55%	0%	0%	0%	0%	0%	0%	**19%**
25	12%	0%	0%	0%	31%	0%	0%	0%	**10%**
26	38%	0%	49%	0%	13%	0%	0%	0%	**26%**
27	0%	0%	0%	49%	37%	0%	0%	0%	**28%**
28	55%	0%	23%	0%	53%	0%	0%	0%	**31%**
29	47%	27%	0%	35%	20%	0%	0%	0%	**27%**
30	36%	0%	0%	0%	19%	0%	0%	0%	**12%**
Combined	**26%**	**27%**	**16%**	**14%**	**27%**	**2%**	**5%**	**0%**	**19%**

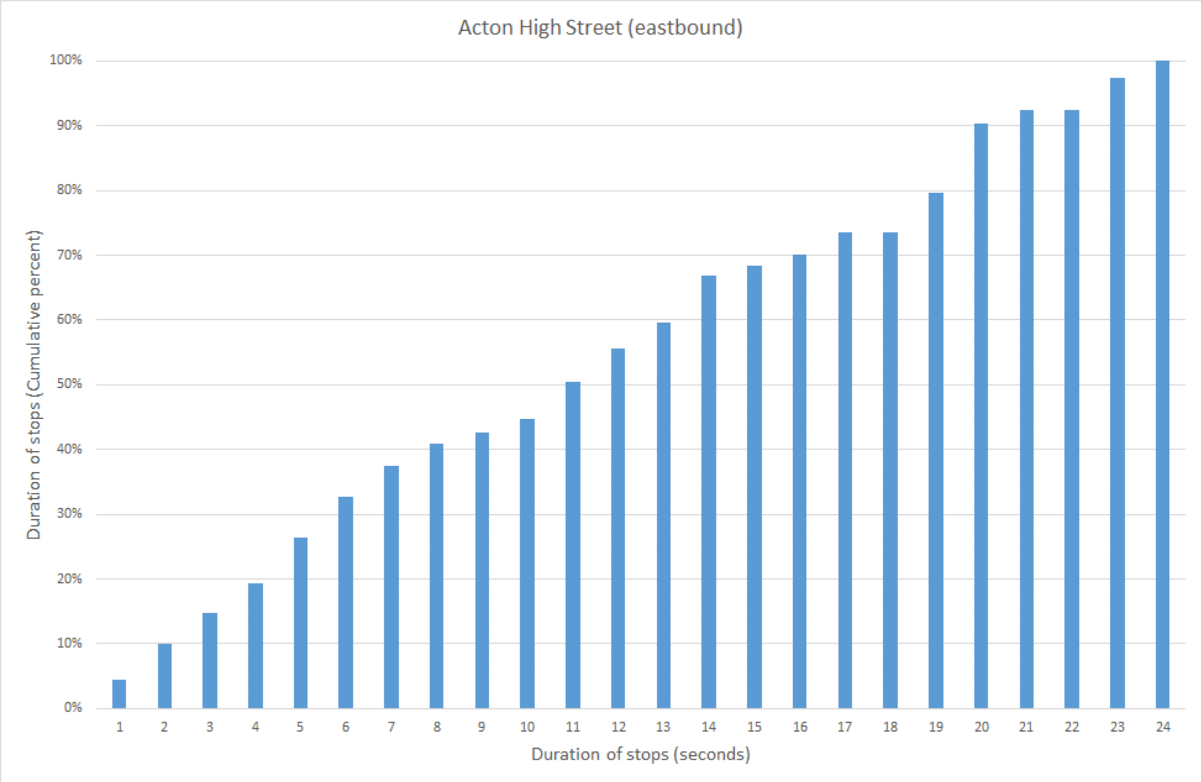

Figure 13: Acton High Street (eastbound) – Duration of stops

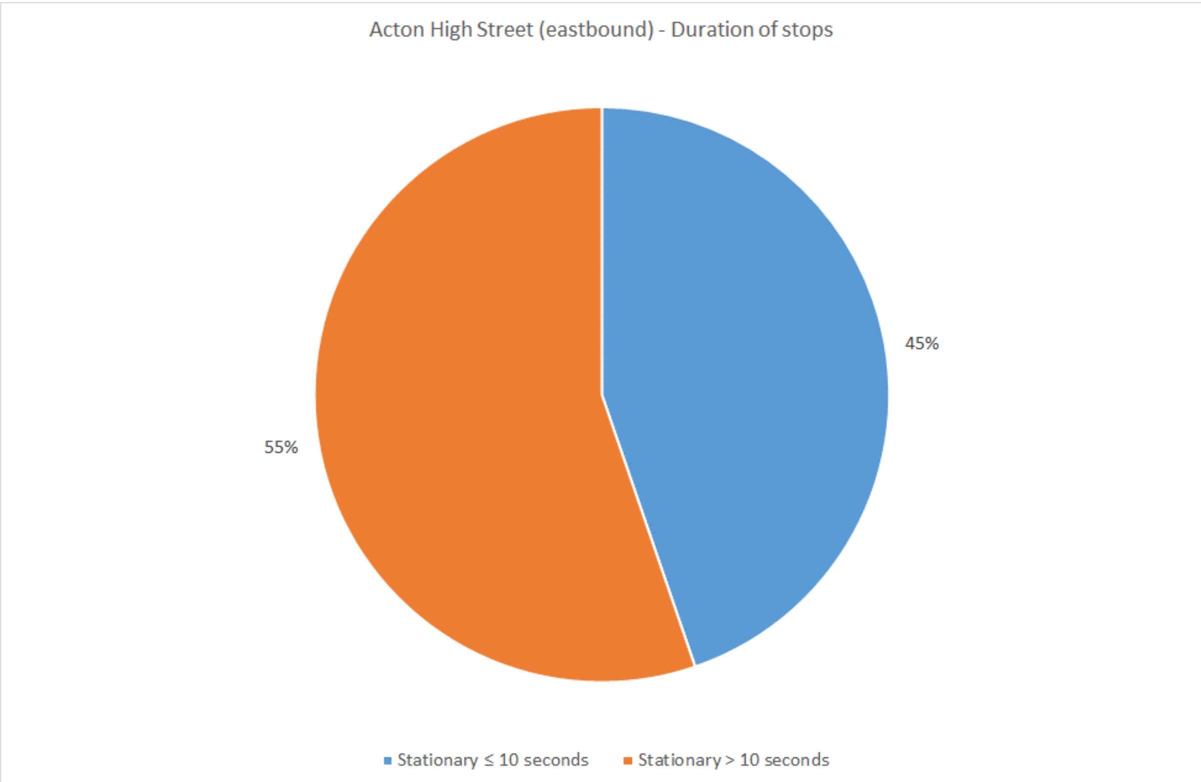

Figure 14: Acton High Street (eastbound) – Time spent stationary >10 seconds

Table 10: Acton High Street (eastbound) - Percentage time >20mph

Acton High Street (eastbound)
Percentage (%) time spent >20mph (>32.2kph)

	Section								
Run	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Combined**
1	0%	0%	17%	32%	0%	0%	0%	0%	**7%**
2	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
3	0%	0%	0%	0%	0%	0%	0%	83%	**1%**
4	6%	0%	29%	17%	2%	0%	21%	79%	**9%**
5	0%	0%	0%	0%	0%	0%	1%	77%	**1%**
6	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
7	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
8	0%	6%	61%	0%	28%	0%	0%	0%	**8%**
9	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
10	0%	0%	52%	0%	0%	0%	25%	100%	**6%**
11	54%	35%	1%	0%	27%	42%	79%	100%	**32%**
12	0%	0%	0%	0%	1%	0%	83%	100%	**6%**
13	0%	0%	15%	44%	0%	0%	0%	0%	**4%**
14	53%	0%	0%	0%	0%	0%	0%	0%	**4%**
15	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
16	0%	0%	0%	0%	0%	0%	1%	79%	**1%**
17	16%	0%	7%	0%	0%	0%	8%	100%	**4%**
18	0%	0%	21%	80%	9%	0%	0%	0%	**9%**
19	0%	0%	0%	0%	16%	33%	56%	100%	**11%**
20	0%	0%	0%	0%	0%	0%	17%	100%	**2%**
21	0%	0%	1%	78%	100%	6%	0%	0%	**15%**
22	0%	0%	0%	0%	0%	0%	2%	7%	**0%**
23	86%	22%	0%	0%	0%	0%	4%	100%	**9%**
24	0%	0%	19%	73%	38%	15%	2%	21%	**11%**
25	0%	0%	0%	0%	0%	0%	36%	100%	**3%**
26	0%	0%	0%	33%	9%	2%	17%	100%	**5%**
27	70%	47%	15%	0%	0%	11%	20%	100%	**12%**
28	0%	0%	0%	21%	6%	0%	0%	0%	**3%**
29	0%	0%	0%	0%	0%	0%	38%	100%	**3%**
30	0%	0%	0%	61%	4%	15%	33%	100%	**12%**
Combined	**3%**	**2%**	**5%**	**8%**	**4%**	**3%**	**11%**	**43%**	**5%**

4. Base year light vehicle NO and NO_2 emission rates

4.1 Processing of emissions data

The primary NO_2 and NO emission data collected during the remote sensing surveys in London in 2012 were processed to conform to the light vehicle type categories utilised in the current study, i.e. passenger cars (M1) by fuel type, 'Euro' standard, and engine capacity; diesel vans (N1) by 'Euro' standard; and diesel taxis (black cabs) by model and 'Euro' standard. Emission observations with valid speed and acceleration measurements from the 2012 data set were utilised to define the dynamic relationship between emission rates of NO_2 and NO, and the corresponding levels of engine load (power in watts required to achieve the observed combination of speed and acceleration, taking into account highway gradient and the mean physical parameters of each vehicle sub-class).

Engine load power (W) =

$(C_f \times m \times g) \times v$	Rolling resistance power (W)
$+ (0.5 \times \rho \times C_d \times A \times v^2) \times v$	Aerodynamic drag power (W)
$+ ((m \times g \times \sin(\alpha)) \times v$	Gradient power (W)
$+ (a \times m \times v \times k_m)$	Acceleration power (W)

where:

Quantity	Description	Units
W	Power	Watts
m	Vehicle mass	kg
v	Vehicle speed	m/s
a	Vehicle acceleration	m/s^2
α	Highway gradient	Degrees °
C_d	Drag coefficient	Constant
A	Vehicle frontal area	m^2
ρ	Air density	kg/m^3
C_f	Coefficient of rolling resistance	Constant
k_m	Rotational inertia coefficient	Constant
g	Gravity	m/s^2

Highway gradient was determined locally at the remote sensing survey sites in 2012, derived from Ordnance Survey spot heights. These were calculated as: Aldersgate Street, -0.5 degrees; Queen Victoria Street, +0.93 degrees; Greenford Road, +1.19 degrees; and, A40 Slip Road, +0.94 degrees.

Local light vehicle mean physical parameters were derived from the 2012 remote sensing survey sites, where data were available. These local parameters included vehicle mass (m), and vehicle frontal area (A). These locally derived mean parameters are presented in Table 11, together with estimates of vehicle drag coefficient (C_d), obtained from available literature and professional judgement.

Table 11: Light vehicle mean physical parameters

		Euro standard	Vehicle mass m	Drag coefficient C_d	Frontal area A
Cars (M1) Petrol	<1.4 liters	Euro 5	1072	0.32	2.395
		Euro 4	1037	0.33	2.318
		Euro 3	1008	0.34	2.317
		Euro 2	1008	0.34	2.317
		Euro 1	1008	0.34	2.317
		Pre Euro	1008	0.34	2.317
	1.4 - 2.0 liters	Euro 5	1375	0.30	2.551
		Euro 4	1331	0.31	2.518
		Euro 3	1293	0.32	2.453
		Euro 2	1293	0.32	2.453
		Euro 1	1293	0.32	2.453
		Pre Euro	1293	0.32	2.453
	>2.0 liters	Euro 5	1906	0.30	2.527
		Euro 4	1877	0.31	2.538
		Euro 3	1792	0.32	2.510
		Euro 2	1792	0.32	2.510
		Euro 1	1792	0.32	2.510
		Pre Euro	1792	0.32	2.510
Cars (M1) Diesel	<2.0 liters	Euro 5	1525	0.30	2.762
		Euro 4	1612	0.31	2.640
		Euro 3	1525	0.32	2.643
		Euro 2	1525	0.32	2.643
		Euro 1	1525	0.32	2.643
		Pre Euro	1525	0.32	2.643
	>2.0 liters	Euro 5	1920	0.30	2.826
		Euro 4	1946	0.31	2.701
		Euro 3	1920	0.32	2.868
		Euro 2	1920	0.32	2.868
		Euro 1	1920	0.32	2.868
		Pre Euro	1920	0.32	2.868
Taxi	Mercedes Vito 113	Euro 5	2235	0.33	3.832
	LTI TX4	Euro 5	2095	0.35	3.361
	Mercedes Vito 111	Euro 4	2235	0.33	3.832
	LTI TX4	Euro 4	2050	0.35	3.361
	Metrocab	Euro 3	2030	0.35	2.780
	LTI TXII	Euro 3	2050	0.35	3.361
	LTI TX1	Euro 3	2050	0.35	3.361
	Metrocab	Euro 2	2030	0.35	2.780
	LTI TX1	Euro 2	2050	0.35	3.361
	LTI FX	Euro 2	1675	0.35	2.764
Van (N1)	Diesel	Euro 5	2191	0.35	3.726
		Euro 4	2166	0.35	3.677
		Euro 3	2166	0.35	3.677
		Euro 2	2166	0.35	3.677
		Euro 1	2166	0.35	3.677
		Pre Euro	2166	0.35	3.677

Vehicle mass was assumed to equate to kerb weight for passenger cars and taxis, and kerb weight plus 40% load for vans (N1), based on the difference between the known van kerb weights and van gross vehicle weights for the vehicles observed during the surveys. Frontal area (A) was calculated as 0.9 × (track × height). Air density (ρ) was assumed constant at 1.225kg/m^2. The coefficient of rolling resistance (C_f) was assumed constant across all light vehicle classes at 0.025 (Bosch, 2007). The rotational inertia coefficient (k_m) compensates for the apparent increase in vehicle mass due to the rotating masses. This of course varies with engine size, gear selection, wheel specification etc., but a representative value of 1.1 was adopted throughout (Bosch, 2007). Finally, acceleration due to gravity (g) was assumed constant at 9.81m/s^2.

4.2 Emission rates utilised in the scenario analysis

As noted in Section 1, the emission rates measured by the remote sensing instrumentation utilised in Ealing in 2012 are molar ratios of pollutant to carbon dioxide i.e. NO_2/CO_2 and NO/CO_2. Such ratios themselves do not tell us in absolute terms the quantity of nitrogen dioxide or nitric oxide emitted. However, these ratios can be converted into ratios of grams of pollutant per kilogram of fuel burned (g/kg) by carbon balance using the molecular weight of each species and the fuel's carbon mass fraction (Burgard et al, 2006). This conversion was carried out, allowing emission rate (g/kg) to be plotted against engine load power (W), to characterise the dynamic relationship between emission rates and light vehicle dynamics, by vehicle category.

Appendix A presents the mean nitrogen dioxide (NO_2) and nitric oxide (NO) light vehicle emission rates derived from the 2012 remote sensing surveys, in terms of grams of pollutant per kilogram of fuel consumed (g/kg) with respect to engine load power (kW) as calculated above. Values highlighted in green generally have sample size (n) of 30 or more per cell. Where sample size is less than 30, adjacent cells have been aggregated to provide a more robust estimate. This tends to occur either at the extremes of the kW ranges (positive and negative), or where sample sizes are generally low for particular vehicle classes, for example earlier 'Euro' standards. Of course, given the range of vehicle mass (m) observed in the light vehicle fleet (Table 11), there is a tendency for lighter vehicles to have lower kW values, and heavier vehicles to have higher kW values, all other things being equal. For this reason, the results have also been standardised by dividing through by vehicle mass (m) to present results in terms of kW/tonne. The standardised results for nitric oxide (NO) are presented in Table 12, Table 14, and Table 16 for diesel cars & vans, taxis, and petrol cars respectively. The standardised results for nitrogen dioxide (NO_2) are presented in Table 18, Table 20, and Table 22. The 95% confidence intervals about the mean (±) are also presented in the intervening tables, and the relevant sample sizes (n) are presented in Table 24, Table 25, and Table 26.

These standardised mean emission rates are carried forward to the scenario analysis.

Table 12: Observed nitric oxide emission rates in 2012 - Diesel cars and vans

Mean nitric oxide (NO) emission rates derived from 2012 remote sensing surveys.

Grams of nitric oxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW/tonne).

Diesel cars and vans

	Diesel cars <2.0 litres						Diesel cars > 2.0 litres						Diesel vans (up to 3.5 tonnes)					
kW/tonne	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**
<-10				9.78	7.57	8.39				7.23	4.47	4.96				10.15	7.19	6.10
-10 to -8					7.57	8.31					4.82						5.92	7.10
-8 to -6					6.31											10.52	7.82	6.33
-6 to -4					5.83											12.18	6.77	7.80
-4 to -2				9.84	7.71	8.08				6.76	5.84	6.86				12.52	7.42	6.72
-2 to 0				10.48	6.57	8.36				7.05	4.71	5.68				12.07	7.11	8.08
0 to 2				10.15	7.35	7.35				9.66	5.25	6.01				11.56	7.25	8.55
2 to 4				10.89	6.82	7.30				7.66	5.56	5.62				11.91	7.30	8.01
4 to 6				10.44	6.74	7.38				9.70	5.02	5.74				12.72	8.15	8.58
6 to 8				12.05	6.92	8.80				9.11	6.29	5.86				12.50	8.17	8.91
8 to 10				11.72	7.19	10.11				9.68	6.85	7.87				13.53	8.77	9.40
10 to 12				11.38	8.61	9.70				11.09	8.31	8.52				14.39	9.10	9.70
12 to 14				13.87	9.15	9.69				12.59	7.76	10.74				13.84	9.06	10.21
14 to 16				14.73	9.93	11.06					9.88	10.77				13.07	9.69	11.09
16 to 18				14.90	8.25	11.47					10.88					14.88	10.77	13.10
18 to 20				16.75	11.57	13.58					10.57					14.78	12.11	12.75
20 to 22					12.25												13.65	14.76
22 to 24					13.96													
>=24				15.97	14.58	16.20												
Total	7.89	11.37	13.68	11.69	7.76	8.84	6.71	8.18	11.29	9.38	6.32	6.69	9.29	12.79	12.79	12.54	8.07	8.81

Table 13: Observed nitric oxide confidence intervals in 2012 - Diesel cars and vans

Mean nitric oxide (NO) emission rates derived from 2012 remote sensing surveys.

Grams of nitric oxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW/tonne).

Confidence interval (95%) about the mean (±).

Diesel cars and vans

	Diesel cars <2.0 litres					
kW/tonne	Pre Euro	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5
<-10				1.58	1.34	1.80
-10 to -8						1.63
-8 to -6					1.48	
-6 to -4					1.36	
-4 to -2				2.11	1.19	1.44
-2 to 0				1.47	0.77	0.94
0 to 2				1.21	0.81	0.87
2 to 4				1.17	0.63	0.65
4 to 6				1.00	0.64	0.67
6 to 8				0.95	0.63	0.84
8 to 10				1.04	0.70	1.03
10 to 12				1.60	0.92	1.14
12 to 14				1.95	1.34	1.51
14 to 16				2.27	1.30	1.93
16 to 18				3.71	1.33	1.93
18 to 20				2.78	2.10	1.66
20 to 22					2.88	
22 to 24					3.14	
>=24				3.72	1.97	3.02
Total			1.20	0.41	0.25	0.30

	Diesel cars > 2.0 litres					
kW/tonne	Pre Euro	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5
<-10				1.58	1.37	1.17
-10 to -8					0.96	
-8 to -6						
-6 to -4						
-4 to -2				1.38	1.29	1.51
-2 to 0				1.43	0.76	1.11
0 to 2				1.95	0.75	0.97
2 to 4				1.13	0.83	0.78
4 to 6				1.44	0.60	0.87
6 to 8				1.66	0.77	0.79
8 to 10				1.74	0.95	1.03
10 to 12				2.06	1.33	1.81
12 to 14				1.65	1.57	2.88
14 to 16					2.04	1.77
16 to 18					2.44	
18 to 20					1.96	
20 to 22						
22 to 24						
>=24						
Total			1.55	0.54	0.30	0.36

	Diesel vans (up to 3.5 tonnes)					
kW/tonne	Pre Euro	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5
<-10				1.37	1.25	1.22
-10 to -8					1.84	2.34
-8 to -6				2.43	2.25	2.07
-6 to -4				2.74	1.35	1.96
-4 to -2				1.89	0.95	1.19
-2 to 0				1.32	0.61	0.90
0 to 2				1.19	0.66	0.84
2 to 4				1.17	0.58	0.67
4 to 6				0.98	0.59	0.72
6 to 8				1.03	0.70	0.81
8 to 10				1.20	0.77	0.89
10 to 12				2.10	1.06	1.09
12 to 14				1.64	1.13	1.58
14 to 16				2.32	1.63	1.70
16 to 18				2.82	1.90	2.65
18 to 20				1.81	3.24	2.51
20 to 22					2.23	2.41
22 to 24						
>=24						
Total			1.62	0.39	0.23	0.28

Table 14: Observed nitric oxide emission rates in 2012 - Diesel taxis

Mean nitric oxide (NO) emission rates derived from 2012 remote sensing surveys.

Grams of nitric oxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW/tonne).

Diesel taxis

kW/tonne	Taxi FX Euro 2	Taxi Metrocab Euro 2	Taxi TX1 Euro 2	Taxi Metrocab Euro 3	Taxi TXII Euro 3	Taxi Vito 111 Euro 4	Taxi TX4 Euro 4	Taxi Vito 113 Euro 5	Taxi TX4 Euro 5
<-10									
-10 to -8			22.68		8.27		7.51		
-8 to -6	22.11					10.59			
-6 to -4					9.63		7.19	7.41	
-4 to -2			23.54		8.20		8.14		
-2 to 0	24.42		22.94		8.26		8.95		
0 to 2	22.14		22.97		9.26	9.98	9.28		
2 to 4	19.39		20.46		9.11	10.70	8.55	5.86	
4 to 6	15.69		16.86		9.57	10.76	8.34	8.56	
6 to 8	12.63		14.09		10.39	11.08	8.55	8.93	
8 to 10	10.46		11.78		11.69	12.55	9.16		
10 to 12			11.61		12.64		9.77		
12 to 14							10.72		
14 to 16									
16 to 18	12.79					13.79		10.67	
18 to 20			14.59		13.81		12.05		
20 to 22									
22 to 24									
>=24									
Total	17.23	31.10	17.77	9.74	9.84	11.19	8.87	8.53	12.82

Table 15: Observed nitric oxide confidence intervals in 2012 – Diesel taxis

Mean nitric oxide (NO) emission rates derived from 2012 remote sensing surveys.

Grams of nitric oxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW/tonne).

Confidence interval (95%) about the mean (±).

Diesel taxis

kW/tonne	Taxi FX Euro 2	Taxi Metrocab Euro 2	Taxi TX1 Euro 2	Taxi Metrocab Euro 3	Taxi TXII Euro 3	Taxi Vito 111 Euro 4	Taxi TX4 Euro 4	Taxi Vito 113 Euro 5	Taxi TX4 Euro 5
<-10									
-10 to -8					1.11		1.16		
-8 to -6	2.41		1.46			0.88			
-6 to -4					1.91		1.72	1.09	
-4 to -2			2.40		1.48		1.61		
-2 to 0	2.36		1.52		0.95		0.68		
0 to 2	1.70		0.88		0.71	1.01	0.57		
2 to 4	1.62		0.66		0.54	0.98	0.50	0.86	
4 to 6	1.19		0.51		0.47	0.61	0.43	1.49	
6 to 8	0.74		0.41		0.51	0.84	0.46	1.71	
8 to 10	1.19		0.52		0.81	0.84	0.48		
10 to 12			0.93		1.21		0.60		
12 to 14							0.98		
14 to 16									
16 to 18	2.30					1.74		1.39	
18 to 20			2.90		1.75		0.99		
20 to 22									
22 to 24									
>=24									
Total	0.67	6.32	0.30	0.80	0.24	0.36	0.19	0.66	1.60

Table 16: Observed nitric oxide emission rates in 2012 – Petrol cars

Mean nitric oxide (NO) emission rates derived from 2012 remote sensing surveys.

Grams of nitric oxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW/tonne).

Petrol cars

	Petrol cars <1.4 litres						Petrol cars 1.4 to 2.0 litres						Petrol cars >2.0 litres					
kW/tonne	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**
<-10			5.20*	1.49	1.03*	1.46*			8.14	1.81	1.75	0.92*			3.56*	2.13*	1.06*	
-10 to -8				3.72*					7.55*	1.76*	1.32							
-8 to -6					1.02						2.28							
-6 to -4				1.40	0.91				9.68	1.75	2.92							
-4 to -2			6.26	3.45	0.93				4.56	3.56	1.54							
-2 to 0			4.84	2.23	1.32	0.86			11.20	2.44	1.76	0.98				1.70	1.09	
0 to 2			4.46	2.21	1.54	0.62			7.59	2.97	2.06	0.43			7.55	2.84	1.04	
2 to 4			5.59	2.76	1.36	1.05			9.18	3.56	1.70	0.34			4.33	2.09	0.72	
4 to 6			5.22	3.29	2.31	0.63			8.95	3.58	2.14	0.65			8.25	2.28	0.52	
6 to 8			7.51	1.93	1.94	0.72			10.95	2.67	2.68	0.52			6.55	4.17	0.47	
8 to 10			6.53	2.83	2.04	0.76			8.58	3.34	2.13	0.78			7.82	1.35	1.24	
10 to 12			9.47	3.99	1.87	1.28			9.92	3.45	2.46	1.07			7.03*	3.50	0.73	
12 to 14			8.71	3.75	3.52	2.42			12.78	3.19	2.91	1.87*				2.87*	2.29	
14 to 16			7.09*	6.03	2.99	1.01			10.54	2.58	3.26						1.39*	
16 to 18				1.82	3.49	1.54*			11.17*	5.49	3.93							
18 to 20				2.34	3.74					7.12	2.81							
20 to 22				2.34*	1.75					3.44*	4.26							
22 to 24					3.94*						2.93							
>=24				3.14						3.22	2.85							
Total	19.69	13.72	6.37	2.91	2.02	1.09	20.75	12.01	9.42	3.21	2.30	0.89	16.37	7.05	6.10	2.55	0.97	0.64

Table 17: Observed nitric oxide confidence intervals in 2012 – Petrol cars

Mean nitric oxide (NO) emission rates derived from 2012 remote sensing surveys.

Grams of nitric oxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW/tonne).

Confidence interval (95%) about the mean (±).

Petrol cars

	Petrol cars <1.4 litres						Petrol cars 1.4 to 2.0 litres						Petrol cars >2.0 litres					
kW/tonne	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**
<-10			2.37	0.86	0.57	0.61			3.22	0.92	0.92	0.45			1.34	1.21	0.51	
-10 to -8				2.40					3.69	0.90	1.48							
-8 to -6					0.64						1.81							
-6 to -4				0.90	0.48				4.13	0.96	2.01							
-4 to -2			2.99	3.50	0.43				2.31	1.69	0.69							
-2 to 0			2.72	1.12	0.63	0.50			2.91	0.83	0.61	0.60				1.00	0.59	
0 to 2			2.11	0.83	0.47	0.57			2.28	0.90	0.52	0.67			4.47	1.52	0.76	
2 to 4			1.93	1.16	0.44	0.60			2.57	0.95	0.45	0.25			2.00	1.55	1.02	
4 to 6			1.92	1.12	0.77	0.43			2.11	0.95	0.52	0.60			3.82	1.20	0.49	
6 to 8			2.63	0.80	0.63	0.26			2.44	0.80	0.90	0.35			3.06	2.32	0.28	
8 to 10			2.98	1.19	0.74	0.48			2.23	1.09	0.73	0.59			3.96	1.04	1.16	
10 to 12			4.38	1.75	0.84	0.82			3.28	1.26	0.90	0.91			2.71	3.13	0.37	
12 to 14			5.28	1.76	1.73	2.78			4.43	1.38	1.13	0.85				1.19	2.49	
14 to 16			1.91	2.95	1.75	0.74			5.64	1.38	1.38						0.89	
16 to 18				1.20	2.72	0.59			3.27	2.54	2.80							
18 to 20				1.12	2.97					3.82	2.04							
20 to 22				1.82	0.90					2.17	2.77							
22 to 24					1.79						2.93							
>=24				2.13						1.89	1.51							
Total	4.57	3.17	0.82	0.39	0.24	0.25	4.61	2.00	0.80	0.31	0.23	0.27	4.39	2.42	1.15	0.54	0.30	0.42

Table 18: Observed nitrogen dioxide emission rates in 2012 – Diesel cars and vans

Mean nitrogen dioxide (NO_2) emission rates derived from 2012 remote sensing surveys.

Grams of nitrogen dioxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW/tonne).

Diesel cars and vans

	Diesel cars <2.0 litres						Diesel cars > 2.0 litres						Diesel vans (up to 3.5 tonnes)					
kW/tonne	Pre Euro	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Pre Euro	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Pre Euro	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5
<-10				4.37	4.06	4.45				3.65	4.79	5.82				3.17	4.55	4.23
-10 to -8						4.19					5.95						4.77	6.01
-8 to -6					3.57											2.77	4.79	4.05
-6 to -4					3.86											3.20	4.41	4.26
-4 to -2				2.88	3.43	4.30				3.82	5.53	6.68				3.02	5.01	4.05
-2 to 0				3.60	3.08	3.53				4.52	5.60	4.83				2.90	5.13	4.28
0 to 2				2.83	3.13	3.43				3.41	5.95	4.88				2.78	4.89	4.23
2 to 4				2.54	3.40	3.65				4.42	5.80	4.45				2.46	4.26	4.02
4 to 6				2.60	3.38	3.35				3.85	5.05	4.20				2.56	4.64	4.16
6 to 8				2.84	3.46	3.24				3.08	4.88	3.81				2.43	4.40	4.19
8 to 10				2.41	3.63	3.34				3.55	5.46	4.12				2.38	3.83	4.00
10 to 12				3.20	3.71	3.61				4.30	6.23	4.37				2.33	3.70	4.12
12 to 14				2.58	3.53	3.79				4.71	5.29	3.87				2.61	4.73	3.83
14 to 16				1.69	3.79	4.91					5.33	5.37				2.13	4.27	4.17
16 to 18				3.28	4.69	4.98					7.92					2.38	5.12	4.98
18 to 20				2.52	5.06	4.00					6.27					2.46	6.26	5.55
20 to 22					5.25												6.74	5.55
22 to 24					3.43													
>=24				4.63	5.28	4.94												
Total	1.91	3.26	1.82	2.86	3.59	3.66	2.15	2.22	1.74	4.00	5.55	4.53	0.00	2.40	1.81	2.61	4.56	4.21

Table 19: Observed nitrogen dioxide confidence intervals in 2012 – Diesel cars and vans

Mean nitrogen dioxide (NO_2) emission rates derived from 2012 remote sensing surveys.

Grams of nitrogen dioxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW/tonne).

Confidence interval (95%) about the mean (±).

Diesel cars and vans

	Diesel cars <2.0 litres						Diesel cars > 2.0 litres						Diesel vans (up to 3.5 tonnes)					
kW/tonne	Pre Euro	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Pre Euro	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Pre Euro	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5
<-10				1.03	0.88	1.23				1.23	1.51	1.47				0.69	0.85	1.12
-10 to -8						0.94					1.40						0.95	2.23
-8 to -6					1.07											1.07	1.42	1.11
-6 to -4					1.04											1.57	0.98	1.35
-4 to -2				0.83	0.72	0.85				1.88	1.23	1.43				0.80	0.82	0.67
-2 to 0				0.86	0.53	0.61				1.28	0.80	0.85				0.47	0.52	0.55
0 to 2				0.58	0.45	0.50				1.02	0.86	0.79				0.43	0.51	0.51
2 to 4				0.50	0.38	0.43				1.08	0.76	0.65				0.31	0.41	0.45
4 to 6				0.44	0.36	0.42				0.73	0.62	0.54				0.26	0.43	0.45
6 to 8				0.43	0.38	0.47				0.79	0.62	0.54				0.34	0.45	0.48
8 to 10				0.47	0.50	0.38				0.76	0.66	0.66				0.45	0.43	0.47
10 to 12				0.75	0.53	0.68				1.17	1.04	0.77				0.48	0.48	0.60
12 to 14				0.78	0.61	0.78				0.90	1.04	0.98				0.69	0.91	0.69
14 to 16				0.48	0.75	1.14					1.17	0.96				1.04	1.03	0.98
16 to 18				1.24	1.17	1.26					1.61					1.09	1.31	1.72
18 to 20				0.80	1.29	0.71					1.17					0.96	1.76	1.77
20 to 22					1.57												1.50	1.27
22 to 24					1.31													
>=24				1.81	0.97	1.38												
Total			0.22	0.18	0.14	0.16			0.28	0.33	0.24	0.24			0.56	0.13	0.16	0.17

Table 20: Observed nitrogen dioxide emission rates in 2012 – Diesel taxis

Mean nitrogen dioxide (NO_2) emission rates derived from 2012 remote sensing surveys.

Grams of nitrogen dioxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW/tonne).

Diesel taxis

kW/tonne	Taxi FX Euro 2	Taxi Metrocab Euro 2	Taxi TX1 Euro 2	Taxi Metrocab Euro 3	Taxi TXII Euro 3	Taxi Vito 111 Euro 4	Taxi TX4 Euro 4	Taxi Vito 113 Euro 5	Taxi TX4 Euro 5
<-10									
-10 to -8					2.97		2.06		
-8 to -6	1.70		2.86						
-6 to -4					2.37	4.39	1.95	7.90	
-4 to -2			2.88		2.48		2.31		
-2 to 0	1.60		2.45		2.20		2.24		
0 to 2	1.54		2.47		2.30	4.11	2.28		
2 to 4	1.36		2.06		2.02	3.54	2.15	7.50	
4 to 6	0.95		1.38		1.56	2.70	1.50	7.50	
6 to 8	0.71		1.00		1.40	3.38	1.31	8.01	
8 to 10	0.52		0.79		1.56	3.62	1.09		
10 to 12			0.76		1.62		1.30		
12 to 14							1.10		
14 to 16									
16 to 18	0.62					3.44		6.74	
18 to 20			1.01		1.84		1.15		
20 to 22									
22 to 24									
>=24									
Total	1.11	3.46	1.64	0.95	1.82	3.49	1.68	7.46	4.72

Table 21: Observed nitrogen dioxide confidence intervals in 2012 – Diesel taxis

Mean nitrogen dioxide (NO_2) emission rates derived from 2012 remote sensing surveys.

Grams of nitrogen dioxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW/tonne).

Confidence interval (95%) about the mean (±).

Diesel taxis

kW/tonne	Taxi FX Euro 2	Taxi Metrocab Euro 2	Taxi TX1 Euro 2	Taxi Metrocab Euro 3	Taxi TXII Euro 3	Taxi Vito 111 Euro 4	Taxi TX4 Euro 4	Taxi Vito 113 Euro 5	Taxi TX4 Euro 5
<-10									
-10 to -8			0.50		0.70		0.69		
-8 to -6	0.65					1.14			
-6 to -4					0.63		0.75	0.71	
-4 to -2			0.75		0.47		0.82		
-2 to 0	0.41		0.44		0.39		0.35		
0 to 2	0.32		0.24		0.26	1.24	0.29		
2 to 4	0.27		0.19		0.17	0.93	0.29	1.31	
4 to 6	0.15		0.13		0.12	0.47	0.15	1.08	
6 to 8	0.13		0.08		0.10	0.76	0.16	1.05	
8 to 10	0.12		0.11		0.17	0.98	0.12		
10 to 12			0.16		0.27		0.21		
12 to 14							0.28		
14 to 16									
16 to 18	0.29					0.95		0.82	
18 to 20			0.44		0.33		0.31		
20 to 22									
22 to 24									
>=24									
Total	0.11	0.78	0.07	0.15	0.07	0.33	0.08	0.46	0.74

Table 22: Observed nitrogen dioxide emission rates in 2012 – Petrol cars

Mean nitrogen dioxide (NO_2) emission rates derived from 2012 remote sensing surveys.

Grams of nitrogen dioxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW/tonne).

Petrol cars

	Petrol cars <1.4 litres						Petrol cars 1.4 to 2.0 litres						Petrol cars >2.0 litres					
kW/tonne	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**
<-10			0.14	0.00	0.05	0.18			0.08	0.22	0.10	0.05			0.15	0.00	0.00	
-10 to -8									0.21	0.22	0.21							
-8 to -6					0.09						0.00							
-6 to -4				0.00	0.08				0.00	0.00	0.12							
-4 to -2			0.12	0.05	0.19				0.00	0.06	0.06							
-2 to 0			0.26	0.14	0.00	0.02			0.23	0.21	0.16	0.00				0.00	0.15	
0 to 2			0.04	0.14	0.18	0.32			0.13	0.12	0.23	0.30			0.04	0.22	0.64	
2 to 4			0.18	0.07	0.09	0.22			0.21	0.15	0.07	0.08			0.14	0.11	0.00	
4 to 6			0.00	0.17	0.09	0.09			0.33	0.04	0.04	0.36			0.13	0.00	0.05	
6 to 8			0.07	0.10	0.06	0.19			0.47	0.04	0.22	0.07			0.00	0.25	0.00	
8 to 10			0.45	0.15	0.17	0.23			0.23	0.04	0.12	0.22			0.00	0.13	0.12	
10 to 12			0.12	0.10	0.22	0.16			0.08	0.15	0.18	0.39			0.24	0.00	0.07	
12 to 14			0.00	0.10	0.19	0.00			0.12	0.01	0.12	0.27				0.00	0.02	
14 to 16			0.20	0.00	0.01	0.10			0.10	0.00	0.08						0.12	
16 to 18				0.06	0.13	0.33			0.05	0.11	0.28							
18 to 20				0.15	0.14					0.42	0.09							
20 to 22				0.18	0.03					0.00	0.43							
22 to 24					0.24						0.00							
>=24				0.10						0.04	0.02							
Total	0.22	0.27	0.12	0.09	0.12	0.17	0.18	0.15	0.21	0.09	0.13	0.19	0.13	0.19	0.10	0.06	0.09	0.00

Table 23: Observed nitrogen dioxide confidence intervals in 2012 – Petrol cars

Mean nitrogen dioxide (NO_2) emission rates derived from 2012 remote sensing surveys.

Grams of nitrogen dioxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW/tonne).

Confidence interval (95%) about the mean (±).

Petrol cars

	Petrol cars <1.4 litres						Petrol cars 1.4 to 2.0 litres						Petrol cars >2.0 litres					
kW/tonne	Pre Euro	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Pre Euro	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Pre Euro	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5
<-10					0.29				0.22	0.29	0.16							
-10 to -8			0.23	0.30					0.41	0.25	0.37							
-8 to -6					0.30	0.31					0.29	0.38			0.25	0.23	0.17	
-6 to -4				0.35	0.33				0.38	0.24	0.26							
-4 to -2			0.32	0.32	0.36				0.28	0.14	0.15							
-2 to 0			0.43	0.17	0.14	0.23			0.21	0.24	0.12	0.39				0.21	0.31	
0 to 2			0.25	0.18	0.16	0.31			0.29	0.15	0.15	0.34			0.35	0.28	0.81	
2 to 4			0.27	0.13	0.10	0.15			0.12	0.12	0.09	0.14			0.21	0.15	0.16	
4 to 6			0.24	0.18	0.14	0.13			0.33	0.08	0.07	0.40			0.22	0.13	0.17	
6 to 8			0.13	0.15	0.08	0.17			0.39	0.09	0.14	0.17			0.12	0.34	0.16	
8 to 10			0.32	0.16	0.15	0.39			0.28	0.15	0.12	0.23			0.28	0.14	0.21	
10 to 12			0.21	0.16	0.22	0.17			0.16	0.12	0.13	0.44				0.14	0.14	
12 to 14			0.35	0.14	0.13	0.26			0.21	0.12	0.13						0.20	
14 to 16				0.31	0.20	0.32			0.17	0.12	0.11							
16 to 18				0.24	0.15					0.16	0.26				0.20			
18 to 20			0.16	0.20	0.24					0.47	0.19	0.17				0.09	0.11	
20 to 22				0.32	0.24	0.23			0.14	0.18	0.62							
22 to 24					0.18						0.16							
>=24				0.25						0.18	0.15							
Total	0.34	0.19	0.08	0.05	0.04	0.08	0.22	0.17	0.09	0.04	0.04	0.10	0.14	0.14	0.10	0.07	0.10	0.07

Table 24: Sample size (n) from 2012 remote sensing surveys – Diesel cars and vans

Sample size (n)

Diesel cars and vans

	Diesel cars <2.0 litres						Diesel cars > 2.0 litres						Diesel vans (up to 3.5 tonnes)					
kW/tonne	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**
<-10				67	92	40				48	35	58				87	84	80
-10 to -8						59					55						45	30
-8 to -6					42											43	44	41
-6 to -4					66											47	71	43
-4 to -2				39	122	71				31	52	51				66	134	112
-2 to 0				71	205	139				52	120	87				142	331	238
0 to 2				115	243	190				49	148	121				175	392	338
2 to 4				153	327	288				90	157	160				227	509	405
4 to 6				161	381	275				85	216	202				287	542	446
6 to 8				197	352	245				65	186	184				213	469	345
8 to 10				157	260	209				70	141	133				181	334	268
10 to 12				81	201	121				53	90	81				104	207	183
12 to 14				64	134	88				102	67	46				65	117	102
14 to 16				49	108	63					51	71				39	68	74
16 to 18				39	56	45					32					32	49	48
18 to 20				37	55	68					60					42	40	35
20 to 22					31												58	55
22 to 24					31													
>=24				32	77	37												
Total	3	19	172	1262	2783	1938	7	21	100	645	1410	1194	1	14	61	1750	3494	2843

Table 25: Sample size (n) from 2012 remote sensing surveys – Diesel taxis

Sample size (n)

Diesel taxis

kW/tonne	Taxi FX Euro 2	Taxi Metrocab Euro 2	Taxi TX1 Euro 2	Taxi Metrocab Euro 3	Taxi TXII Euro 3	Taxi Vito 111 Euro 4	Taxi TX4 Euro 4	Taxi Vito 113 Euro 5	Taxi TX4 Euro 5
<-10									
-10 to -8					51		60		
-8 to -6	44		76						
-6 to -4					45	54	30	52	
-4 to -2			65		68		51		
-2 to 0	43		144		125		274		
0 to 2	100		446		412	40	405		
2 to 4	93		477		464	59	439	34	
4 to 6	105		552		649	93	601	45	
6 to 8	119		537		510	59	540	35	
8 to 10	55		303		223	44	388		
10 to 12			107		93		184		
12 to 14							79		
14 to 16							34		
16 to 18							11	62	
18 to 20	30		41		52	37	4		
20 to 22							3		
22 to 24							3		
>=24							2		
Total	589	45	2748	87	2692	386	3108	228	125

Table 26: Sample size (n) from 2012 remote sensing surveys – Petrol cars

Sample size (n)

Petrol cars

	Petrol cars <1.4 litres						Petrol cars 1.4 to 2.0 litres						Petrol cars >2.0 litres					
kW/tonne	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**
<-10				37	95				50	72	128							
-10 to -8			60	28					33	48	41							
-8 to -6					45	92					62	45			61	81	79	
-6 to -4				30	52				32	59	70							
-4 to -2			28	48	81				51	87	152							
-2 to 0			46	101	144	53			87	133	232	32				58	43	
0 to 2			68	106	220	66			100	200	328	51			30	69	65	
2 to 4			90	145	258	81			122	276	398	71			41	69	82	
4 to 6			78	162	294	86			161	292	422	56			32	78	96	
6 to 8			102	146	308	84			147	298	408	54			38	76	77	
8 to 10			61	117	275	76			120	216	338	58			30	72	78	
10 to 12			50	97	188	65			72	155	233	33				47	40	
12 to 14			38	70	129	46			42	100	169						32	
14 to 16				67	87	34			32	77	133							
16 to 18				33	65					60	89				49			
18 to 20			93	31	52					45	63	92				108	83	
20 to 22				37	33	83			92	48	48							
22 to 24					87						38							
>=24				32						47	83							
Total	37	92	714	1287	2413	766	68	160	1141	2213	3435	492	42	54	281	658	675	179

5. Light vehicle forecasting assumptions

5.1 Assumed future light vehicle fleet profile in Ealing

In order to generate scenarios of future year vehicle emissions in Ealing, it is necessary to make assumptions about the mix of the future light vehicle fleet in terms of age, fuel type, engine capacity, and Euro standards. Two snap shots of the past vehicle fleet mix are available to us to inform scenario development:

a) The light vehicle fleet mix observed in the 2008 remote sensing surveys (eight survey sites) carried out in Ealing in late March / early April 2008;
b) The light vehicle fleet mix observed in the 2012 remote sensing surveys (two survey sites) carried out in Ealing in June 2012.

5.2 Passenger cars

5.2.1 Age profile

Figure 15 and Figure 16 present the observed passenger car fleet profiles in Ealing in 2008 and 2012 respectively. Generally, the overall shape of the profile at the two points in time is similar. However, some differences can be noted:

a) The increase in the relative market share of diesel cars over the four year period can be observed in the 2012 data;
b) The difference in seasonal timing of the remote sensing surveys (late March / April 2008 versus June 2012) is observable in the relative numbers of 2008 registered vehicles observed in 2008, and the relative numbers of 2012 registered vehicles observed in 2012;
c) The influence of the economic recession on vehicle purchasing rates. In the 2008 data (pre-recession), there are relatively higher numbers of newer cars (<5 years old). In the 2012 data (after the start of the recession), there are relatively fewer newer cars, with a more distinct 'peak' in the profile when vehicles are around seven or eight years old.

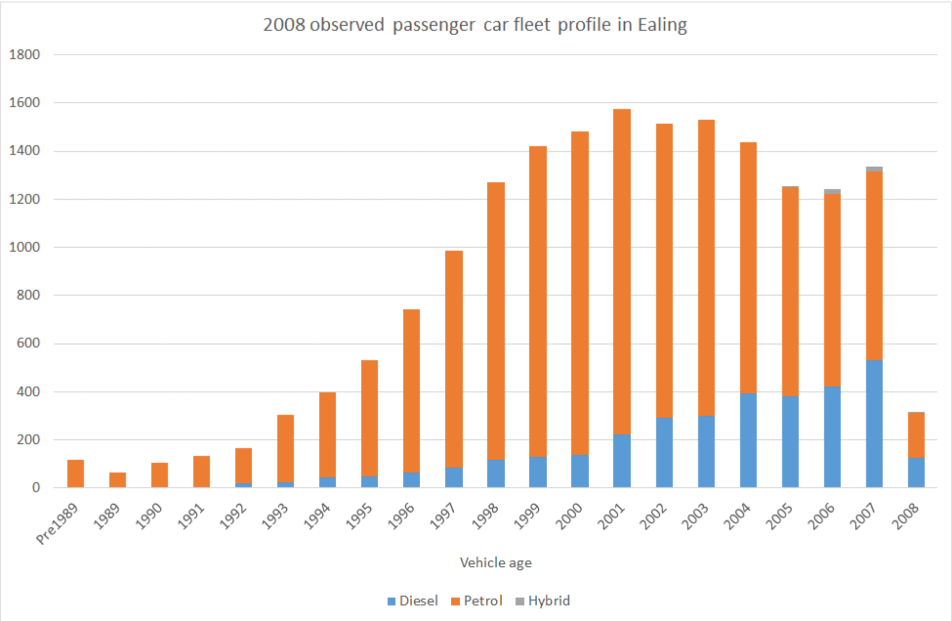

Figure 15: 2008 observed passenger car fleet profile in Ealing

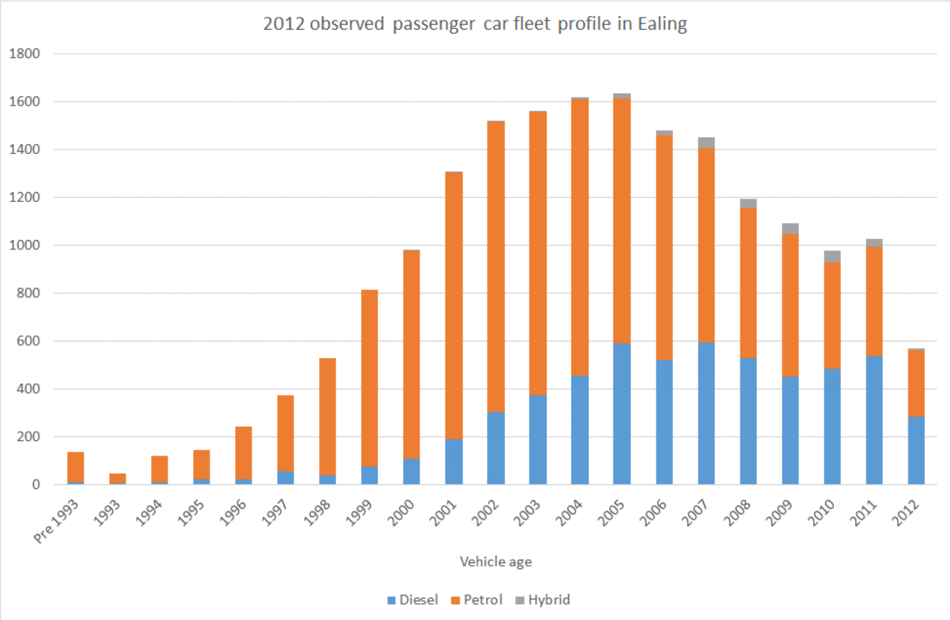

Figure 16: 2012 observed passenger car fleet profile in Ealing

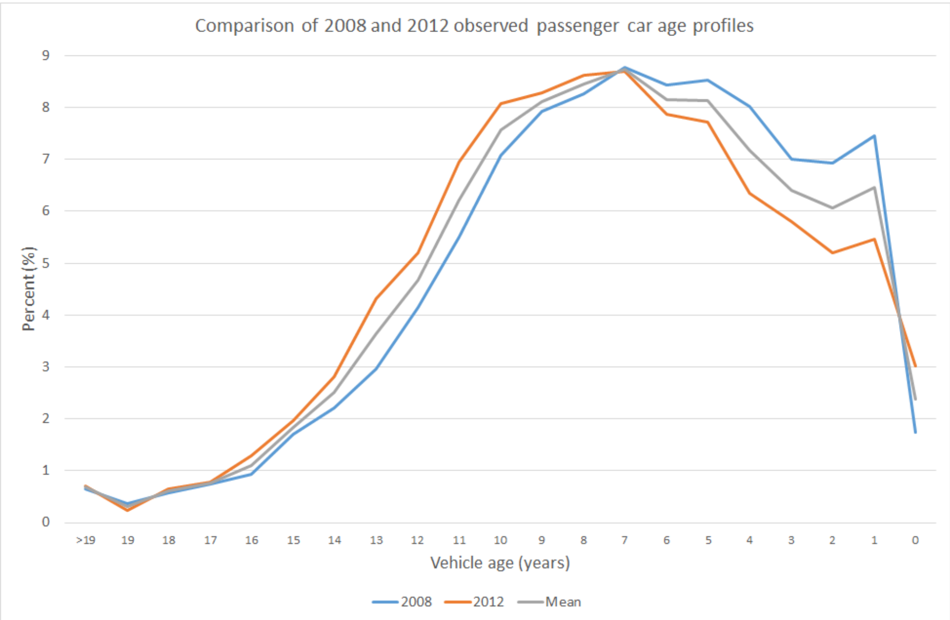

Figure 17: Comparison of 2008 and 2012 observed passenger car age profiles

Given the uncertainty regarding future economic conditions, it is proposed that an average of the 2008 and 2012 age profiles, as illustrated in Figure 17, is adopted as a basis for the future scenarios.

5.2.2 Market share by fuel type

The overall proportion of diesel passenger cars in the Ealing fleet has increased from 18.7% in 2008 to 30% in 2012 (Table 27). Figure 18 illustrates this progressive increase by year of registration, based on the 2008 and 2012 remote sensing data sets. National figures published by SMMT (Table 28) indicate that the proportion of diesel car sales increased to 2012, but have since stabilised at around 50% of new sales (SMMT, 2014a). Diesel market share actually declined slightly in 2013, relative to 2012. SMMT forecast that sales of diesel passenger cars will remain at around 50%

market share in 2014 and 2015 (SMMT, 2014b). It is therefore proposed that the Ealing scenarios assume a 50% market share for diesel to 2017. National sales of 'Other' fuel types (predominantly petrol hybrid cars) have been increasing in recent years from around 0.7% in 2008, to 1.4% in 2012 (SMMT, 2014a); (comparative observed Ealing figures are 0.3% and 1.5% respectively). It is considered likely that sales of hybrid technologies will continue to increase as new hybrid products are brought to market. It is proposed that an assumption of a 3.5% market share for new sales of hybrid technologies at 2017 be adopted for the scenarios, based on existing trends.

Table 27: Observed passenger cars in Ealing by main fuel type – 2008 and 2012

	2008	2012
Petrol	81.0%	68.5%
Diesel	18.7%	30%
Hybrid	0.3%	1.5%

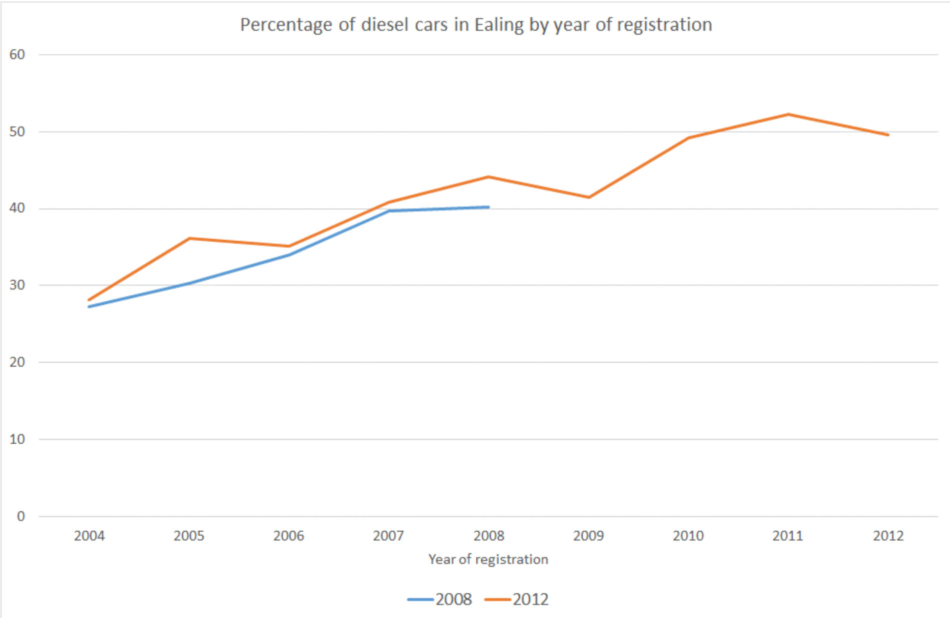

Figure 18: Percentage of diesel cars in Ealing by year of registration

Table 28: SMMT recorded national vehicle sales by fuel type

Year	Petrol	Diesel	Other
2004	67.3%	32.5%	0.2%
2005	62.9%	36.8%	0.3%
2006	61.3%	38.3%	0.4%
2007	59.1%	40.2%	0.7%
2008	55.7%	43.6%	0.7%
2009	57.5%	41.7%	0.8%
2010	52.8%	46.1%	1.1%
2011	48.1%	50.6%	1.3%
2012	47.8%	50.8%	1.4%
2013	48.8%	49.8%	1.4%
*2014**	*48.1%*	*50.1%*	*1.8%*
*2015**		*50.0%*	

SMMT forecasts (SMMT, 2014b)

5.2.3 Market share by engine capacity

In recent years there has been a general reduction in engine capacity (swept volume) for new car sales in response to the introduction of European targets for CO_2 reduction, and the associated objective of reducing fuel consumption with increased engine efficiency. Table 29 presents the market share by year of manufacture, fuel type and capacity band observed in Ealing in 2012. Between 2006 and 2012, the proportion of petrol cars with engines of less than 1.4 litres has increased from 38% to 62%. In particular, there was a step change in year 2009 as can be observed in Figure 19. Since 2009, there has still been a general reduction in petrol engine capacity, but at a slower rate of change. For the purpose of scenario development, it is proposed that the market share of engines less than 1.4 litres (as a proportion of all petrol engines) is assumed to continue to increase at a rate of 2% per annum from 2012 to 2017, as illustrated in Figure 19. This is broadly consistent with the observed rate of change between 2009 and 2012.

Table 29: Observed passenger car engine capacity in Ealing by main fuel type in 2012

		Year of manufacture			
	Capacity	**2006**	**2008**	**2010**	**2012**
Petrol	< 1.4 litres	38.0%	41.3%	57.6%	62.0%
	1.4 to 2.0 litres	53.1%	51.4%	37.2%	34.1%
	> 2.0 litres	8.9%	7.3%	5.2%	3.9%
Diesel	< 2.0 litres	67.3%	70.0%	77.0%	79.1%
	> 2.0 litres	32.7%	30.0%	23.0%	20.9%

Between 2006 and 2012, the proportion of diesel cars with engines of less than 2.0 litres capacity has increased from 67.3% to 79.1%. Again, there was something of a step change in the period from 2007 to 2009, as can be observed in Figure 20. Between 2009 and 2012, diesel vehicles with smaller engines continued to gain market share (as a proportion of all diesel engines) at a more modest annual rate when compared to petrol cars. For the purpose of scenario development, it is proposed that the market share of diesel less than 2.0 litres (as a proportion of all diesel engines) is assumed to continue to increase at a rate of 1% per annum from 2012 to 2017, as illustrated in Figure 20. This is broadly consistent with the observed rate of change between 2009 and 2012.

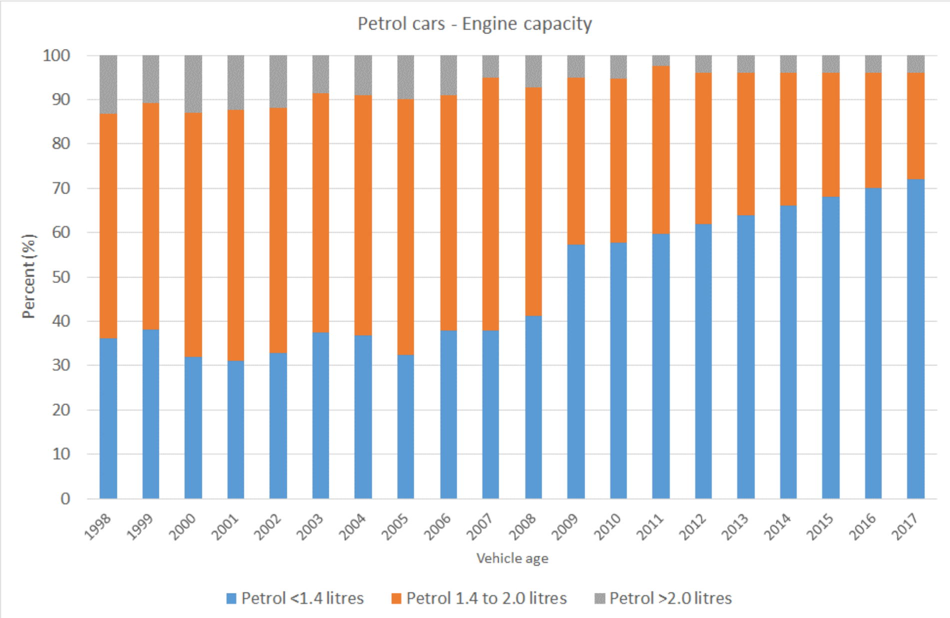

Figure 19: Petrol cars – Engine capacity observed in Ealing in 2012

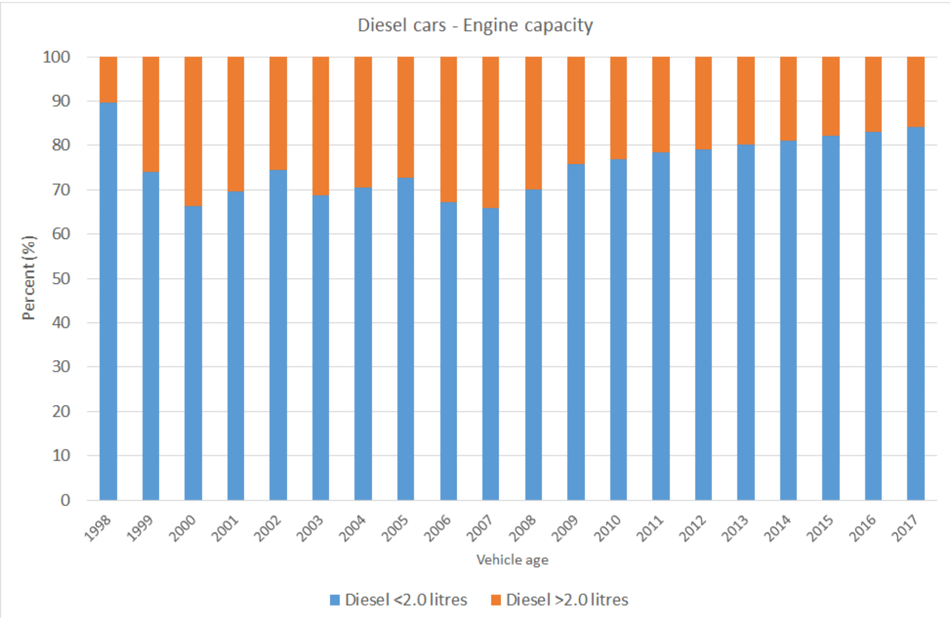

Figure 20: Diesel cars – Engine capacity observed in Ealing in 2012

5.2.4 Market share by Euro emissions standard

The **Euro 5** emissions standard applied from **September 1st 2009** for the type approval of passenger cars, and from **January 1st 2011** for the registration and sale of passenger cars in the EU.

The **Euro 6** emissions standard applies from **September 1st 2014** for the type approval of passenger cars, and from **September 1st 2015** for the registration and sale of passenger cars in the EU (European Commission, 2008, 2012).

For scenario development, it is necessary to make some assumptions regarding the rate of introduction of the Euro 6 emissions standard into the Ealing passenger car fleet. One method of determining this is to review the observed rate of introduction of the Euro 5 emissions standard. Figure 21 presents the observed profile of the introduction of the Euro 5 emissions standard in Ealing, based on the relative proportions of passenger cars by fuel type in the 2012 remote sensing data set. The two key dates for Euro 5 (type approval deadline, and sales & registration deadline, as above) are highlighted. There was a sixteen month gap between these two dates.

Euro 5 type approval deadline

Euro 5 sales & registration deadline

		Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4
		2007	**2008**	**2009**	**2010**	**2011**	**2012**
Diesel	**E3**	0.5	0.0	0.2	0.0	0.0	0.0
	E4	99.5	99.8	75.0	45.9	7.3	1.4
	E5	0.0	0.2	24.8	54.1	92.7	98.2
Petrol	**E3**	0.0	0.0	0.0	0.0	0.0	0.0
	E4	100.0	100.0	82.4	45.3	7.3	0.4
	E5	0.0	0.0	17.6	54.7	92.7	99.6

Figure 21: Observed profile of introduction of Euro 5 emissions standard in Ealing

It can be seen from Figure 21 that for passenger cars registered in 2009 (the year of the type approval deadline), 24.8% of diesel cars observed in Ealing were Euro 5; the corresponding figure for petrol cars was 17.6%. For cars registered in 2010 (the year immediately preceding the sales and registration deadline on January 1st 2011), 54.1% of registered diesel cars were Euro 5, and 54.7% of registered petrol cars were Euro 5, i.e. 45.9% of newly registered diesel cars were still Euro 4, and 45.3% of newly registered petrol cars were still Euro 4. This highlights the fact that significant volumes of the previous Euro standard light vehicles are sold and registered right up to the legislated sales and registration deadline for the new Euro standard.

It is assumed for the scenario development that the introduction of the Euro 6 emissions standard for light vehicles will exhibit a similar profile, subject to two factors; firstly, the gap between the two legislated dates for Euro 6 is shorter than for Euro 5 (twelve months, rather than sixteen months), and; secondly, the observed rate of Euro 6 passenger car type approvals reported by the UK Vehicle Certification Agency (VCA) to August 2013 (the latest available figures).

VCA produce an annual summary of new vehicle type approvals. In the 2012 VCA release, 2.8% of diesel cars were Euro 6. No type approved petrol cars were Euro 6. In the 2013 VCA release, 5% of diesel cars were Euro 6, and 10.8% of petrol cars were Euro 6. Given that there will be a lead time between type approval and actual sales, Figure 22 presents the assumed profile of the introduction of Euro 6 in Ealing. The 3.9% assumed value for Euro 6 diesels in 2013 is based on an average of the VCA type approval values at 2012 and 2013. Similarly, the 5.4% value for Euro 6 petrol cars in 2013 is estimated in the same manner. In 2015, the Euro 6 market shares for diesel and petrol cars are based on the proportions previously observed in 2010 for the introduction of Euro 5, but factored to reflect the fact that Euro 6 is introduced on September 1st, rather than at the end of the year for Euro 5. Clearly, these assumed values are estimates, but appear reasonable based on observed past experience with Euro 5.

Euro 6 type approval deadline (2014 Q3/Q4) | Euro 6 sales & registration deadline (2015 Q4)

		2012 (Q1 Q2 Q3 Q4)	2013 (Q1 Q2 Q3 Q4)	2014 (Q1 Q2 Q3 Q4)	2015 (Q1 Q2 Q3 Q4)	2016 (Q1 Q2 Q3 Q4)	2017 (Q1 Q2 Q3 Q4)
Diesel	**E4**	1.4	0.0	0.0	0.0	0.0	0.0
	E5	98.2	96.1	68.4	33.0	5.0	0.0
	E6	0.0	3.9	31.6	67.0	95.0	100.0
Petrol	**E4**	0.4	0.0	0.0	0.0	0.0	0.0
	E5	99.6	94.6	67.7	30.0	2.0	0.0
	E6	0.0	5.4	32.3	70.0	98.0	100.0

Figure 22: Assumed profile of introduction of Euro 6 emissions standard in Ealing

5.2.5 Passenger car fleet profile in Ealing in 2017 and 2020

Combining all of the above analysis, the assumed passenger car fleet composition in Ealing in 2017 will be as illustrated in Figure 24. The observed passenger car fleet composition in 2012 is presented for comparison in Figure 23. The abbreviations in the key are as follows:

P1 = Petrol cars with engines < 1.4 litres
P2 = Petrol cars with engines 1.4 to 2.0 litres
P3 = Petrol cars with engines > 2.0 litres

D1 = Diesel cars with engines < 2.0 litres
D2 = Diesel cars with engines > 2.0 litres
Hyb = Hybrid

The suffix E0 through E6 designates the 'Euro' standard, e.g. P1E4 (Petrol cars with engines < 1.4 litres at Euro 4).

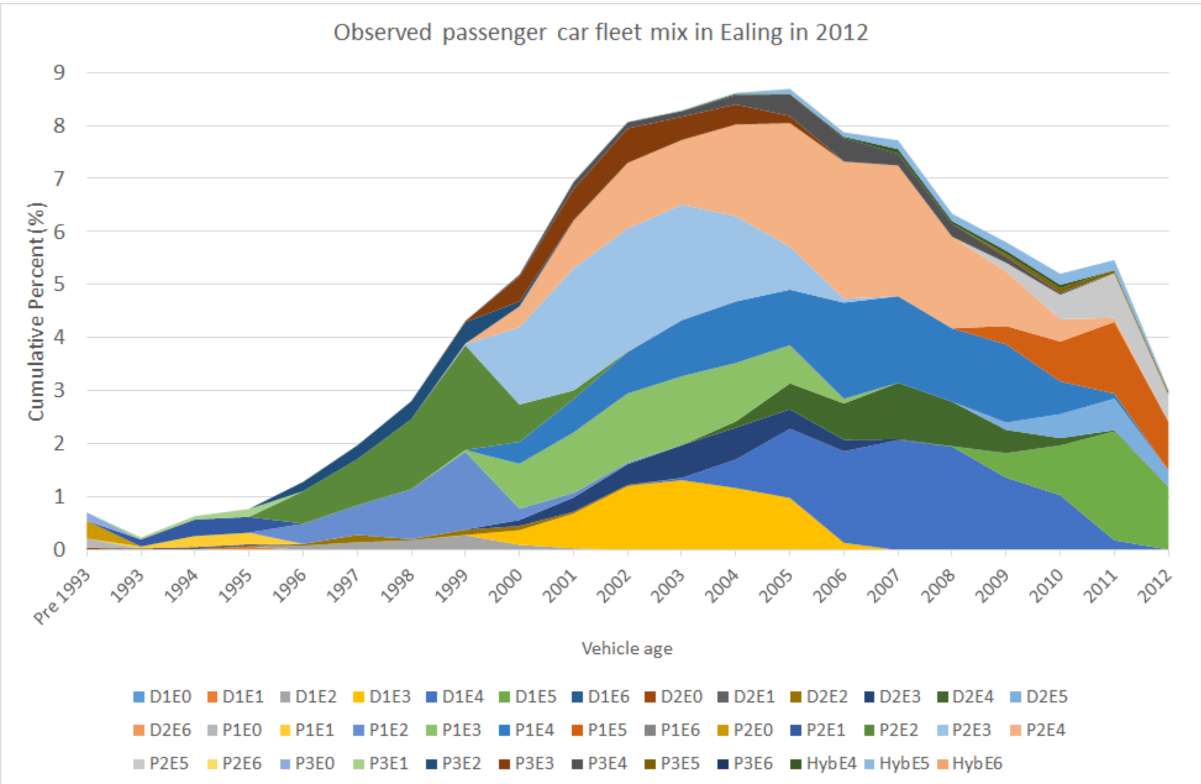

Figure 23: Observed passenger car fleet composition in Ealing in 2012

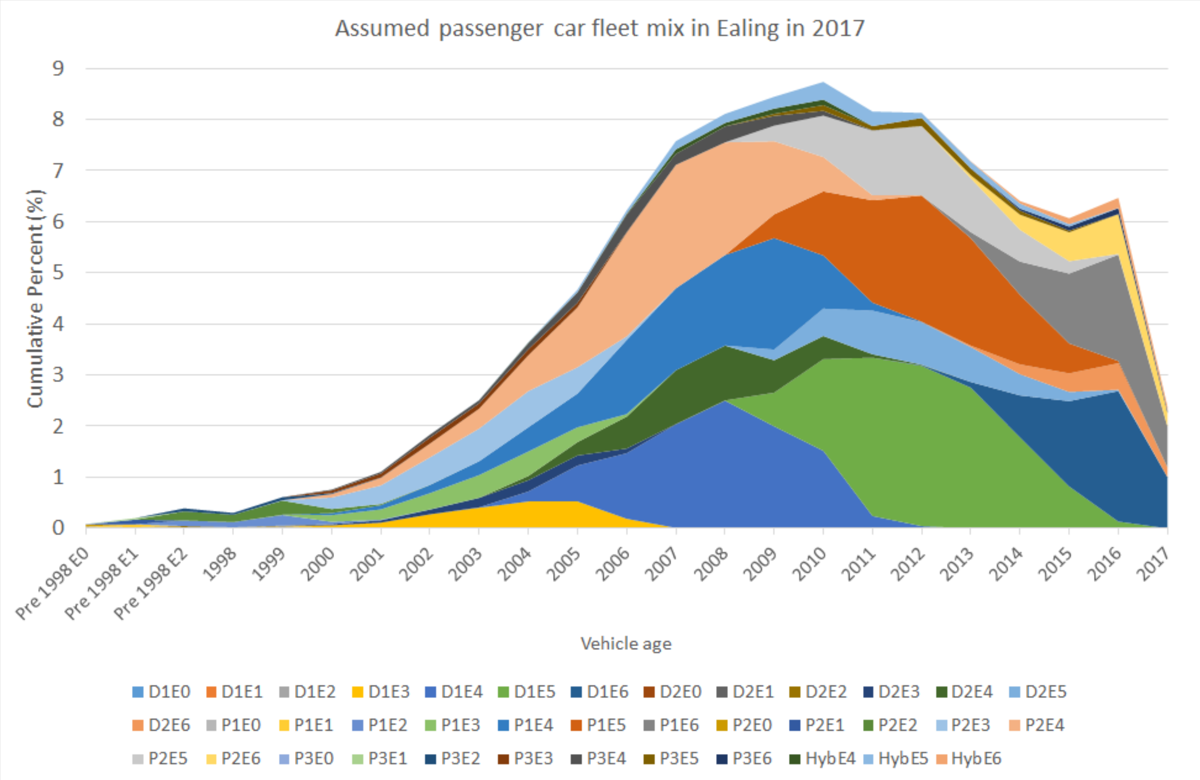

Figure 24: Assumed passenger car fleet composition in Ealing in 2017

For completeness, Figure 25 extends these forecasting assumptions a further three years to illustrate the assumed passenger car fleet composition in Ealing in 2020.

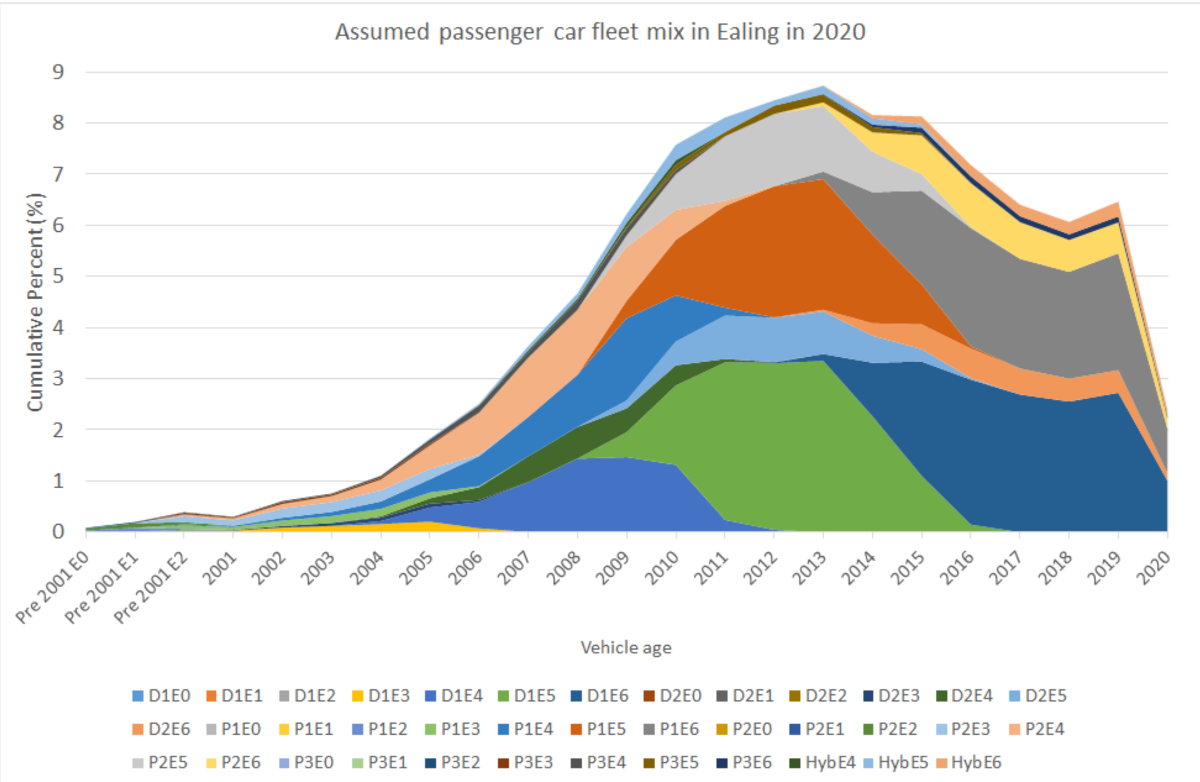

Figure 25: Assumed passenger car fleet composition in Ealing in 2020

5.3 Vans (up to 3.5 tonnes gross) - N1

5.3.1 Age profile

Figure 26 presents the observed diesel van (N1) fleet profiles in Ealing in 2008 and 2012 respectively. The N1 class encompasses goods vehicles up to 3.5 tonnes. It can be seen that the two profiles differ, with the 2008 profile being quite smooth, and the 2012 profile displaying more variability. In particular, the 2012 profile exhibits a 'dip' in vehicles registered at 2 and 3 years old (2010 and 2009), and a 'peak' at 5 years old (2007). Again, the dip at 2009 and 2010 may be due to the economic circumstances prevailing at the time. As with passenger cars, for the purpose of scenario development, it is proposed to use the average of the two profiles in the future scenarios, given the uncertainty regarding economic future conditions.

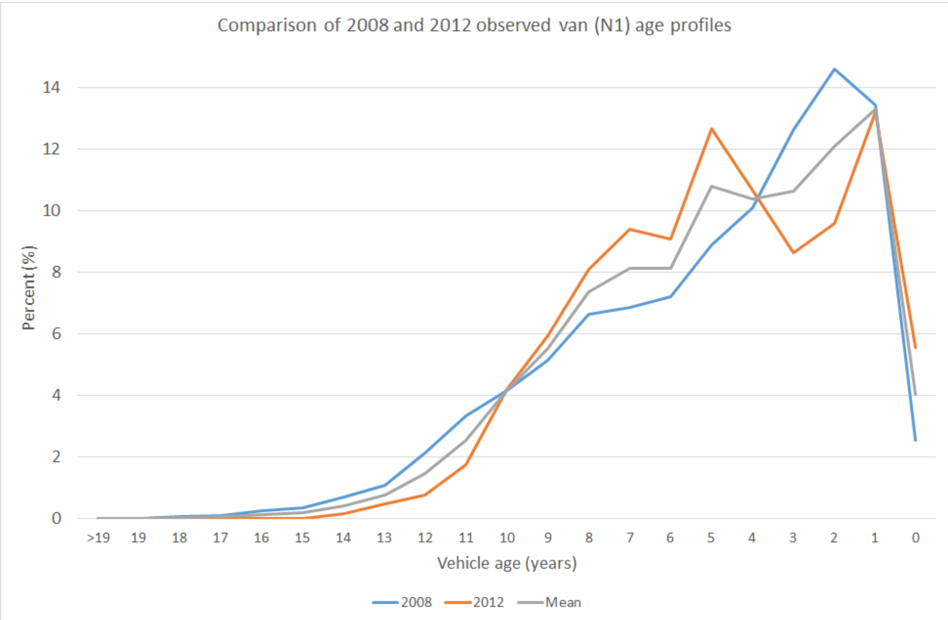

Figure 26: Comparison of 2008 and 2012 observed diesel van (N1) age profiles in Ealing

5.3.2 Market share by Euro emissions standard

The timing of the introduction of the Euro 6 emissions standard for vans (N1) is complicated by the fact that different timings apply for different N1 sub-classes.

- N1 Class I: reference mass ≤ 1305kg
- N1 Class II: 1305kg < reference mass ≤ 1760kg
- N1 Class III: reference mass > 1760kg

Reference mass is defined in European directives as being the mass of the vehicle in running order less the mass of the driver of 75kg and increased by a mass of 100kg (European Commission, 2007), i.e. mass in running order plus 25kg.

The Euro 6 emissions standard for N1 vans in Class I is applied with the same timings as passenger cars (M1), i.e. from **September 1st 2014** for type approval, and from **September 1st 2015** for registration and sale. However, the Euro 6 emissions standard for N1 vans in Classes II and III applies one year later, i.e. the deadline for registration and sales is **September 1st 2016** (European Commission, 2008 and 2012). This is significant because approximately 14.1% of N1 vans in Ealing are Class I, and 85.9% Class II & III.

The van (N1) fleet mix by Euro standard as observed in Ealing in 2012 is presented in Figure 27. The observed van fleet mix will be influenced by the presence of the London Low Emission Zone (LEZ) regulations applying to light commercial vehicles, i.e. the introduction of the Euro 3 emission standard for particulate matter in the London Low Emission Zone, generally applicable to N1 class vans between 1.2 and 3.5 tonnes from January 2012. The effect of the Euro 3 standard on N1 vans is to essentially remove many vehicles first registered before 2002 from the fleet operating within the LEZ (with some exceptions for early adopters of Euro 3 emissions control technology). At 2012, approximately 29% of observed vans in Ealing were Euro 5, and 41% Euro 4, with the remaining 30% being Euro 3 standard.

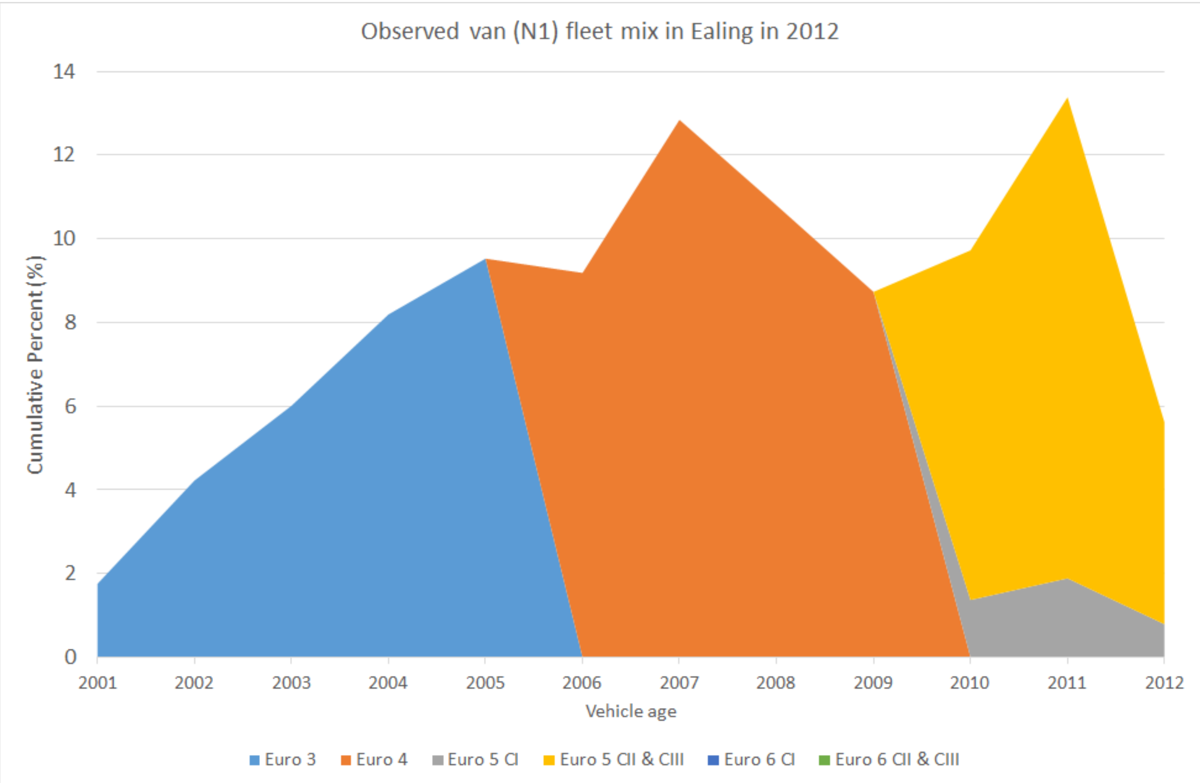

Figure 27: Observed van (N1) fleet composition in Ealing in 2012

Figure 28 presents the assumed van (N1) fleet composition in Ealing in 2017. It is dominated by Euro 5 vehicles (≈59%), whereas the proportion of Euro 6 is approximately 19%. The proportion of Euro 4 vans is approximately 20%.

Figure 29 presents the assumed van (N1) fleet composition in Ealing in 2020. The proportion of Euro 6 vehicles is now approximately 52%, whereas Euro 5 has reduced to approximately 43%. The proportion of Euro 4 vans has reduced to approximately 5%.

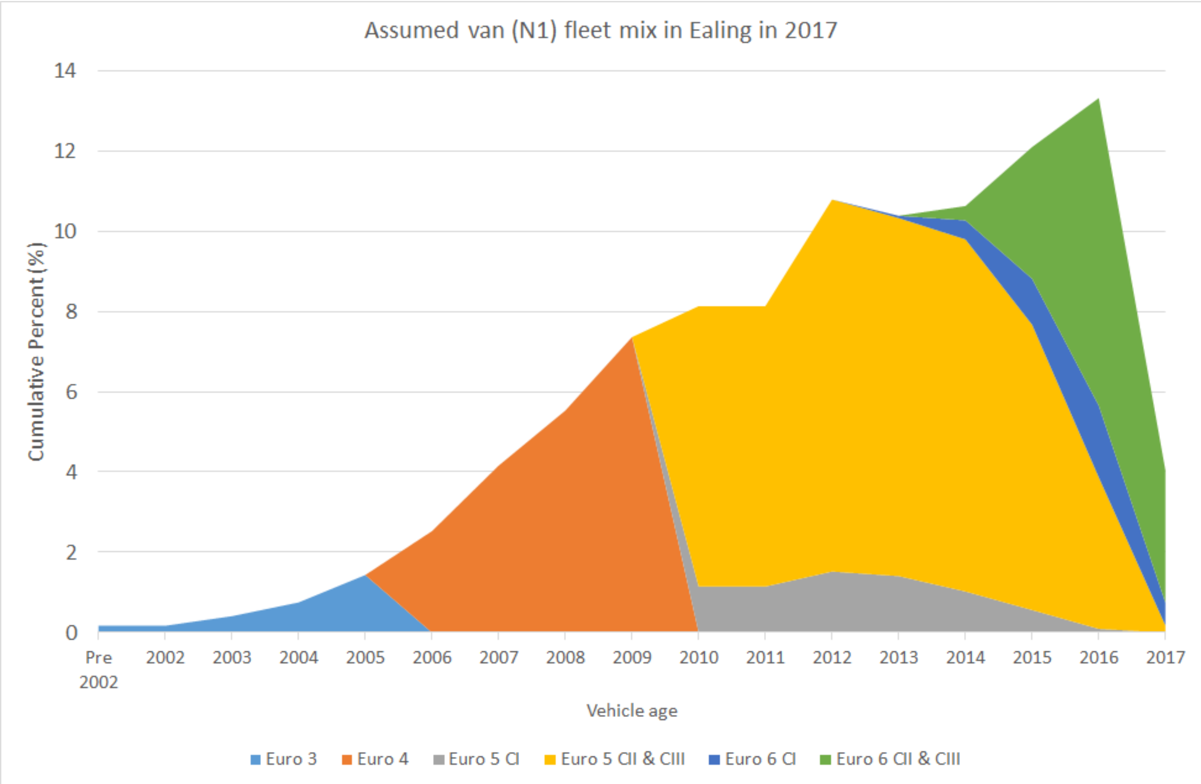

Figure 28: Assumed van (N1) fleet composition in Ealing in 2017

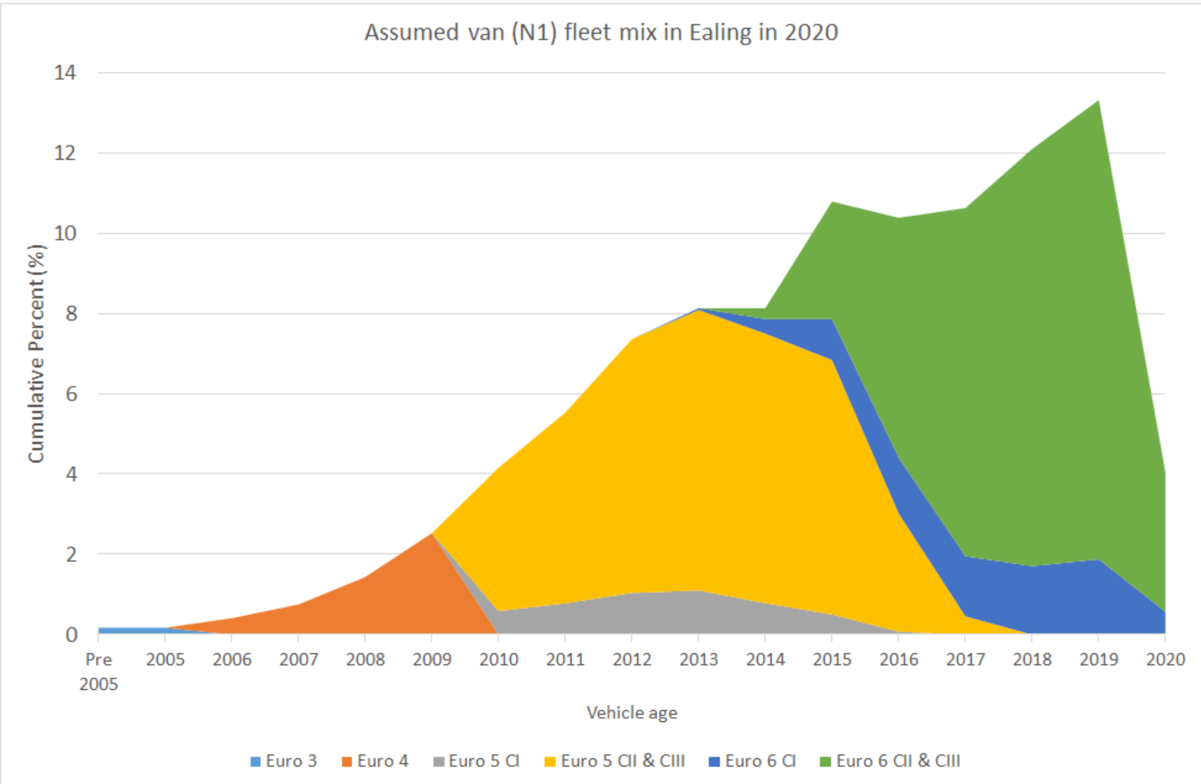

Figure 29: Assumed van (N1) fleet composition in Ealing in 2020

5.4 London Taxis (Black Cabs)

5.4.1 Age profile

London taxis (black cabs) comprised only between 0.3% and 0.4% of light passenger (M1) vehicles observed at the two remote sensing survey sites in Ealing (Greenford Road and the A40 Slip Road) in 2012. They are therefore far less significant proportions of the overall fleet, compared to other surveyed locations (such as the central London survey sites). They have been included here for completeness, and because higher concentrations of taxis can be observed at some locations in Ealing, for example at the taxi ranks at Haven Green / Ealing Broadway Station.

Figure 30 presents the observed London taxi (black cab) fleet age profiles in 2008 and 2012 respectively. It should be noted that these data are for all remote sensing survey sites in London in 2008 and 2012, because the sample size observed in Ealing alone is too small. It should also be noted that the total sample size observed in 2008 (n=689) is far smaller than the total sample observed in 2012 (n=9996). Notwithstanding the difference in sample size, there are some similarities between the two profiles. There is a common 'peak' in the profiles at 5 years old, and both profiles decline sharply when the vehicles are greater than 15 years old. As with passenger cars, for the purpose of scenario development, it is proposed to use the average of the two profiles in the future scenarios, given the uncertainty regarding future conditions.

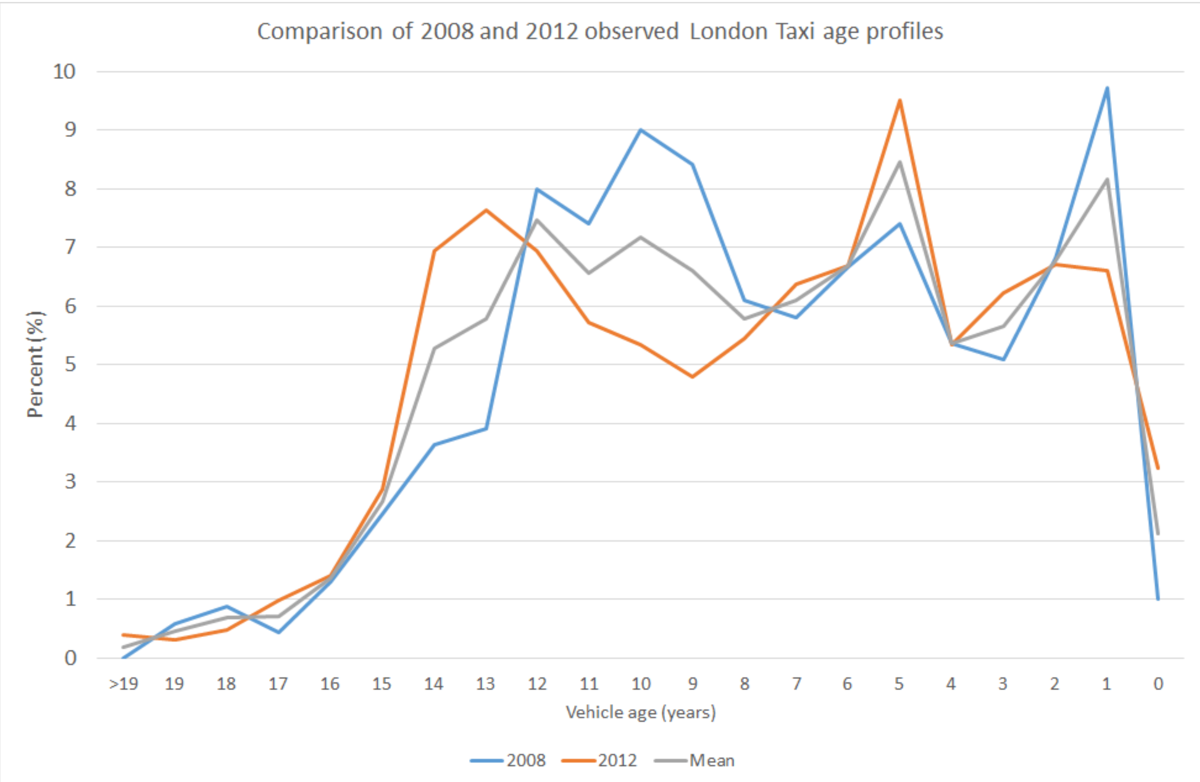

Figure 30: Comparison of 2008 and 2012 observed London Taxi (Black Cab) age profiles in London

Figure 31 presents the observed breakdown of London taxis by manufacturer and Euro standard. It should be noted that the Euro standard noted in Figure 31 is the 'as originally manufactured' standard. All London taxis are required to be Euro 3 compliant for NO_x and PM_{10}; this is usually achieved through retro-fitting of approved emissions control equipment. The abbreviations in the key are as follows:

FX E2 = LTI FX4 (Euro 2)
Metro E2 = Metrocab (Euro 2)
TX1 E2 = LTI TX1 (Euro 2)
Metro E3 = Metrocab (Euro 3)
TXII E3 = LTI TXII (Euro 3)
TX4 E4 = LTI TX4 (Euro 4)
Vito 111 E4 = Mercedes Vito 111 (Euro 4)
TX4 E5 = LTI TX4 (Euro 5)
Vito 113 E5 = Mercedes Vito 113 (Euro 5)
TXX E6 = Assumed LTI (Euro 6)
Vito XXX E6 = Assumed Mercedes Vito (Euro 6)

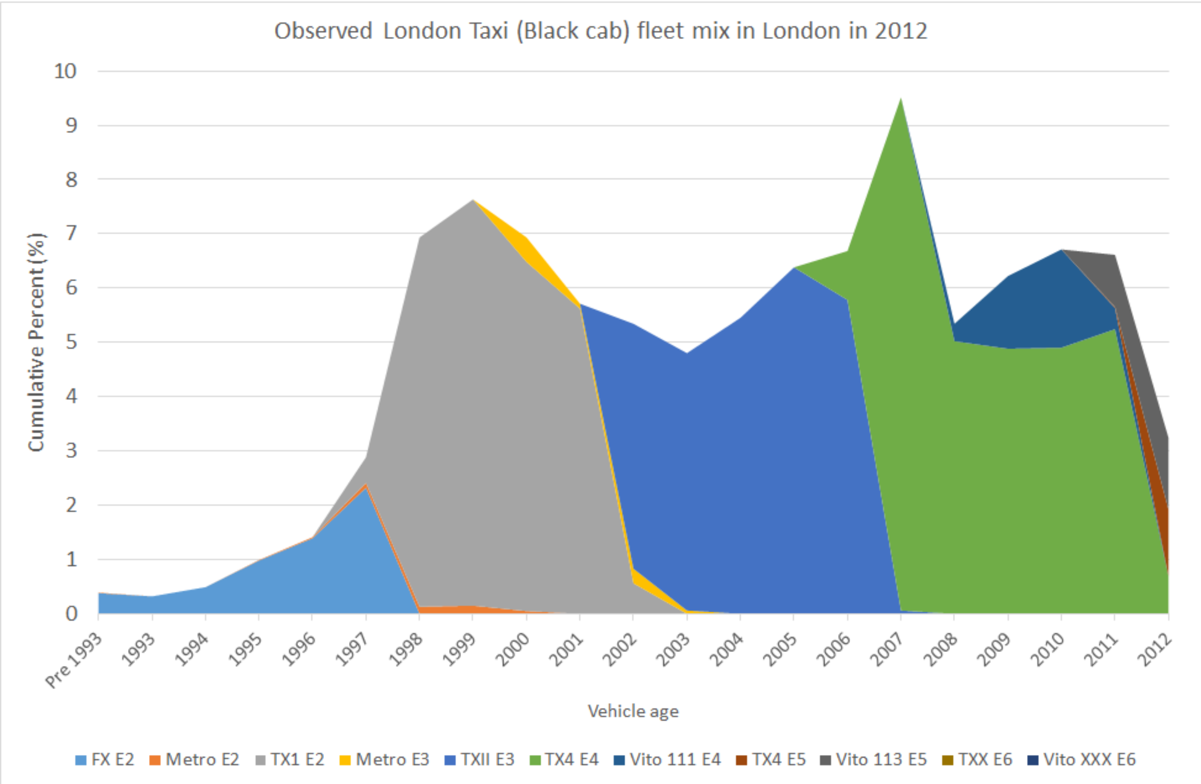

Figure 31: Observed London Taxi (Black Cab) fleet composition in London in 2012

5.4.2 Market share by Euro emissions standard

In the absence of other information, the introduction of the Euro 6 emissions standard for taxis (black cabs) is assumed to follow the same profile and timing as for diesel passenger cars. No information is available regarding the technical specifications (or indeed manufacturers) of future Euro 6 taxis. Therefore, it has been assumed for scenario development purposes that Euro 6 compliant versions of existing Euro 5 taxis (namely the LTI TX4 and Mercedes Vito 113) would be introduced into the Ealing fleet. These have been labelled the LTI TXX and Mercedes Vito XXX.

Figure 32 presents the assumed composition of the taxi fleet operating in Ealing in 2017. Figure 33 presents the assumed composition of the taxi fleet operating in Ealing in 2020. As noted above, the absolute volumes of black cabs operating on the majority of case study routes will be relatively small, with the possible exception of Haven Green.

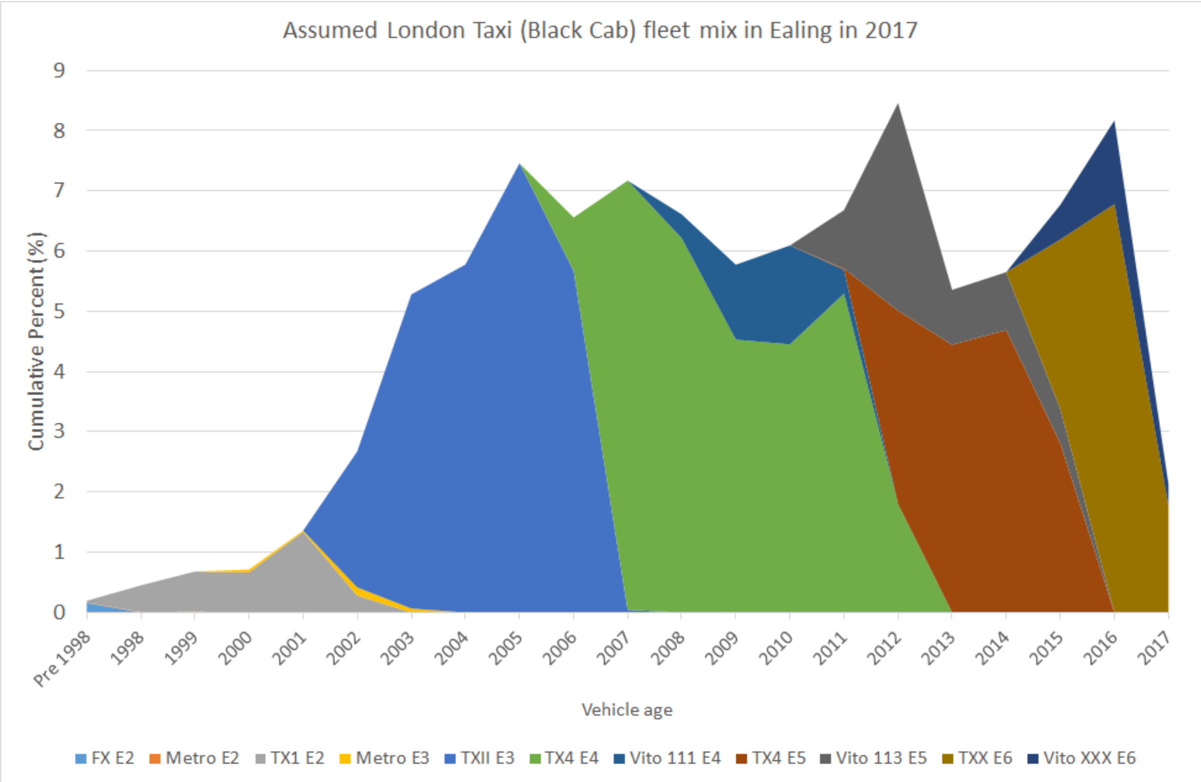

Figure 32: Assumed London Taxi (Black Cab) fleet composition in Ealing in 2017

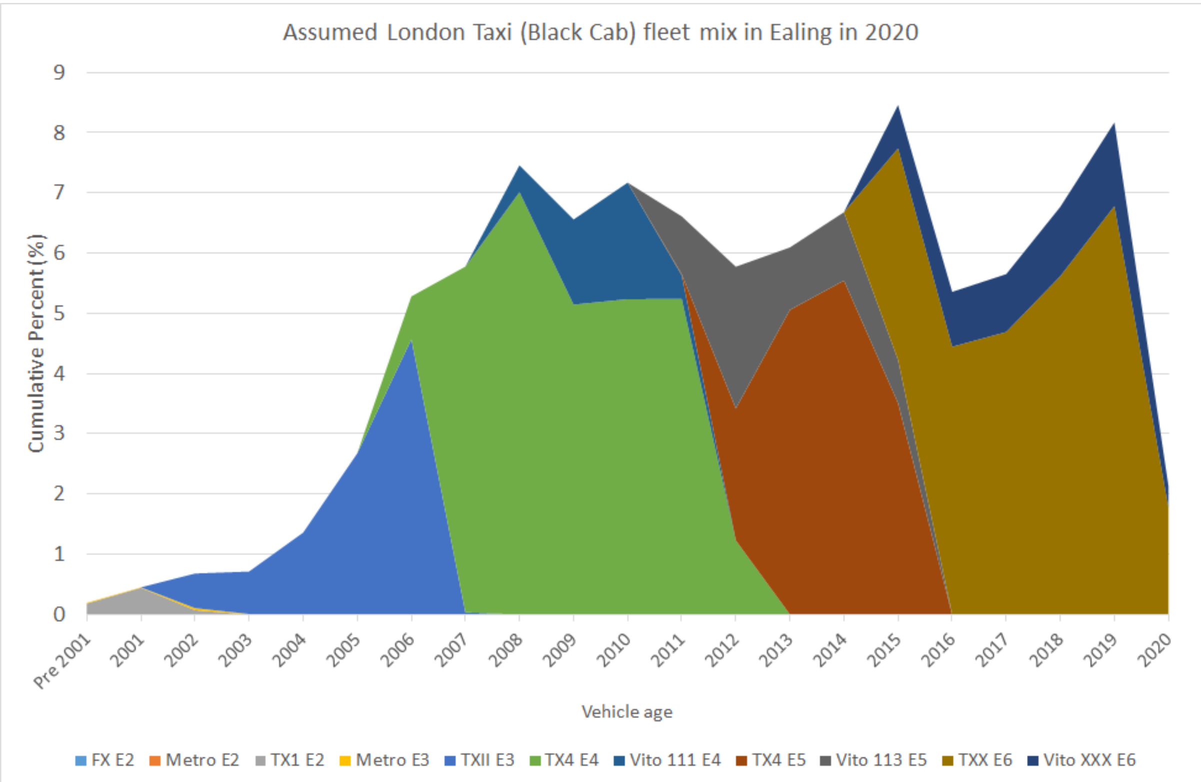

Figure 33: Assumed London Taxi (Black Cab) fleet composition in Ealing in 2020

6. Future year light vehicle scenarios

6.1 Method

As outlined in section 1, the basic approach entails integrating the emissions results from the 2012 remote sensing surveys with the probe vehicle survey results collected in the case study areas in 2013, to produce estimates of mass of NO and NO_2 (grams) for the case study areas. The results are disaggregated by light vehicle class (fuel type, Euro standard, engine capacity), probe vehicle survey 'run' by case study area and direction, and case study spatial area (generally down to 100 meter highway sections). Essentially, results are being generated for each light vehicle class in each case study location, as if each of the different vehicle classes were being driven through the case study routes in a manner (speed, acceleration, stops, delays) characterised by the data collected in the probe vehicle surveys in October 2013.

Step 1: Calculate kW values from probe vehicle data at 10Hz.

Using the probe vehicle survey data (instantaneous speed, acceleration, local gradient, at 10Hz) from each of the case study areas, kilowatt (kW) values are generated for each tenth of a second observation, for each of 28 different light vehicle classes.

Petrol cars	Diesel cars	Diesel vans	Taxis
<1.4 litre (Euro 3)	<2.0 litre (Euro 3)	N1 van (Euro 3)	LTI FX (Euro 2)
<1.4 litre (Euro 4)	<2.0 litre (Euro 4)	N1 van (Euro 4)	Metrocab (Euro 2)
<1.4 litre (Euro 5)	<2.0 litre (Euro 5)	N1 van (Euro 5)	LTI TX1 (Euro 2)
1.4-2.0 litre (Euro 3)	>2.0 litre (Euro 3)		LTI TX1 (Euro 3)
1.4-2.0 litre (Euro 4)	>2.0 litre (Euro 4)		LTI TXII (Euro 3)
1.4-2.0 litre (Euro 5)	>2.0 litre (Euro 5)		Metrocab (Euro 3)
>2.0 litre (Euro 3)			LTI TX4 (Euro 4)
>2.0 litre (Euro 4)			Mercedes Vito 111 (Euro 4)
>2.0 litre (Euro 5)			LTI TX4 (Euro 5)
			Mercedes Vito 113 (Euro 5)

The engine load power (W) equation defined in section 4.1 is utilised, with vehicle physical parameters for the 28 vehicle classes being derived from Table 11. Watts (W) are converted into kW by dividing by 1000.

Output: kW values for each tenth of a second observation in the probe vehicle survey data, for each of the 28 vehicle classes. For example, for Acton High Street (eastbound), 1.37 hours of probe vehicle survey data (actually 4937.6 seconds) or 49376 observations at 10Hz, multiplied by 28 vehicle classes, equals 1,382,528 calculated individual kW values.

Step 2: Convert kW values from Step 1 to kW/tonne values

The kW values created in Step 1 are converted into kW/tonne values by multiplying by 1000/m. For example, the kW values for Euro 5 diesel cars with engine capacity less than 2.0 litres are multiplied by 1000/1525kg = 0.656.

Output: kW/tonne values for each tenth of a second observation in the probe vehicle survey data, for each of the 28 vehicle classes.

Step 3: Allocate the kW/tonne values obtained from Step 2 to kW/tonne bins.

Allocate the kW/tonne values obtained from Step 2 to kW/tonne bins in the range -10 kW/tonne to +24 kW/tonne, in steps of 2 kW/tonne, i.e. <-10, -10 to -8, -8 to -6, -6 to -4, -4 to -2, -2 to 0, 0 to 2, 2 to 4, 4 to 6, 6 to 8, 8 to 10, 10 to 12, 12 to 14, 14 to 16, 16 to 18, 18 to 20, 20 to 22, 22 to 24, and >24. This gives a total of 19 possible bin allocations.

Output: Data set with each kW/tonne value labelled with one of 19 possible range allocations.

Step 4: Assign NO and NO_2 emission rate values (g/kg) to kW/tonne data.

Assign NO and NO_2 emission rate values (g/kg of fuel burned) to the kW/tonne data generated in Step 4. The NO emission rate values are obtained from Table 12, Table 14, and Table 16 for diesel cars and vans, taxis, and petrol cars respectively. The NO_2 emission rate values are obtained from Table 18, Table 20, and Table 22 for diesel cars and vans, taxis, and petrol cars respectively.

Output: Data set for each case study area, with each 10Hz probe vehicle observation allocated an NO and NO_2 emissions rate (g/kg), for each of the 28 vehicle classes defined.

Step 5: Calculate mean NO and NO_2 emission rates

For each case study area (by direction), calculate mean NO and NO_2 emission rates (g/kg) for each probe vehicle run, and for each geographic section, by vehicle class. This involves summing the emission rates within each run and geographic section (by vehicle class), and dividing by the number of observations. This results in 28 matrices of emission rates for NO and NO_2 respectively, for each case study area (by direction).

Output: Mean emission rates of NO and NO_2, by case study area, direction, ‘run’, and geographic section, by vehicle class. Table 30 presents an example of this output. The table presents mean NO_2 emission rates for Acton High Street (eastbound) from Euro 4 diesel cars with engine capacity <2.0 litres.

Step 6: Calculate absolute NO and NO_2 emissions in grams

Absolute emissions of NO and NO_2 in grams for each case study area (by direction), probe vehicle run, geographic section, and vehicle class are calculated as follows:

Absolute emissions (grams) = Emissions rate (g/kg of fuel burned)

× Journey time (seconds)

× Fuel consumption rate (kg per second)

× Traffic flow (for the vehicle class and time period in question)

The emissions rate of NO or NO_2 (g/kg) is taken from the output of Step 5. Journey time in seconds is taken from the journey time matrices presented in Volume 2 of this report (an example for Acton High Street (eastbound) is presented in Table 7). Fuel consumption has been derived from official fuel consumption (type approval) values for the light vehicles observed in the remote sensing surveys in 2012. As observed in section 1, fuel consumption rates are traditionally reported in terms of volume of fuel per unit distance (litres/100km), or distance per unit volume (miles per gallon). However, given that official fuel consumption values for light vehicles are calculated over a pre-defined test cycle of known distance and time, it is equally possible to present fuel consumption (for example over the legislated urban, inter-urban, or combined cycles) in units of litres per unit time. It is desirable to convert litres of fuel (volume) into kilograms of fuel (mass) because mass is independent of temperature. European regulations define fuel density for both petrol and diesel within prescribed temperature ranges for fuel consumption tests within vehicle type approval. Table 31 presents the light vehicle fuel consumption rates used in this analysis. The kg/100km values are calculated by converting litres to kilograms assuming density values of 0.743 kg/litre (petrol) and 0.832 kg/litre (diesel). The kg/second values are calculated using the known times and average speeds over the urban, extra-urban, and combined elements of the New European Driving Cycle (NEDC) respectively. The urban fuel consumption values are used for all case study areas with the exception of the A40 Western Avenue where the combined values are used (because of the higher 40mph speed limit on the A40).

Table 30: Acton High St. (eastb'd). Mean NO_2 emission rates (g/kg), Euro 4 diesel cars <2.0 litres

		Section							
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Run	**1**	3.34	3.58	3.35	3.61	3.34	3.55	3.52	3.53
	2	3.44	3.21	3.31	3.31	3.31	3.48	3.40	3.32
	3	3.39	3.27	3.31	3.36	3.29	3.40	3.45	3.62
	4	3.55	3.25	3.60	3.38	3.51	3.56	3.51	3.49
	5	3.24	3.39	3.44	3.42	3.32	3.47	3.49	3.63
	6	3.36	3.28	3.26	3.21	3.46	3.30	3.45	3.55
	7	3.35	3.34	3.39	3.44	3.45	3.38	3.29	3.68
	8	3.50	3.33	3.57	3.39	3.57	3.38	3.28	3.41
	9	3.32	3.41	3.37	3.41	3.31	3.45	3.40	4.21
	10	3.21	3.50	3.67	3.26	3.29	3.41	3.48	3.57
	11	3.59	3.48	3.48	3.46	3.46	3.57	3.49	3.39
	12	3.19	3.45	3.49	3.39	3.35	3.51	3.50	3.61
	13	3.19	3.32	3.47	3.40	3.29	3.52	3.44	3.41
	14	3.61	3.30	3.42	3.43	3.38	3.36	3.48	3.41
	15	3.35	3.43	3.27	3.32	3.32	3.48	3.44	3.47
	16	3.47	3.42	3.31	3.49	3.29	3.45	3.48	3.45
	17	3.62	3.30	3.73	3.51	3.30	3.45	3.61	3.62
	18	3.40	3.28	3.61	3.63	3.32	3.57	3.43	3.42
	19	3.34	3.27	3.44	3.42	3.27	3.59	3.57	3.49
	20	3.32	3.28	3.56	3.39	3.31	3.51	3.53	3.69
	21	3.40	3.29	3.29	3.56	3.50	3.55	3.40	3.42
	22	3.18	3.28	3.29	3.39	3.33	3.45	3.47	3.63
	23	3.75	3.52	3.26	3.41	3.30	3.46	3.54	3.46
	24	3.22	3.26	3.47	3.55	3.50	3.59	3.48	3.38
	25	3.25	3.37	3.39	3.46	3.26	3.45	3.52	3.55
	26	3.20	3.54	3.32	3.46	3.47	3.54	3.53	3.49
	27	3.66	3.51	3.48	3.22	3.29	3.49	3.56	3.81
	28	3.25	3.42	3.29	3.47	3.32	3.45	3.47	3.44
	29	3.20	3.31	3.48	3.30	3.39	3.36	3.55	3.49
	30	3.32	3.41	3.47	3.49	3.46	3.51	3.58	3.79
	Mean	3.29	3.33	3.39	3.37	3.34	3.46	3.45	3.54

Table 31: Light vehicle fuel consumption rates

		Fuel consumption litres/100km			Fuel consumption kg/100km			Fuel consumption kg/second		
		Urban	Extra-urban	Combined	Urban	Extra-urban	Combined	Urban	Extra-urban	Combined
Car Diesel										
< 2.0 l	Euro 2	8.067	5.092	6.176	6.712	4.237	5.138	0.000349	0.000736	0.000480
< 2.0 l	Euro 3	7.708	4.948	5.908	6.413	4.117	4.915	0.000334	0.000716	0.000459
< 2.0 l	Euro 4	7.690	4.960	5.955	6.398	4.127	4.955	0.000333	0.000717	0.000462
< 2.0 l	Euro 5	6.396	4.472	5.643	5.321	3.721	4.695	0.000277	0.000647	0.000438
> 2.0 l	Euro 2	11.582	7.454	8.956	9.636	6.202	7.451	0.000501	0.001078	0.000696
> 2.0 l	Euro 3	10.926	6.601	8.136	9.090	5.492	6.769	0.000473	0.000955	0.000632
> 2.0 l	Euro 4	10.588	6.363	7.999	8.809	5.294	6.655	0.000458	0.000920	0.000621
> 2.0 l	Euro 5	8.473	5.491	6.614	7.050	4.569	5.503	0.000367	0.000794	0.000514
Car Petrol										
< 1.4 l	Euro 2	8.870	5.746	6.855	6.590	4.269	5.093	0.000343	0.000742	0.000475
< 1.4 l	Euro 3	8.274	5.324	6.389	6.148	3.956	4.747	0.000320	0.000688	0.000443
< 1.4 l	Euro 4	7.990	5.135	6.128	5.937	3.815	4.553	0.000309	0.000663	0.000425
< 1.4 l	Euro 5	6.987	4.546	5.447	5.191	3.378	4.047	0.000270	0.000587	0.000378
1.4 - 2.0 l	Euro 2	11.344	6.576	8.343	8.429	4.886	6.199	0.000439	0.000849	0.000579
1.4 - 2.0 l	Euro 3	10.699	6.279	7.909	7.949	4.665	5.876	0.000414	0.000811	0.000548
1.4 - 2.0 l	Euro 4	10.170	6.100	7.562	7.556	4.532	5.619	0.000393	0.000788	0.000524
1.4 - 2.0 l	Euro 5	9.166	5.501	6.846	6.810	4.087	5.087	0.000354	0.000710	0.000475
> 2.0 l	Euro 2	15.858	8.571	11.297	11.782	6.368	8.394	0.000613	0.001107	0.000783
> 2.0 l	Euro 3	15.484	8.315	10.923	11.505	6.178	8.116	0.000599	0.001074	0.000758
> 2.0 l	Euro 4	16.244	8.519	11.307	12.069	6.330	8.401	0.000628	0.001100	0.000784
> 2.0 l	Euro 5	16.151	9.060	11.536	12.000	6.732	8.571	0.000624	0.001170	0.000800
Van Diesel										
	Euro 2	11.200	7.151	8.625	9.318	5.950	7.176	0.000485	0.001034	0.000670
	Euro 3	10.621	6.583	8.005	8.837	5.477	6.660	0.000460	0.000952	0.000622
	Euro 4	10.418	6.454	7.954	8.668	5.370	6.618	0.000451	0.000933	0.000618
	Euro 5	8.457	6.173	6.994	7.036	5.136	5.819	0.000366	0.000893	0.000543
Taxi										
LTI FX	Euro 2	10.900	8.200	9.200	9.069	6.822	7.654	0.000472	0.001186	0.000714
Metrocab	Euro 2	10.900	7.700	8.900	9.069	6.406	7.405	0.000472	0.001114	0.000691
LTI TX1	Euro 2	10.900	8.200	9.200	9.069	6.822	7.654	0.000472	0.001186	0.000714
Metrocab	Euro 3	12.500	9.800	10.800	10.400	8.154	8.986	0.000541	0.001417	0.000839
LTI TX1	Euro 3	11.200	8.100	9.200	9.318	6.739	7.654	0.000485	0.001171	0.000714
LTI TXII	Euro 3	11.200	8.100	9.200	9.318	6.739	7.654	0.000485	0.001171	0.000714
Merc Vito 111	Euro 4	11.400	7.000	8.600	9.485	5.824	7.155	0.000493	0.001012	0.000668
LTI TX4	Euro 4	11.200	7.500	8.800	9.318	6.240	7.322	0.000485	0.001085	0.000683
Merc Vito 113	Euro 5	10.100	6.900	8.100	8.403	5.741	6.739	0.000437	0.000998	0.000629
LTI TX4	Euro 5	11.000	7.000	8.400	9.152	5.824	6.989	0.000476	0.001012	0.000652

Table 32: Acton High St. (eastbound). Mean NO_2 emissions (grams), Euro 4 diesel cars <2.0 litres

		Section								
		A	B	C	D	E	F	G	H	Total
	1	10.2	6.6	13.1	6.0	14.0	6.0	5.8	0.8	62.4
	2	7.3	22.0	7.7	7.2	13.3	6.8	7.1	1.1	72.4
	3	8.6	17.0	8.1	10.5	13.2	9.9	8.1	0.6	76.0
	4	5.8	19.2	5.7	11.4	5.4	6.2	5.4	0.6	59.7
	5	19.2	10.0	6.7	9.0	12.8	7.7	5.4	0.6	71.3
	6	12.1	15.5	8.6	25.2	7.9	14.2	6.5	0.6	90.7
	7	11.0	11.2	7.4	5.9	6.7	9.7	17.9	0.9	70.8
	8	6.1	15.8	5.0	9.8	5.7	9.9	13.4	0.7	66.4
	9	11.2	6.8	8.0	8.6	10.8	6.2	7.5	0.9	59.9
	10	20.9	6.1	5.4	16.1	11.1	8.3	5.1	0.5	73.5
	11	4.9	5.1	6.0	6.1	5.2	5.2	4.7	0.6	37.8
	12	25.7	9.5	6.3	6.4	16.1	7.4	4.7	0.6	76.7
	13	29.7	9.1	8.1	5.0	16.1	8.7	7.6	1.0	85.4
	14	5.1	12.5	9.5	9.6	11.1	12.3	6.4	0.7	67.3
Run	15	11.9	7.6	15.8	13.8	11.0	6.7	6.1	0.7	73.6
	16	8.5	7.9	16.7	6.1	17.5	7.3	6.7	0.6	71.3
	17	6.1	16.1	6.4	6.0	14.5	9.9	5.8	0.6	65.3
	18	8.1	18.0	5.4	4.9	15.5	6.6	6.7	0.8	66.1
	19	8.9	15.0	6.6	9.0	15.2	5.6	5.1	0.5	65.9
	20	12.2	15.1	7.2	7.4	14.2	7.7	5.5	0.6	69.8
	21	9.8	12.9	12.3	4.9	4.9	6.9	7.2	1.0	59.9
	22	31.0	14.8	12.7	9.3	16.7	7.9	5.4	0.6	98.5
	23	4.7	5.2	14.9	9.1	12.0	7.8	5.9	0.6	60.2
	24	20.1	17.5	7.7	4.8	5.1	6.5	5.5	0.6	67.9
	25	16.2	7.9	9.7	5.8	15.8	7.6	5.3	0.5	68.8
	26	22.1	6.0	17.7	5.0	9.1	5.6	5.4	0.5	71.3
	27	4.9	5.2	7.3	29.5	14.4	6.0	5.7	0.6	73.6
	28	23.9	6.9	11.0	5.3	15.8	5.6	8.3	0.9	77.6
	29	28.1	12.9	7.7	12.9	11.6	8.2	5.2	0.6	87.2
	30	13.6	8.9	6.2	4.9	9.1	7.2	5.7	0.6	56.1
Mean		13.6	11.5	9.0	9.2	11.7	7.7	6.7	0.7	70.1
25th percentile		7.5	7.1	6.5	5.8	9.1	6.3	5.4	0.6	48.2
75th percentile		19.9	15.4	10.7	9.8	15.0	8.3	7.0	0.7	86.8

Light vehicle traffic flow is determined for the local case study area based on the traffic flow values reported in Table 1 to Table 5, taking into account the relative proportions of different vehicle classes within the total flow.

As an illustration of this calculation, we can take Acton High Street (eastbound) in 2012 as an ongoing example.

The mean NO_2 emission rate from Euro 4 diesel cars of capacity <2.0 litres in probe vehicle 'Run' 1, geographic section A, is 3.34 gNO_2/kg of diesel consumed (from Table 30). The journey time on this run and section is known to be 24.0 seconds (from Table 7). The fuel consumption rate for Euro 4 diesel cars (<2.0 litres) is 0.000333 kg/second (from Table 31). The 12 hour eastbound traffic flow on Acton High Street (cars & taxis) is 3734 (from Table 1), of which 99.61% are assumed to be cars (the remainder taxis). Finally, from Figure 23 it is known that 10.23% of passenger cars are Euro 4 diesel with capacity <2.0 litres.

Therefore, the emissions of NO_2 on Acton High Street (eastbound), 'Run' 1, geographic section 'A' from Euro 4 diesel cars (<2.0 litres) is calculated as:

NO_2 (grams) = 3.34gNO_2/kg × 24 seconds × 0.000333kg fuel/second × (3734 × 0.9961 × 0.1023)

= 10.2 grams of NO_2 (see Table 32, Run 1, Section A)

Step 7: Basic forecasting assumptions

For forecasting to 2017 and 2020, it is necessary to make an assumption regarding the efficacy of the light vehicle Euro 6 emissions standard. For the purpose of this study, the parameter of interest is the NO_x limit value, particularly for diesel cars and vans. At Euro 6, the NO_x limit value for diesel passenger cars (M1) and light vans (N1 class I) is 80 mg/km. This compares to a limit value of 180 mg/km at Euro 5, i.e. a reduction of 80/180 = 0.444. For diesel N1 class II, the limit value reduces from 235mg/km to 105mg/km, and for diesel N1 class III, the limit value reduces from 280mg/km to 125mg/km, but in both cases the reduction factor from Euro 5 to Euro 6 remains at approximately 0.45. For future year scenario development, it has therefore been assumed that the NO_x emissions from Euro 6 diesel light vehicles will be 0.444 times the NO_x emissions from the equivalent Euro 5 diesel light vehicle. The legislated type approval limit values do not differentiate between NO and NO_2 (yet), so for the purpose of this study the same factor has been applied to both species of pollutant. Note that in applying such a factor in this analysis, the Euro 6 diesel fuel consumption rate is assumed to be the same as the Euro 5 diesel fuel consumption rate; if a reduction of fuel consumption was assumed **in addition** to the application of the above factor, this would result in double counting of emission reduction benefits (in reality, the 0.444 reduction, if it happens, is likely to be obtained by a combination of both improvements in emissions control technology and improvements in fuel consumption).

The other changes assumed in forecast years relate to the traffic flow and fleet composition. In consultation with officers at the London Borough of Ealing, it was agreed that a 'standard' forecasting assumption would be a traffic growth rate of 1% per annum compound. Therefore, the traffic growth factor from 2012 to 2017 has been calculated as 1.01^5 or 1.051, and the traffic growth factor from 2012 to 2020 has been calculated as 1.01^8 or 1.083. Within the overall light vehicle traffic volume, the fleet composition (in terms of Euro standard, engine capacity, fuel types) evolves over time, consistent with the assumptions in Figure 24 (passenger cars at year 2017), Figure 25 (passenger cars at year 2020), Figure 28 (diesel vans at year 2017), Figure 29 (diesel vans at year 2020), Figure 32 (taxis at year 2017), and Figure 33 (taxis at year 2020).

It is important to note that in the basic forecasting assumptions for scenario development, the emission rates of existing classes of light vehicles (e.g. Euro 4 diesel cars with capacity <2.0 litre) are assumed to remain constant over time, i.e. a Euro 4 diesel car will have the same NO_2 emission rate in 2017 as it does in 2012.

In addition, it is assumed that the journey times observed in the probe vehicle surveys in 2013 remain fixed over time. This is a simplifying assumption, and may require refinement in any future analysis.

6.2 Aggregate light vehicle results across case study areas

Table 33 to Table 38 present the aggregate nitric oxide (NO) and nitrogen dioxide (NO_2) emissions in grams for each of the case study areas, by direction, and by light vehicle category, for a weekday 12 hour period. The abbreviations used in the tables for the case study areas are as follows:

AHEB	Acton High Street eastbound
AHWB	Acton High Street westbound
HGEB	The Mall eastbound
HGLP	Haven Green clockwise loop
HGWB	The Mall westbound
HLNB	Horn Lane northbound
HLSB	Horn Lane southbound
WAEB	A40 Western Avenue eastbound
WAWB	A40 Western Avenue westbound
WREB	Western Road, Southall eastbound
WRWB	Western Road, Southall westbound

In 2012, 75.3kg of nitric oxide is emitted by light vehicles during an average weekday 12 hour period, across all of the case study areas under consideration (Table 33). It is noteworthy that the aggregate NO emissions from diesel cars and petrol cars is almost identical (24.0kg and 24.1kg respectively). This is due to the fact that whilst the NO emissions rates (g/kg fuel burned) from diesel cars (Table 12) are generally higher than for petrol cars (Table 16), the petrol cars are more numerous (and still have relatively high NO emission rates prior to Euro 5). This highlights the fact that at 2012, for the nitric oxide component of total NO_x, older petrol cars (pre Euro 5) are a significant contributor to the NO_x air quality issue. Diesel vans (N1) at 2012 emit 26.4kg of NO i.e. 10% more than diesel cars.

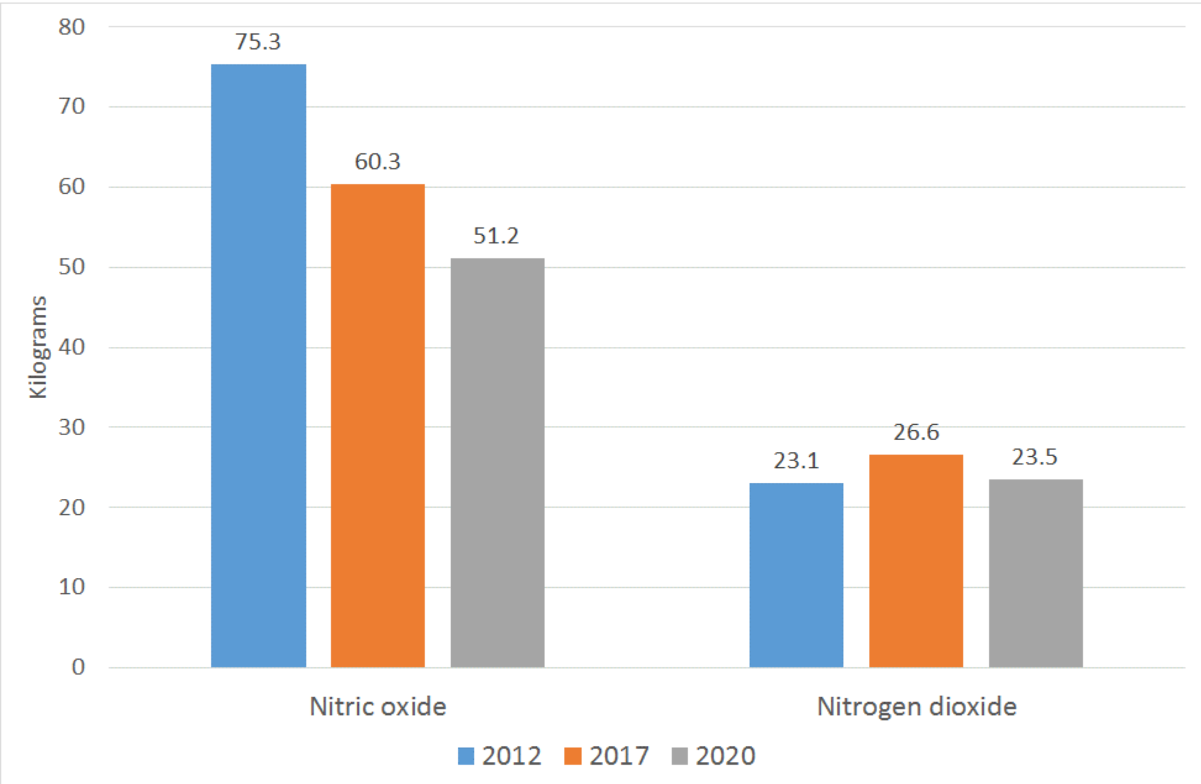

Figure 34: Aggregate emissions of light vehicle NO and NO_2 across case study areas

At 2017, total NO has reduced from 75.3kg to 60.3kg (Table 35), a reduction of almost 20%. However, aggregate emissions of NO from diesel cars have increased from 24.0kg to 28.8kg, due largely to the increased proportion of diesel cars in the total passenger car fleet (43% of cars at 2017, compared to 30% at 2012). The reason for the aggregate light vehicle reduction in NO emissions is that NO emissions from petrol cars have decreased drastically from 24.1kg to 9.8kg. This is a consequence of the evolution of the passenger car fleet over the five year period, and in particular the end of life of large numbers of older (Euro 2, 3, and 4) petrol cars (Figure 24). Emissions from diesel vans are assumed to reduce from 26.4kg to 21.1kg, a consequence of the faster fleet turnover of commercial vans compared to private cars, relatively greater penetration of Euro 6 into the fleet at 2017, and improvements in average fuel consumption between Euro 4 and Euro 5.

In 2012, emissions of primary NO_2 from light vehicles across the case study areas totalled 23.1kg (Table 34). As is to be expected, NO_2 emissions from petrol cars are relatively low (1.0kg), and the total is dominated by diesel cars (10.9kg) and diesel vans (11.1kg). In 2017, the aggregate light vehicle total of NO_2 increases to 26.6kg, an increase of 15% compared to 2012, due largely to the increase in the market share of diesel passenger cars (15.0kg of NO_2 in 2017, compared to 10.9kg in 2012, an increase of 37%).

Figure 34 illustrates the assumed evolution of the nitric oxide and nitrogen dioxide components of total NO_x from light vehicles across the case study areas from 2012 to 2020. The nitric oxide component is assumed to decline from 75.3kg in 2012, to 60.3kg in 2017 (-20% relative to 2012), and finally 51.2kg in 2020 (-32% relative to 2012).

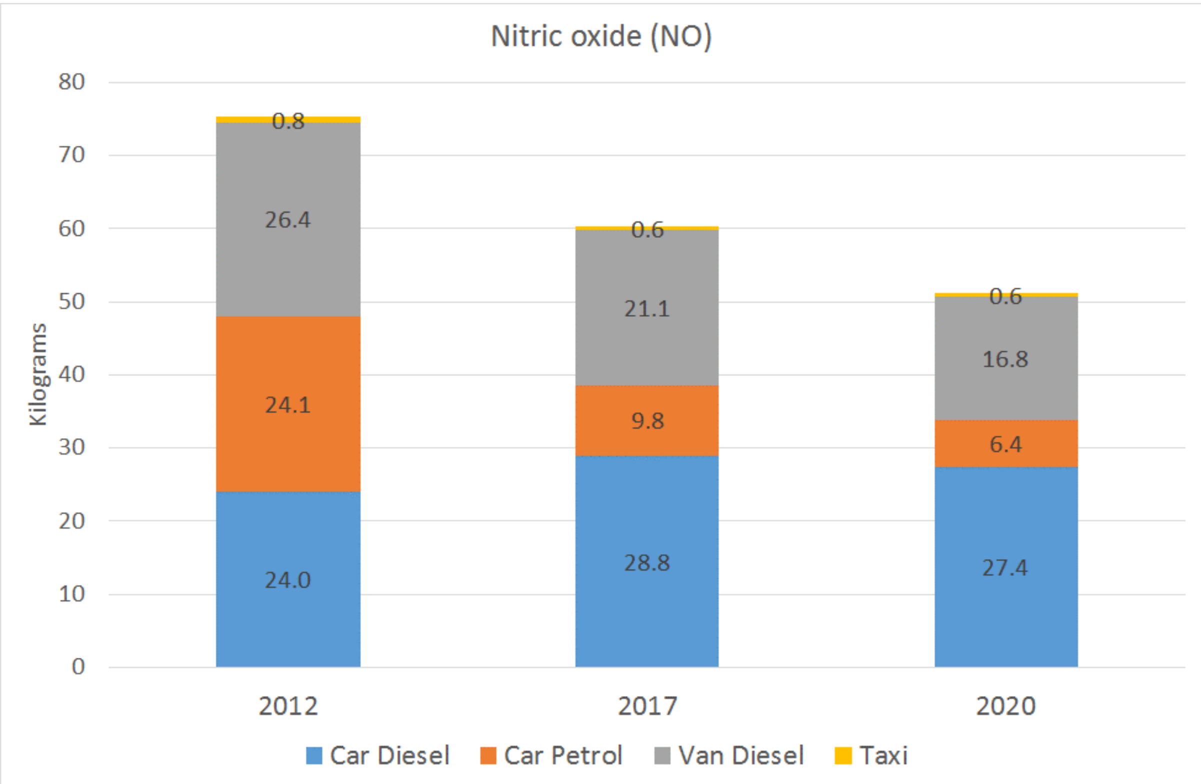

Figure 35: Nitric oxide emissions by light vehicle type

However, the nitrogen dioxide component of total NO_x is observed to increase from 23.1kg in 2012, to 26.6kg in 2017 (+15% relative to 2012), before reducing to 23.5kg in 2020 (+2% relative to 2012). NO_2 emissions from light vehicles increase to 2017, and whilst they decline in the following period to 2020, they remain marginally above 2012 absolute levels.

Figure 35 and Figure 36 illustrate the breakdown of emissions by light vehicle class at these reference years for nitric oxide (NO) and nitrogen dioxide (NO_2) respectively.

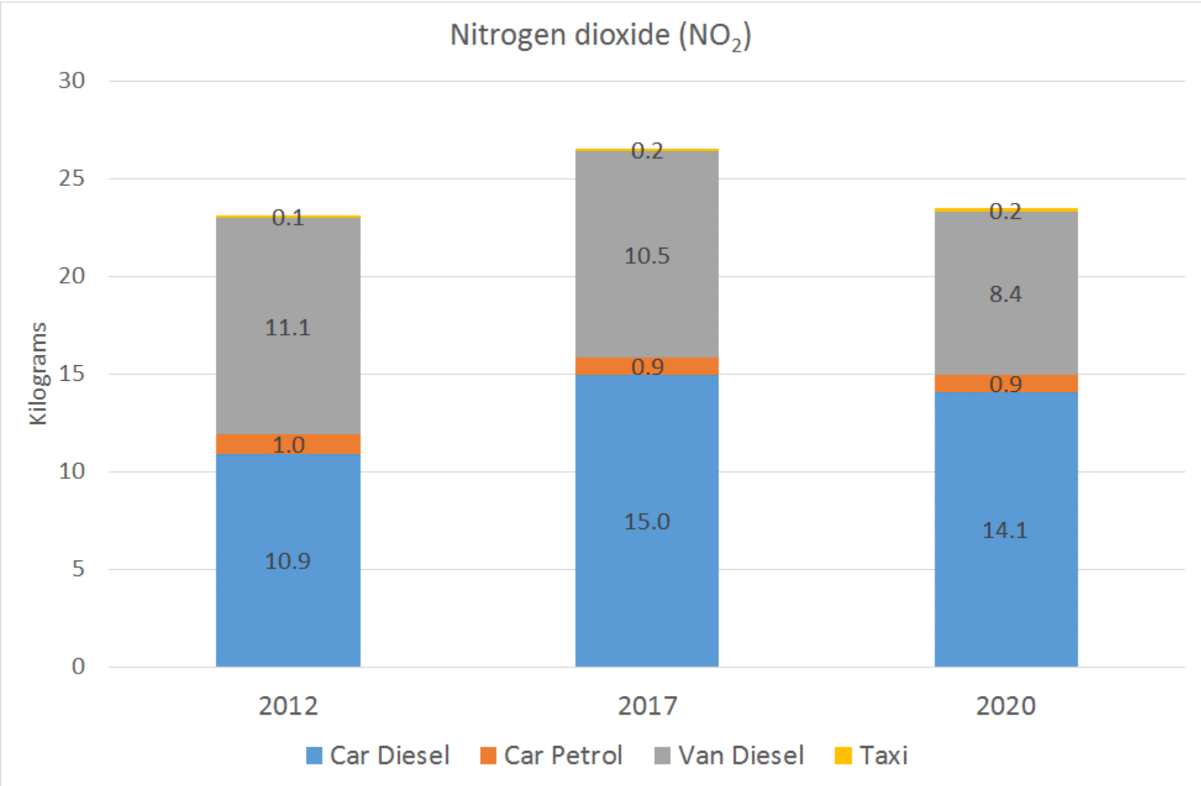

Figure 36: Nitrogen dioxide emissions by light vehicle type

Traffic growth assumptions are a potential source of uncertainty in forecasting future emissions. In the base 2017 and 2020 scenarios, a traffic growth rate of 1% per annum compound was assumed from 2012. Figure 37 presents a comparison of the NO and NO_2 emissions for each scenario reference year, with and without traffic growth. Light vehicle nitric oxide emissions at 2017 without traffic growth are approximately 4.8% lower than the base scenario at 2017. At 2020, the NO results without traffic growth are approximately 7.6% lower than the base scenario at 2020. For NO_2, the relatively differences at 2017 and 2020 and approximately 4.9% and 7.7% respectively.

Figure 38 presents the aggregate light vehicle total NO_x emissions across the case study areas by reference year. In this context, NO_x is expressed in terms of NO_2 equivalent values (by mass), where the NO component is factored by 46/30 (the mass ratio of NO_2 to NO). Note that NO_x is reported in NO_2 equivalent values for the definition of European vehicle type approval limit values (European Commission, 2008). The base 2017 scenario light vehicle total NO_x emissions are approximately 14% lower than 2012; the base 2020 scenario NO_x emissions are approximately 27% lower than 2012.

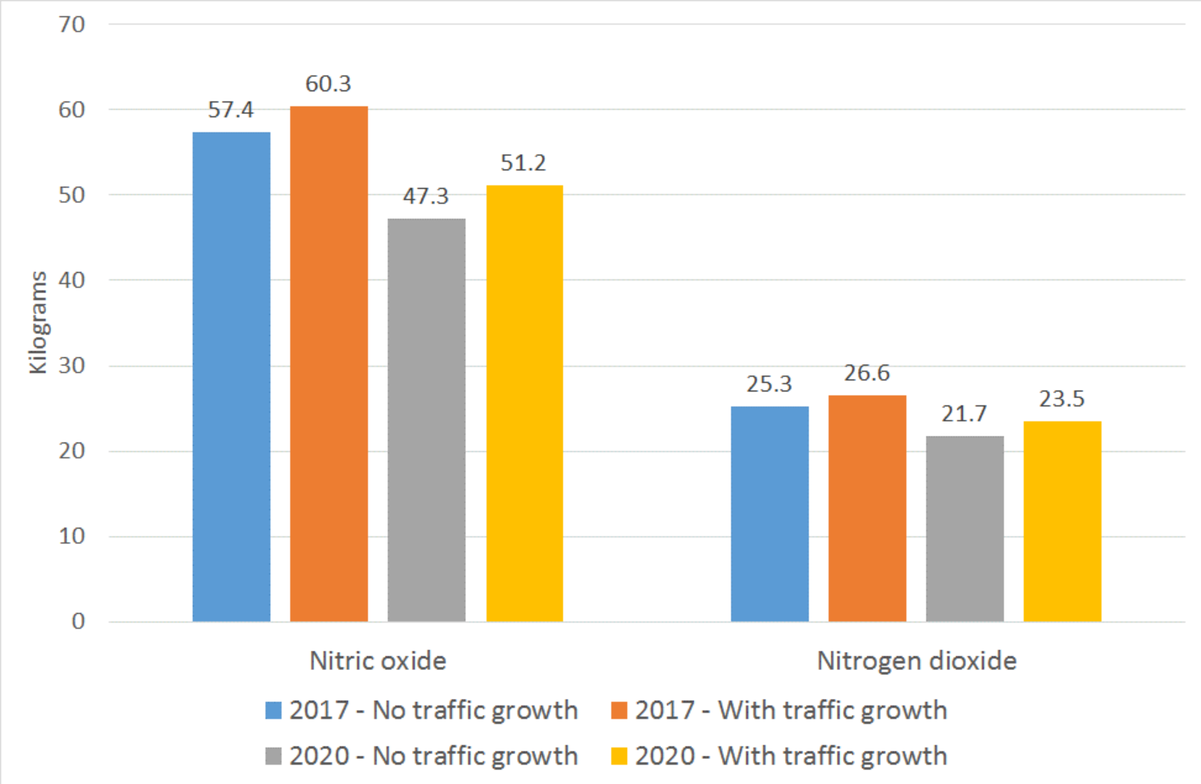

Figure 37: Sensitivity of light vehicle emissions to assumed traffic growth

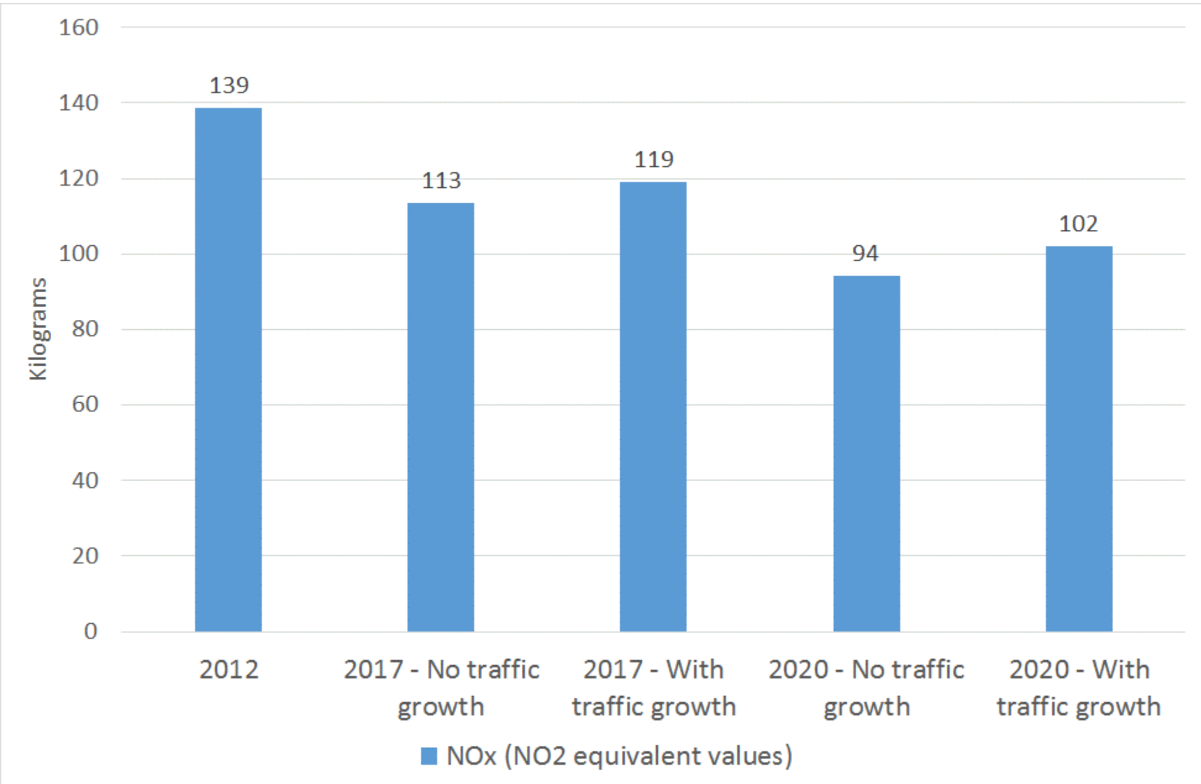

Figure 38: Light vehicle NO_x emissions (NO_2 equivalent values)

Table 33: Mean NO (grams) in 2012: Light vehicles, average weekday (12 hour period)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	1	0	2	3	1	0	**8**
	Euro 1	2	4	1	5	2	7	3	27	31	7	5	**94**
	Euro 2	25	43	12	58	18	83	33	305	346	81	56	**1060**
	Euro 3	124	214	62	294	89	419	175	1595	1898	405	283	**5557**
	Euro 4	149	261	74	361	109	517	215	1957	2315	499	344	**6802**
	Euro 5	63	107	32	150	45	212	92	953	1136	203	144	**3136**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
> 2.0 l	Euro 0	1	1	0	2	1	3	1	10	11	3	2	**33**
	Euro 1	3	5	1	7	2	9	4	35	40	9	6	**121**
	Euro 2	15	25	7	34	11	49	20	181	206	48	33	**628**
	Euro 3	65	117	32	159	49	231	91	811	969	223	151	**2899**
	Euro 4	58	100	30	141	42	201	86	767	945	191	135	**2696**
	Euro 5	20	35	10	49	15	70	29	272	334	67	47	**949**
	Euro 6	0	0	0	0	0	0	0	0	1	0	0	**2**
	Sub total												**23985**
Car Petrol													
< 1.4 l	Euro 0	7	12	3	16	5	24	9	88	99	23	16	**303**
	Euro 1	13	23	6	31	10	45	18	166	188	44	30	**575**
	Euro 2	41	68	21	97	29	136	59	554	666	129	95	**1895**
	Euro 3	33	54	16	76	23	106	45	424	502	103	74	**1457**
	Euro 4	35	61	18	86	26	124	53	485	619	117	83	**1707**
	Euro 5	5	8	3	12	3	17	8	73	86	15	12	**243**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
1.4 - 2.0 l	Euro 0	19	33	9	44	14	63	25	221	251	61	42	**781**
	Euro 1	24	42	12	56	17	81	32	285	323	79	54	**1004**
	Euro 2	131	223	65	304	93	429	182	1597	1891	419	294	**5627**
	Euro 3	80	140	39	188	58	269	107	960	1153	264	180	**3438**
	Euro 4	80	138	40	192	58	274	114	1012	1214	262	184	**3567**
	Euro 5	3	5	2	7	2	10	5	43	54	9	7	**146**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
> 2.0 l	Euro 0	10	17	5	23	7	33	13	113	128	32	22	**402**
	Euro 1	7	12	3	16	5	22	9	76	86	22	15	**271**
	Euro 2	28	53	13	69	22	102	37	321	381	100	65	**1193**
	Euro 3	24	43	12	58	18	85	33	277	323	83	56	**1012**
	Euro 4	8	13	4	18	6	27	11	89	104	26	17	**322**
	Euro 5	1	1	0	1	0	2	1	7	8	2	1	**25**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
Hybrid	Euro 4	0	0	0	0	0	1	0	2	3	1	0	**9**
	Euro 5	2	3	1	5	1	7	3	25	28	7	4	**87**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
	Sub total												**24063**
Van Diesel													
	Euro 3	195	351	91	354	139	827	235	3076	4263	650	449	**10631**
	Euro 4	168	300	80	310	120	722	212	2774	3933	560	392	**9572**
	Euro 5	103	190	49	191	75	452	128	1823	2601	353	242	**6208**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
	Sub total												**26410**
Taxi													
LTI FX	Euro 2	1	2	1	16	1	5	2	17	18	5	3	**71**
Metrocab	Euro 2	0	0	0	2	0	1	0	2	2	1	0	**9**
LTI TX1	Euro 2	6	12	3	78	5	22	8	83	89	22	14	**343**
Metrocab	Euro 3	0	0	0	1	0	0	0	2	2	0	0	**6**
LTI TXII	Euro 3	3	5	1	37	2	10	4	41	49	10	7	**168**
LTI TX4	Euro 4	3	6	2	39	2	11	4	41	48	11	7	**175**
Merc Vito 111	Euro 4	0	1	0	6	0	2	1	6	7	2	1	**26**
LTI TX4	Euro 5	0	0	0	2	0	1	0	2	3	1	0	**10**
Merc Vito 113	Euro 5	0	0	0	2	0	1	0	3	3	1	0	**10**
LTI TXX	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
Merc Vito XXX	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
	Total	1556	2732	760	3601	1124	5709	2109	21603	27358	5148	3575	**75276**

Table 34: Mean NO_2 (grams) in 2012: Light vehicles, average weekday (12 hour period)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	1	1	0	0	**2**
	Euro 1	1	1	0	1	0	2	1	8	9	2	1	**27**
	Euro 2	3	6	2	8	2	11	4	41	46	11	7	**141**
	Euro 3	36	61	18	84	26	120	51	456	498	116	81	**1547**
	Euro 4	70	119	35	167	50	236	100	919	1066	226	160	**3148**
	Euro 5	29	49	14	68	20	96	40	421	480	93	65	**1374**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
> 2.0 l	Euro 0	0	0	0	1	0	1	0	3	3	1	1	**11**
	Euro 1	1	1	0	2	1	3	1	9	11	3	2	**33**
	Euro 2	2	4	1	5	2	8	3	28	32	7	5	**97**
	Euro 3	29	49	14	67	20	94	39	350	407	92	64	**1226**
	Euro 4	61	107	29	143	44	206	81	736	839	203	137	**2586**
	Euro 5	16	28	8	39	12	55	23	209	232	54	37	**712**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**1**
	Sub total												**10904**
Car Petrol													
< 1.4 l	Euro 0	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 1	0	0	0	1	0	1	0	3	4	1	1	**11**
	Euro 2	1	1	0	2	1	3	1	13	15	3	2	**42**
	Euro 3	1	3	1	3	1	5	2	15	18	5	3	**57**
	Euro 4	3	5	1	7	2	11	4	34	39	10	7	**122**
	Euro 5	1	2	1	3	1	4	2	14	16	4	3	**50**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
1.4 - 2.0 l	Euro 0	0	0	0	0	0	1	0	2	2	1	0	**7**
	Euro 1	0	1	0	1	0	1	0	4	4	1	1	**13**
	Euro 2	3	4	1	6	2	8	3	30	34	8	6	**104**
	Euro 3	3	6	1	7	2	11	4	37	39	11	7	**130**
	Euro 4	6	12	3	15	5	23	7	67	76	23	14	**249**
	Euro 5	1	2	0	2	1	3	1	9	11	3	2	**35**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 1	0	0	0	0	0	1	0	2	2	1	0	**7**
	Euro 2	0	1	0	1	0	2	1	7	8	1	1	**23**
	Euro 3	1	2	0	3	1	4	1	9	10	4	2	**38**
	Euro 4	2	5	1	5	2	9	2	16	16	10	5	**73**
	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
Hybrid	Euro 4	0	0	0	0	0	0	0	1	1	0	0	**2**
	Euro 5	1	1	0	1	0	2	1	8	9	2	1	**26**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
	Sub total												**995**
Van Diesel													
	Euro 3	45	81	20	81	32	191	53	685	897	151	102	**2339**
	Euro 4	106	194	48	192	77	455	127	1655	2234	360	242	**5689**
	Euro 5	53	96	24	96	38	227	64	912	1236	178	122	**3046**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
	Sub total												**11073**
Taxi													
LTI FX	Euro 2	0	0	0	1	0	0	0	1	1	0	0	**5**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**1**
LTI TX1	Euro 2	1	1	0	8	1	2	1	9	9	2	1	**35**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**1**
LTI TXII	Euro 3	1	1	0	8	1	2	1	9	10	2	2	**37**
LTI TX4	Euro 4	1	1	0	9	1	2	1	9	9	3	2	**37**
Merc Vito 111	Euro 4	0	0	0	2	0	1	0	2	2	1	0	**9**
LTI TX4	Euro 5	0	0	0	1	0	0	0	1	1	0	0	**4**
Merc Vito 113	Euro 5	0	0	0	2	0	1	0	2	3	1	0	**10**
LTI TXX	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
Merc Vito XXX	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
	Total	478	848	226	1044	346	1799	622	6736	8332	1594	1086	**23110**

Table 35: Mean NO (grams) in 2017: Light vehicles, average weekday (12 hour period)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	1	1	0	0	**4**
	Euro 1	0	1	0	1	0	1	0	4	4	1	1	**13**
	Euro 2	3	6	2	8	3	12	5	43	49	11	8	**149**
	Euro 3	47	81	23	112	34	159	66	605	720	154	107	**2109**
	Euro 4	161	282	80	389	118	558	232	2112	2498	538	371	**7340**
	Euro 5	202	344	102	483	145	683	295	3069	3657	654	464	**10097**
	Euro 6	39	66	20	93	28	132	57	593	707	127	90	**1953**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	1	1	0	0	**5**
	Euro 1	0	1	0	1	0	1	0	4	4	1	1	**13**
	Euro 2	2	3	1	4	1	6	3	24	27	6	4	**82**
	Euro 3	23	41	11	55	17	80	32	281	336	77	52	**1004**
	Euro 4	69	118	35	166	50	236	101	903	1114	225	160	**3177**
	Euro 5	54	93	27	130	39	185	78	721	883	178	124	**2511**
	Euro 6	8	14	4	20	6	29	12	111	136	27	19	**387**
	Sub total												**28843**
Car Petrol													
< 1.4 l	Euro 0	1	2	1	2	1	4	1	13	15	3	2	**45**
	Euro 1	2	3	1	4	1	6	2	21	24	6	4	**73**
	Euro 2	6	9	3	13	4	19	8	76	92	18	13	**261**
	Euro 3	10	17	5	23	7	33	14	131	155	32	23	**449**
	Euro 4	30	53	16	74	22	106	45	416	531	100	71	**1466**
	Euro 5	17	25	9	39	11	53	26	235	277	49	38	**780**
	Euro 6	8	12	4	19	5	26	13	115	135	24	19	**381**
1.4 - 2.0 l	Euro 0	2	4	1	5	2	8	3	27	31	8	5	**96**
	Euro 1	3	5	1	7	2	10	4	37	42	10	7	**129**
	Euro 2	17	29	9	40	12	57	24	211	249	55	39	**742**
	Euro 3	24	42	12	56	17	80	32	287	344	79	54	**1027**
	Euro 4	60	104	30	145	44	208	86	766	920	199	140	**2702**
	Euro 5	9	14	5	22	6	29	15	129	164	27	21	**440**
	Euro 6	3	5	2	7	2	10	5	45	57	9	7	**152**
> 2.0 l	Euro 0	1	1	0	2	1	3	1	10	11	3	2	**34**
	Euro 1	1	1	0	2	1	3	1	10	11	3	2	**34**
	Euro 2	4	8	2	10	3	15	6	47	56	15	10	**176**
	Euro 3	5	10	3	13	4	19	7	62	72	18	12	**225**
	Euro 4	6	11	3	16	5	23	9	76	88	22	15	**274**
	Euro 5	2	3	1	4	1	5	2	19	21	5	4	**67**
	Euro 6	1	1	0	2	1	2	1	8	10	2	2	**30**
Hybrid	Euro 4	0	0	0	1	0	1	0	3	3	1	1	**11**
	Euro 5	3	6	2	8	2	11	4	40	46	11	7	**140**
	Euro 6	1	1	0	2	1	3	1	11	12	3	2	**37**
	Sub total												**9771**
Van Diesel													
	Euro 3	20	36	9	37	14	86	24	319	442	67	47	**1103**
	Euro 4	83	149	40	153	60	358	105	1373	1947	277	194	**4737**
	Euro 5	223	409	105	412	162	975	276	3928	5603	761	521	**13375**
	Euro 6	31	57	15	58	23	137	39	552	787	107	73	**1879**
	Sub total												**21095**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	1	0	0	**2**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**1**
LTI TX1	Euro 2	1	2	0	10	1	3	1	11	12	3	2	**45**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	1	0	0	**2**
LTI TXII	Euro 3	3	5	2	38	2	10	4	42	50	10	7	**174**
LTI TX4	Euro 4	3	6	2	40	2	11	4	42	49	11	7	**179**
Merc Vito 111	Euro 4	0	1	0	6	0	2	1	6	7	2	1	**26**
LTI TX4	Euro 5	2	4	1	29	2	8	3	29	33	8	5	**123**
Merc Vito 113	Euro 5	1	1	0	7	0	2	1	8	9	2	1	**33**
LTI TXX	Euro 6	1	1	0	9	1	3	1	10	11	3	2	**41**
Merc Vito XXX	Euro 6	0	0	0	1	0	0	0	1	1	0	0	**5**
	Total	1194	2091	590	2782	863	4410	1653	17587	22458	3952	2760	**60340**

Table 36: Mean NO_2 (grams) in 2017: Light vehicles, average weekday (12 hour period)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	1	1	0	0	**4**
	Euro 2	0	1	0	1	0	2	1	6	6	2	1	**20**
	Euro 3	14	23	7	32	10	45	19	173	189	44	31	**587**
	Euro 4	76	128	38	180	54	254	108	992	1150	244	173	**3397**
	Euro 5	92	157	45	218	66	308	130	1355	1545	298	209	**4423**
	Euro 6	18	30	9	42	13	60	25	262	299	58	40	**855**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	1	1	0	0	**4**
	Euro 2	0	1	0	1	0	1	0	4	4	1	1	**13**
	Euro 3	10	17	5	23	7	33	14	121	141	32	22	**425**
	Euro 4	71	126	34	168	52	243	96	867	989	239	161	**3047**
	Euro 5	44	75	21	102	31	146	60	552	613	143	98	**1885**
	Euro 6	7	12	3	16	5	22	9	85	94	22	15	**290**
	Sub total												**14951**
Car Petrol													
< 1.4 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 2	0	0	0	0	0	0	0	2	2	0	0	**6**
	Euro 3	0	1	0	1	0	1	0	5	6	2	1	**17**
	Euro 4	2	5	1	6	2	9	3	29	33	9	6	**105**
	Euro 5	4	7	2	9	3	14	5	45	50	14	9	**162**
	Euro 6	2	4	1	5	1	7	2	22	24	7	4	**79**
1.4 - 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	0	1	0	0	**2**
	Euro 2	0	1	0	1	0	1	0	4	4	1	1	**14**
	Euro 3	1	2	0	2	1	3	1	11	12	3	2	**39**
	Euro 4	5	9	2	11	4	17	6	51	57	17	10	**189**
	Euro 5	2	5	1	6	2	9	3	28	34	9	6	**105**
	Euro 6	1	2	0	2	1	3	1	10	12	3	2	**36**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 2	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 3	0	1	0	1	0	1	0	2	2	1	1	**8**
	Euro 4	2	4	1	4	2	8	2	14	14	8	4	**62**
	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
Hybrid	Euro 4	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 5	1	2	0	2	1	3	1	12	14	3	2	**43**
	Euro 6	0	0	0	1	0	1	0	3	4	1	1	**11**
	Sub total												**887**
Van Diesel													
	Euro 3	5	8	2	8	3	20	5	71	93	16	11	**243**
	Euro 4	52	96	24	95	38	225	63	819	1106	178	120	**2816**
	Euro 5	114	206	53	208	82	488	138	1964	2662	384	263	**6562**
	Euro 6	16	29	7	29	12	69	19	276	374	54	37	**922**
	Sub total												**10543**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TX1	Euro 2	0	0	0	1	0	0	0	1	1	0	0	**5**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TXII	Euro 3	1	1	0	9	1	2	1	9	10	2	2	**38**
LTI TX4	Euro 4	1	1	0	9	1	3	1	9	9	3	2	**38**
Merc Vito 111	Euro 4	0	0	0	2	0	1	0	2	2	1	0	**9**
LTI TX4	Euro 5	1	1	0	10	1	3	1	11	12	3	2	**45**
Merc Vito 113	Euro 5	1	1	0	7	0	2	1	7	8	2	1	**31**
LTI TXX	Euro 6	0	0	0	3	0	1	0	3	4	1	1	**15**
Merc Vito XXX	Euro 6	0	0	0	1	0	0	0	1	1	0	0	**5**
	Total	543	958	259	1219	394	2008	720	7834	9590	1806	1237	**26567**

Table 37: Mean NO (grams) in 2020: Light vehicles, average weekday (12 hour period)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	1	2	0	2	1	3	1	12	14	3	2	**43**
	Euro 3	17	29	8	40	12	56	24	214	255	54	38	**747**
	Euro 4	100	175	50	242	73	347	144	1313	1553	335	230	**4562**
	Euro 5	224	381	113	535	160	756	327	3400	4052	725	514	**11187**
	Euro 6	100	169	50	238	71	336	145	1512	1801	322	228	**4973**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	1	0	1	0	1	1	5	6	1	1	**18**
	Euro 3	8	14	4	19	6	28	11	99	119	27	19	**355**
	Euro 4	41	70	21	98	29	140	60	533	658	133	94	**1876**
	Euro 5	59	102	30	142	43	202	85	787	965	194	136	**2744**
	Euro 6	19	33	10	46	14	66	28	255	313	63	44	**890**
	Sub total												**27394**
Car Petrol													
< 1.4 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	2	3	1	4	1	5	2	21	25	5	4	**70**
	Euro 3	3	6	2	8	2	11	5	45	54	11	8	**156**
	Euro 4	18	31	9	44	13	62	27	244	311	59	42	**859**
	Euro 5	18	28	10	44	12	59	29	262	309	55	42	**868**
	Euro 6	21	32	11	49	14	67	32	295	347	62	48	**977**
1.4 - 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	5	8	2	11	3	15	6	56	66	15	10	**196**
	Euro 3	8	15	4	20	6	28	11	100	120	27	19	**358**
	Euro 4	32	55	16	77	23	110	45	404	485	105	74	**1426**
	Euro 5	10	15	5	24	7	32	16	141	179	29	23	**480**
	Euro 6	7	11	4	16	5	22	11	99	125	20	16	**337**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	1	2	0	2	1	4	1	11	13	3	2	**42**
	Euro 3	2	3	1	5	1	7	3	22	25	6	4	**79**
	Euro 4	3	6	2	8	2	12	5	39	45	11	8	**141**
	Euro 5	2	3	1	4	1	6	2	21	23	6	4	**74**
	Euro 6	2	3	1	4	1	6	2	21	23	6	4	**74**
Hybrid	Euro 4	0	0	0	0	0	1	0	2	2	1	0	**7**
	Euro 5	3	5	1	7	2	9	4	35	40	9	6	**121**
	Euro 6	3	4	1	6	2	9	3	32	36	8	6	**111**
	Sub total												**6375**
Van Diesel													
	Euro 3	2	4	1	4	2	10	3	38	53	8	6	**131**
	Euro 4	22	40	11	41	16	96	28	370	525	75	52	**1277**
	Euro 5	167	307	79	310	122	733	207	2952	4211	572	391	**10051**
	Euro 6	89	164	42	165	65	391	111	1576	2248	305	209	**5367**
	Sub total												**16826**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TX1	Euro 2	0	0	0	2	0	1	0	2	2	1	0	**9**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TXII	Euro 3	1	2	1	15	1	4	2	16	20	4	3	**67**
LTI TX4	Euro 4	3	6	2	42	2	12	5	43	51	11	8	**184**
Merc Vito 111	Euro 4	1	1	0	7	0	2	1	7	8	2	1	**31**
LTI TX4	Euro 5	3	5	1	32	2	9	3	32	36	9	6	**136**
Merc Vito 113	Euro 5	1	1	0	7	0	2	1	7	9	2	1	**31**
LTI TXX	Euro 6	2	3	1	23	1	6	3	23	26	6	4	**99**
Merc Vito XXX	Euro 6	0	0	0	3	0	1	0	3	3	1	0	**12**
	Total	999	1739	496	2344	720	3667	1394	15050	19158	3291	2309	**51167**

Table 38: Mean NO_2 (grams) in 2020: Light vehicles, average weekday (12 hour period)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	2	2	0	0	**6**
	Euro 3	5	8	2	11	3	16	7	61	67	16	11	**208**
	Euro 4	47	80	23	112	34	158	67	617	715	152	107	**2111**
	Euro 5	102	174	50	241	73	342	144	1501	1711	330	231	**4900**
	Euro 6	45	77	22	107	32	152	64	667	761	147	103	**2178**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 3	4	6	2	8	2	12	5	43	50	11	8	**150**
	Euro 4	42	75	20	99	31	143	57	512	584	141	95	**1799**
	Euro 5	48	82	23	112	34	160	65	604	669	156	107	**2059**
	Euro 6	15	27	7	36	11	52	21	196	217	51	35	**668**
	Sub total												**14083**
Car Petrol													
< 1.4 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	0	1	0	0	**2**
	Euro 3	0	0	0	0	0	1	0	2	2	1	0	**6**
	Euro 4	1	3	1	4	1	5	2	17	20	5	3	**62**
	Euro 5	4	8	2	10	3	16	5	50	56	16	10	**180**
	Euro 6	5	9	2	12	4	18	6	56	63	18	11	**202**
1.4 - 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	1	1	0	0	**4**
	Euro 3	0	1	0	1	0	1	0	4	4	1	1	**13**
	Euro 4	2	5	1	6	2	9	3	27	30	9	5	**100**
	Euro 5	2	5	1	7	2	10	3	30	37	10	6	**115**
	Euro 6	2	4	1	5	1	7	2	21	26	7	4	**80**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 3	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 4	1	2	0	2	1	4	1	7	7	4	2	**32**
	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
Hybrid	Euro 4	0	0	0	0	0	0	0	1	1	0	0	**2**
	Euro 5	1	1	0	2	1	3	1	11	12	3	2	**37**
	Euro 6	1	1	0	2	1	3	1	10	11	3	2	**34**
	Sub total												**872**
Van Diesel													
	Euro 3	1	1	0	1	0	2	1	8	11	2	1	**29**
	Euro 4	14	26	6	26	10	61	17	221	298	48	32	**759**
	Euro 5	86	155	40	156	62	367	104	1476	2001	288	197	**4931**
	Euro 6	46	83	21	83	33	196	55	788	1068	154	105	**2633**
	Sub total												**8353**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TX1	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**1**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TXII	Euro 3	0	0	0	3	0	1	0	4	4	1	1	**15**
LTI TX4	Euro 4	1	1	0	9	1	3	1	9	10	3	2	**39**
Merc Vito 111	Euro 4	0	0	0	3	0	1	0	3	3	1	0	**11**
LTI TX4	Euro 5	1	2	0	12	1	3	1	12	13	3	2	**50**
Merc Vito 113	Euro 5	1	1	0	7	0	2	1	7	8	2	1	**29**
LTI TXX	Euro 6	1	1	0	8	0	2	1	8	10	2	2	**36**
Merc Vito XXX	Euro 6	0	0	0	3	0	1	0	3	3	1	0	**11**
	Total	478	840	229	1089	346	1750	638	6978	8477	1585	1088	**23499**

6.3 Scenario 1 – Scrapping older diesel vehicles

Scenario 1 investigates the likely impact of a 'scrappage' scheme for older diesel vehicles on NO and NO_2 emissions across the case study areas. Specifically, the scheme is targeted at diesel passenger cars and vans which are Euro 5 emissions standard and older. The rationale for this 'cut-off' can be seen in Table 12 and Table 18. From Table 12 it can be seen that Euro 5 emission rates of NO (g/kg of fuel burned) from diesel cars and vans are actually higher than Euro 4 (albeit lower than Euro 3). From Table 18 it can be seen that Euro 5 emission rates of NO_2 (g/kg of fuel burned) from diesel cars with engine capacity less than 2 litres are higher than Euro 4 compliant vehicles; for cars with engine capacity greater than 2 litres, and for diesel vans (N1), Euro 5 NO_2 emission rates are lower than Euro 4 compliant vehicles, but not by a wide margin (and in any event, the rates are higher than the smaller engine cars). For the purposes of reducing overall emissions of NO_x within the case study areas, it therefore appeared appropriate to include all diesel cars and vans at Euro 5 and earlier, the key assumption being that the Euro 6 emissions standard will be effective in reducing NO_x emissions to the extent assumed in Section 6.1, i.e. 0.444 times the observed Euro 5 emissions rates, as observed in Ealing in 2012.

Two scrappage options have been considered. The first option assumes that there will be a 10% take-up of the scheme (uniformly distributed across all the eligible diesel cars and vans), i.e. 10% of the eligible Euro 5 vehicles, 10% of Euro 4, 10% of Euro 3 etc. It is assumed that these vehicles are replaced by Euro 6 vehicles. For passenger cars, the replacement vehicles are a mixture of diesel and petrol vehicles (including hybrids), allocated pro rata depending on the assumed distribution of Euro 6 passenger cars in the 2017 base scenario. For diesel vans (N1), the replacements are all assumed to be Euro 6 compliant diesel vehicles. It is therefore assumed that total traffic volume within the case study areas will remain the same as the base scenario at 2017.

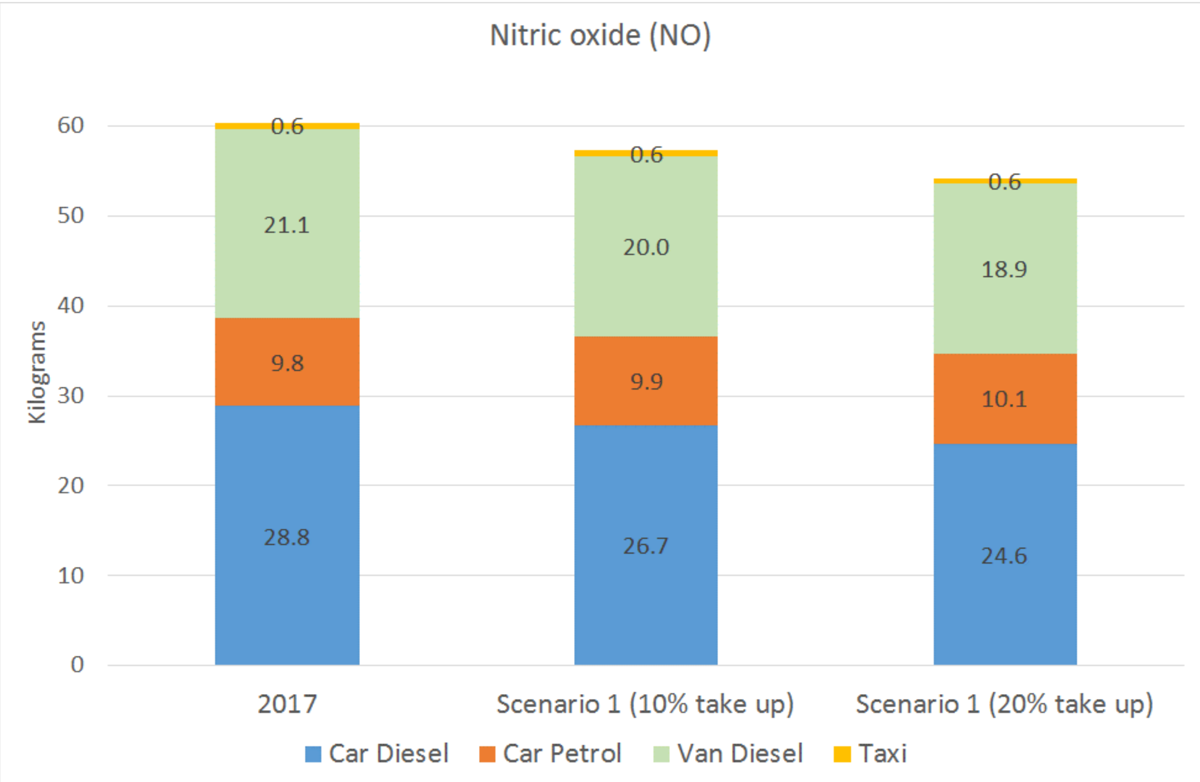

Figure 39: Diesel car and van scrappage scheme – Nitric oxide emissions

The second 'scrappage' option is the same as the first option in principle, but with a 20% take-up instead of a 10% take-up.

Table 39 and Table 40 present the scenario results with 10% take-up, for NO and NO_2 respectively. Table 41 and Table 42 present the scenario results with 20% take-up, for NO and NO_2 respectively. It can be seen that with 10% take-up, the overall light vehicle nitric oxide emissions reduce from 60.3kg to 57.3kg, i.e. a reduction of approximately 5%, relative to the base 2017 scenario. Nitrogen dioxide emissions reduce from 26.6kg to 24.9kg, a reduction of approximately 6.4%.

With a 20% take-up of the scrappage scheme, the overall light vehicle nitric oxide emissions reduce from 60.3kg to 54.2kg, i.e. a reduction of approximately 10%, relative to the base 2017 scenario. Nitrogen dioxide emissions reduce from 26.6kg to 23.3kg, a reduction of approximately 12.4%.

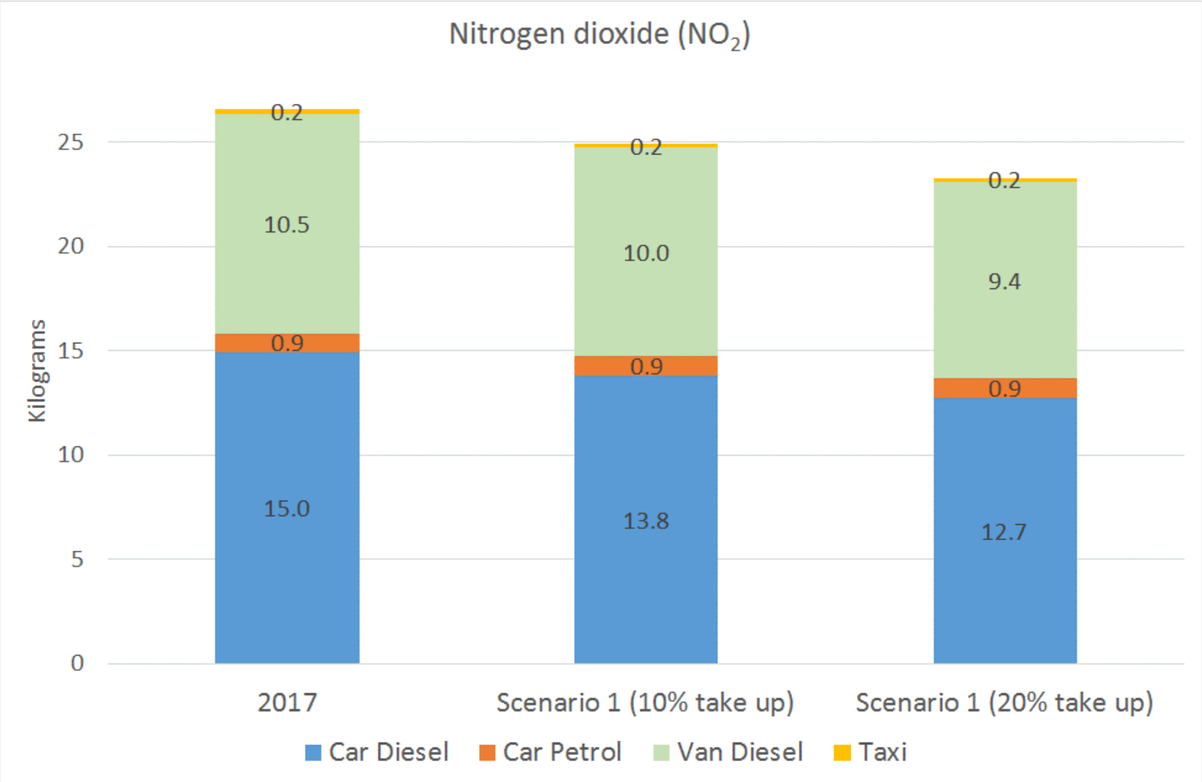

Figure 40: Diesel car and van scrappage scheme – Nitrogen dioxide emissions

In terms of overall NO_x emissions (NO_2 equivalent values), the scrappage scheme reduces total NOx from light vehicles by approximately 5.3% assuming 10% take-up, and 10.6% assuming 20% take-up.

Table 39: Scrapping older diesel vehicles – 10% take up at 2017 (Mean NO grams)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	1	1	0	0	**4**
	Euro 1	0	0	0	1	0	1	0	3	4	1	1	**12**
	Euro 2	3	5	1	7	2	10	4	39	44	10	7	**134**
	Euro 3	42	73	21	101	30	143	60	545	648	138	96	**1898**
	Euro 4	145	254	72	350	106	502	209	1901	2248	484	334	**6606**
	Euro 5	182	309	92	435	130	615	265	2762	3291	589	418	**9088**
	Euro 6	48	82	24	115	35	163	70	734	874	156	111	**2413**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	1	1	0	0	**4**
	Euro 1	0	0	0	1	0	1	0	3	4	1	1	**12**
	Euro 2	2	3	1	4	1	6	2	21	24	6	4	**74**
	Euro 3	20	37	10	49	15	72	28	253	302	70	47	**904**
	Euro 4	62	106	32	150	45	213	91	813	1002	202	144	**2859**
	Euro 5	48	84	24	117	35	167	70	649	795	160	112	**2260**
	Euro 6	10	18	5	25	7	35	15	137	168	34	24	**478**
	Sub total												**26745**
Car Petrol													
< 1.4 l	Euro 0	1	2	1	2	1	4	1	13	15	3	2	**45**
	Euro 1	2	3	1	4	1	6	2	21	24	6	4	**73**
	Euro 2	6	9	3	13	4	19	8	76	92	18	13	**261**
	Euro 3	10	17	5	23	7	33	14	131	155	32	23	**449**
	Euro 4	30	53	16	74	22	106	45	416	531	100	71	**1466**
	Euro 5	17	25	9	39	11	53	26	235	277	49	38	**780**
	Euro 6	10	15	5	24	7	32	15	142	167	30	23	**470**
1.4 - 2.0 l	Euro 0	2	4	1	5	2	8	3	27	31	8	5	**96**
	Euro 1	3	5	1	7	2	10	4	37	42	10	7	**129**
	Euro 2	17	29	9	40	12	57	24	211	249	55	39	**742**
	Euro 3	24	42	12	56	17	80	32	287	344	79	54	**1027**
	Euro 4	60	104	30	145	44	208	86	766	920	199	140	**2702**
	Euro 5	9	14	5	22	6	29	15	129	164	27	21	**440**
	Euro 6	4	6	2	9	3	13	6	55	70	11	9	**188**
> 2.0 l	Euro 0	1	1	0	2	1	3	1	10	11	3	2	**34**
	Euro 1	1	1	0	2	1	3	1	10	11	3	2	**34**
	Euro 2	4	8	2	10	3	15	6	47	56	15	10	**176**
	Euro 3	5	10	3	13	4	19	7	62	72	18	12	**225**
	Euro 4	6	11	3	16	5	23	9	76	88	22	15	**274**
	Euro 5	2	3	1	4	1	5	2	19	21	5	4	**67**
	Euro 6	1	2	0	2	1	3	1	10	12	3	2	**37**
Hybrid	Euro 4	0	0	0	1	0	1	0	3	3	1	1	**11**
	Euro 5	3	6	2	8	2	11	4	40	46	11	7	**140**
	Euro 6	1	2	1	2	1	4	1	13	15	3	2	**45**
	Sub total												**9913**
Van Diesel													
	Euro 3	18	33	9	33	13	77	22	287	398	61	42	**993**
	Euro 4	75	134	36	138	54	322	94	1236	1752	249	175	**4264**
	Euro 5	201	368	94	371	146	877	248	3535	5043	685	469	**12038**
	Euro 6	45	83	21	83	33	197	56	793	1132	154	105	**2701**
	Sub total												**19995**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	1	0	0	**2**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**1**
LTI TX1	Euro 2	1	2	0	10	1	3	1	11	12	3	2	**45**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	1	0	0	**2**
LTI TXII	Euro 3	3	5	2	38	2	10	4	42	50	10	7	**174**
LTI TX4	Euro 4	3	6	2	40	2	11	4	42	49	11	7	**179**
Merc Vito 111	Euro 4	0	1	0	6	0	2	1	6	7	2	1	**26**
LTI TX4	Euro 5	2	4	1	29	2	8	3	29	33	8	5	**123**
Merc Vito 113	Euro 5	1	1	0	7	0	2	1	8	9	2	1	**33**
LTI TXX	Euro 6	1	1	0	9	1	3	1	10	11	3	2	**41**
Merc Vito XXX	Euro 6	0	0	0	1	0	0	0	1	1	0	0	**5**
	Total	1133	1983	560	2646	819	4184	1569	16698	21323	3749	2619	**57283**

Table 40: Scrapping older diesel vehicles – 10% take up at 2017 (Mean NO_2 grams)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 2	0	1	0	1	0	1	1	5	6	1	1	**18**
	Euro 3	12	21	6	29	9	41	17	156	170	40	28	**528**
	Euro 4	68	115	34	162	49	229	98	893	1035	219	155	**3057**
	Euro 5	83	141	41	196	59	277	117	1219	1390	268	188	**3981**
	Euro 6	22	38	11	52	16	74	31	324	369	71	50	**1057**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 2	0	0	0	1	0	1	0	3	4	1	1	**11**
	Euro 3	9	15	4	21	6	29	12	109	127	29	20	**382**
	Euro 4	64	114	31	151	47	218	86	780	890	215	145	**2742**
	Euro 5	39	68	19	92	28	131	54	497	551	129	88	**1696**
	Euro 6	8	14	4	19	6	28	11	105	117	27	19	**359**
	Sub total												**13841**
Car Petrol													
< 1.4 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 2	0	0	0	0	0	0	0	2	2	0	0	**6**
	Euro 3	0	1	0	1	0	1	0	5	6	2	1	**17**
	Euro 4	2	5	1	6	2	9	3	29	33	9	6	**105**
	Euro 5	4	7	2	9	3	14	5	45	50	14	9	**162**
	Euro 6	2	4	1	6	2	9	3	27	30	8	5	**97**
1.4 - 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	0	1	0	0	**2**
	Euro 2	0	1	0	1	0	1	0	4	4	1	1	**14**
	Euro 3	1	2	0	2	1	3	1	11	12	3	2	**39**
	Euro 4	5	9	2	11	4	17	6	51	57	17	10	**189**
	Euro 5	2	5	1	6	2	9	3	28	34	9	6	**105**
	Euro 6	1	2	0	3	1	4	1	12	15	4	2	**45**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 2	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 3	0	1	0	1	0	1	0	2	2	1	1	**8**
	Euro 4	2	4	1	4	2	8	2	14	14	8	4	**62**
	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
Hybrid	Euro 4	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 5	1	2	0	2	1	3	1	12	14	3	2	**43**
	Euro 6	0	1	0	1	0	1	0	4	5	1	1	**14**
	Sub total												**917**
Van Diesel													
	Euro 3	4	8	2	8	3	18	5	64	84	14	10	**218**
	Euro 4	47	86	21	86	34	203	56	737	995	160	108	**2534**
	Euro 5	103	185	47	187	74	440	124	1768	2396	345	236	**5906**
	Euro 6	23	42	11	42	17	99	28	397	538	77	53	**1325**
	Sub total												**9984**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TX1	Euro 2	0	0	0	1	0	0	0	1	1	0	0	**5**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TXII	Euro 3	1	1	0	9	1	2	1	9	10	2	2	**38**
LTI TX4	Euro 4	1	1	0	9	1	3	1	9	9	3	2	**38**
Merc Vito 111	Euro 4	0	0	0	2	0	1	0	2	2	1	0	**9**
LTI TX4	Euro 5	1	1	0	10	1	3	1	11	12	3	2	**45**
Merc Vito 113	Euro 5	1	1	0	7	0	2	1	7	8	2	1	**31**
LTI TXX	Euro 6	0	0	0	3	0	1	0	3	4	1	1	**15**
Merc Vito XXX	Euro 6	0	0	0	1	0	0	0	1	1	0	0	**5**
	Total	509	898	242	1144	369	1884	674	7352	9005	1693	1159	**24927**

Table 41: Scrapping older diesel vehicles – 20% take up at 2017 (Mean NO grams)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 1	0	0	0	1	0	1	0	3	3	1	1	**10**
	Euro 2	3	5	1	7	2	9	4	34	39	9	6	**119**
	Euro 3	38	65	19	89	27	127	53	484	576	123	86	**1687**
	Euro 4	129	226	64	311	95	447	186	1690	1999	431	297	**5872**
	Euro 5	162	275	82	386	116	546	236	2455	2926	523	371	**8078**
	Euro 6	58	98	29	137	41	194	84	874	1041	186	132	**2874**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	1	1	0	0	**4**
	Euro 1	0	0	0	1	0	1	0	3	3	1	1	**10**
	Euro 2	2	3	1	4	1	5	2	19	22	5	3	**66**
	Euro 3	18	33	9	44	14	64	25	225	268	62	42	**803**
	Euro 4	55	94	28	133	40	189	81	723	891	180	128	**2541**
	Euro 5	43	75	22	104	31	148	62	576	707	142	99	**2009**
	Euro 6	12	21	6	29	9	42	18	163	200	40	28	**569**
	Sub total												**24647**
Car Petrol													
< 1.4 l	Euro 0	1	2	1	2	1	4	1	13	15	3	2	**45**
	Euro 1	2	3	1	4	1	6	2	21	24	6	4	**73**
	Euro 2	6	9	3	13	4	19	8	76	92	18	13	**261**
	Euro 3	10	17	5	23	7	33	14	131	155	32	23	**449**
	Euro 4	30	53	16	74	22	106	45	416	531	100	71	**1466**
	Euro 5	17	25	9	39	11	53	26	235	277	49	38	**780**
	Euro 6	12	18	6	28	8	38	18	169	199	35	27	**560**
1.4 - 2.0 l	Euro 0	2	4	1	5	2	8	3	27	31	8	5	**96**
	Euro 1	3	5	1	7	2	10	4	37	42	10	7	**129**
	Euro 2	17	29	9	40	12	57	24	211	249	55	39	**742**
	Euro 3	24	42	12	56	17	80	32	287	344	79	54	**1027**
	Euro 4	60	104	30	145	44	208	86	766	920	199	140	**2702**
	Euro 5	9	14	5	22	6	29	15	129	164	27	21	**440**
	Euro 6	5	7	3	11	3	15	8	66	83	14	11	**224**
> 2.0 l	Euro 0	1	1	0	2	1	3	1	10	11	3	2	**34**
	Euro 1	1	1	0	2	1	3	1	10	11	3	2	**34**
	Euro 2	4	8	2	10	3	15	6	47	56	15	10	**176**
	Euro 3	5	10	3	13	4	19	7	62	72	18	12	**225**
	Euro 4	6	11	3	16	5	23	9	76	88	22	15	**274**
	Euro 5	2	3	1	4	1	5	2	19	21	5	4	**67**
	Euro 6	1	2	1	3	1	4	1	12	14	4	2	**44**
Hybrid	Euro 4	0	0	0	1	0	1	0	3	3	1	1	**11**
	Euro 5	3	6	2	8	2	11	4	40	46	11	7	**140**
	Euro 6	1	2	1	3	1	4	2	16	18	4	3	**54**
	Sub total												**10054**
Van Diesel													
	Euro 3	16	29	8	29	12	69	20	255	354	54	37	**883**
	Euro 4	66	119	32	123	48	286	84	1098	1557	222	155	**3790**
	Euro 5	178	327	84	330	130	780	221	3142	4483	609	417	**10700**
	Euro 6	59	108	28	109	43	257	73	1034	1476	200	137	**3523**
	Sub total												**18895**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	1	0	0	**2**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**1**
LTI TX1	Euro 2	1	2	0	10	1	3	1	11	12	3	2	**45**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	1	0	0	**2**
LTI TXII	Euro 3	3	5	2	38	2	10	4	42	50	10	7	**174**
LTI TX4	Euro 4	3	6	2	40	2	11	4	42	49	11	7	**179**
Merc Vito 111	Euro 4	0	1	0	6	0	2	1	6	7	2	1	**26**
LTI TX4	Euro 5	2	4	1	29	2	8	3	29	33	8	5	**123**
Merc Vito 113	Euro 5	1	1	0	7	0	2	1	8	9	2	1	**33**
LTI TXX	Euro 6	1	1	0	9	1	3	1	10	11	3	2	**41**
Merc Vito XXX	Euro 6	0	0	0	1	0	0	0	1	1	0	0	**5**
	Total	1073	1876	530	2510	775	3957	1485	15809	20188	3546	2479	**54226**

Table 42: Scrapping older diesel vehicles – 20% take up at 2017 (Mean NO_2 grams)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 2	0	1	0	1	0	1	0	5	5	1	1	**16**
	Euro 3	11	19	5	26	8	36	15	138	151	35	25	**469**
	Euro 4	61	103	30	144	43	203	87	794	920	195	138	**2718**
	Euro 5	74	126	36	174	53	247	104	1084	1236	239	167	**3538**
	Euro 6	26	45	13	62	19	88	37	386	440	85	59	**1259**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 2	0	0	0	1	0	1	0	3	3	1	1	**10**
	Euro 3	8	14	4	18	6	26	11	97	113	26	18	**340**
	Euro 4	57	101	27	135	42	194	77	693	791	191	129	**2437**
	Euro 5	35	60	17	82	25	117	48	442	490	114	78	**1508**
	Euro 6	10	17	5	23	7	33	14	125	139	32	22	**427**
	Sub total												**12730**
Car Petrol													
< 1.4 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 2	0	0	0	0	0	0	0	2	2	0	0	**6**
	Euro 3	0	1	0	1	0	1	0	5	6	2	1	**17**
	Euro 4	2	5	1	6	2	9	3	29	33	9	6	**105**
	Euro 5	4	7	2	9	3	14	5	45	50	14	9	**162**
	Euro 6	3	5	1	7	2	10	4	32	36	10	6	**116**
1.4 - 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	0	1	0	0	**2**
	Euro 2	0	1	0	1	0	1	0	4	4	1	1	**14**
	Euro 3	1	2	0	2	1	3	1	11	12	3	2	**39**
	Euro 4	5	9	2	11	4	17	6	51	57	17	10	**189**
	Euro 5	2	5	1	6	2	9	3	28	34	9	6	**105**
	Euro 6	1	2	1	3	1	5	2	14	17	5	3	**54**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 2	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 3	0	1	0	1	0	1	0	2	2	1	1	**8**
	Euro 4	2	4	1	4	2	8	2	14	14	8	4	**62**
	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
Hybrid	Euro 4	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 5	1	2	0	2	1	3	1	12	14	3	2	**43**
	Euro 6	0	1	0	1	0	1	1	5	5	1	1	**16**
	Sub total												**947**
Van Diesel													
	Euro 3	4	7	2	7	3	16	4	57	74	13	8	**194**
	Euro 4	42	77	19	76	30	180	50	655	885	143	96	**2252**
	Euro 5	91	165	42	166	66	391	111	1571	2130	307	210	**5250**
	Euro 6	30	54	14	55	22	129	36	517	701	101	69	**1728**
	Sub total												**9425**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TX1	Euro 2	0	0	0	1	0	0	0	1	1	0	0	**5**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TXII	Euro 3	1	1	0	9	1	2	1	9	10	2	2	**38**
LTI TX4	Euro 4	1	1	0	9	1	3	1	9	9	3	2	**38**
Merc Vito 111	Euro 4	0	0	0	2	0	1	0	2	2	1	0	**9**
LTI TX4	Euro 5	1	1	0	10	1	3	1	11	12	3	2	**45**
Merc Vito 113	Euro 5	1	1	0	7	0	2	1	7	8	2	1	**31**
LTI TXX	Euro 6	0	0	0	3	0	1	0	3	4	1	1	**15**
Merc Vito XXX	Euro 6	0	0	0	1	0	0	0	1	1	0	0	**5**
	Total	474	838	226	1068	344	1759	628	6870	8421	1580	1081	**23288**

6.4 Scenario 2 – Reducing purchases of new diesel cars

Scenario 2 investigated a possible reduction in the purchasing of new diesel cars. This assumes that some form of policy intervention is introduced to reduce the attractiveness of new diesel cars relative to other fuel types, perhaps through the use of adjustments to fuel duty, vehicle excise duty, environmental taxes, or sales taxes. This scenario assumes that sales of new Euro 6 diesel cars will be reduced by 25%, relative to the base scenario at 2017, and that sales of alternative fuel Euro 6 compliant cars (petrol, hybrid) will increase pro rata. With reference to Figure 22, sales of new Euro 5 diesel cars end on August 30th 2015; the implicit assumption is that the scenario intervention will not be introduced until September 2015 at the earliest. Given the lead time of consultation processes and possible new legislation, it is considered unlikely that such a policy could be introduced in a shorter period of time. Hence the scenario is limited in practice to influencing the sales of new Euro 6 diesel cars from September 2015 to the middle of 2017.

Table 43 and Table 44 present the results for this scenario at 2017 in terms of nitric oxide emissions and nitrogen dioxide emissions respectively. It can be seen that the overall light vehicle nitric oxide emissions across the case study areas reduce from 60.3kg to 59.9kg, i.e. a reduction of approximately 0.7%, relative to the base 2017 scenario. Nitrogen dioxide emissions reduce from 26.6kg to 26.3kg, a reduction of approximately 1.1%.

Figure 41 and Figure 42 illustrate the impact of the scenario on light vehicle emissions of NO and NO_2 respectively, by light vehicle type at 2017.

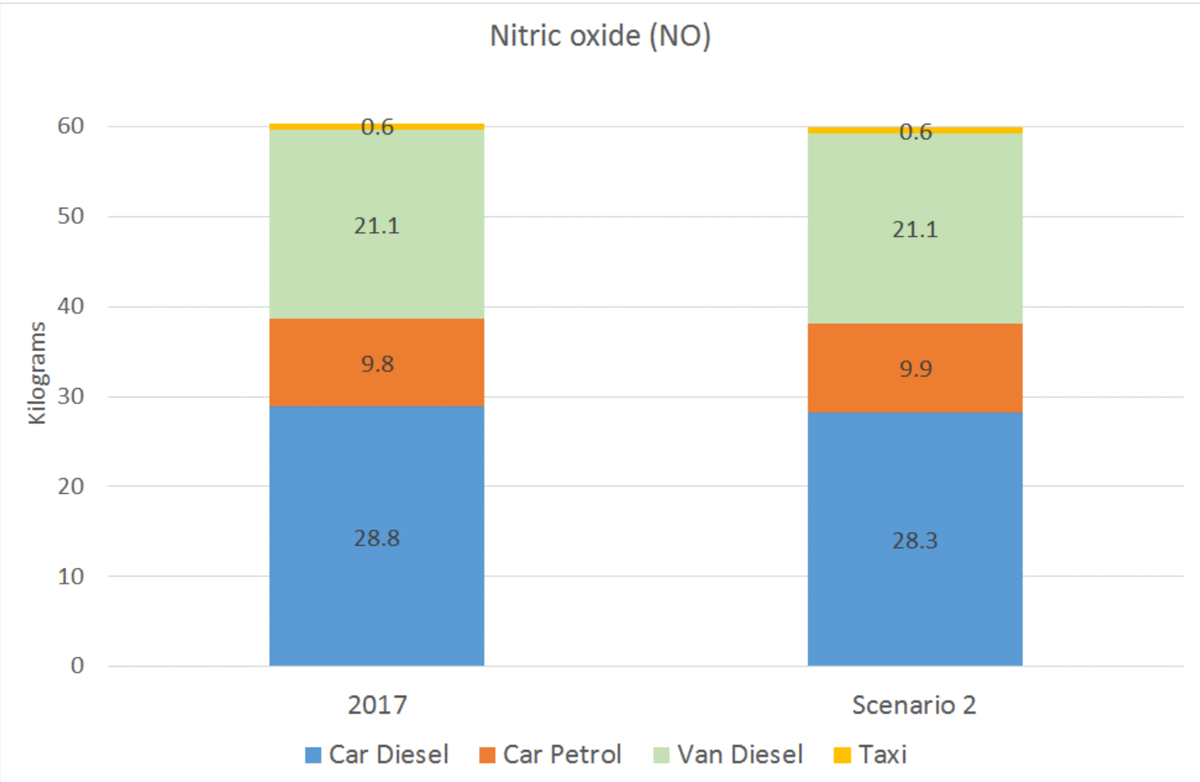

Figure 41: Reduce diesel car purchases – Nitric oxide emissions

The relatively insignificant impact of this scenario intervention at 2017 illustrates the challenge of dealing with the legacy of vehicle sales which have already taken place, and the relatively long time periods required for interventions influencing purchasing decisions to have a significant impact on overall light vehicle fleet emissions. This is a function of the average age of passenger cars operating on the highway network in Ealing (circa 7 years). In the base 2017 scenario, only 7.5% of passenger cars at mid 2017 are Euro 6 diesel; 35.8% of passenger cars are Euro 5 diesel and earlier. Therefore, a policy which targets 25% of new sales of (Euro 6) diesel cars only impacts on 25% of 7.5% = 1.9% of the passenger car fleet in mid 2017.

At 2020, 18.1% of passenger cars are assumed to be Euro 6 diesel (29.0% are Euro 5 diesel and earlier), which would still imply that the scenario would only impact on 4.5% of the total passenger car fleet at 2020.

This is not an argument for not influencing purchasing decisions for environmental benefit. Such interventions may be part of a wider package of policy measures to improve local air quality. However, it is a recognition that such policies would have an influence over a much longer time scale, given the average age of the passenger car fleet, and the rate of fleet turnover. If benefits are required over shorter time scales, then the legacy problem of existing high polluting vehicles also needs to be addressed.

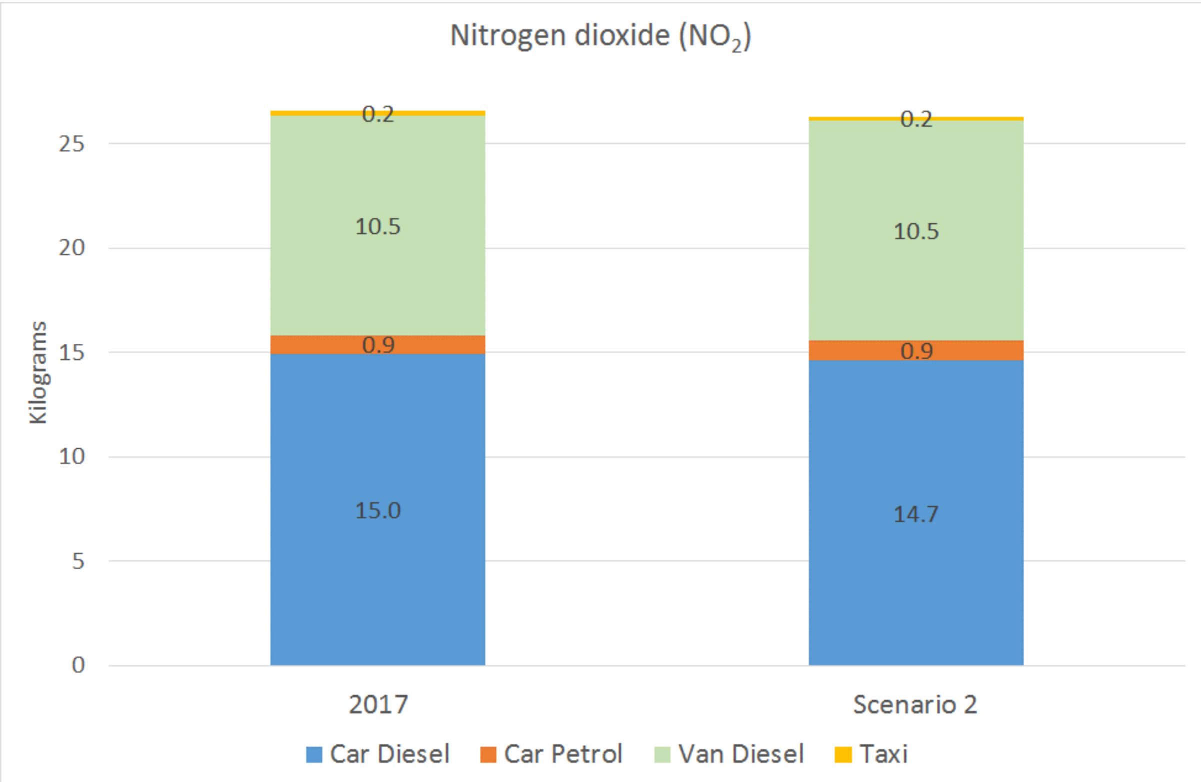

Figure 42: Reduce diesel car purchases – Nitrogen dioxide emissions

Table 43: Reduce sales of new diesel cars by 25% at 2017 (Mean NO grams)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	1	1	0	0	**4**
	Euro 1	0	1	0	1	0	1	0	4	4	1	1	**13**
	Euro 2	3	6	2	8	3	12	5	43	49	11	8	**149**
	Euro 3	47	81	23	112	34	159	66	605	720	154	107	**2109**
	Euro 4	161	282	80	389	118	558	232	2112	2498	538	371	**7340**
	Euro 5	202	344	102	483	145	683	295	3069	3657	654	464	**10097**
	Euro 6	29	50	15	70	21	99	43	445	530	95	67	**1464**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	1	1	0	0	**5**
	Euro 1	0	1	0	1	0	1	0	4	4	1	1	**13**
	Euro 2	2	3	1	4	1	6	3	24	27	6	4	**82**
	Euro 3	23	41	11	55	17	80	32	281	336	77	52	**1004**
	Euro 4	69	118	35	166	50	236	101	903	1114	225	160	**3177**
	Euro 5	54	93	27	130	39	185	78	721	883	178	124	**2511**
	Euro 6	6	11	3	15	5	21	9	83	102	21	14	**290**
	Sub total												**28258**
Car Petrol													
< 1.4 l	Euro 0	1	2	1	2	1	4	1	13	15	3	2	**45**
	Euro 1	2	3	1	4	1	6	2	21	24	6	4	**73**
	Euro 2	6	9	3	13	4	19	8	76	92	18	13	**261**
	Euro 3	10	17	5	23	7	33	14	131	155	32	23	**449**
	Euro 4	30	53	16	74	22	106	45	416	531	100	71	**1466**
	Euro 5	17	25	9	39	11	53	26	235	277	49	38	**780**
	Euro 6	10	15	5	24	7	32	16	142	168	30	23	**473**
1.4 - 2.0 l	Euro 0	2	4	1	5	2	8	3	27	31	8	5	**96**
	Euro 1	3	5	1	7	2	10	4	37	42	10	7	**129**
	Euro 2	17	29	9	40	12	57	24	211	249	55	39	**742**
	Euro 3	24	42	12	56	17	80	32	287	344	79	54	**1027**
	Euro 4	60	104	30	145	44	208	86	766	920	199	140	**2702**
	Euro 5	9	14	5	22	6	29	15	129	164	27	21	**440**
	Euro 6	4	6	2	9	3	13	6	55	70	11	9	**189**
> 2.0 l	Euro 0	1	1	0	2	1	3	1	10	11	3	2	**34**
	Euro 1	1	1	0	2	1	3	1	10	11	3	2	**34**
	Euro 2	4	8	2	10	3	15	6	47	56	15	10	**176**
	Euro 3	5	10	3	13	4	19	7	62	72	18	12	**225**
	Euro 4	6	11	3	16	5	23	9	76	88	22	15	**274**
	Euro 5	2	3	1	4	1	5	2	19	21	5	4	**67**
	Euro 6	1	2	0	2	1	3	1	10	12	3	2	**37**
Hybrid	Euro 4	0	0	0	1	0	1	0	3	3	1	1	**11**
	Euro 5	3	6	2	8	2	11	4	40	46	11	7	**140**
	Euro 6	1	2	1	2	1	4	1	13	15	3	2	**46**
	Sub total												**9916**
Van Diesel													
	Euro 3	20	36	9	37	14	86	24	319	442	67	47	**1103**
	Euro 4	83	149	40	153	60	358	105	1373	1947	277	194	**4737**
	Euro 5	223	409	105	412	162	975	276	3928	5603	761	521	**13375**
	Euro 6	31	57	15	58	23	137	39	552	787	107	73	**1879**
	Sub total												**21095**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	1	0	0	**2**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**1**
LTI TX1	Euro 2	1	2	0	10	1	3	1	11	12	3	2	**45**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	1	0	0	**2**
LTI TXII	Euro 3	3	5	2	38	2	10	4	42	50	10	7	**174**
LTI TX4	Euro 4	3	6	2	40	2	11	4	42	49	11	7	**179**
Merc Vito 111	Euro 4	0	1	0	6	0	2	1	6	7	2	1	**26**
LTI TX4	Euro 5	2	4	1	29	2	8	3	29	33	8	5	**123**
Merc Vito 113	Euro 5	1	1	0	7	0	2	1	8	9	2	1	**33**
LTI TXX	Euro 6	1	1	0	9	1	3	1	10	11	3	2	**41**
Merc Vito XXX	Euro 6	0	0	0	1	0	0	0	1	1	0	0	**5**
	Total	1186	2075	585	2761	857	4380	1640	17454	22299	3923	2740	**59900**

Table 44: Reduce sales of new diesel cars by 25% at 2017 (Mean NO_2 grams)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	1	1	0	0	**4**
	Euro 2	0	1	0	1	0	2	1	6	6	2	1	**20**
	Euro 3	14	23	7	32	10	45	19	173	189	44	31	**587**
	Euro 4	76	128	38	180	54	254	108	992	1150	244	173	**3397**
	Euro 5	92	157	45	218	66	308	130	1355	1545	298	209	**4423**
	Euro 6	13	23	7	32	10	45	19	197	224	43	30	**641**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	1	1	0	0	**4**
	Euro 2	0	1	0	1	0	1	0	4	4	1	1	**13**
	Euro 3	10	17	5	23	7	33	14	121	141	32	22	**425**
	Euro 4	71	126	34	168	52	243	96	867	989	239	161	**3047**
	Euro 5	44	75	21	102	31	146	60	552	613	143	98	**1885**
	Euro 6	5	9	2	12	4	17	7	64	71	17	11	**218**
	Sub total												**14664**
Car Petrol													
< 1.4 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 2	0	0	0	0	0	0	0	2	2	0	0	**6**
	Euro 3	0	1	0	1	0	1	0	5	6	2	1	**17**
	Euro 4	2	5	1	6	2	9	3	29	33	9	6	**105**
	Euro 5	4	7	2	9	3	14	5	45	50	14	9	**162**
	Euro 6	2	4	1	6	2	9	3	27	30	8	5	**98**
1.4 - 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	0	1	0	0	**2**
	Euro 2	0	1	0	1	0	1	0	4	4	1	1	**14**
	Euro 3	1	2	0	2	1	3	1	11	12	3	2	**39**
	Euro 4	5	9	2	11	4	17	6	51	57	17	10	**189**
	Euro 5	2	5	1	6	2	9	3	28	34	9	6	**105**
	Euro 6	1	2	0	3	1	4	1	12	15	4	2	**45**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 2	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 3	0	1	0	1	0	1	0	2	2	1	1	**8**
	Euro 4	2	4	1	4	2	8	2	14	14	8	4	**62**
	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
Hybrid	Euro 4	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 5	1	2	0	2	1	3	1	12	14	3	2	**43**
	Euro 6	0	1	0	1	0	1	0	4	5	1	1	**14**
	Sub total												**918**
Van Diesel													
	Euro 3	5	8	2	8	3	20	5	71	93	16	11	**243**
	Euro 4	52	96	24	95	38	225	63	819	1106	178	120	**2816**
	Euro 5	114	206	53	208	82	488	138	1964	2662	384	263	**6562**
	Euro 6	16	29	7	29	12	69	19	276	374	54	37	**922**
	Sub total												**10543**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TX1	Euro 2	0	0	0	1	0	0	0	1	1	0	0	**5**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TXII	Euro 3	1	1	0	9	1	2	1	9	10	2	2	**38**
LTI TX4	Euro 4	1	1	0	9	1	3	1	9	9	3	2	**38**
Merc Vito 111	Euro 4	0	0	0	2	0	1	0	2	2	1	0	**9**
LTI TX4	Euro 5	1	1	0	10	1	3	1	11	12	3	2	**45**
Merc Vito 113	Euro 5	1	1	0	7	0	2	1	7	8	2	1	**31**
LTI TXX	Euro 6	0	0	0	3	0	1	0	3	4	1	1	**15**
Merc Vito XXX	Euro 6	0	0	0	1	0	0	0	1	1	0	0	**5**
	Total	538	949	256	1207	390	1990	712	7755	9501	1789	1225	**26311**

6.5 Scenario 3 – Ultra low emission zone

Scenario 3 assumes the introduction of an ultra-low emission zone (ULEZ) in Ealing by 2017. In the scenario, the zone applies to all light vehicles (passenger cars, taxis, and vans). With reference to Table 12 and Table 14, it can be seen that nitric oxide emission rates from diesel cars, vans, and taxis are generally relatively high up to and including Euro 5. With reference to Table 35, it can be seen that nitric oxide emissions across the case study areas in 2017 from Euro 4 and earlier petrol cars are still quite significant, but decrease with the introduction of the Euro 5 standard. Nitrogen dioxide emissions from light vehicles are dominated by diesel cars and vans as can be seen in Table 18 and Table 36. NO_2 rates from diesel engines (g/kg of fuel burned) remain high up to and including Euro 5, and are only assumed to decrease significantly with the introduction of the Euro 6 standard.

It was therefore decided to set the compliance criteria for the light vehicle ULEZ as being Euro 6 for diesel light vehicles, and Euro 5/6 for petrol light vehicles. This is applied to all passenger cars, vans, and taxis. It is assumes that vehicles are replaced on a like-for-like basis, adopting the compliant Euro standard for the ULEZ. Therefore, for example, pre-Euro 6 diesel cars with engines of capacity less than 2.0 litres are replaced with Euro 6 diesel cars with engines of capacity less than 2.0 litres. Pre Euro 5 petrol cars are replaced with an equivalent Euro 5 or Euro 6 petrol car, the proportions being determined by the relative proportions of Euro 5 and Euro 6 petrol cars assumed in the base scenario at 2017. Therefore, pre Euro 5 petrol cars can either be replaced with new or pre-owned Euro 5 petrol cars, or Euro 6 petrol cars.

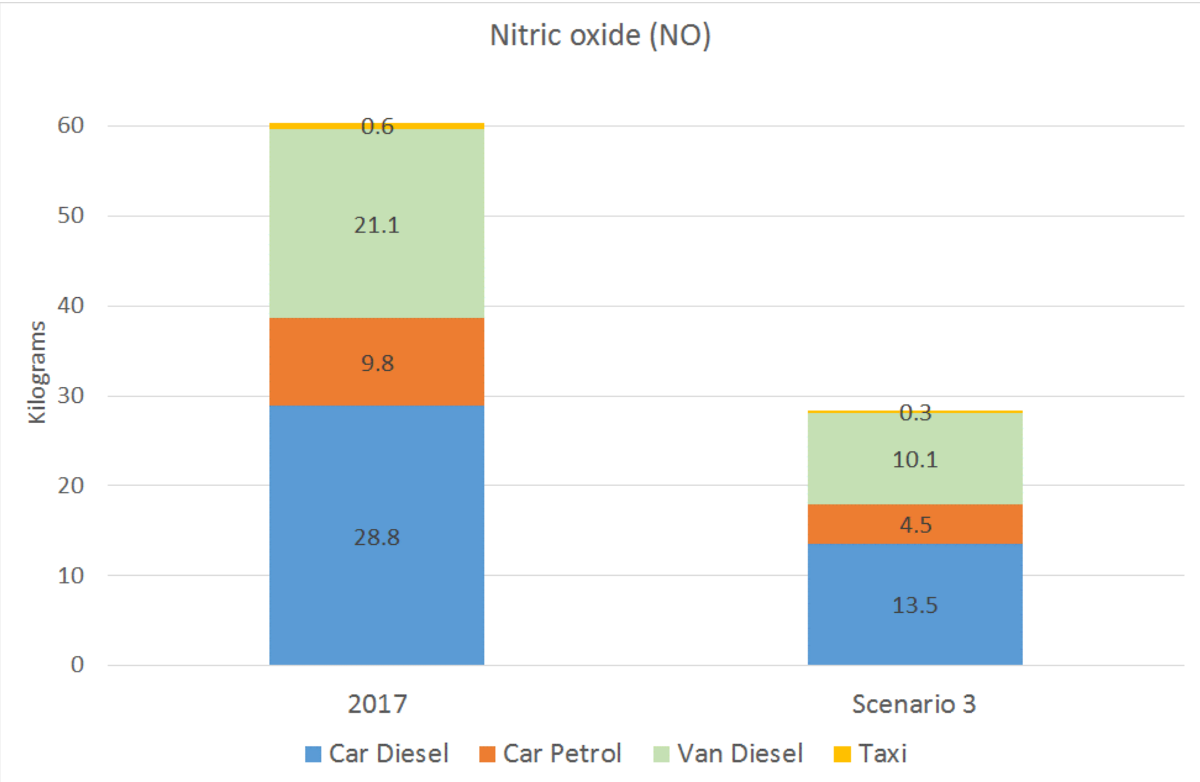

Figure 43: Light vehicle ULEZ – Nitric oxide emissions

Table 45 and Table 46 present the emissions results for the light vehicle ULEZ at 2017 for nitric oxide and nitrogen dioxide respectively. . It can be seen that the overall light vehicle nitric oxide emissions across the case study areas reduce from 60.3kg to 28.4kg, i.e. a reduction of approximately 52.9%, relative to the base 2017 scenario. Nitrogen dioxide emissions reduce from 26.6kg to 12.9kg, a reduction of approximately 51.5%.

Figure 43 and Figure 44 illustrate the impact of the scenario on light vehicle emissions of NO and NO_2 respectively, by light vehicle type at 2017.

In terms of overall NO_x emissions (NO_2 equivalent values), the light vehicle ULEZ scenario reduces total NO_x from light vehicles by approximately 52.6% relative to the base 2017 situation, by far the most effective individual scenario considered.

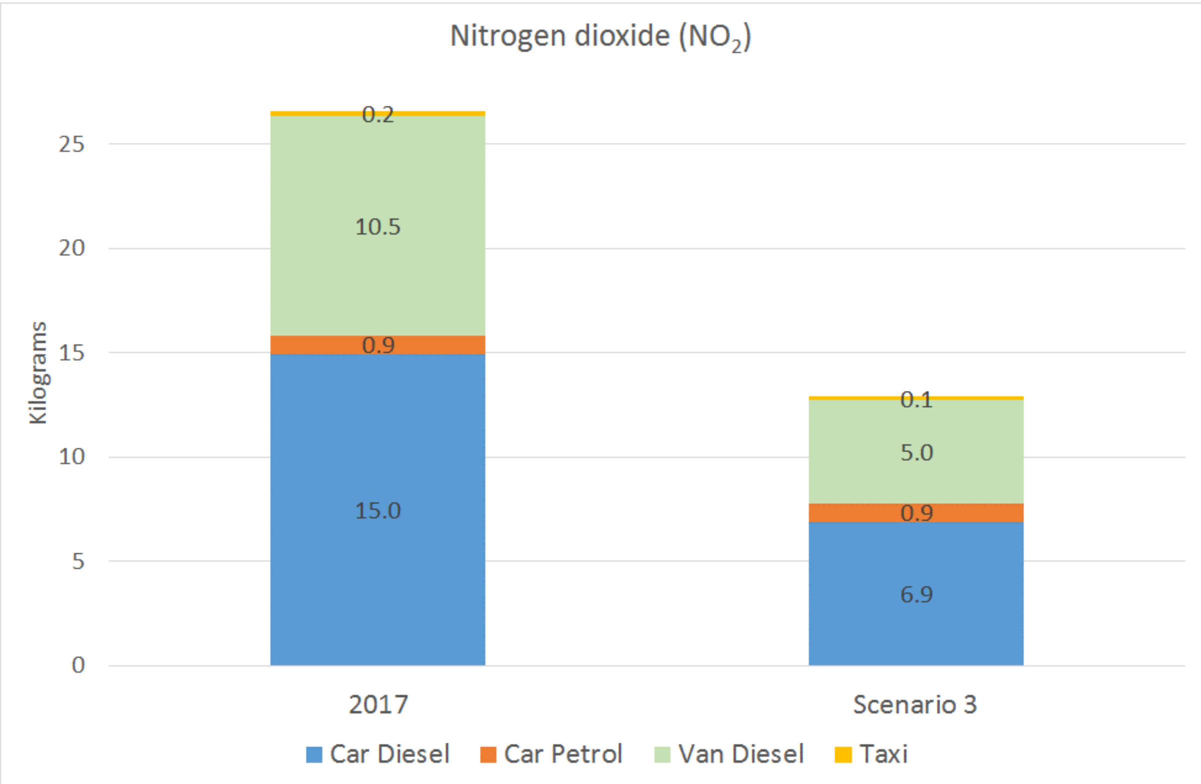

Figure 44: Light vehicle ULEZ – Nitrogen dioxide emissions

Table 45: Light vehicle ULEZ at 2017 (Mean NO grams)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 6	210	356	106	500	150	708	306	3180	3790	678	481	**10463**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 6	65	113	33	158	47	225	94	876	1074	216	151	**3054**
	Sub total												**13517**
Car Petrol													
< 1.4 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 5	30	46	16	71	20	96	46	425	502	89	69	**1411**
	Euro 6	15	22	8	35	10	47	23	207	245	43	34	**688**
1.4 - 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 5	27	42	15	65	18	89	45	391	496	81	64	**1332**
	Euro 6	9	14	5	23	6	31	16	135	172	28	22	**462**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 5	6	10	3	14	4	20	8	69	78	20	13	**245**
	Euro 6	3	5	1	6	2	9	4	31	35	9	6	**109**
Hybrid	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 5	4	7	2	9	3	13	5	48	54	13	9	**166**
	Euro 6	1	2	0	2	1	3	1	13	14	3	2	**44**
	Sub total												**4457**
Van Diesel													
	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 6	168	309	79	311	123	736	208	2965	4229	575	393	**10096**
	Sub total												**10096**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TX1	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TXII	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TX4	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
Merc Vito 111	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TX4	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
Merc Vito 113	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TXX	Euro 6	6	10	3	69	4	19	8	70	79	19	13	**299**
Merc Vito XXX	Euro 6	1	1	0	8	0	2	1	9	10	2	1	**36**
	Total	544	937	272	1271	389	1998	764	8419	10778	1774	1258	**28405**

Table 46: Light vehicle ULEZ at 2017 (Mean NO_2 grams)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 6	96	163	47	226	68	319	135	1404	1601	309	216	**4583**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 6	53	91	25	124	38	178	73	672	745	174	119	**2292**
	Sub total												**6875**
Car Petrol													
< 1.4 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 5	7	13	3	17	5	26	9	81	91	25	16	**292**
	Euro 6	3	6	1	8	3	13	4	40	44	12	8	**143**
1.4 - 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 5	7	14	3	18	6	28	9	84	104	27	17	**318**
	Euro 6	2	5	1	6	2	10	3	29	36	9	6	**110**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
Hybrid	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 5	1	2	1	3	1	4	2	15	17	4	3	**51**
	Euro 6	0	1	0	1	0	1	0	4	4	1	1	**13**
	Sub total												**927**
Van Diesel													
	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 6	86	156	40	157	62	369	104	1482	2010	290	198	**4953**
	Sub total												**4953**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TX1	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TXII	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TX4	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
Merc Vito 111	Euro 4	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TX4	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
Merc Vito 113	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TXX	Euro 6	2	4	1	25	1	7	3	25	29	7	5	**109**
Merc Vito XXX	Euro 6	1	1	0	8	0	2	1	8	9	2	1	**34**
	Total	258	456	123	593	188	956	343	3844	4689	861	589	**12899**

6.6 Scenario 4 – Turn off engines during stops

One of the significant insights gained from the probe vehicle surveys implemented within the case study areas was the proportion of journey time spent stationary. Table 6 presented some summary statistics from the probe vehicle surveys, showing that the proportion of journey time spent stationary across the case study areas on average ranged from 8% to 40% depending on case study area and direction. Detailed statistics relating to each case study area are presented in Volume 2: 'Probe Vehicle Survey Results'. Perhaps more significantly, up to 33% of total journey time on these sections of route during the probe vehicle surveys was spent stationary for periods of 10 seconds or more. This has the effect of creating significant air pollution 'hotspots' on the highway network, typically in the vicinity of junctions, in addition to contributing to the wider NO_2 air quality problem.

For this scenario, it is hypothesised that if all (or a significant proportion of) vehicle engines were consistently switched off during these stationary episodes, there would be a significant reduction in the absolute emissions of NO_2 and NO_x into the local atmosphere at these emission 'hot spots' (in addition to reductions in other pollutants and greenhouse gases).

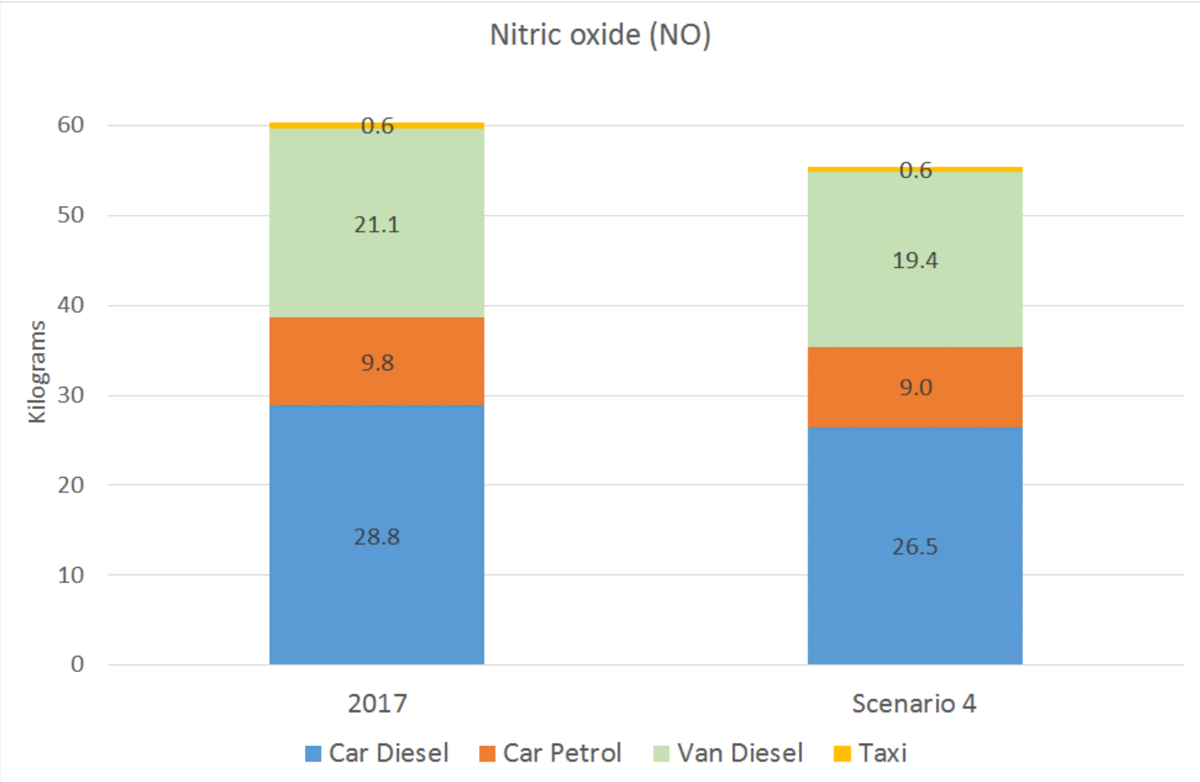

Figure 45: Switch off engines during stops – Nitric oxide emissions

Currently we do not know what proportions of drivers systematically switch off their engines in such circumstances. Some new passenger cars are now fitted with automatic stop/start systems which facilitate easy stopping and starting of the engine when the vehicle is taken out of gear. However, there is no published data on the current, or likely future, market penetration of such technologies into the UK passenger car, commercial vehicle, or bus fleets. The Department for Transport does not hold data on this issue (personal communication dated July 9th 2014). Similarly, the Society of Motor

Manufacturers and Traders has stated that SMMT do not explicitly record this aspect of vehicle technology in their databases (personal communication SMMT, dated July 11th 2014).

This light vehicle scenario assumes that if a stop within a journey has a duration of longer than 10 seconds, the vehicle engine is switched off for the duration of the episode that is greater than 10 seconds, i.e. if a stop had a duration of 30 seconds, the engine would be allowed to idle for 10 seconds and would be switched off for 20 seconds. The 10 seconds 'cut-off' is a nominal period to permit driver decision making, and re-starting prior to recommencement of motion. If a stop had a duration of 45 seconds, the engine would be allowed to idle for 10 seconds and would be switched off for 35 seconds. The scenario has no impact on stops of 10 seconds duration or less.

Of course, some drivers already switch of engines during stops, but the proportion who do so, and their decision making processes, are unknown. The scenario can be characterised as quantifying the difference in emissions between (a) all light vehicle drivers not switching off their engines, and (b) all light vehicles drivers systematically switching off their engines during longer duration stops, within the rules set out above.

Table 47 and Table 48 present the emissions results for this light vehicle scenario at 2017 for nitric oxide and nitrogen dioxide respectively. . It can be seen that the overall light vehicle nitric oxide emissions across the case study areas reduce from 60.3kg to 55.4kg, i.e. a reduction of approximately 8.1%, relative to the base 2017 scenario. Nitrogen dioxide emissions reduce from 26.6kg to 24.3kg, a reduction of approximately 8.6%.

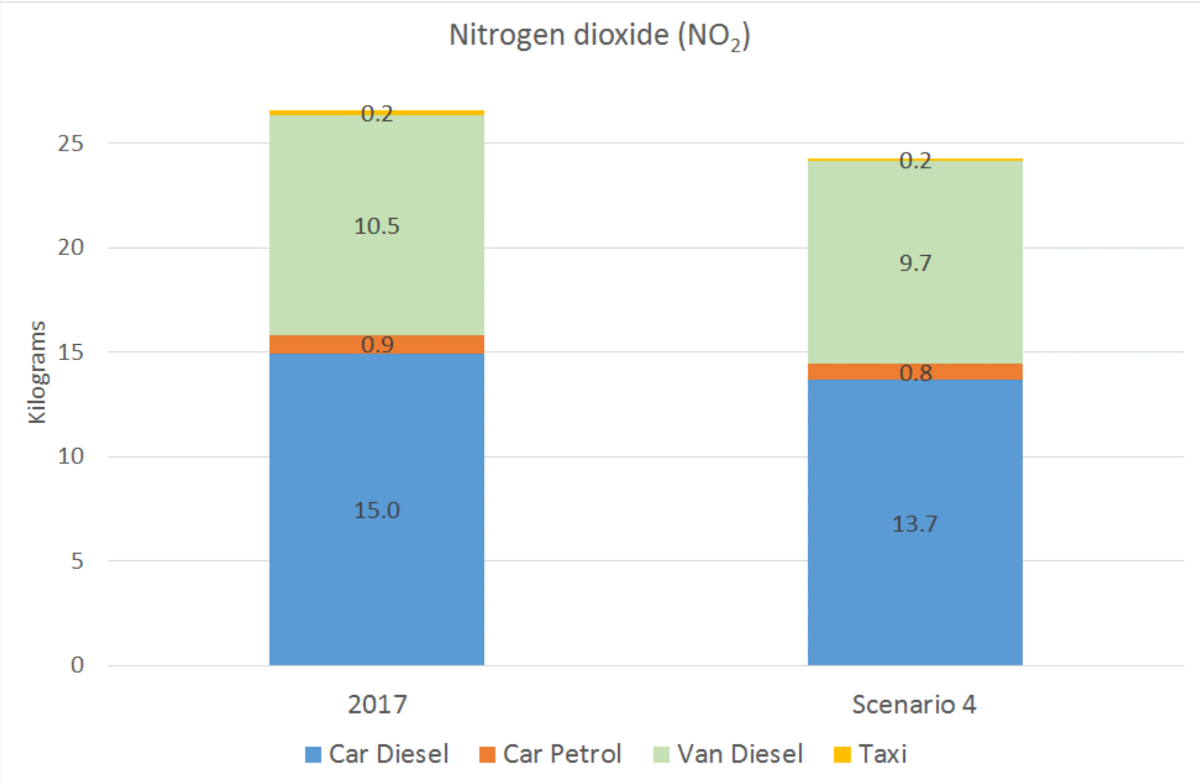

Figure 46: Switch off engines during stops – Nitrogen dioxide emissions

Figure 45 and Figure 46 illustrate the impact of this scenario on light vehicle emissions of NO and NO_2 respectively, by light vehicle type at 2017.

In terms of overall NO_x emissions (NO_2 equivalent values), the scenario reduces total NO_x from light vehicles across the case study areas by approximately 8.2% relative to the base 2017 situation. Of course, this scenario differs from the other scenarios considered in that its impact will vary spatially, with significantly higher benefits observed in locations where stopping is most prevalent, for example adjacent to junctions and traffic lights. One of the particular benefits of this scenario is therefore that it explicitly targets known emission 'hot spots'. The issues of 'spatial' and 'dynamic' variation in vehicle emissions will be discussed later in this report, but Figure 47 to Figure 51 illustrate the spatial variation in NO_x emissions (as expressed in NO_2 equivalent values by mass), including the impact of this scenario. Absolute values for the individual species NO and NO_2 are presented in Table 49 to Table 58 inclusive. The definition of spatial sections within case study areas (labelled 'A', 'B', 'C'….) is presented graphically in Volume 2: 'Probe Vehicle Survey Results'. The tables and figures demonstrate the proportionally greater impact of the scenario in locations such as the approaches to junctions within the case study areas where stopping behaviour is most prevalent. For example, on Horn Lane at the northbound approach to the junction with the A40 Western Avenue (Section 'A', where traffic volumes and delays are particularly high), the scenario achieves a local reduction in NO and NO_2 emissions of more than 54% compared to the 2017 base case (Table 51 and Table 52). In addition, the more congested case study areas will generally tend to benefit more from this scenario intervention.

Table 47: Turn off engines at stops at 2017 (Mean NO grams)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	1	1	0	0	**4**
	Euro 1	0	0	0	1	0	1	0	3	4	1	1	**12**
	Euro 2	3	5	2	7	2	8	4	40	47	9	7	**135**
	Euro 3	45	73	23	97	29	116	63	562	701	124	97	**1931**
	Euro 4	155	253	80	339	103	404	220	1958	2430	433	335	**6709**
	Euro 5	195	308	102	422	126	500	279	2855	3560	530	421	**9298**
	Euro 6	38	60	20	82	24	97	54	552	688	102	81	**1798**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	1	1	0	0	**4**
	Euro 1	0	0	0	1	0	1	0	3	4	1	1	**12**
	Euro 2	2	3	1	4	1	5	2	22	26	5	4	**75**
	Euro 3	22	36	11	48	15	57	30	260	326	62	47	**914**
	Euro 4	66	106	35	145	43	172	95	840	1086	182	145	**2915**
	Euro 5	52	84	27	113	34	135	73	669	860	143	113	**2303**
	Euro 6	8	13	4	17	5	21	11	103	133	22	17	**355**
	Sub total												**26464**
Car Petrol													
< 1.4 l	Euro 0	1	2	1	2	1	3	1	12	14	3	2	**41**
	Euro 1	2	3	1	3	1	4	2	20	23	4	3	**67**
	Euro 2	5	8	3	12	3	14	8	71	89	14	12	**241**
	Euro 3	10	15	5	21	6	24	13	122	151	26	21	**413**
	Euro 4	29	47	16	65	19	77	43	387	519	81	65	**1348**
	Euro 5	16	23	9	35	10	40	24	221	270	40	35	**723**
	Euro 6	8	11	4	17	5	20	12	108	132	20	17	**353**
1.4 - 2.0 l	Euro 0	2	4	1	5	1	6	3	25	30	6	5	**87**
	Euro 1	3	5	1	6	2	7	4	34	40	8	6	**118**
	Euro 2	17	26	9	35	11	41	23	196	243	45	35	**680**
	Euro 3	23	38	12	49	15	58	30	266	335	63	49	**937**
	Euro 4	58	94	30	127	38	150	81	711	895	160	126	**2471**
	Euro 5	9	12	5	19	5	22	14	121	160	22	19	**409**
	Euro 6	3	4	2	7	2	8	5	42	55	8	7	**142**
> 2.0 l	Euro 0	1	1	0	2	1	2	1	9	11	2	2	**31**
	Euro 1	1	1	0	2	1	2	1	9	11	2	2	**31**
	Euro 2	4	7	2	9	3	11	5	43	55	12	9	**159**
	Euro 3	5	9	3	11	3	13	7	57	70	15	11	**204**
	Euro 4	6	10	3	14	4	16	9	70	86	18	13	**250**
	Euro 5	2	3	1	3	1	4	2	17	21	4	3	**61**
	Euro 6	1	1	0	1	0	2	1	8	9	2	1	**27**
Hybrid	Euro 4	0	0	0	1	0	1	0	3	3	1	1	**10**
	Euro 5	3	5	2	7	2	8	4	38	45	9	7	**127**
	Euro 6	1	1	0	2	1	2	1	10	12	2	2	**33**
	Sub total												**8962**
Van Diesel													
	Euro 3	20	33	9	32	13	61	23	296	430	54	42	**1013**
	Euro 4	80	133	40	134	52	254	99	1276	1895	224	176	**4362**
	Euro 5	215	366	105	359	141	686	260	3640	5455	612	470	**12310**
	Euro 6	30	51	15	50	20	96	37	511	767	86	66	**1730**
	Sub total												**19415**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**2**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**1**
LTI TX1	Euro 2	1	1	0	9	1	2	1	10	11	2	2	**40**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	1	0	0	**2**
LTI TXII	Euro 3	3	5	2	33	2	7	4	39	49	8	6	**158**
LTI TX4	Euro 4	3	5	2	35	2	8	4	39	48	9	7	**162**
Merc Vito 111	Euro 4	0	1	0	5	0	1	1	6	7	1	1	**24**
LTI TX4	Euro 5	2	4	1	25	1	6	3	27	32	6	5	**111**
Merc Vito 113	Euro 5	1	1	0	6	0	1	1	7	9	2	1	**30**
LTI TXX	Euro 6	1	1	0	8	0	2	1	9	11	2	2	**37**
Merc Vito XXX	Euro 6	0	0	0	1	0	0	0	1	1	0	0	**5**
	Total	1151	1874	588	2426	752	3176	1562	16331	21863	3189	2499	**55411**

Table 48: Turn off engines at stops at 2017 (Mean NO_2 grams)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 2	0	1	0	1	0	1	1	5	6	1	1	**18**
	Euro 3	13	21	7	28	9	33	18	161	183	36	28	**536**
	Euro 4	73	115	38	157	47	186	103	923	1119	197	157	**3113**
	Euro 5	89	141	45	190	57	224	123	1259	1501	241	189	**4060**
	Euro 6	17	27	9	37	11	43	24	243	290	47	37	**785**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 2	0	0	0	1	0	1	0	3	4	1	1	**12**
	Euro 3	10	15	5	20	6	24	13	113	137	26	20	**389**
	Euro 4	69	113	34	146	45	174	91	802	960	192	145	**2772**
	Euro 5	42	67	21	89	27	106	56	512	595	115	88	**1719**
	Euro 6	6	10	3	14	4	16	9	79	92	18	14	**265**
	Sub total												**13676**
Car Petrol													
< 1.4 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 2	0	0	0	0	0	0	0	2	2	0	0	**5**
	Euro 3	0	1	0	1	0	1	0	4	5	1	1	**16**
	Euro 4	2	4	1	5	2	6	3	26	32	7	5	**94**
	Euro 5	4	6	2	8	3	10	5	41	49	11	8	**144**
	Euro 6	2	3	1	4	1	5	2	20	24	5	4	**70**
1.4 - 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	0	1	0	0	**1**
	Euro 2	0	1	0	1	0	1	0	4	4	1	1	**13**
	Euro 3	1	2	0	2	1	2	1	10	11	3	2	**35**
	Euro 4	4	8	2	9	3	12	5	46	55	14	9	**168**
	Euro 5	2	4	1	5	2	6	3	25	33	7	5	**94**
	Euro 6	1	1	0	2	1	2	1	9	12	2	2	**33**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 2	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 3	0	0	0	0	0	1	0	2	2	1	0	**7**
	Euro 4	2	4	1	4	1	5	2	12	13	6	3	**52**
	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
Hybrid	Euro 4	0	0	0	0	0	0	0	1	1	0	0	**2**
	Euro 5	1	2	0	2	1	2	1	11	14	3	2	**39**
	Euro 6	0	0	0	1	0	1	0	3	4	1	1	**10**
	Sub total												**792**
Van Diesel													
	Euro 3	4	8	2	7	3	14	5	66	90	13	10	**222**
	Euro 4	50	86	24	83	33	158	59	758	1074	143	108	**2576**
	Euro 5	110	185	53	181	72	344	131	1821	2587	309	237	**6029**
	Euro 6	15	26	7	25	10	48	18	256	363	43	33	**847**
	Sub total												**9674**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TX1	Euro 2	0	0	0	1	0	0	0	1	1	0	0	**4**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TXII	Euro 3	1	1	0	7	0	2	1	8	10	2	1	**34**
LTI TX4	Euro 4	1	1	0	8	0	2	1	8	9	2	1	**34**
Merc Vito 111	Euro 4	0	0	0	2	0	0	0	2	2	0	0	**8**
LTI TX4	Euro 5	1	1	0	9	1	2	1	10	12	2	2	**41**
Merc Vito 113	Euro 5	1	1	0	6	0	1	1	7	8	2	1	**28**
LTI TXX	Euro 6	0	0	0	3	0	1	0	3	4	1	1	**13**
Merc Vito XXX	Euro 6	0	0	0	1	0	0	0	1	1	0	0	**4**
	Total	523	859	258	1061	342	1437	679	7263	9316	1454	1117	**24309**

6.7 Intra case study area spatial variation in emissions

The study has sought to quantify the degree of intra case study spatial variation in emissions from light vehicles. This spatial variation is driven by a number of factors including:

- Changes in traffic volume spatially
- Variation in levels of congestion and delays
- Variation in highway gradient

All of these factors, individually or in combination, can influence the absolute mass of NO_x being emitted by light vehicles in different locations within the case study areas. This type of analysis is particularly important for air quality management because it serves to identify and quantify local pollution 'hot spots' on the highway network which have the potential to cause localised health problems for people in the immediate vicinity. Figure 47 to Figure 51 inclusive, and Table 49 to Table 58 inclusive, illustrate and quantify the spatial variation of NOx emissions within the case study areas, internalising the causal factors identified above. The definition of spatial sections within case study areas (labelled 'A', 'B', 'C'….) is presented graphically in Volume 2: 'Probe Vehicle Survey Results'.

Figure 47 to Figure 51 inclusive illustrate the spatial variation of NO_x emissions (NO_2 equivalent values by mass) at 2012, 2017, and 2017 with scenario 4 (turn off engines when stationary) for each of the case study areas. On Acton High Street (Figure 47) one can see that there is significant spatial variation across sections 'A' to 'G', which are all 100m long (section 'H' is a 12m stub at the end of the case study area). Section 'B' has the highest NO_x emissions at 1.34kg of NO_x in a 12 hour average weekday (2012), whereas section 'G' is lowest at 0.82kg of NO_x.

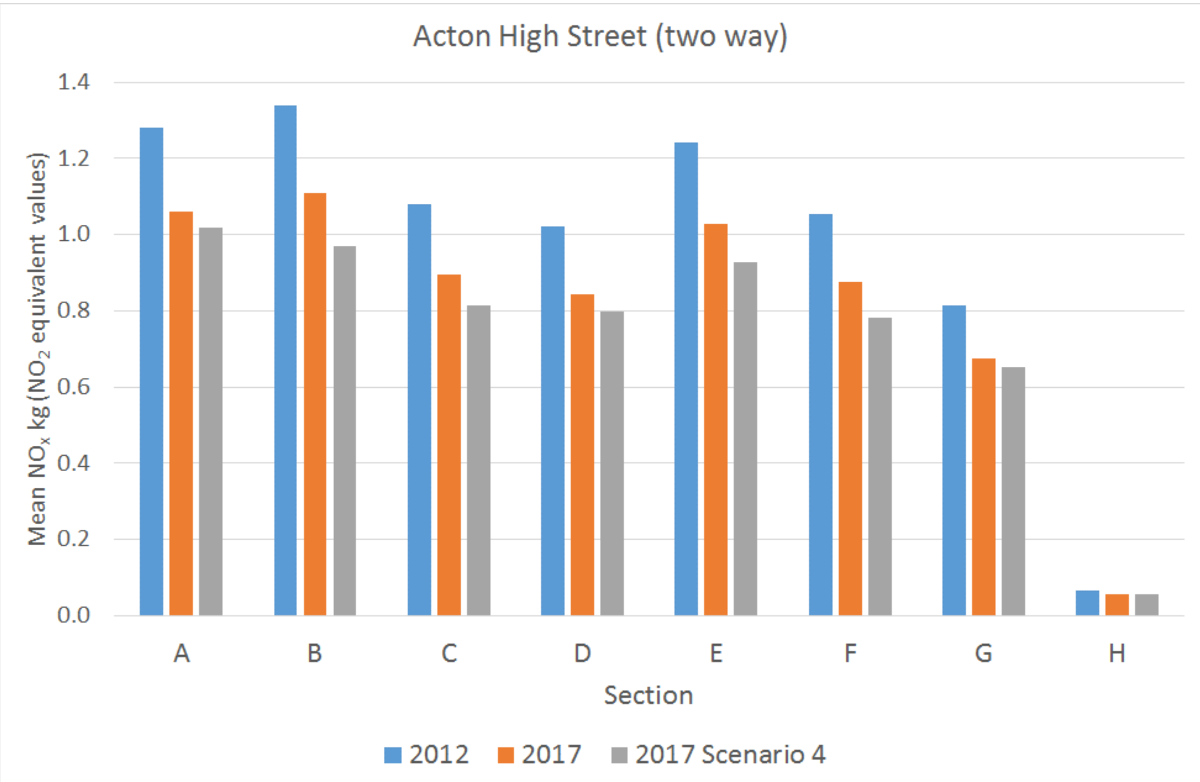

Figure 47: Acton High Street – Spatial variability of NO_x emissions

NO_x emissions from section 'B' are 63% higher than from section 'G' (with the same assumed traffic flow) due primarily to higher levels of congestion and delay (increased journey time and stops). Section 'G' is relatively free flowing, whereas Section 'B' is impacted by significant delays, particularly westbound on the approach to the junction with Crown Street, where the observed average speed was 7kph. This section has a heavily utilised signalised pedestrian crossing facility near bus stops and the shopping centre. Another section of the case study area with relatively high NO_x emissions (1.24kg) is section 'E' which includes the signalised junction with Acton Lane, outside the Old Town Hall (51% higher than section 'G').

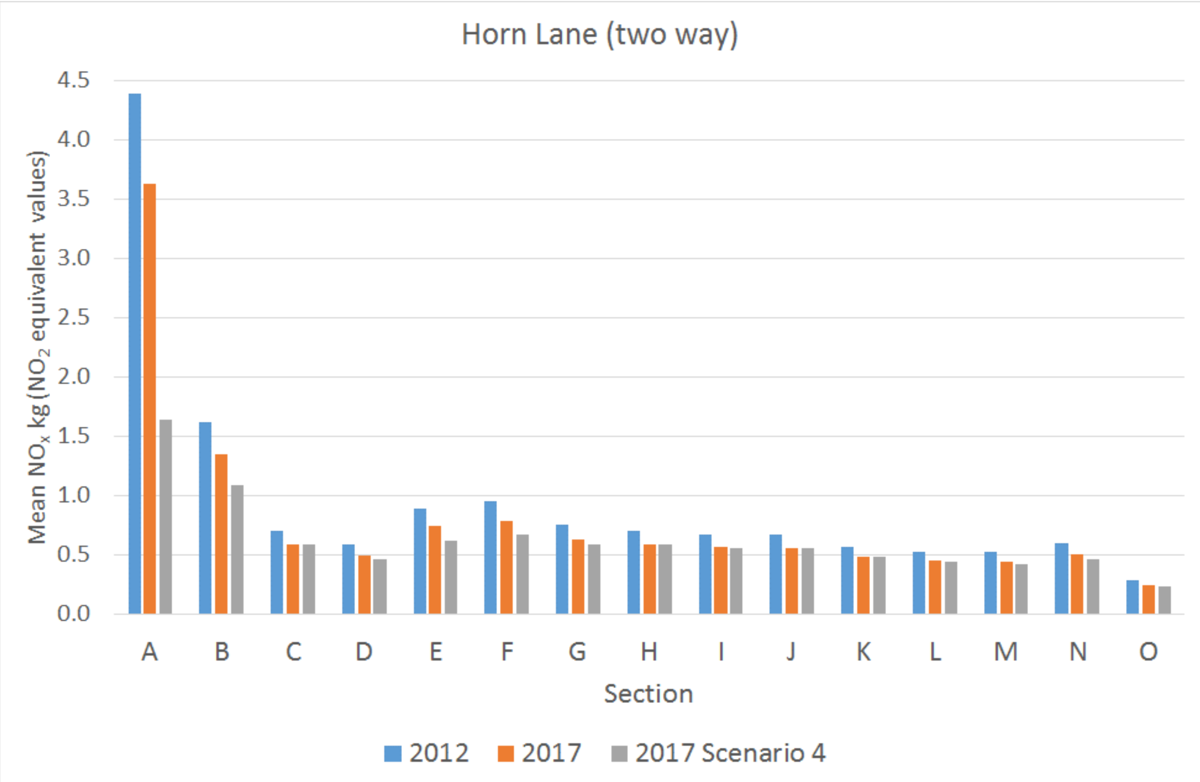

Figure 48: Horn Lane – Spatial variability of NO_x emissions

Horn Lane (Figure 48) is a particularly extreme example of spatial variation in NO_x emissions, due almost entirely to the step change in traffic flow and delays observed on the northbound approach to the junction with the A40 Western Avenue. Vehicles travelling westbound on the A40 wishing to travel north at this junction have to come off the A40 onto the one way Leamington Park before turning right onto the short one way northbound section of Horn Lane on the approach to the A40 (sections 'A' and 'B'). This is a five lane approach to the signalised junction, with significant stop times, particularly in section 'A'. Section 'A' has NO_x emissions of 4.38kg in 2012, whereas section 'B' has NOx emissions of 1.62kg, the difference being due almost entirely to the larger proportion of time spent stationary northbound in section 'A' (70%) compared to section 'B' (31%). The impact of scenario 4 (turn off engines when stationary) in this context is particularly effective in reducing NO_x emissions in section 'A' from 3.63kg in 2017 to 1.64kg (i.e. >50%) if engines are systematically turned off when stationary.

Relatively high levels of NO_x emissions on Horn Lane are also observed in sections ‘E’ and ‘F’ on the northbound and southbound approaches to the signalised junction with Friary Road (adjacent to the railway bridge). The percentage of journey time spent stationary on these two approaches are both greater than 40%.

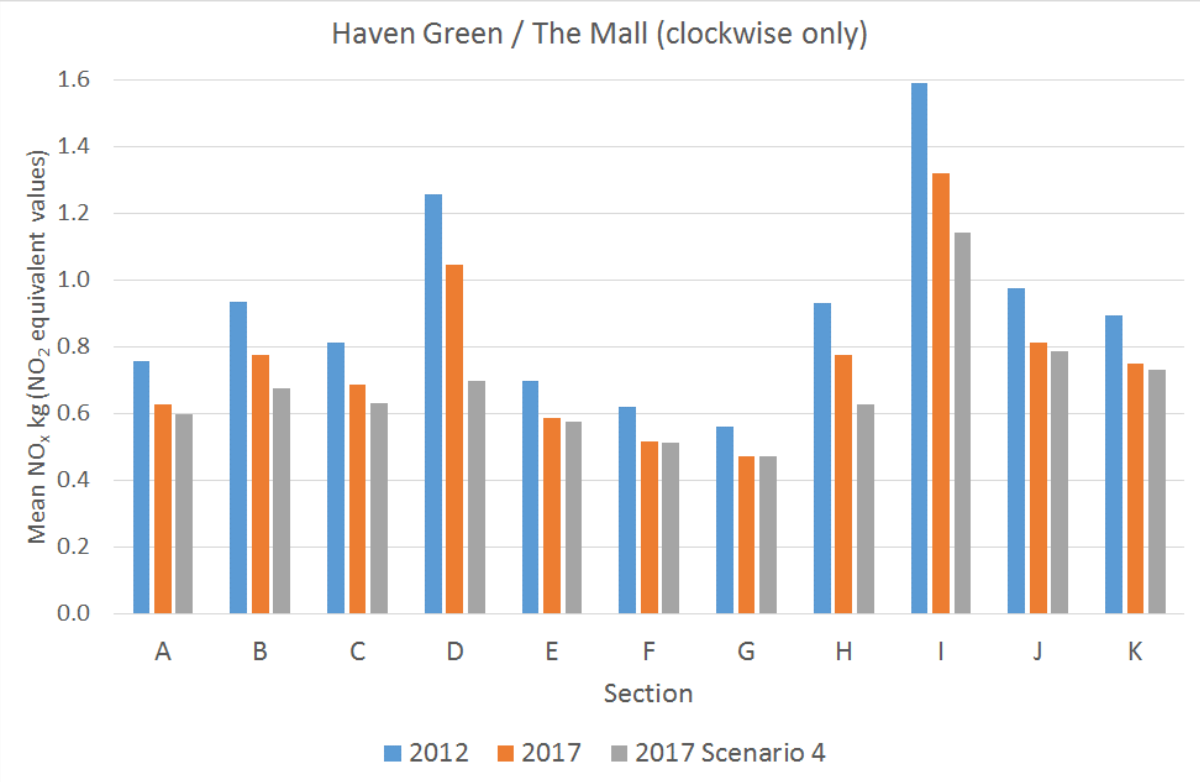

Figure 49: Haven Green / The Mall – Spatial variability of NO_x emissions

At Haven Green (Figure 49) the highest levels of NO_x emissions from light vehicles are observed in sections ‘I’ and ‘D’. N.B. in Figure 49, only one way clockwise traffic flows are presented on the two way sections ‘A’ and ‘B’ (The Broadway) and sections ‘E’ and ‘F’ (Haven Green). Section ‘I’ is the two way section including the westbound approach to Haven Green from The Mall. Section ‘D’ includes the one way northbound approach to the signalised junction with Castlebar Road. If two way traffic flows were included on sections ‘A’ and ‘B’ (The Broadway) and sections ‘E’ and ‘F’ (Haven Green), the emission results would be higher (approximately doubled), but the probe vehicle surveys were only carried out in a clockwise direction around Haven Green itself.

It is notable when comparing the NO_x emissions on sections ‘C’ and ‘D’ (Spring Bridge Road), which have the same traffic volume, that the emissions on section ‘D’ (1.26kg in 2012) are significantly higher (55%) than the emissions on section ‘C’ (0.81kg in 2012), due to the increased journey time, stops, and delay. There is a similar situation when comparing sections ‘G’ (0.56kg) and ‘H’ (0.93kg) where the difference is 66%.

On the A40 Western Avenue (Figure 50) there are notable local spatial peaks in NO_x emissions in sections ‘E’, ‘I’, ‘J’, ‘K’, and ‘P’. The peak in NO_x emissions in section ‘E’ (adjacent to Wendover Court) is associated particularly with westbound delays on the approach to the signalised junction with

Mansfield Road, where the average journey time spent stationary was observed to be 30%. Sections 'I', 'J', 'K' of the A40 Western Avenue case study area straddle the junction with Horn Lane at Gipsy Corner. As is to be expected, the peak in NO_x is dominated by sections 'K' and 'J' westbound, and by sections 'I', 'J' eastbound, corresponding with the location of queuing traffic on the approaches to this signalised junction. The peak in NO_x emissions in Section 'P' is due mainly to the queuing behaviour at the traffic signals travelling eastbound towards London. However, it should be noted that the eastbound results for section 'P' relate only to the right turning traffic from the A40 into Old Oak Road, as this was the route used during the probe vehicle surveys. Hence, for section 'P' eastbound, only the right turning traffic flow is used in the emissions calculations (the straight ahead traffic on the A40 towards London is excluded).

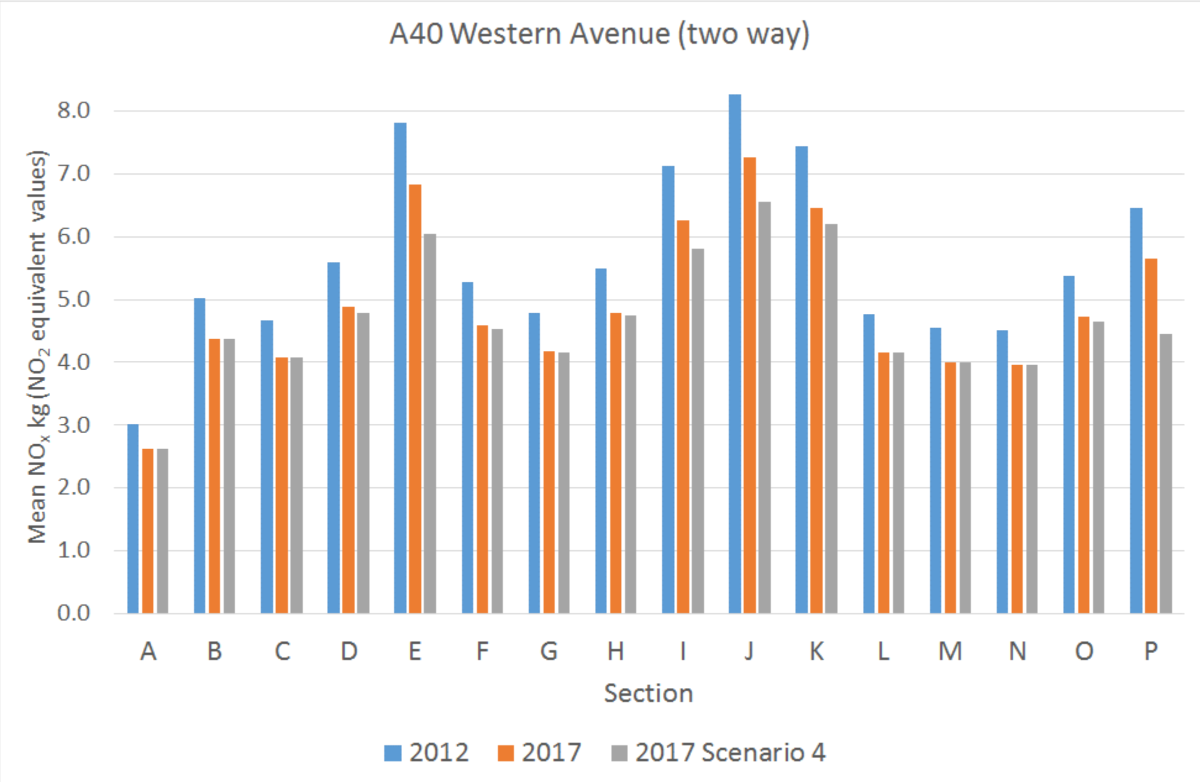

Figure 50: A40 Western Avenue – Spatial variability of NO_x emissions

The spatial variation in NO_x emissions on Western Road, Southall is illustrated in Figure 51. It should be noted that the probe vehicle results for Western Road were influenced by the presence of temporary traffic signals in the vicinity of the junctions with Albert Road / Leonard Road (section 'E'). This tended to influence eastbound traffic flows on sections 'C', 'D', and 'E', and westbound traffic flows on section 'F'. Temporary traffic signals are a common occurrence in urban areas, so the results are considered valid, as long as the existence of the temporary traffic signals is taken into account. As is to be expected, the additional delays caused by the temporary traffic signals have resulted in increased NO_x emissions in this local area. The other notable peak in NOx emissions, unrelated to the temporary traffic signals, is located in section 'K'. This is entirely due to westbound queuing on the approach to the signalised junction with King Street, at the eastern end of the case study area. Mean NO_x emissions in section 'K' (2.16kg at 2012) are 145% higher than section 'J' (0.88kg at 2012).

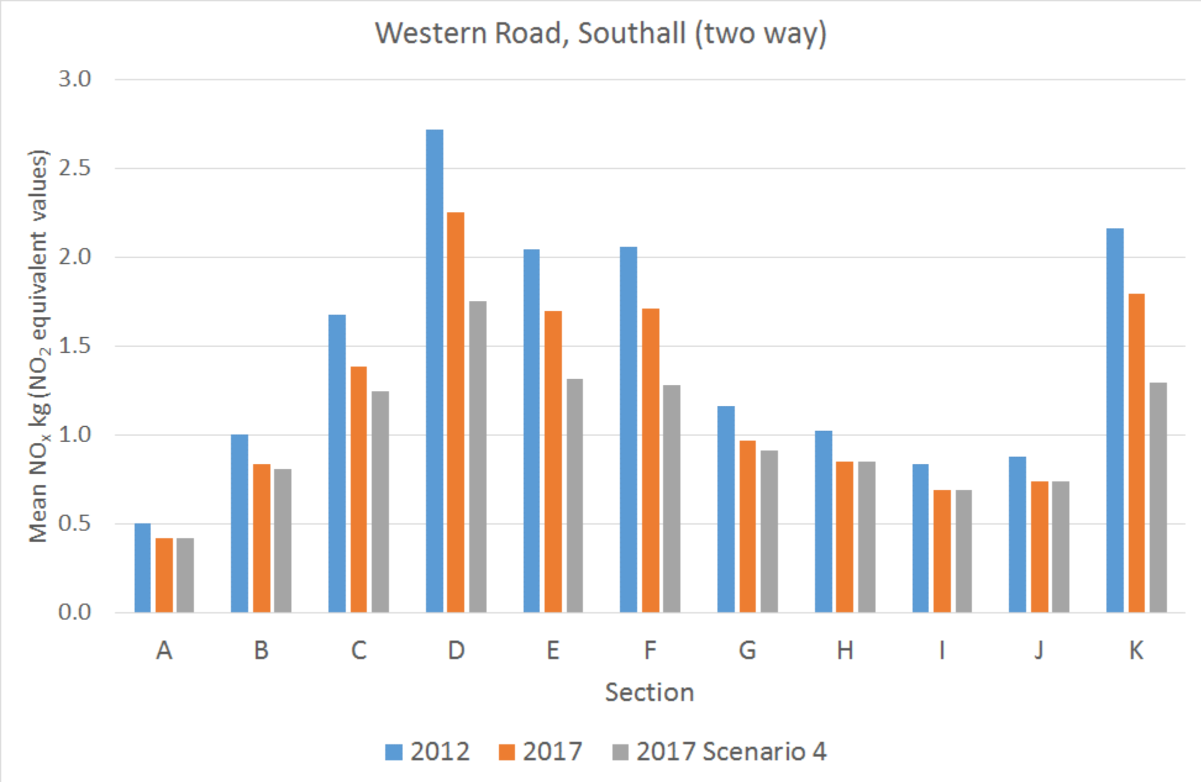

Figure 51: Western Road, Southall – Spatial variability of NO_x emissions

Table 49: Acton High Street – NO emissions by section and direction

Eastbound										
75th percentile	2017 Scenario 4	330	227	184	162	235	140	116	13	**1407**
75th percentile	2017	350	265	184	162	261	140	116	13	**1491**
75th percentile	2012	459	348	240	211	340	182	151	17	**1949**
Mean	2017 Scenario 4	228	183	148	152	189	128	111	12	**1151**
Mean	2017	237	198	154	154	200	128	112	12	**1194**
Mean	2012	310	259	200	201	260	166	145	15	**1556**
25th percentile	2017 Scenario 4	128	122	108	94	149	103	90	10	**804**
25th percentile	2017	128	122	108	94	149	103	90	10	**804**
25th percentile	2012	168	159	139	122	194	133	116	13	**1045**
Nitric oxide (NO) grams on section:		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Total**
25th percentile	2012	184	175	147	210	178	239	139	15	**1288**
25th percentile	2017	141	135	113	161	137	184	107	12	**989**
25th percentile	2017 Scenario 4	141	135	113	161	137	184	107	12	**989**
Mean	2012	385	468	386	353	415	408	297	21	**2732**
Mean	2017	295	358	296	270	317	312	227	16	**2091**
Mean	2017 Scenario 4	283	303	262	250	277	266	216	16	**1874**
75th percentile	2012	598	601	421	449	454	462	375	21	**3381**
75th percentile	2017	457	459	322	342	346	354	286	16	**2584**
75th percentile	2017 Scenario 4	425	393	305	301	339	271	274	16	**2323**
Westbound										

Table 50: Acton High Street – NO_2 emissions by section and direction

Eastbound										
75th percentile	2017 Scenario 4	151	102	84	75	108	63	54	5	**643**
75th percentile	2017	160	121	84	75	119	63	54	5	**681**
75th percentile	2012	141	107	74	66	105	56	47	5	**601**
Mean	2017 Scenario 4	103	82	67	70	87	59	50	5	**523**
Mean	2017	107	89	69	71	92	59	51	5	**543**
Mean	2012	94	79	61	63	81	51	44	4	**478**
25th percentile	2017 Scenario 4	56	53	48	44	69	47	40	4	**361**
25th percentile	2017	56	53	48	44	69	47	40	4	**361**
25th percentile	2012	49	46	42	38	60	41	35	4	**316**
Nitrogen dioxide (NO_2) grams on section:		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Total**
25th percentile	2012	58	54	44	63	52	71	42	4	**387**
25th percentile	2017	66	61	50	72	59	80	47	5	**439**
25th percentile	2017 Scenario 4	66	61	50	72	59	80	47	5	**439**
Mean	2012	122	147	119	108	128	125	92	6	**848**
Mean	2017	138	166	135	122	144	141	104	7	**958**
Mean	2017 Scenario 4	132	141	120	113	126	120	99	7	**859**
75th percentile	2012	190	189	129	139	141	142	117	6	**1054**
75th percentile	2017	213	213	146	156	159	161	132	7	**1189**
75th percentile	2017 Scenario 4	199	182	139	137	156	124	127	7	**1070**
Westbound										

Table 51: Horn Lane – NO emissions by section and direction

Nitric oxide (NO) grams on section:		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Total
Northbound																	
75th percentile	2017 Scenario 4	840	525	224	127	131	263	227	166	175	198	205	107	94	102	64	**3448**
75th percentile	2017	2537	525	224	127	131	442	227	166	175	198	205	107	94	102	64	**5324**
75th percentile	2012	3309	683	290	164	169	575	296	210	228	255	264	135	119	130	82	**6909**
Mean	2017 Scenario 4	821	480	177	129	131	216	186	177	152	173	149	118	101	109	58	**3176**
Mean	2017	1813	610	180	136	131	278	205	178	153	173	151	119	101	123	58	**4410**
Mean	2012	2361	790	233	175	168	361	267	229	197	224	193	152	129	157	74	**5709**
25th percentile	2017 Scenario 4	724	296	97	87	98	133	107	110	109	102	93	88	85	88	40	**2258**
25th percentile	2017	926	296	97	87	98	133	107	110	109	102	93	88	85	88	40	**2460**
25th percentile	2012	1201	375	123	111	125	171	138	138	139	130	116	110	108	111	50	**3145**
25th percentile	2012		64	118	103	137	134	113	116	126	122	105	105	98	99	50	**1490**
25th percentile	2017		51	95	84	108	104	88	92	99	97	85	84	78	77	40	**1183**
25th percentile	2017 Scenario 4		51	95	84	108	104	88	92	99	97	85	84	78	77	40	**1183**
Mean	2012		85	151	146	315	154	143	152	167	140	117	135	156	170	79	**2109**
Mean	2017		67	119	116	244	119	112	120	130	111	94	107	122	132	62	**1653**
Mean	2017 Scenario 4		66	119	105	181	119	112	120	130	111	94	107	113	126	60	**1562**
75th percentile	2012		71	145	129	479	161	151	165	198	150	117	153	109	124	79	**2232**
75th percentile	2017		56	116	104	369	124	118	129	153	119	94	118	87	97	63	**1746**
75th percentile	2017 Scenario 4		56	116	104	235	124	118	129	153	119	94	118	87	97	63	**1613**
Southbound																	

Table 52: Horn Lane – NO_2 emissions by section and direction

Nitrogen dioxide (NO_2) grams on section:		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Total
Northbound																	
75th percentile	2017 Scenario 4	393	233	101	58	60	120	102	71	79	91	94	46	40	43	27	**1555**
75th percentile	2017	1187	233	101	58	60	201	102	71	79	91	94	46	40	43	27	**2430**
75th percentile	2012	1075	209	90	51	53	179	90	62	70	80	83	40	35	37	23	**2179**
Mean	2017 Scenario 4	383	220	79	59	58	97	83	78	68	78	67	53	44	47	25	**1437**
Mean	2017	845	279	80	62	58	125	92	79	68	79	68	53	44	53	25	**2008**
Mean	2012	764	252	71	55	51	111	82	70	60	70	60	47	39	47	22	**1799**
25th percentile	2017 Scenario 4	334	131	41	38	42	56	46	46	48	45	40	38	36	37	17	**993**
25th percentile	2017	424	131	41	38	42	56	46	46	48	45	40	38	36	37	17	**1084**
25th percentile	2012	382	116	36	34	37	49	40	40	42	40	35	33	32	32	15	**963**
25th percentile	2012		18	33	29	40	39	33	35	37	34	30	30	28	29	15	**428**
25th percentile	2017		21	38	34	46	46	38	40	43	39	35	35	33	33	17	**498**
25th percentile	2017 Scenario 4		21	38	34	46	46	38	40	43	39	35	35	33	33	17	**498**
Mean	2012		24	43	42	95	47	43	46	50	39	33	39	46	52	23	**622**
Mean	2017		28	50	49	110	54	50	53	57	46	39	45	53	60	27	**720**
Mean	2017 Scenario 4		28	50	44	82	54	50	53	57	46	39	45	49	57	26	**679**
75th percentile	2012		20	42	36	148	49	46	49	59	42	33	45	31	39	23	**664**
75th percentile	2017		23	49	42	170	57	53	57	68	49	39	53	36	45	26	**768**
75th percentile	2017 Scenario 4		23	49	42	107	57	53	57	68	49	39	53	36	45	26	**705**
Southbound																	

Table 53: Haven Green / The Mall – NO emissions by section and direction

Clockwise and westbound													
75th percentile	2017 Scenario 4	303	410	331	392	296	319	285	379	373	331	201	**3621**
75th percentile	2017	303	477	335	699	296	319	285	499	531	358	201	**4304**
75th percentile	2012	395	622	426	916	379	416	364	652	694	467	259	**5592**
Mean	2017 Scenario 4	303	339	323	353	294	258	240	317	353	216	182	**3178**
Mean	2017	319	390	353	527	301	260	241	390	443	230	190	**3645**
Mean	2012	415	508	449	687	385	339	307	509	578	300	246	**4725**
25th percentile	2017 Scenario 4	228	263	270	268	242	187	187	236	284	103	90	**2359**
25th percentile	2017	228	263	270	363	242	187	187	236	336	103	90	**2506**
25th percentile	2012	294	341	338	467	308	242	235	307	438	132	115	**3217**
Nitric oxide (NO) grams on section:		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Total**
25th percentile	2012									198	171	149	**518**
25th percentile	2017									157	134	118	**409**
25th percentile	2017 Scenario 4									157	134	118	**409**
Mean	2012									287	231	242	**760**
Mean	2017									222	180	188	**590**
Mean	2017 Scenario 4									222	180	187	**588**
75th percentile	2012									282	233	312	**827**
75th percentile	2017									218	180	241	**639**
75th percentile	2017 Scenario 4									218	180	241	**639**
Eastbound													

Table 54: Haven Green / The Mall – NO_2 emissions by section and direction

Clockwise and westbound													
75th percentile	2017 Scenario 4	133	188	137	176	125	141	123	171	172	153	88	**1608**
75th percentile	2017	133	218	137	316	125	141	123	224	244	166	88	**1916**
75th percentile	2012	116	190	116	271	106	121	105	192	215	146	76	**1654**
Mean	2017 Scenario 4	132	154	134	158	123	114	103	142	162	99	81	**1403**
Mean	2017	139	178	147	236	126	115	103	175	204	105	85	**1613**
Mean	2012	120	154	124	202	107	99	88	150	179	93	74	**1390**
25th percentile	2017 Scenario 4	95	119	108	120	99	81	75	105	132	45	38	**1017**
25th percentile	2017	95	119	108	161	99	81	75	105	155	45	38	**1081**
25th percentile	2012	81	103	91	138	83	69	64	90	136	40	33	**928**
Nitrogen dioxide (NO_2) grams on section:		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Total**
25th percentile	2012									56	49	43	**148**
25th percentile	2017									64	57	49	**171**
25th percentile	2017 Scenario 4									64	57	49	**171**
Mean	2012									85	69	72	**226**
Mean	2017									97	79	83	**259**
Mean	2017 Scenario 4									97	79	82	**258**
75th percentile	2012									84	72	94	**250**
75th percentile	2017									97	83	107	**286**
75th percentile	2017 Scenario 4									97	83	107	**286**
Eastbound													

Table 55: A40 Western Avenue – NO emissions by section and direction

Eastbound																		
75th percentile	2017 Scenario 4	448	806	796	1647	1242	913	867	1017	2308	1926	1122	1085	885	884	951	717	**17614**
75th percentile	2017	448	806	796	1655	1242	913	867	1017	2798	1960	1122	1085	885	884	951	1433	**18862**
75th percentile	2012	545	996	987	2049	1493	1121	1073	1256	3432	2397	1367	1339	1086	1088	1171	1787	**23186**
Mean	2017 Scenario 4	420	783	785	1183	1140	964	906	1166	1690	1493	1191	1068	860	913	1135	633	**16331**
Mean	2017	420	783	785	1231	1199	964	911	1186	1922	1749	1191	1068	860	913	1171	1232	**17587**
Mean	2012	511	967	972	1523	1440	1186	1129	1466	2341	2120	1461	1318	1054	1127	1449	1537	**21603**
25th percentile	2017 Scenario 4	383	758	747	806	920	810	782	913	1044	1029	901	848	726	768	762	375	**12572**
25th percentile	2017	383	758	747	806	920	810	782	913	1044	1029	901	848	726	768	762	841	**13038**
25th percentile	2012	469	937	927	996	1097	993	967	1127	1250	1200	1098	1043	886	944	939	1046	**15917**
Nitric oxide (NO) grams on section:		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Total**
25th percentile	2012	621	1222	1295	1332	1309	1136	1207	1154	1337	1653	1809	1168	1237	1198	1264	1738	**20681**
25th percentile	2017	510	1008	1077	1103	1064	931	1010	958	1115	1391	1466	971	1041	1008	1071	1479	**17204**
25th percentile	2017 Scenario 4	510	1008	1077	1103	1064	931	1010	958	1115	1391	1465	971	1041	1008	1071	1479	**17202**
Mean	2012	1127	1763	1577	1517	2797	1678	1472	1511	1531	2356	2548	1278	1423	1334	1473	1973	**27358**
Mean	2017	911	1433	1299	1249	2262	1359	1210	1238	1270	1925	2056	1056	1187	1113	1238	1651	**22458**
Mean	2017 Scenario 4	911	1433	1299	1249	1922	1334	1210	1238	1270	1829	1926	1056	1187	1113	1238	1646	**21863**
75th percentile	2012	1185	1529	1459	1544	4022	1607	1363	1321	1660	2661	3089	1281	1368	1389	1590	1949	**29017**
75th percentile	2017	958	1245	1209	1275	3257	1300	1120	1086	1376	2155	2489	1064	1138	1154	1334	1612	**23772**
75th percentile	2017 Scenario 4	958	1245	1209	1275	2467	1300	1120	1086	1376	2149	2271	1064	1138	1154	1334	1612	**22758**
Westbound																		

Table 56: A40 Western Avenue – NO_2 emissions by section and direction

Nitrogen dioxide (NO_2) grams on section:		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Total**
Eastbound																		
75th percentile	2017 Scenario 4	182	360	373	788	485	389	384	467	1042	857	473	479	396	403	421	341	**7840**
75th percentile	2017	182	360	373	791	485	389	384	467	1255	872	473	479	396	403	421	679	**8408**
75th percentile	2012	155	310	321	681	413	333	330	401	1082	752	406	411	341	346	363	590	**7234**
Mean	2017 Scenario 4	175	350	365	546	453	417	407	533	741	644	518	474	387	418	534	300	**7263**
Mean	2017	175	350	365	568	477	417	409	542	843	755	518	474	387	418	552	584	**7834**
Mean	2012	149	301	314	489	406	358	352	467	725	648	445	408	332	359	476	508	**6736**
25th percentile	2017 Scenario 4	163	338	349	357	356	344	347	412	430	406	386	373	325	347	360	178	**5470**
25th percentile	2017	163	338	349	357	356	344	347	412	430	406	386	373	325	347	360	396	**5689**
25th percentile	2012	139	290	299	306	303	295	298	353	367	345	329	319	278	297	309	343	**4871**
25th percentile	2012	182	348	360	381	414	346	351	333	396	504	608	340	349	336	346	483	**6078**
25th percentile	2017	211	405	420	444	476	400	407	385	458	585	698	395	406	391	405	564	**7049**
25th percentile	2017 Scenario 4	211	405	420	444	476	400	407	385	458	585	698	395	406	391	405	564	**7049**
Mean	2012	356	537	454	443	914	530	438	456	460	759	848	374	411	376	411	565	**8332**
Mean	2017	406	617	526	511	1044	607	505	524	531	871	969	433	476	436	478	656	**9590**
Mean	2017 Scenario 4	406	617	526	511	887	596	505	524	531	827	908	433	476	436	478	654	**9316**
75th percentile	2012	368	466	412	443	1344	503	400	380	502	863	1042	376	389	384	439	558	**8871**
75th percentile	2017	423	532	477	512	1533	577	462	438	581	989	1188	435	452	446	512	645	**10203**
75th percentile	2017 Scenario 4	423	532	477	512	1143	577	462	438	581	989	1080	435	452	446	512	645	**9704**
Westbound																		

Table 57: Western Road, Southall – NO emissions by section and direction

Eastbound													
75th percentile	2017 Scenario 4	59	253	689	735	511	126	170	227	214	153	580	**3717**
75th percentile	2017	59	253	736	1041	663	126	170	227	214	153	948	**4591**
75th percentile	2012	75	331	963	1363	864	159	218	297	277	194	1240	**5981**
Mean	2017 Scenario 4	80	266	461	653	424	121	163	201	193	150	477	**3189**
Mean	2017	80	281	533	888	615	121	163	201	193	150	726	**3952**
Mean	2012	103	367	698	1163	802	154	209	261	251	192	949	**5148**
25th percentile	2017 Scenario 4	55	110	258	543	318	109	144	163	139	131	348	**2317**
25th percentile	2017	55	110	258	745	579	109	144	163	139	131	491	**2923**
25th percentile	2012	70	142	335	976	750	138	185	212	180	166	641	**3794**
Nitric oxide (NO) grams on section:		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Total**
25th percentile	2012	103	165	180	194	232	582	227	242	174	187	197	**2484**
25th percentile	2017	80	128	140	155	183	449	176	186	135	149	155	**1936**
25th percentile	2017 Scenario 4	80	128	140	155	183	348	176	186	135	149	155	**1835**
Mean	2012	170	179	209	311	308	965	420	297	202	287	224	**3575**
Mean	2017	131	140	162	241	239	740	323	229	157	225	175	**2760**
Mean	2017 Scenario 4	131	140	162	227	239	522	295	229	157	225	175	**2499**
75th percentile	2012	205	189	215	319	371	1054	580	354	217	291	235	**4030**
75th percentile	2017	157	147	166	247	285	807	443	272	167	226	181	**3098**
75th percentile	2017 Scenario 4	157	147	166	247	285	545	410	272	167	226	181	**2802**
Westbound													

Table 58: Western Road, Southall – NO_2 emissions by section and direction

Eastbound													
75th percentile	2017 Scenario 4	24	117	321	341	229	53	74	104	94	64	267	**1689**
75th percentile	2017	24	117	345	482	303	53	74	104	94	64	441	**2103**
75th percentile	2012	21	104	308	427	268	46	65	91	82	56	389	**1857**
Mean	2017 Scenario 4	34	122	215	303	193	51	72	91	86	65	222	**1454**
Mean	2017	34	129	249	412	280	51	72	91	86	65	337	**1806**
Mean	2012	30	114	221	365	247	45	63	80	76	56	298	**1594**
25th percentile	2017 Scenario 4	22	49	120	251	144	46	64	74	62	55	162	**1048**
25th percentile	2017	22	49	120	346	260	46	64	74	62	55	228	**1324**
25th percentile	2012	19	43	106	306	228	40	56	64	54	48	201	**1165**
Nitrogen dioxide (NO_2) grams on section:		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Total**
25th percentile	2012	33	48	53	56	68	181	69	71	54	56	55	**744**
25th percentile	2017	37	55	60	64	78	206	79	81	61	64	63	**851**
25th percentile	2017 Scenario 4	37	55	60	64	78	160	79	81	61	64	63	**805**
Mean	2012	54	53	62	93	94	299	130	88	62	87	64	**1086**
Mean	2017	61	61	71	106	107	339	148	101	70	100	73	**1237**
Mean	2017 Scenario 4	61	61	71	99	107	239	135	101	70	100	73	**1117**
75th percentile	2012	63	56	64	94	115	328	182	106	65	89	68	**1229**
75th percentile	2017	71	63	73	108	131	371	206	121	74	101	78	**1397**
75th percentile	2017 Scenario 4	71	63	73	108	131	249	189	121	74	101	78	**1258**
Westbound													

6.8 Intra case study area dynamic variation in emissions

Dynamic variation in NO_x emissions differs from spatial variation in this context in that dynamic variation is addressing variation due to differences in journey time, stops, and delays between individual runs or journeys. With reference to Volume 2: 'Probe Vehicle Survey Results', multiple probe vehicle 'runs' were carried out in each direction through each of the case study areas. As stated earlier in Section 3, in most case study areas (with the exception of Western Road, Southall), data from 30 or more runs was collected. This provided reasonable information on the degree of variability in journey times, stops, and delays typically encountered during an average weekday between 9.00am and 6.00pm.

Emission results for NO and NO_2 were calculated for every run in the probe vehicle surveys, for each light vehicle class. This permitted the variability in NO_x emissions due to vehicle dynamics to be quantified for each case study area, by spatial section and direction. This provides us with information regarding which case study areas, or sections of case study areas, are more prone to such variability, and potentially highlights opportunities for intervention to reduce NO_x emissions by managing such variability.

Figure 52 to Figure 60 inclusive illustrate the calculated variability in NO_x emissions (NO_2 equivalent values by mass) from light vehicles by direction for each of the case study areas. Table 49 to Table 58 inclusive present these data in numerical form, with the NO_x species, NO and NO_2, presented separately. The data present three key pollutant values: the mean (average) value; the 25th percentile value; and, the 75th percentile value. The mean value is obviously calculated from all of the relevant data to provide an average. The 25th percentile value tells us the value at which 25% of the data (probe vehicle runs) are equal to or less than this value. The 75th percentile value tells us the value at which only 25% of the data (probe vehicle runs) are greater than this value. I.e. 50% of the data (probe vehicle runs) falls between the 25th and 75th percentile values, with the remaining quarters being either lower than the 25th percentile, or higher than the 75th percentile. Hence, these values tell us something about the statistical distribution of these data. If there is a large difference between the 25th and 75th percentile values, variability is high; if there is only a small (or no) gap between the 25th and 75th percentile values, then variability is low.

On Acton High Street (Figure 52 and Figure 53) it can be seen that there is generally greater dynamic variability between runs for traffic travelling westbound, where the differences between the 25th and 75th percentile values of NO_x emissions are generally greater. Such variability tends to be observed across all spatial sections for westbound traffic. In contrast, high variability for eastbound traffic tends to be more notable in locations impacted directly by junctions and pedestrian crossings, for example, sections 'A', 'B', and 'E'. In less congested eastbound sections of Acton High Street such as 'F' and 'G', the difference between the 25th and 75th percentile values of NO_x are relatively small.

On Horn Lane (Figure 54 and Figure 55), as previously noted, the major emissions feature northbound is the spike in NO_x emissions on the approach to the A40 Western Avenue (section 'A'), due to the high traffic flow and significant stop times. The difference in NO_x emissions between the 75th percentile (6.15kg of NO_x) and the 25th percentile (2.22kg of NO_x) is very large, and demonstrates the potential for NO_x reduction in this hotspot if, for example, emissions from idling vehicles can be addressed. There is another spike northbound in section 'F' on the approach to the signalised junction with Friary Road, but this is obscured to some extent by the scale on the y axis of Figure 54 (because of the magnitude of NO_x emissions in section 'A').

On Horn Lane southbound, the main feature in the NO_x data occurs in section 'E', the southbound approach to the Friary Road junction, where the 75th percentile value is 0.88kg of NO_x, and the 25th percentile value is 0.25kg of NO_x. This can be loosely interpreted as the difference in NO_x emissions between encountering a red aspect or green aspect at the traffic signals at Friary Road. One notable feature on Horn lane southbound is in sections 'M' and 'N' in particular, where the mean value is larger than the 75th percentile value. This indicates that the majority of the data (probe vehicle runs) are stable and homogenous, with only one or two runs in the survey data encountering significant delays to skew the mean value upwards. This can in fact be seen in the survey data for Horn Lane (southbound) in Volume 2 of this report, where two runs encounter severe delays, but the remainder of the runs are generally free flowing and consistent.

At Haven Green (Figure 56), there is quite notable variability in journey times across runs, and consequent variation in NO_x emissions. The largest relative differences between the 75th and 25th percentile values occur in sections 'B', 'D', 'H', 'I', and 'J'. Perhaps understandably, these locations tend to be on the immediate approaches to traffic signals, where encountering a green aspect would result in a lower delay (and NO_x emissions), and encountering a red aspect would result in a higher delay (and NO_x emissions). The 75th percentile value on section 'D' is 1.68kg of NOx, whereas the 25th percentile value is 0.85kg of NO_x, i.e. approximately half.

On the A40 Western Avenue (Figure 57 and Figure 58), large differences between the 75th and 25th percentile values can be seen eastbound in sections 'D', 'I', 'J', and 'P'. These are on the approaches to the junctions with Mansfield Road, Horn Lane / Gipsy Corner, and Savoy Circus (Old Oak Road) respectively. In the westbound direction, the largest differences occur in sections 'E', 'J', and 'K', again, the approaches to the junctions at Mansfield Road and Horn Lane / Gipsy Corner. Elsewhere on the A40 Western Avenue, variability tends to be relatively quite low.

Finally, on Western Road, Southall (Figure 59 and Figure 60), the main variability eastbound tends to occur on the approach to the temporary traffic signals in the vicinity of the junctions with Albert Road / Leonard Road, and on the approach to the signalised junction at King Street. This causes variability in NOx emissions in sections 'C' and 'D', and in section 'K'. Elsewhere, variability tends to be relatively low. In the westbound direction on Western Road, the main variability in NOx emissions is observed in sections 'G' and 'F', on the approach to the temporary traffic signals.

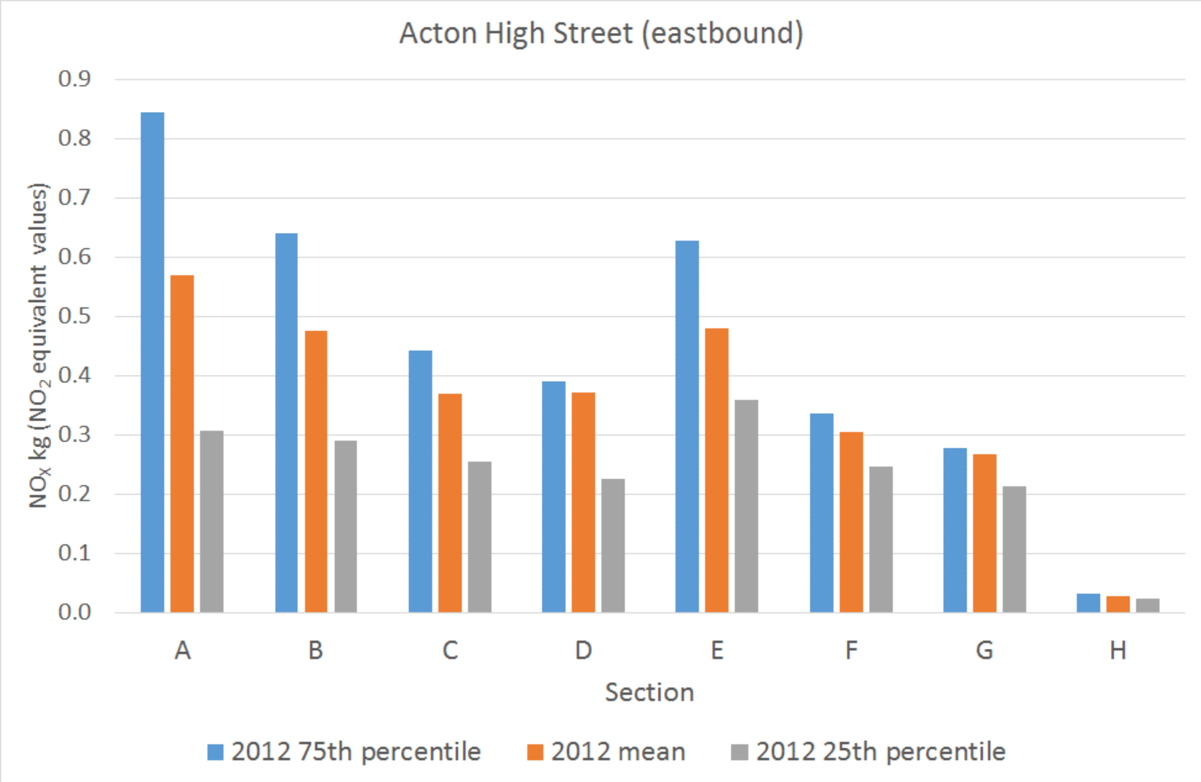

Figure 52: Acton High Street (eastbound) – Dynamic variation in NO_x emissions

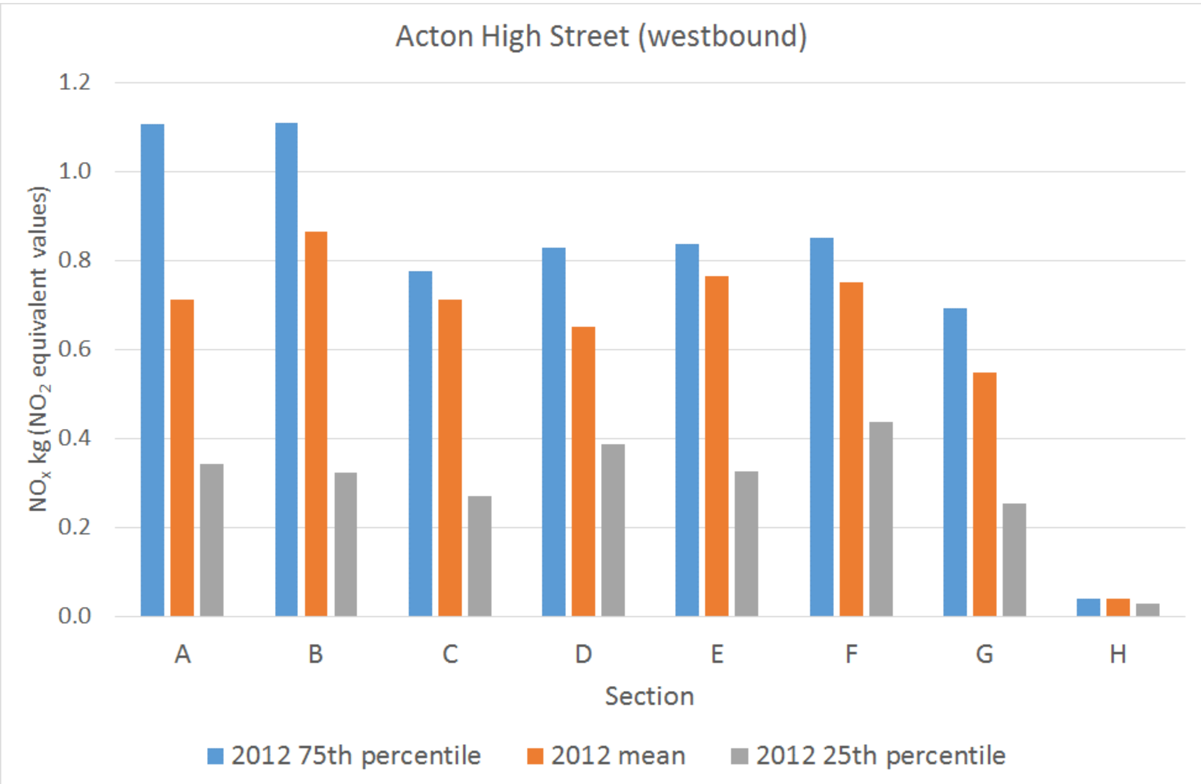

Figure 53: Acton High Street (westbound) – Dynamic variation in NO_x emissions

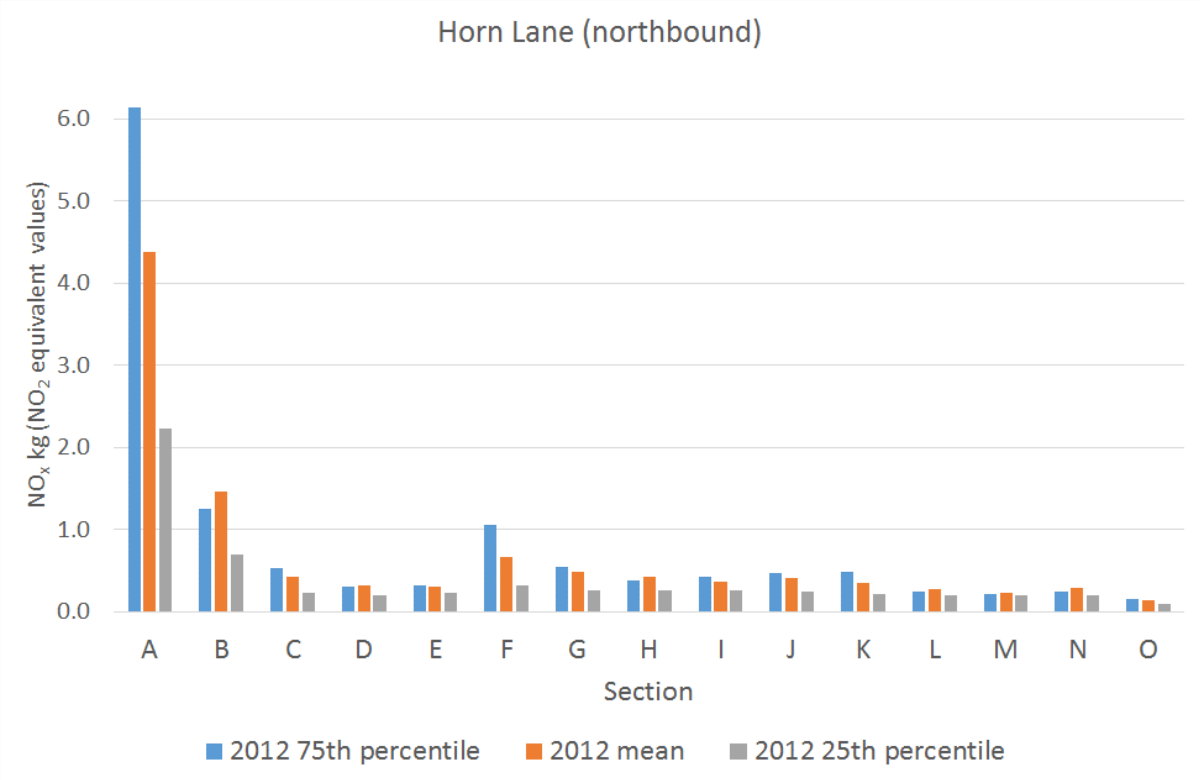

Figure 54: Horn Lane (northbound) – Dynamic variation in NO_x emissions

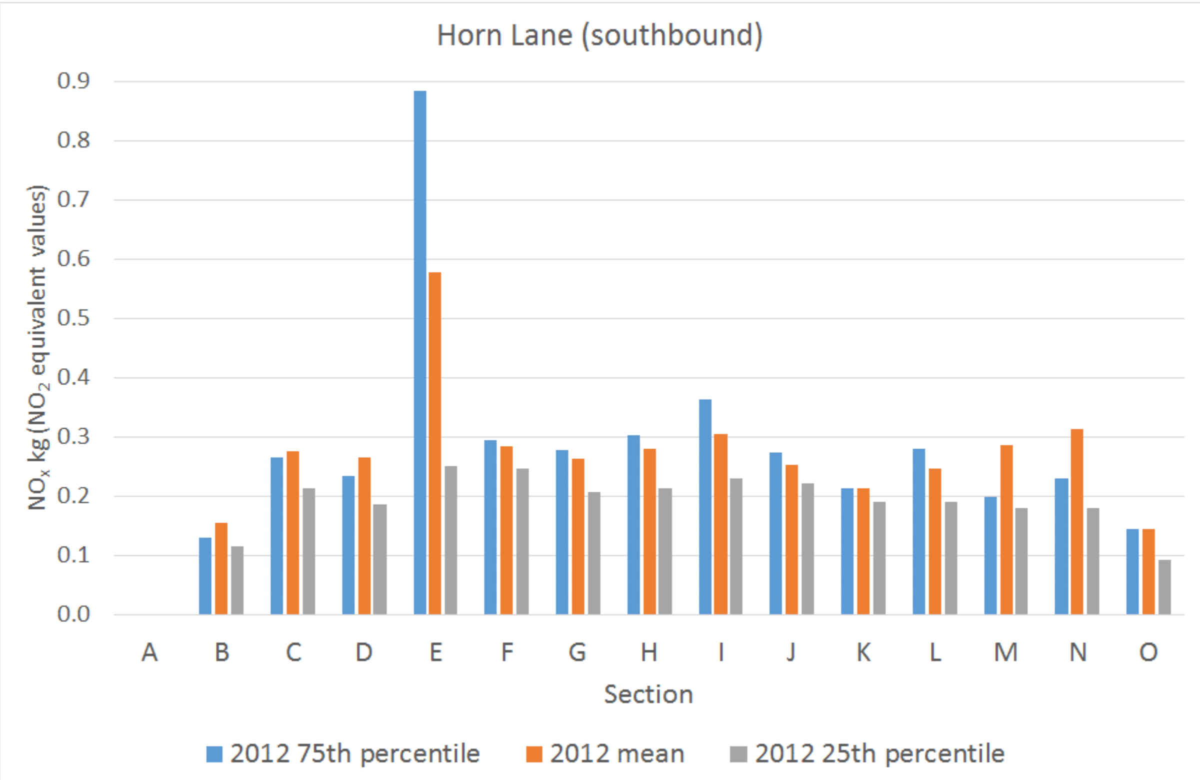

Figure 55: Horn Lane (southbound) – Dynamic variation in NO_x emissions

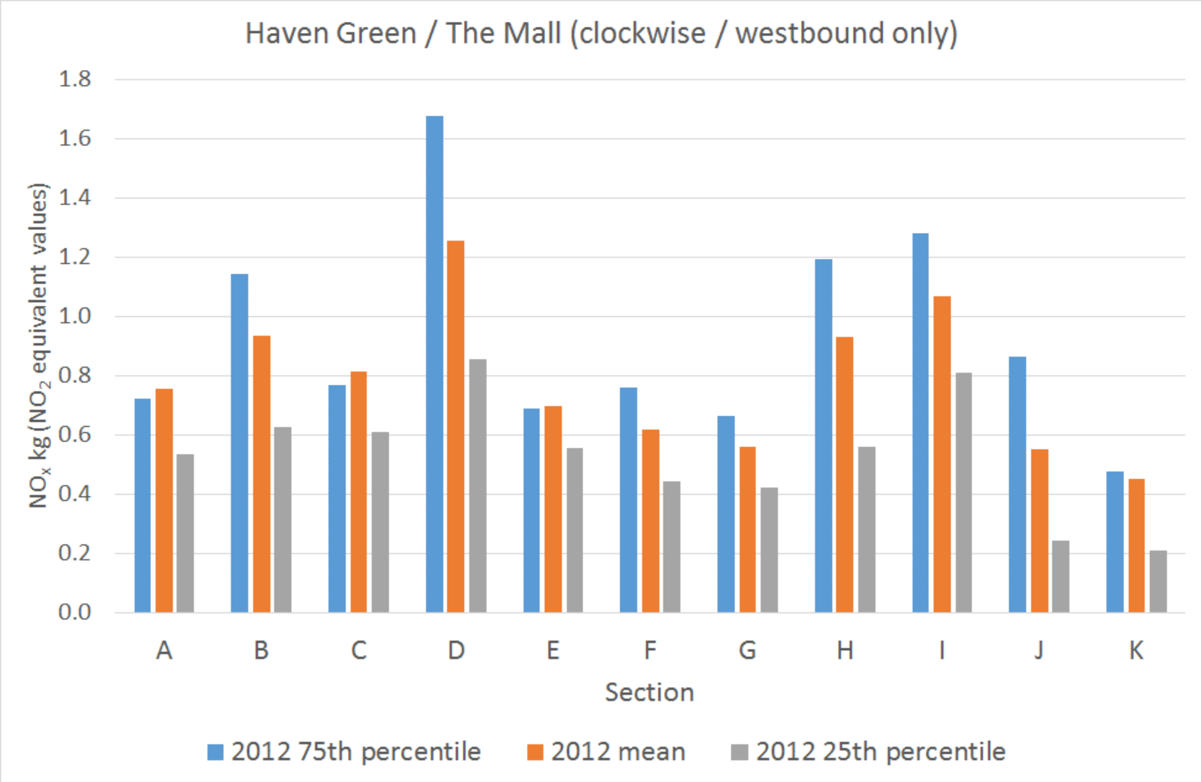

Figure 56: Haven Green / The Mall – Dynamic variation in NO_x emissions

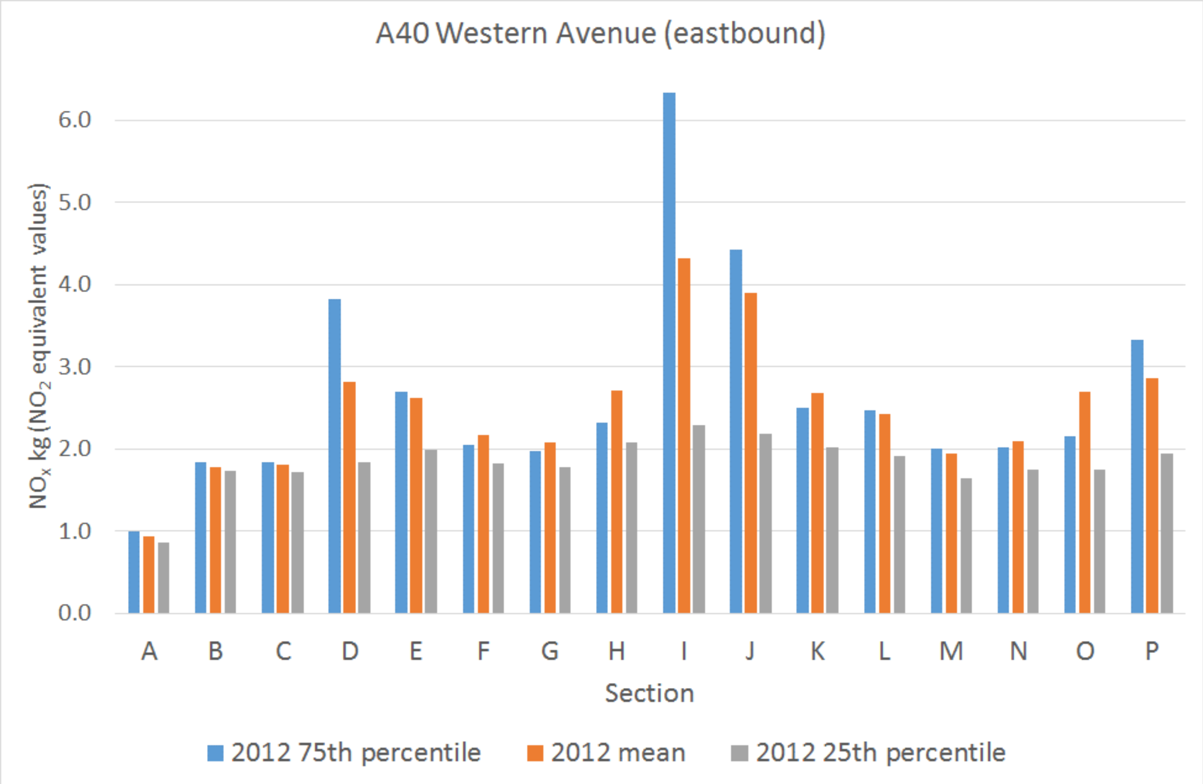

Figure 57: A40 Western Avenue (eastbound) – Dynamic variation in NO_x emissions

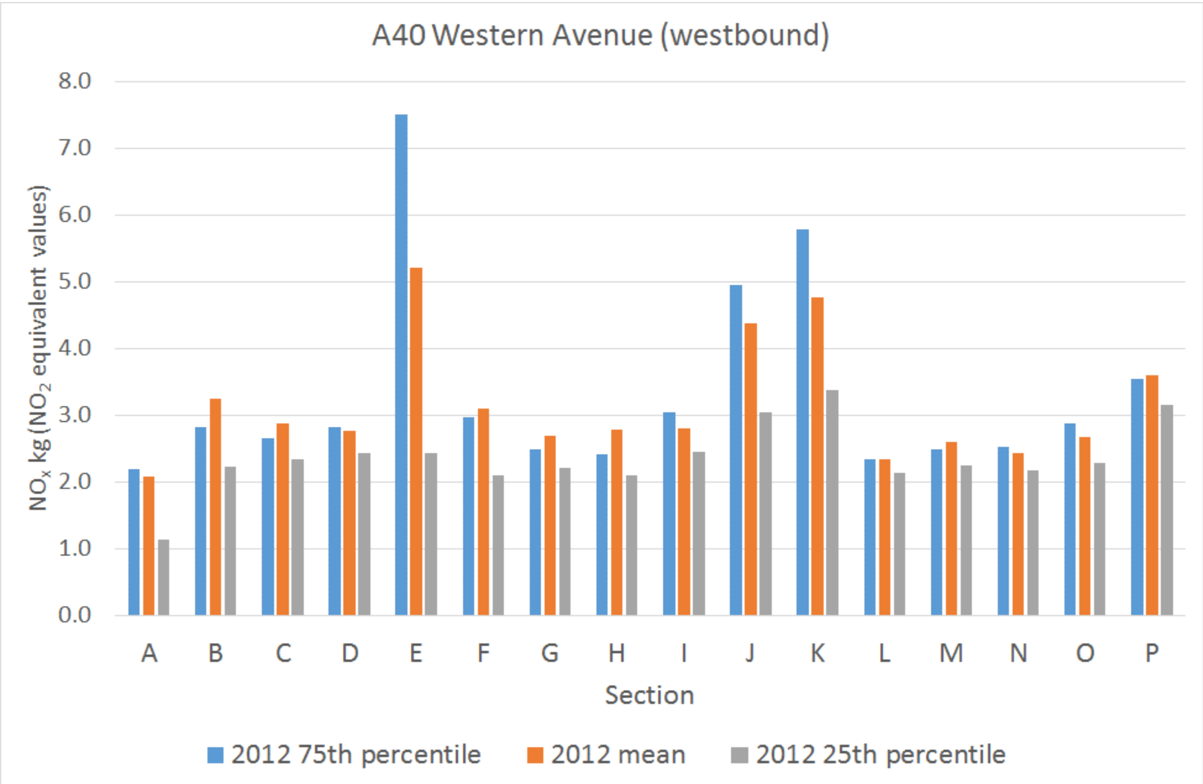

Figure 58: A40 Western Avenue (westbound) – Dynamic variation in NO_x emissions

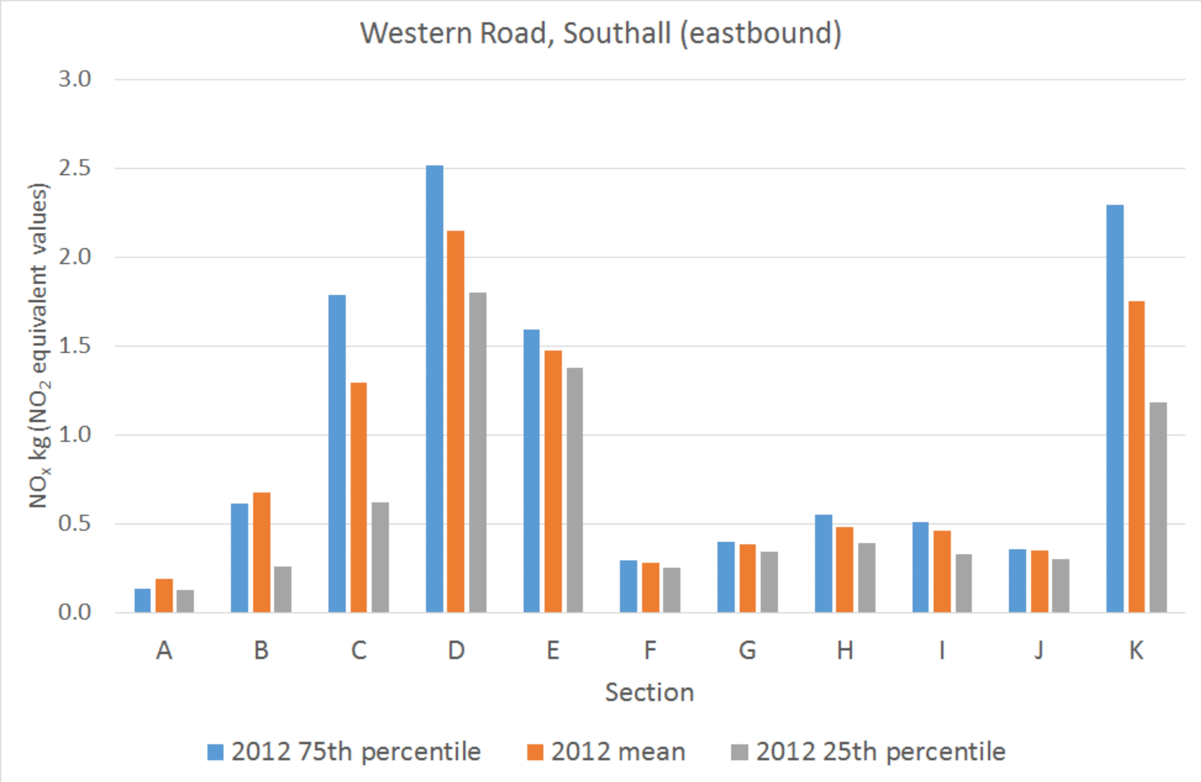

Figure 59: Western Road, Southall (eastbound) – Dynamic variation in NO_x emissions

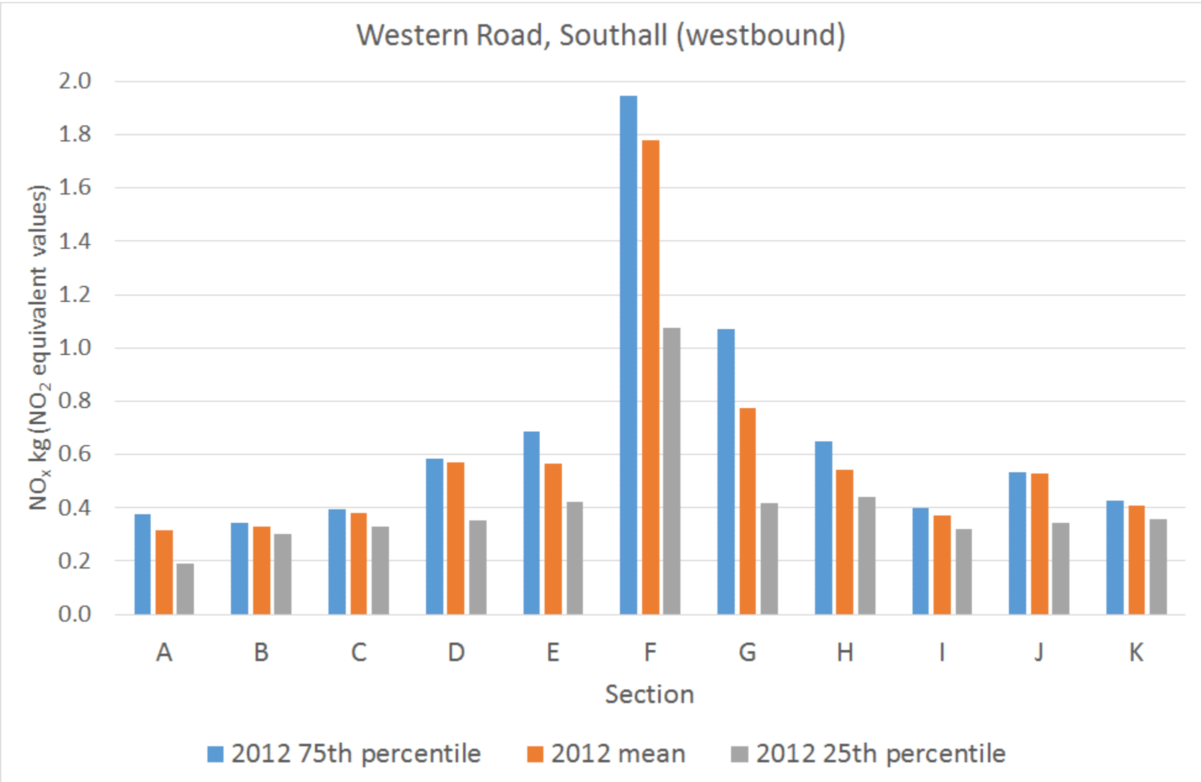

Figure 60: Western Road, Southall (westbound) – Dynamic variation in NO_x emissions

6.9 Euro 6 efficacy – Sensitivity test

A key issue in this analysis is the assumed efficacy of the Euro 6 emissions standard. It has generally been assumed in the previous sections that Euro 6 NO_x emissions from light duty diesel vehicles would be reduced pro rata in line with the reduction in NO_x type approval limit values from Euro 5 (180mg/km for diesel passenger cars) to Euro 6 (80mg/km for diesel passenger cars), i.e. a reduction of approximately 56%. Utilising these assumptions, it was calculated that light vehicle NO_x emissions (NO_2 equivalent values) summed over the case study areas would reduce by approximately 14% between 2012 and 2017, and by approximately 26% between 2012 and 2020.

However, past experience indicates that reductions in type approval limit values may not always translate into proportional 'real-world' reductions in pollutant emissions. There is very little empirical data available regarding real world performance of Euro 6 compliant light diesel vehicles at a fleet level, although a small number of portable emissions measurement system (PEMS) studies have been undertaken in Europe.

A small sample of data on Euro 6 diesel car emissions was collected in a remote sensing survey carried out in 2013 (Carslaw, 2013). This suggested that, for the vehicles observed, the relative reduction in NO_x emissions from Euro 6 diesel cars compared to Euro 5 was of the order of 40%, rather than the 56% expected from the change in type approval limit values. As a sensitivity test, the 2017 and 2020 baseline scenarios (with traffic growth) have been recalculated assuming this more conservative reduction in NO_x for Euro 6 light duty diesel vehicles (cars, vans, and taxis).

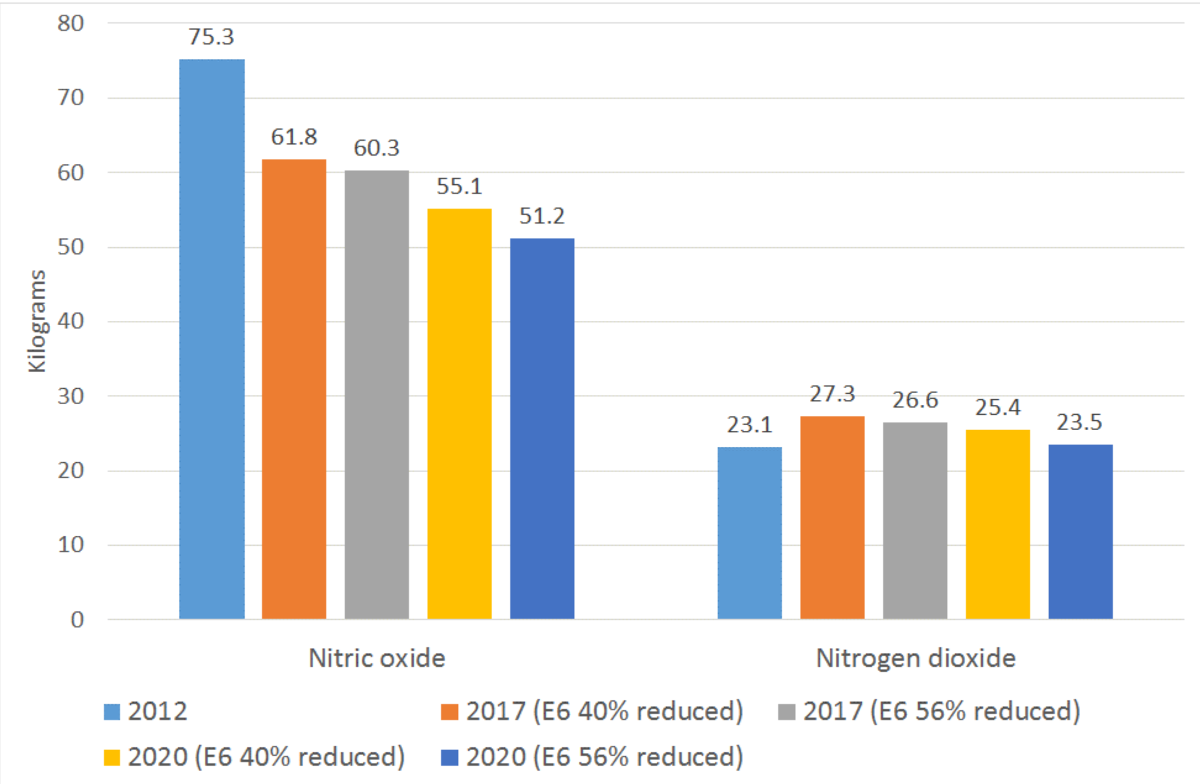

Figure 61: Sensitivity test for Euro 6 diesel NO and NO_2 reduction efficacy

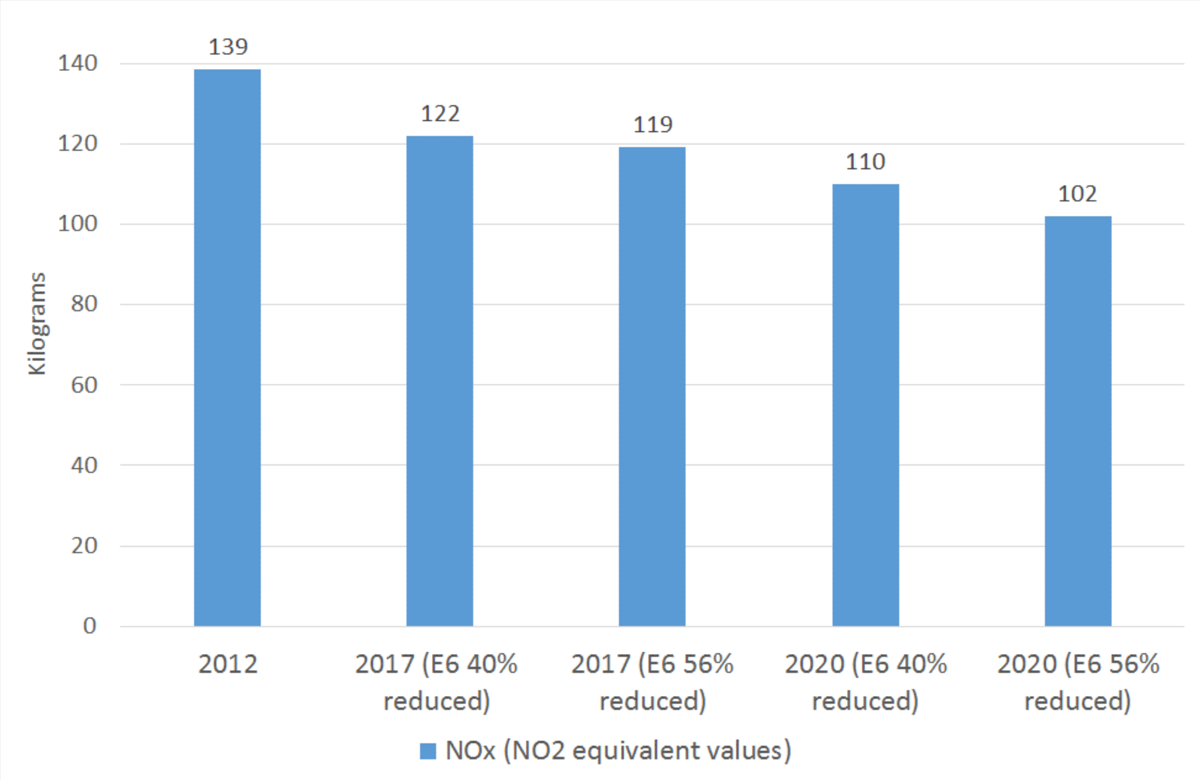

Figure 62: Sensitivity test for Euro 6 diesel NO_x reduction efficacy

Figure 61 presents the impact on emissions of NO and NO_2 summed over the case study areas as a result of the change in assumed NO_x emissions reduction at Euro 6 (-40% rather than -56%, relative to Euro 5). The nitric oxide component is assumed to decline from 75.3kg in 2012, to 61.8kg in 2017 (-18% relative to 2012, compared to -20% with the original more optimistic assumption), and finally 55.1kg in 2020 (-27% relative to 2012, compared to -32% with the original more optimistic assumption). However, the nitrogen dioxide component of total NO_x is observed to increase from 23.1kg in 2012, to 27.3kg in 2017 (+18% relative to 2012, compared to +15% with the original assumption), before reducing to 25.4kg in 2020 (+10% relative to 2012, compared to +2% with the original assumption). Primary NO_2 emissions from light vehicles in the case study areas increase to 2017, and whilst they decline in the following period to 2020, they remain above 2012 absolute levels.

Figure 62 presents the aggregate light vehicle total NO_x emissions across the case study areas by reference year. The base 2017 scenario light vehicle total NO_x emissions are approximately 12% lower than 2012 (compared to 14% lower with the original Euro 6 assumption); the base 2020 scenario NO_x emissions are approximately 21% lower than 2012 (compared to 27% lower with the original Euro 6 assumption). Table 59 to Table 62 present the revised emissions results by vehicle type and case study area for NO and NO_2 at 2017 and 2020, assuming a 40% reduction in NO_x from Euro 6 compliant light duty diesel vehicles, instead of the originally assumed 56% reduction.

It is important to note that the Euro 5 to Euro 6 NO_x reduction assumption of 40% in this sensitivity test is based upon a small sample of early Euro 6 diesel light vehicles. It is not known whether this will prove to be representative in future years as more Euro 6 vehicles enter the fleet.

In addition, it should be noted that if the 40% reduction in NO_x observed in 2013 was measured in terms of NO_x/CO_2 ratio or grams of NO_x per kilogram of fuel burnt, then any improvement in fuel consumption in the transition from Euro 5 to Euro 6 would result in a reduction in NO_x *mass* emissions of greater than the 40% reduction observed (because less fuel is being consumed). For example, if fuel consumption reduced by 5%, the reduction in NO_x *mass* emissions at Euro 6 would be 43%. Of course, if fuel consumption became higher at Euro 6, the opposite would be true.

Finally, the light vehicle type approval test procedure is likely to change in 2017, moving from the current New European Driving Cycle (NEDC) to the more stringent World-wide Harmonized Light vehicles Test Procedure (WHLTP). Whilst the Euro 6 type approval NO_x limit value for light duty diesel vehicles will remain at 80mg/km, the adoption of a test procedure which is more closely aligned to real-world driving is likely to improve the NO_x emissions performance of light duty diesel vehicles from 2017 onwards (if not sooner).

Table 59: Sensitivity test - Euro 6 efficacy reduced for light diesels - 2017 (Mean NO grams)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	1	1	0	0	**4**
	Euro 1	0	1	0	1	0	1	0	4	4	1	1	**13**
	Euro 2	3	6	2	8	3	12	5	43	49	11	8	**149**
	Euro 3	47	81	23	112	34	159	66	605	720	154	107	**2109**
	Euro 4	161	282	80	389	118	558	232	2112	2498	538	371	**7340**
	Euro 5	202	344	102	483	145	683	295	3069	3657	654	464	**10097**
	Euro 6	53	90	27	126	38	178	77	801	955	171	121	**2636**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	1	1	0	0	**5**
	Euro 1	0	1	0	1	0	1	0	4	4	1	1	**13**
	Euro 2	2	3	1	4	1	6	3	24	27	6	4	**82**
	Euro 3	23	41	11	55	17	80	32	281	336	77	52	**1004**
	Euro 4	69	118	35	166	50	236	101	903	1114	225	160	**3177**
	Euro 5	54	93	27	130	39	185	78	721	883	178	124	**2511**
	Euro 6	11	19	6	27	8	39	16	150	184	37	26	**522**
	Sub total												**29662**
Car Petrol													
< 1.4 l	Euro 0	1	2	1	2	1	4	1	13	15	3	2	**45**
	Euro 1	2	3	1	4	1	6	2	21	24	6	4	**73**
	Euro 2	6	9	3	13	4	19	8	76	92	18	13	**261**
	Euro 3	10	17	5	23	7	33	14	131	155	32	23	**449**
	Euro 4	30	53	16	74	22	106	45	416	531	100	71	**1466**
	Euro 5	17	25	9	39	11	53	26	235	277	49	38	**780**
	Euro 6	8	12	4	19	5	26	13	115	135	24	19	**381**
1.4 - 2.0 l	Euro 0	2	4	1	5	2	8	3	27	31	8	5	**96**
	Euro 1	3	5	1	7	2	10	4	37	42	10	7	**129**
	Euro 2	17	29	9	40	12	57	24	211	249	55	39	**742**
	Euro 3	24	42	12	56	17	80	32	287	344	79	54	**1027**
	Euro 4	60	104	30	145	44	208	86	766	920	199	140	**2702**
	Euro 5	9	14	5	22	6	29	15	129	164	27	21	**440**
	Euro 6	3	5	2	7	2	10	5	45	57	9	7	**152**
> 2.0 l	Euro 0	1	1	0	2	1	3	1	10	11	3	2	**34**
	Euro 1	1	1	0	2	1	3	1	10	11	3	2	**34**
	Euro 2	4	8	2	10	3	15	6	47	56	15	10	**176**
	Euro 3	5	10	3	13	4	19	7	62	72	18	12	**225**
	Euro 4	6	11	3	16	5	23	9	76	88	22	15	**274**
	Euro 5	2	3	1	4	1	5	2	19	21	5	4	**67**
	Euro 6	1	1	0	2	1	2	1	8	10	2	2	**30**
Hybrid	Euro 4	0	0	0	1	0	1	0	3	3	1	1	**11**
	Euro 5	3	6	2	8	2	11	4	40	46	11	7	**140**
	Euro 6	1	1	0	2	1	3	1	11	12	3	2	**37**
	Sub total												**9771**
Van Diesel													
	Euro 3	20	36	9	37	14	86	24	319	442	67	47	**1103**
	Euro 4	83	149	40	153	60	358	105	1373	1947	277	194	**4737**
	Euro 5	223	409	105	412	162	975	276	3928	5603	761	521	**13375**
	Euro 6	42	78	20	78	31	185	52	745	1063	144	99	**2538**
	Sub total												**21753**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	1	0	0	**2**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**1**
LTI TX1	Euro 2	1	2	0	10	1	3	1	11	12	3	2	**45**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	1	0	0	**2**
LTI TXII	Euro 3	3	5	2	38	2	10	4	42	50	10	7	**174**
LTI TX4	Euro 4	3	6	2	40	2	11	4	42	49	11	7	**179**
Merc Vito 111	Euro 4	0	1	0	6	0	2	1	6	7	2	1	**26**
LTI TX4	Euro 5	2	4	1	29	2	8	3	29	33	8	5	**123**
Merc Vito 113	Euro 5	1	1	0	7	0	2	1	8	9	2	1	**33**
LTI TXX	Euro 6	1	2	1	13	1	4	1	13	15	3	2	**55**
Merc Vito XXX	Euro 6	0	0	0	1	0	0	0	2	2	0	0	**7**
	Total	1222	2140	604	2845	883	4516	1691	18031	23033	4044	2825	**61833**

Table 60: Sensitivity test – Euro 6 efficacy reduced for light diesels - 2017 (Mean NO_2 grams)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	1	1	0	0	**4**
	Euro 2	0	1	0	1	0	2	1	6	6	2	1	**20**
	Euro 3	14	23	7	32	10	45	19	173	189	44	31	**587**
	Euro 4	76	128	38	180	54	254	108	992	1150	244	173	**3397**
	Euro 5	92	157	45	218	66	308	130	1355	1545	298	209	**4423**
	Euro 6	24	41	12	57	17	80	34	354	403	78	54	**1155**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	1	1	0	0	**4**
	Euro 2	0	1	0	1	0	1	0	4	4	1	1	**13**
	Euro 3	10	17	5	23	7	33	14	121	141	32	22	**425**
	Euro 4	71	126	34	168	52	243	96	867	989	239	161	**3047**
	Euro 5	44	75	21	102	31	146	60	552	613	143	98	**1885**
	Euro 6	9	16	4	21	7	30	12	115	127	30	20	**392**
	Sub total												**15352**
Car Petrol													
< 1.4 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 2	0	0	0	0	0	0	0	2	2	0	0	**6**
	Euro 3	0	1	0	1	0	1	0	5	6	2	1	**17**
	Euro 4	2	5	1	6	2	9	3	29	33	9	6	**105**
	Euro 5	4	7	2	9	3	14	5	45	50	14	9	**162**
	Euro 6	2	4	1	5	1	7	2	22	24	7	4	**79**
1.4 - 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 1	0	0	0	0	0	0	0	0	1	0	0	**2**
	Euro 2	0	1	0	1	0	1	0	4	4	1	1	**14**
	Euro 3	1	2	0	2	1	3	1	11	12	3	2	**39**
	Euro 4	5	9	2	11	4	17	6	51	57	17	10	**189**
	Euro 5	2	5	1	6	2	9	3	28	34	9	6	**105**
	Euro 6	1	2	0	2	1	3	1	10	12	3	2	**36**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 2	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 3	0	1	0	1	0	1	0	2	2	1	1	**8**
	Euro 4	2	4	1	4	2	8	2	14	14	8	4	**62**
	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
Hybrid	Euro 4	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 5	1	2	0	2	1	3	1	12	14	3	2	**43**
	Euro 6	0	0	0	1	0	1	0	3	4	1	1	**11**
	Sub total												**887**
Van Diesel													
	Euro 3	5	8	2	8	3	20	5	71	93	16	11	**243**
	Euro 4	52	96	24	95	38	225	63	819	1106	178	120	**2816**
	Euro 5	114	206	53	208	82	488	138	1964	2662	384	263	**6562**
	Euro 6	22	39	10	39	16	93	26	373	505	73	50	**1245**
	Sub total												**10866**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TX1	Euro 2	0	0	0	1	0	0	0	1	1	0	0	**5**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TXII	Euro 3	1	1	0	9	1	2	1	9	10	2	2	**38**
LTI TX4	Euro 4	1	1	0	9	1	3	1	9	9	3	2	**38**
Merc Vito 111	Euro 4	0	0	0	2	0	1	0	2	2	1	0	**9**
LTI TX4	Euro 5	1	1	0	10	1	3	1	11	12	3	2	**45**
Merc Vito 113	Euro 5	1	1	0	7	0	2	1	7	8	2	1	**31**
LTI TXX	Euro 6	0	1	0	5	0	1	1	5	5	1	1	**20**
Merc Vito XXX	Euro 6	0	0	0	1	0	0	0	2	2	0	0	**6**
	Total	557	983	266	1251	404	2062	739	8053	9860	1853	1269	**27298**

Table 61: Sensitivity test – Euro 6 efficacy reduced for light diesels - 2020 (Mean NO grams)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	1	2	0	2	1	3	1	12	14	3	2	**43**
	Euro 3	17	29	8	40	12	56	24	214	255	54	38	**747**
	Euro 4	100	175	50	242	73	347	144	1313	1553	335	230	**4562**
	Euro 5	224	381	113	535	160	756	327	3400	4052	725	514	**11187**
	Euro 6	134	228	68	321	96	454	196	2041	2432	435	308	**6714**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	1	0	1	0	1	1	5	6	1	1	**18**
	Euro 3	8	14	4	19	6	28	11	99	119	27	19	**355**
	Euro 4	41	70	21	98	29	140	60	533	658	133	94	**1876**
	Euro 5	59	102	30	142	43	202	85	787	965	194	136	**2744**
	Euro 6	26	45	13	62	19	89	37	345	423	85	59	**1202**
	Sub total												**29447**
Car Petrol													
< 1.4 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	2	3	1	4	1	5	2	21	25	5	4	**70**
	Euro 3	3	6	2	8	2	11	5	45	54	11	8	**156**
	Euro 4	18	31	9	44	13	62	27	244	311	59	42	**859**
	Euro 5	18	28	10	44	12	59	29	262	309	55	42	**868**
	Euro 6	21	32	11	49	14	67	32	295	347	62	48	**977**
1.4 - 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	5	8	2	11	3	15	6	56	66	15	10	**196**
	Euro 3	8	15	4	20	6	28	11	100	120	27	19	**358**
	Euro 4	32	55	16	77	23	110	45	404	485	105	74	**1426**
	Euro 5	10	15	5	24	7	32	16	141	179	29	23	**480**
	Euro 6	7	11	4	16	5	22	11	99	125	20	16	**337**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	1	2	0	2	1	4	1	11	13	3	2	**42**
	Euro 3	2	3	1	5	1	7	3	22	25	6	4	**79**
	Euro 4	3	6	2	8	2	12	5	39	45	11	8	**141**
	Euro 5	2	3	1	4	1	6	2	21	23	6	4	**74**
	Euro 6	2	3	1	4	1	6	2	21	23	6	4	**74**
Hybrid	Euro 4	0	0	0	0	0	1	0	2	2	1	0	**7**
	Euro 5	3	5	1	7	2	9	4	35	40	9	6	**121**
	Euro 6	3	4	1	6	2	9	3	32	36	8	6	**111**
	Sub total												**6375**
Van Diesel													
	Euro 3	2	4	1	4	2	10	3	38	53	8	6	**131**
	Euro 4	22	40	11	41	16	96	28	370	525	75	52	**1277**
	Euro 5	167	307	79	310	122	733	207	2952	4211	572	391	**10051**
	Euro 6	121	222	57	223	88	528	149	2128	3036	412	282	**7246**
	Sub total												**18705**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TX1	Euro 2	0	0	0	2	0	1	0	2	2	1	0	**9**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TXII	Euro 3	1	2	1	15	1	4	2	16	20	4	3	**67**
LTI TX4	Euro 4	3	6	2	42	2	12	5	43	51	11	8	**184**
Merc Vito 111	Euro 4	1	1	0	7	0	2	1	7	8	2	1	**31**
LTI TX4	Euro 5	3	5	1	32	2	9	3	32	36	9	6	**136**
Merc Vito 113	Euro 5	1	1	0	7	0	2	1	7	9	2	1	**31**
LTI TXX	Euro 6	3	4	1	31	2	9	3	31	36	8	6	**134**
Merc Vito XXX	Euro 6	0	0	0	4	0	1	0	4	5	1	1	**16**
	Total	1072	1869	532	2511	773	3947	1494	16229	20696	3535	2479	**55138**

Table 62: Sensitivity test – Euro 6 efficacy reduced for light diesels - 2020 (Mean NO_2 grams)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Car Diesel													
< 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	2	2	0	0	**6**
	Euro 3	5	8	2	11	3	16	7	61	67	16	11	**208**
	Euro 4	47	80	23	112	34	158	67	617	715	152	107	**2111**
	Euro 5	102	174	50	241	73	342	144	1501	1711	330	231	**4900**
	Euro 6	61	104	30	145	44	205	86	901	1027	198	139	**2941**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 3	4	6	2	8	2	12	5	43	50	11	8	**150**
	Euro 4	42	75	20	99	31	143	57	512	584	141	95	**1799**
	Euro 5	48	82	23	112	34	160	65	604	669	156	107	**2059**
	Euro 6	21	36	10	49	15	70	29	264	293	68	47	**902**
	Sub total												**15079**
Car Petrol													
< 1.4 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	0	1	0	0	**2**
	Euro 3	0	0	0	0	0	1	0	2	2	1	0	**6**
	Euro 4	1	3	1	4	1	5	2	17	20	5	3	**62**
	Euro 5	4	8	2	10	3	16	5	50	56	16	10	**180**
	Euro 6	5	9	2	12	4	18	6	56	63	18	11	**202**
1.4 - 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	1	1	0	0	**4**
	Euro 3	0	1	0	1	0	1	0	4	4	1	1	**13**
	Euro 4	2	5	1	6	2	9	3	27	30	9	5	**100**
	Euro 5	2	5	1	7	2	10	3	30	37	10	6	**115**
	Euro 6	2	4	1	5	1	7	2	21	26	7	4	**80**
> 2.0 l	Euro 0	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 1	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**1**
	Euro 3	0	0	0	0	0	0	0	1	1	0	0	**3**
	Euro 4	1	2	0	2	1	4	1	7	7	4	2	**32**
	Euro 5	0	0	0	0	0	0	0	0	0	0	0	**0**
	Euro 6	0	0	0	0	0	0	0	0	0	0	0	**0**
Hybrid	Euro 4	0	0	0	0	0	0	0	1	1	0	0	**2**
	Euro 5	1	1	0	2	1	3	1	11	12	3	2	**37**
	Euro 6	1	1	0	2	1	3	1	10	11	3	2	**34**
	Sub total												**872**
Van Diesel													
	Euro 3	1	1	0	1	0	2	1	8	11	2	1	**29**
	Euro 4	14	26	6	26	10	61	17	221	298	48	32	**759**
	Euro 5	86	155	40	156	62	367	104	1476	2001	288	197	**4931**
	Euro 6	62	112	29	113	45	265	75	1064	1442	208	142	**3555**
	Sub total												**9275**
Taxi													
LTI FX	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
Metrocab	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TX1	Euro 2	0	0	0	0	0	0	0	0	0	0	0	**1**
Metrocab	Euro 3	0	0	0	0	0	0	0	0	0	0	0	**0**
LTI TXII	Euro 3	0	0	0	3	0	1	0	4	4	1	1	**15**
LTI TX4	Euro 4	1	1	0	9	1	3	1	9	10	3	2	**39**
Merc Vito 111	Euro 4	0	0	0	3	0	1	0	3	3	1	0	**11**
LTI TX4	Euro 5	1	2	0	12	1	3	1	12	13	3	2	**50**
Merc Vito 113	Euro 5	1	1	0	7	0	2	1	7	8	2	1	**29**
LTI TXX	Euro 6	1	2	0	11	1	3	1	12	13	3	2	**49**
Merc Vito XXX	Euro 6	0	1	0	4	0	1	0	4	4	1	1	**15**
	Total	516	905	247	1173	373	1891	688	7561	9198	1709	1174	**25435**

6.10 Summary

Emissions of nitric oxide and nitrogen dioxide from light vehicles (passenger cars, vans, and taxis) were quantified across the case study areas utilising emissions data gathered during the 2012 remote sensing surveys in London. Emission rates (grams of pollutant emitted per kilogram of fuel burned) were combined with estimates of fuel consumption, journey times, and traffic flow data to produce estimates of absolute mass emissions of pollutant in kilograms. Variability in emissions due to traffic congestion and variability in journey time were quantified using data from probe vehicle surveys implemented in the case study areas in 2013. Reasonable assumptions regarding the evolution of the light vehicle fleet in terms of fuel type, engine capacity, and Euro standard were adopted.

A key issue is the assumed efficacy of the Euro 6 emissions standard. It was assumed that Euro 6 NO_x emissions would be reduced pro rata in line with the reduction in NO_x type approval limit values from Euro 5 (180mg/km for diesel passenger cars) to Euro 6 (80mg/km for diesel passenger cars), i.e. a reduction of approximately 55%. Utilising these assumptions, it was calculated that light vehicle NO_x emissions (NO_2 equivalent values) summed over the case study areas would reduce by approximately 14% between 2012 and 2017, and by approximately 26% between 2012 and 2020.

Significant spatial variability in NO_x emissions was quantified within the case study areas, with emissions 'hotspots' identified which are often related to congested areas and locations where queuing is common, for example on the approaches to signalised junctions and pedestrian crossings. The identification of such 'hotspots' provides an opportunity for policy intervention to manage such situations utilising behavioural or technological interventions. Related to this issue, dynamic variation (across repeated journeys) in journey times, stops, and delays was calculated to result in significant variability in NO_x emissions in these 'hotspot' locations.

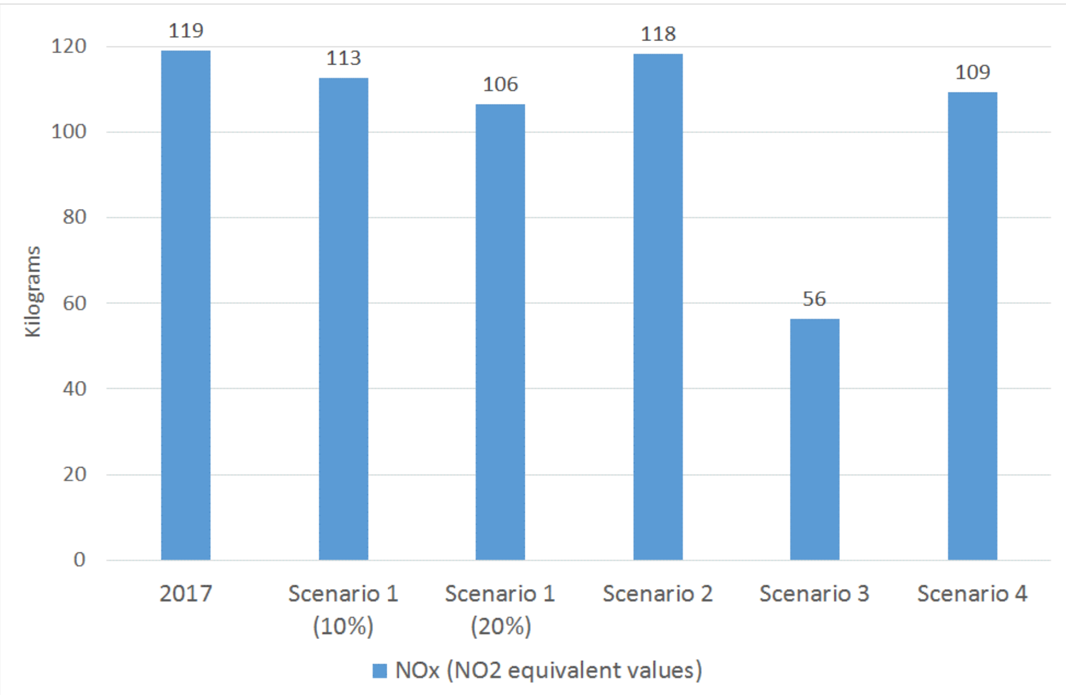

Figure 63: Scenario comparison of light vehicle NO_x emissions at 2017

A number of potential scenario interventions were tested at year 2017 to quantify possible reductions in NO_x emissions. A voluntary light vehicle scrappage scheme targeted at diesel cars and vans which are Euro 5 or older was calculated to reduce NO_x emissions by around 5% with a 10% take up, and by approximately 11% with a 20% take up, relative to the 2017 base line.

A scenario to reduce the sales of new (Euro 6) diesel cars by 25% was calculated to result in only a marginal 1% reduction in overall light vehicle NO_x emissions in 2017. This demonstrates the significance of the 'legacy' challenge in managing emissions from vehicles which are already sold and operating on the network, and the time lag associated with any policy influencing new sales before the policy becomes meaningfully effective (given the average age and turnover rate of the light vehicle fleet).

The probe vehicle surveys demonstrated that the proportion of total journey time spent stationary was very significant in some case study locations. A scenario which assumed that vehicle engines were switched off if the stop exceeded 10 seconds resulted in a reduction in NO_x emissions of approximately 8% overall. The particular benefit of this scenario is that much larger potential reductions in NO_x emissions were calculated for the 'hotspot' locations where most queuing behaviour occurs.

Finally, a more radical 'Ultra Low Emission Zone' scenario which adopted a Euro 6 standard for all diesel light vehicles, and a Euro 5/6 standard for all petrol light vehicles, resulted in a 53% reduction in total light vehicle NO_x emissions at 2017, relative to the 2017 baseline.

7. Goods vehicle emissions (N2 and N3)

7.1 Introduction

Data derived from the remote sensing surveys for medium and heavy goods vehicles (N2 and N3) should be treated with some caution because the survey instrumentation would have difficulty collecting data from some heavy vehicle chassis configurations (due to the need to predict the position of the exhaust plume for measurement purposes, and synchronise the timing of measurements accordingly). Hence, the N2 and N3 vehicle classes may suffer from a degree of sampling bias, with some chassis configurations under-represented. In addition, the numbers of heavy vehicles observed in the remote sensing surveys in 2008 and 2012 were relatively small compared to the light vehicle samples. For this reason, data has been aggregated across all of the available London survey sites, not just those implemented in the London Borough of Ealing. The above caveats notwithstanding, the analysis of heavy vehicles has been included for completeness.

It should be noted at this juncture that the European emissions regulations for light duty vehicles and heavy duty vehicles are quite distinct in a number of aspects. Heavy duty emissions regulations apply to motor vehicles of categories M1 , M2 , N1 and N2 as defined in Annex II of Directive 2007/46/EC with a reference mass exceeding 2610 kg, and to all motor vehicles of categories M3 and N3 , as defined in that Annex (European Commission, 2009). The concept of reference mass has been discussed earlier in the context of N1 class goods vehicles.

Specifically:

- Heavy duty NO_x emissions are defined in terms of grams per kilowatt hour (kWhr), rather than the mg/km metric utilised for light duty vehicles.
- Euro VI heavy duty emissions are quantified over the new World Harmonised Cycles, including a steady state cycle (WHSC), transient cycle (WHTC), and 'off cycle' not to exceed limits (WHNTE). Hence, in comparison to Euro V, Euro VI has adopted a more stringent emissions measurement regime, the objective being to make the measurements more consistent with 'real-world' operating conditions.

For further information on the Euro VI heavy duty emission regulations, see Regulation (EC) No 595/2009 of 18 June 2009, as amended by Commission Regulation (EU) No 582/2011 of 25 May 2011 (European Commission, 2009 and 2011).

In addition to the changes in test cycle and measurement regime, the Euro VI NO_x emissions limits are significantly more stringent than the previous Euro V regulations. The Euro V NO_x emission limit over the previous European Transient Cycle (ETC) is 2.0 g/kW.hr, whereas the Euro VI NO_x emission limit over the World Harmonised Transient Cycle (WHTC) is 0.46 g/kW.hr. It should be noted that, due to the changes in testing regime, Verbeek et al (2008) estimated that NO_x emissions (for a given engine) measured over the World Harmonised Transient Cycle are approximately 1.1 times higher than over the previous European Transient Cycle. Hence, the introduction of the Euro VI limit of 0.46 g/kW.hr, in addition to the change in testing regime, suggests an overall reduction in NO_x of approximately 79% (i.e. a factor of 0.21 applied to the Euro V emissions rate).

The Euro VI emission standard for NO_x will be phased in over a period of time. The initial phase (labelled 'AB' in the following diagrams) applied to new heavy duty vehicle types from **December 31st 2012**, and to all heavy duty vehicle types from **December 31st 2013**, and introduced a NO_x monitoring control limit of 0.9 g/kW.hr over the WHTC. The second phase (labelled 'C' in the diagrams) applies to new heavy duty vehicle types from **December 31st 2015**, and to all heavy duty vehicle types from **December 31st 2016**, and introduces a NO_x limit of 0.46 g/kW.hr over the WHTC. UK provisions for end of series and low volume derogations allow continued sale of some Euro V vehicles during these periods.

7.2 Medium Goods Vehicle fleet (3.5 – 12 tonnes gross)

Figure 64 presents the observed Medium Goods Vehicle (N2) fleet age profiles in 2008 and 2012 respectively. It can be seen that the profiles are broadly consistent for vehicles aged four years and over. However, the 2012 data exhibits a notable dip in the profile for vehicles at three years old (i.e. vehicles manufactured in 2009). In contrast, the maxima of the 2008 profile is for vehicles at three years old. For the future year scenario development, the mean of the two profiles has been adopted, as illustrated in Figure 64.

Figure 65 illustrates the observed medium goods vehicle (N2) fleet composition in London in 2012, based on data collected during the remote sensing surveys. Figure 66 and Figure 67 illustrate the assumed medium goods vehicle (N2) fleet composition in Ealing in 2017 and 2020 respectively, assuming the above 'phase in' dates of Euro VI (phase AB) and Euro VI (phase C). At 2017, 33.7% of the N2 fleet is assumed to be Euro VI (phase AB) standard, and 10.8% Euro VI (phase C) standard. At 2020, 34.4% of the N2 fleet is assumed to be Euro VI (phase AB) standard, and 44.4% Euro VI (phase C) standard.

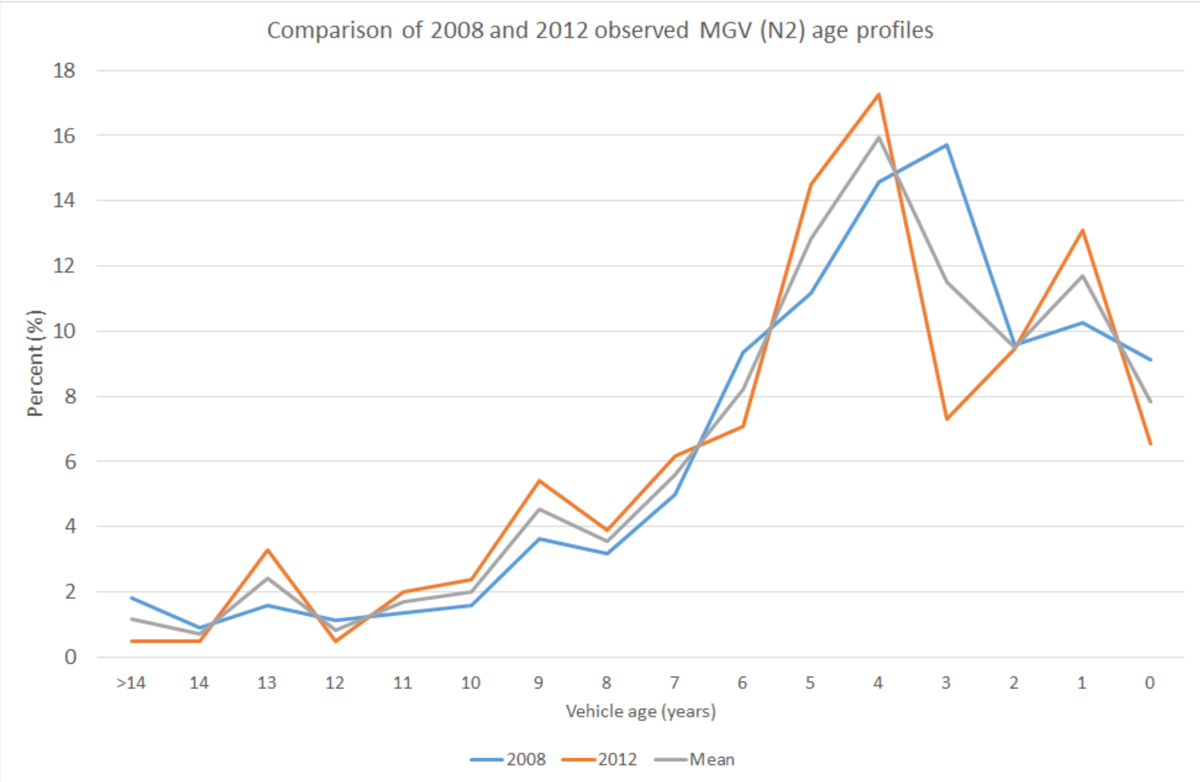

Figure 64: Comparison of 2008 and 2012 observed MGV (N2) age profiles in London

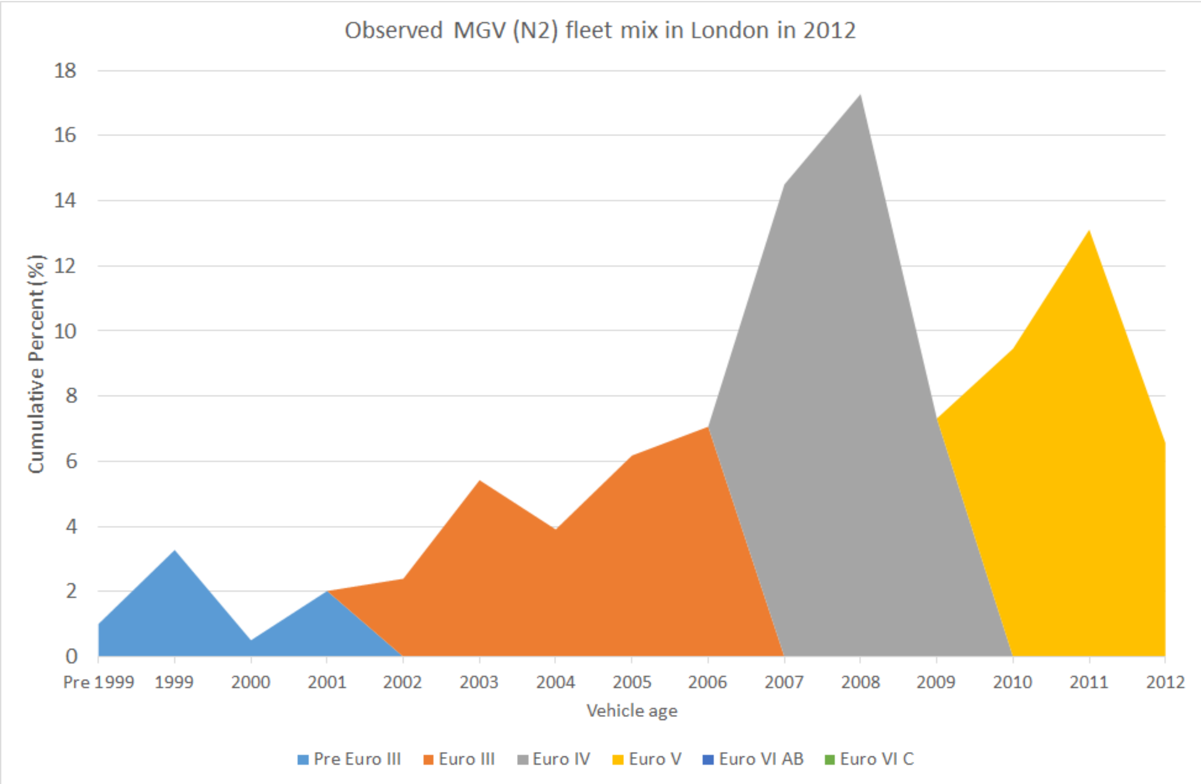

Figure 65: Observed MGV (N2) fleet composition in London in 2012

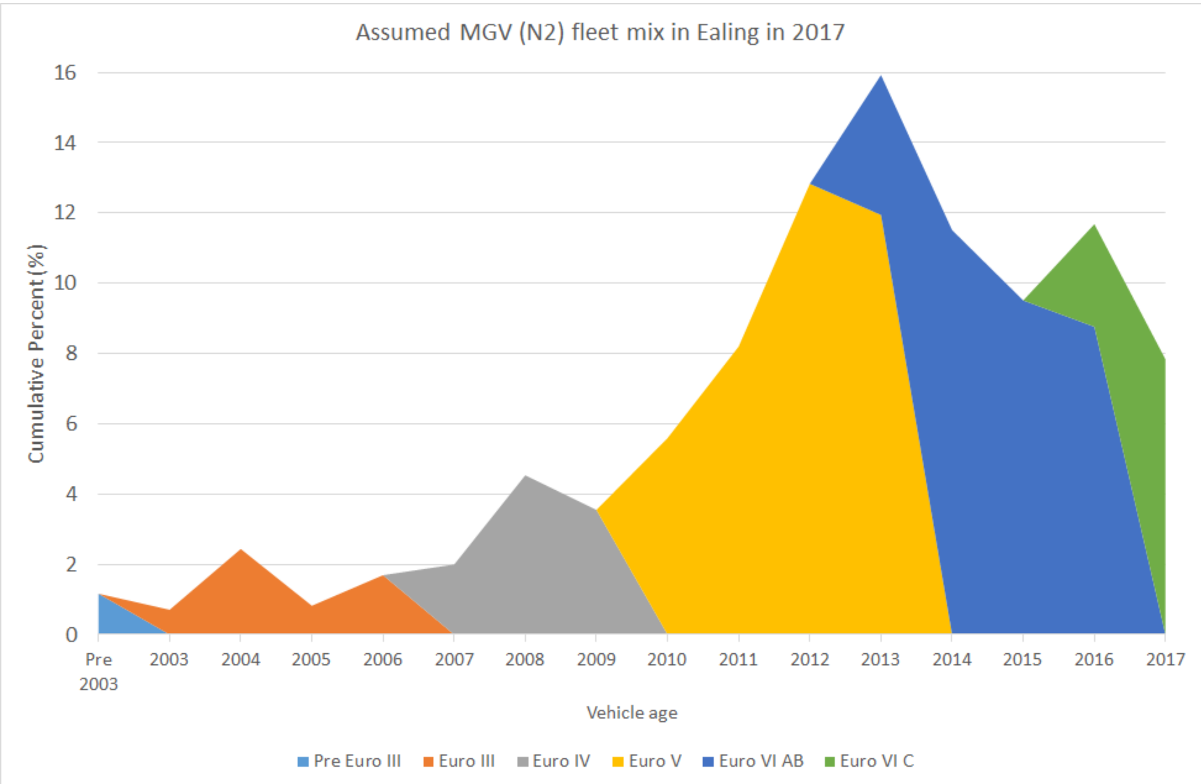

Figure 66: Assumed MGV (N2) fleet composition in Ealing in 2017

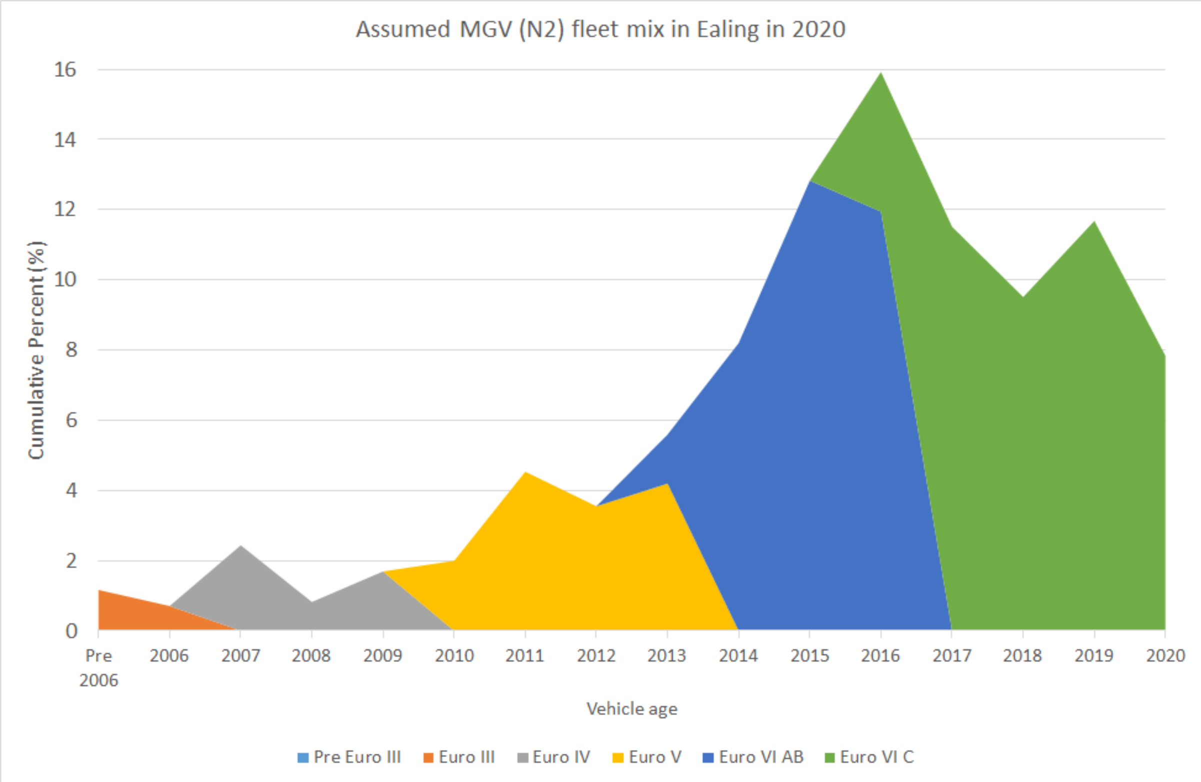

Figure 67: Assumed MGV (N2) fleet composition in Ealing in 2020

7.3 Heavy Goods Vehicle fleet (over 12 tonnes gross)

Figure 68 illustrates the observed Heavy Goods Vehicle (N3) fleet age profiles in 2008 and 2012 respectively. It can be seen that the profiles are broadly consistent, with some variation for vehicles up to three years old, and again for vehicles seven years and older. For the future year scenario development, the mean of the two profiles has been adopted, as illustrated in Figure 68.

Figure 69 illustrates the observed heavy goods vehicle (N3) fleet composition in London in 2012, based on data collected during the remote sensing surveys. Figure 70 and Figure 71 illustrate the assumed heavy goods vehicle (N3) fleet composition in Ealing in 2017 and 2020 respectively, assuming the above 'phase in' dates of Euro VI (phase AB) and Euro VI (phase C). At 2017, 38.3% of the N3 fleet is assumed to be Euro VI (phase AB) standard, and 10.6% Euro VI (phase C) standard. At 2020, 37.5% of the N3 fleet is assumed to be Euro VI (phase AB) standard, and 48.9% Euro VI (phase C) standard.

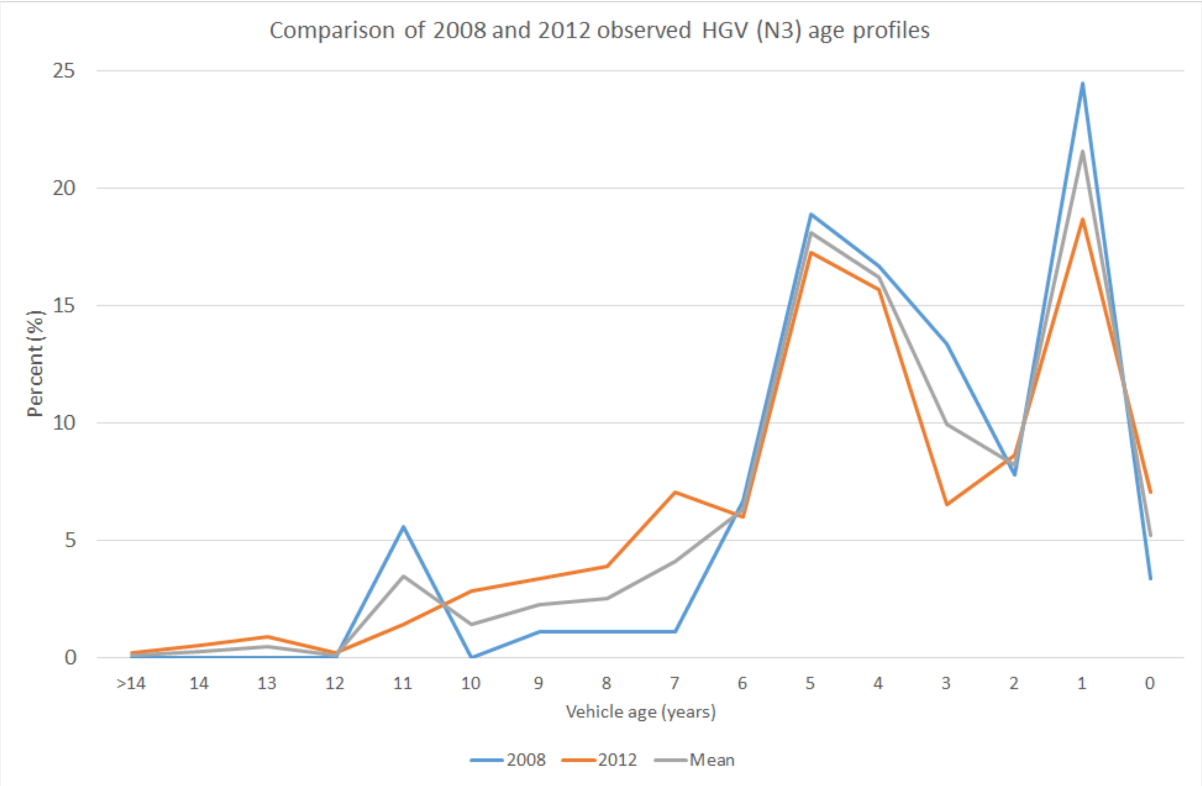

Figure 68: Comparison of 2008 and 2012 observed HGV (N3) age profiles in London

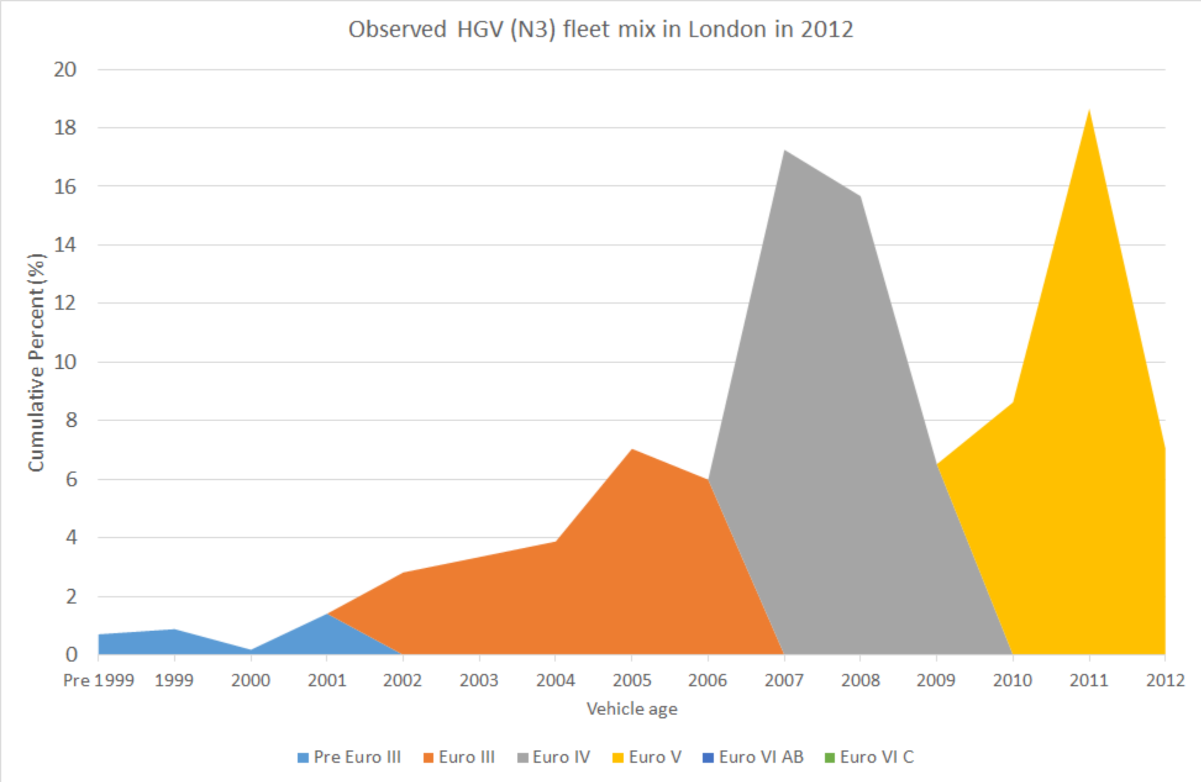

Figure 69: Observed HGV (N3) fleet composition in London in 2012

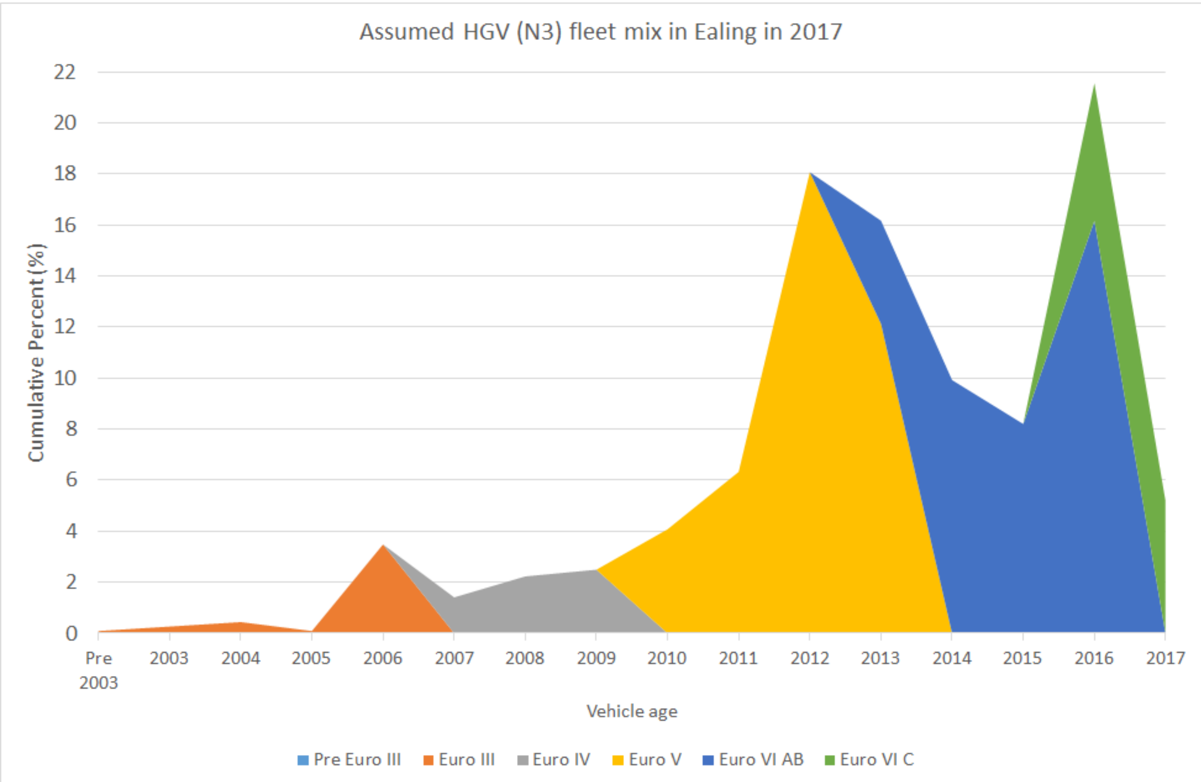

Figure 70: Assumed HGV (N3) fleet composition in Ealing in 2017

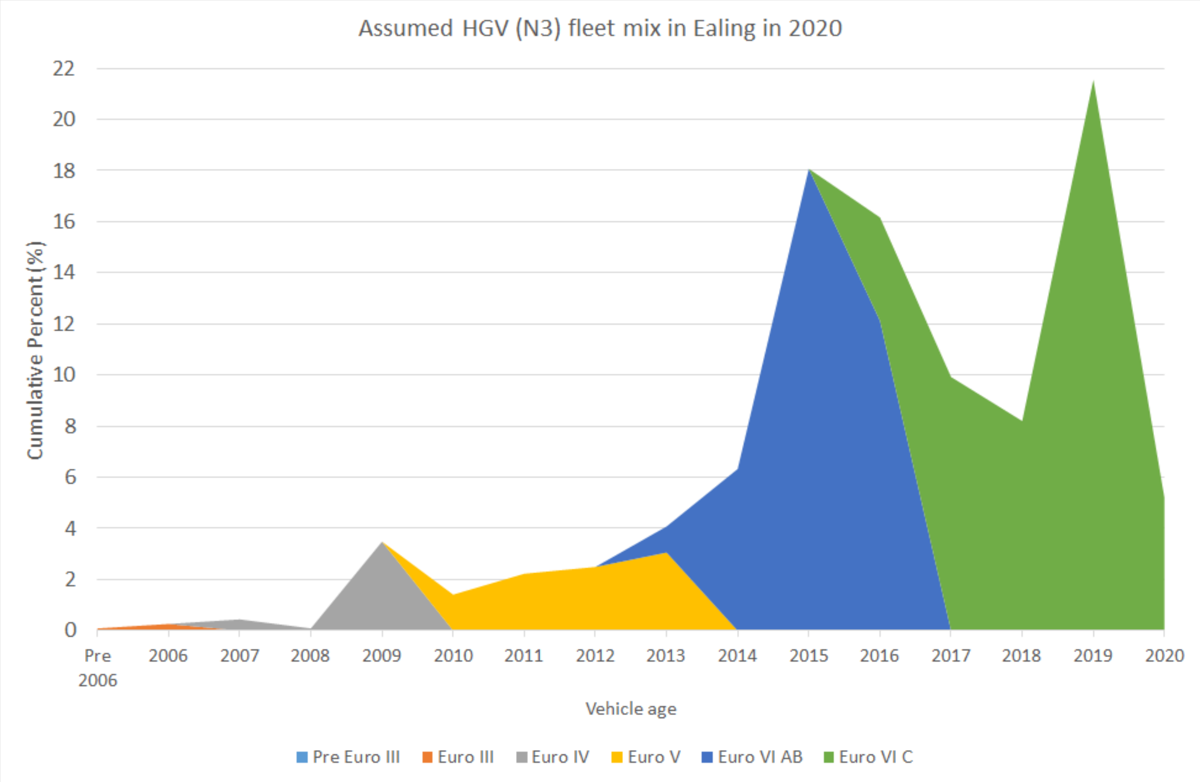

Figure 71: Assumed HGV (N3) fleet composition in Ealing in 2020

7.4 Emission rates from goods vehicles

The sample size of commercial vehicles in the 2012 remote sensing survey data is relatively small, and there is potential for sampling bias as noted earlier, so the results should be treated with some caution. However, they are included here for completeness. Table 63 presents the observed NO and NO_2 emissions rates (g/kg of fuel burned) from medium and heavy goods vehicles, from the remote sensing surveys in 2012. Since the sample sizes are relatively small, only mean values across all observations by category have been presented, without attempting to consider variation in speed, acceleration, and engine load. The locations and characteristics of the 2012 remote sensing survey locations should be considered when interpreting these data.

Table 63: Observed commercial vehicle emission rates at 2012

		Mean observed emission rate	
	Sample (n)	**NO g/kg fuel**	**NO_2 g/kg fuel**
Medium goods vehicles (N2)			
Euro II	50	23.93	9.83
Euro III	198	19.49	6.58
Euro IV	310	23.47	2.94
Euro V	231	23.08	2.97
Heavy goods vehicles (N3)			
Euro III	131	20.60	10.01
Euro IV	224	26.13	1.29
Euro V	195	23.83	1.45

As discussed in Section 7.1, emission limit values from Euro VI medium and heavy goods vehicles (0.46g NO_x/kW.hr) are reduced significantly in comparison with Euro V (2.0g NO_x/kW.hr). When the difference in type approval drive cycles for Euro V (ETC) and Euro VI (WHTC) are also taken into account, the reduction factor from Euro V to Euro VI is approximately 0.21. This factor has been used in estimating emission rates from Euro VI (phase c) compliant heavy duty vehicles.

The European type approval limit value for oxides of nitrogen is expressed in terms of NO_x (NO_2 equivalent values by mass). Since this analysis considers the two species of NO_x (NO and NO_2), it is helpful to make some assumptions about the relative proportions of these two species in total NO_x at Euro VI. Unfortunately, no general data has been found regarding these future proportions. The only indication has been obtained from Euro VI TfL buses where 50% of the mass of NO_x is observed to be NO_2 (presentation by TfL at the Air Pollution Research in London seminar, City Hall, London, June 26th 2014). In this analysis, it has therefore been assumed that at Euro VI (Phase c), the relative proportion of NO and NO_2 from heavy duty engines is assumed to be 50/50 by mass. In reality, it is expected that there may be variations in these proportions at Euro VI depending on the types of engine and emissions control technologies adopted.

Table 64: Assumed emission rates from Euro VI commercial vehicles

	Mean assumed emission rate		
	NO g/kg fuel	**NO_2 g/kg fuel**	**NO_x (g/kg fuel) – NO_2 equivalent values**
Medium goods vehicles (N2)			
Euro V (observed)	23.08	2.97	38.36
Euro VI (Phase ‘ab’)	8.21	3.18	15.77
Euro VI (Phase ‘c’)	3.18	3.18	8.06
Heavy goods vehicles (N3)			
Euro V (observed)	23.83	1.45	37.99
Euro VI (Phase ‘ab’)	8.13	3.15	15.62
Euro VI (Phase ‘c’)	3.15	3.15	7.98

As noted in Section 1.2, a simplified approach to estimating absolute emissions is adopted for goods vehicles, utilising observed mean emission rates (g/kg of fuel burned), fuel consumption rates in units of kilograms per km, traffic volume (counts) by vehicle sub-type and time period, and distance travelled (km). Local data for goods vehicle fuel consumption was not readily available, so reference was made to published Department for Transport National Statistics from the ‘Continuing Survey of Road Goods Transport’, in particular Table ENV0104 (TSGB0304) ‘Average heavy goods vehicle fuel consumption: Great Britain’, and Table RFS0141 ‘Fuel consumption by HGV vehicle type in Great Britain’. The fuel consumption rates derived from these tables is presented in Table 65. For the A40 Western Avenue case study area (40 mph speed limit), these mean fuel consumption values were utilised ‘as is’, but for the other urban case study areas (30 mph speed limit) it was assumed that fuel consumption would be 25% higher due to the greater incidence of junctions, stop/start driving etc. The goods vehicle traffic counts utilised are those presented in Table 1 to Table 5. Distance travelled by case study area is obtained from Table 6.

Table 65: Assumed commercial vehicle fuel consumption rates

		Mean fuel consumption rate	
		Miles per gallon	**Kg per kilometre**
Medium goods vehicles (N2)	Euro II	12.08	0.1946
	Euro III	12.21	0.1925
	Euro IV	12.03	0.1953
	Euro V	11.95	0.1967
Heavy goods vehicles (N3)	Euro III	8.56	0.2746
	Euro IV	8.35	0.2816
	Euro V	8.34	0.2818

Table 66 and Table 67 present the absolute nitric oxide and nitrogen dioxide emissions calculated for each of the case study areas in year 2012. It can be seen that the A40 Western Avenue dominates the results due to (a) the much larger volumes of goods vehicles on this strategic route, and (b) the longer distance travelled on the A40 Western Avenue case study route compared to the other case study areas.

Table 66: Mean NO (grams) in 2012: Goods vehicles, average weekday (12 hour period)

	AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Medium Goods (N2)												
Euro II	58	57	36	89	35	195	130	1311	1308	283	251	**3752**
Euro III	186	181	114	283	113	620	415	4181	4173	903	800	**11968**
Euro IV	356	346	218	541	215	1187	794	7998	7985	1727	1530	**22898**
Euro V	263	256	161	399	159	876	586	5902	5892	1275	1129	**16897**
Euro VI (ab)	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro VI (c)	0	0	0	0	0	0	0	0	0	0	0	**0**
Sub total	863	839	528	1312	522	2878	1926	19391	19358	4187	3710	**55516**
Heavy Goods (N3)												
Euro III	107	143	27	36	30	272	147	3485	4573	281	462	**9562**
Euro IV	237	317	60	79	67	605	327	7750	10170	625	1027	**21263**
Euro V	189	252	48	63	53	481	260	6160	8083	496	816	**16900**
Euro VI (ab)	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro VI (c)	0	0	0	0	0	0	0	0	0	0	0	**0**
Sub total	533	712	135	178	150	1357	733	17395	22826	1402	2304	**47725**
Total	1395	1552	663	1490	672	4235	2659	36787	42184	5589	6014	**103241**

In 2012, 103.2kg of nitric oxide is emitted by goods vehicles during an average weekday 12 hour period, across all of the case study areas under consideration (Table 66). Approximately 54% of NO from goods vehicles is emitted by medium goods vehicles (N2), and 46% by heavy good vehicles (N3). The results are dominated by emissions from the A40 Western Avenue (76%) due to the relatively large numbers of goods vehicles, and the large extent of the case study area. Overall, emissions from Euro IV and Euro V vehicles dominate (76%), although emissions from Euro III vehicles are significant (21%).

Table 67: Mean NO_2 (grams) in 2012: Goods vehicles, average weekday (12 hour period)

	AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Medium Goods (N2)												
Euro II	24	23	15	36	14	80	53	538	537	116	103	**1541**
Euro III	63	61	38	95	38	209	140	1411	1408	305	270	**4039**
Euro IV	45	43	27	68	27	149	100	1002	1000	216	192	**2869**
Euro V	34	33	21	51	20	113	75	758	757	164	145	**2171**
Euro VI (ab)	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro VI (c)	0	0	0	0	0	0	0	0	0	0	0	**0**
Sub total	165	161	101	251	100	551	368	3710	3703	801	710	**10620**
Heavy Goods (N3)												
Euro III	52	69	13	17	15	132	71	1693	2221	136	224	**4645**
Euro IV	12	16	3	4	3	30	16	384	503	31	51	**1052**
Euro V	11	15	3	4	3	29	16	374	491	30	50	**1027**
Euro VI (ab)	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro VI (c)	0	0	0	0	0	0	0	0	0	0	0	**0**
Sub total	75	100	19	25	21	191	103	2451	3216	197	325	**6724**
Total	240	261	120	276	121	742	472	6160	6919	999	1034	**17344**

Table 68: Mean NO (grams) in 2017: Goods vehicles, average weekday (12 hour period)

	AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Medium Goods (N2)												
Euro II	12	11	7	18	7	39	26	261	260	56	50	**747**
Euro III	44	43	27	68	27	148	99	998	996	216	191	**2857**
Euro IV	96	94	59	146	58	321	215	2161	2157	467	413	**6186**
Euro V	363	353	222	552	220	1211	810	8157	8143	1761	1560	**23353**
Euro VI (ab)	113	110	69	172	68	377	252	2540	2535	548	486	**7271**
Euro VI (c)	14	14	9	21	8	47	31	315	315	68	60	**902**
Sub total	642	625	393	977	388	2142	1433	14432	14407	3116	2761	**41317**
Heavy Goods (N3)												
Euro III	20	27	5	7	6	52	28	661	868	53	88	**1814**
Euro IV	37	50	9	12	11	95	51	1220	1601	98	162	**3347**
Euro V	228	304	58	76	64	580	313	7432	9752	599	984	**20390**
Euro VI (ab)	73	98	18	24	21	186	101	2386	3131	192	316	**6545**
Euro VI (c)	8	10	2	3	2	20	11	256	336	21	34	**702**
Sub total	366	489	93	122	103	933	504	11955	15687	963	1584	**32799**
Total	1008	1114	486	1099	491	3075	1937	26387	30094	4080	4344	**74115**

Table 69: Mean NO_2 (grams) in 2017: Goods vehicles, average weekday (12 hour period)

	AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Medium Goods (N2)												
Euro II	5	5	3	7	3	16	11	107	107	23	20	**307**
Euro III	15	15	9	23	9	50	33	337	336	73	64	**964**
Euro IV	12	12	7	18	7	40	27	271	270	58	52	**775**
Euro V	47	45	29	71	28	156	104	1048	1046	226	201	**3001**
Euro VI (ab)	44	43	27	67	26	146	98	984	982	212	188	**2816**
Euro VI (c)	14	14	9	21	8	47	31	315	315	68	60	**902**
Sub total	136	133	83	207	82	454	304	3062	3057	661	586	**8765**
Heavy Goods (N3)												
Euro III	10	13	2	3	3	25	14	321	421	26	43	**881**
Euro IV	2	2	0	1	1	5	3	60	79	5	8	**166**
Euro V	14	18	3	5	4	35	19	452	593	36	60	**1239**
Euro VI (ab)	28	38	7	9	8	72	39	924	1213	74	122	**2536**
Euro VI (c)	8	10	2	3	2	20	11	256	336	21	34	**702**
Sub total	62	82	16	21	17	157	85	2013	2642	162	267	**5524**
Total	198	215	99	228	100	611	389	5075	5698	823	852	**14289**

Table 70: Mean NO (grams) in 2020: Goods vehicles, average weekday (12 hour period)

	AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Medium Goods (N2)												
Euro II	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro III	15	15	9	23	9	51	34	343	342	74	66	**981**
Euro IV	49	48	30	75	30	164	109	1102	1100	238	211	**3155**
Euro V	139	135	85	211	84	463	310	3122	3116	674	597	**8937**
Euro VI (ab)	119	116	73	181	72	396	265	2671	2666	577	511	**7646**
Euro VI (c)	59	58	36	90	36	198	133	1335	1333	288	255	**3823**
Sub total	381	371	234	580	231	1272	851	8573	8558	1851	1640	**24543**
Heavy Goods (N3)												
Euro III	2	3	0	1	1	5	3	63	83	5	8	**174**
Euro IV	25	34	6	8	7	64	35	824	1082	66	109	**2261**
Euro V	53	71	13	18	15	135	73	1731	2271	139	229	**4749**
Euro VI (ab)	74	99	19	25	21	188	101	2407	3158	194	319	**6603**
Euro VI (c)	37	50	9	12	10	95	51	1216	1596	98	161	**3336**
Sub total	191	256	48	64	54	487	263	6241	8190	503	827	**17123**
Total	573	627	282	644	284	1759	1115	14814	16748	2354	2467	**41665**

Table 71: Mean NO_2 (grams) in 2020: Goods vehicles, average weekday (12 hour period)

	AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Medium Goods (N2)												
Euro II	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro III	5	5	3	8	3	17	11	116	115	25	22	**331**
Euro IV	6	6	4	9	4	20	14	138	138	30	26	**395**
Euro V	18	17	11	27	11	60	40	401	400	87	77	**1148**
Euro VI (ab)	46	45	28	70	28	154	103	1035	1033	223	198	**2962**
Euro VI (c)	59	58	36	90	36	198	133	1335	1333	288	255	**3823**
Sub total	135	131	82	205	81	449	300	3025	3019	653	579	**8659**
Heavy Goods (N3)												
Euro III	1	1	0	0	0	2	1	31	40	2	4	**84**
Euro IV	1	2	0	0	0	3	2	41	54	3	5	**112**
Euro V	3	4	1	1	1	8	4	105	138	8	14	**289**
Euro VI (ab)	29	38	7	10	8	73	39	932	1224	75	124	**2558**
Euro VI (c)	37	50	9	12	10	95	51	1216	1596	98	161	**3336**
Sub total	71	95	18	24	20	181	98	2325	3051	187	308	**6379**
Total	206	226	100	228	101	630	398	5350	6071	841	887	**15038**

At 2017, total emissions of NO has reduced from 103.2kg to 74.1kg (Table 68), a reduction of over 28%. NO emissions from medium goods vehicles (N2) decrease by over 25%, whilst NO emissions from heavy goods vehicles (N3) decrease by over 31%. At 2020 (Table 70), total emissions of NO reduce further to 41.7kg, with the largest reductions being attributable to the retirement of significant numbers of Euro V vehicles from the fleet (and the assumed improved emissions performance of the Euro VI vehicles which replace them).

In 2012, emissions of primary NO_2 from goods vehicles across the case study areas totalled 17.3kg during an average weekday 12 hour period (

Table 67). Again, emissions from the A40 Western Avenue dominate (75%). Overall, medium goods vehicles (N2) are calculated to emit 61% of the total, whilst heavy goods vehicles (N3) emit 39%. Euro III vehicles are calculated to emit 50% (8.7kg) of this total.

At 2017, total emissions of NO_2 has reduced from 17.3kg to 14.3kg (Table 69), a reduction of just over 17% relative to 2012. NO_2 emissions from medium goods vehicles (N2) and heavy goods vehicles (N3) decrease by between 17% and 18% relative to 2012. At 2020 (Table 71), total emissions of NO_2 increase slightly to 15.0kg net, with emissions of NO_2 from medium goods vehicles (N2) decreasing to 8.7kg (-28% relative to 2012), but emissions of NO_2 from heavy goods vehicles (N3) increasing to 6.4kg (but still -5% relative to 2012).

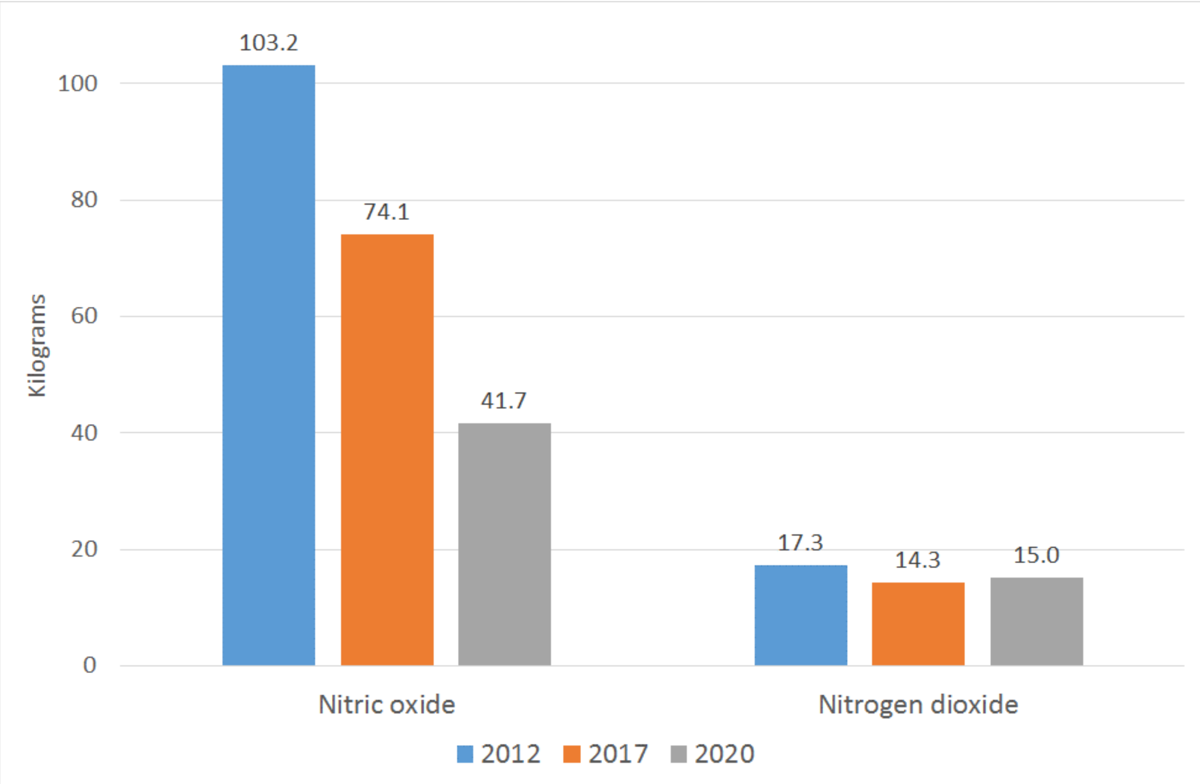

Figure 72: Aggregate emissions of goods vehicle NO and NO_2 across case study areas

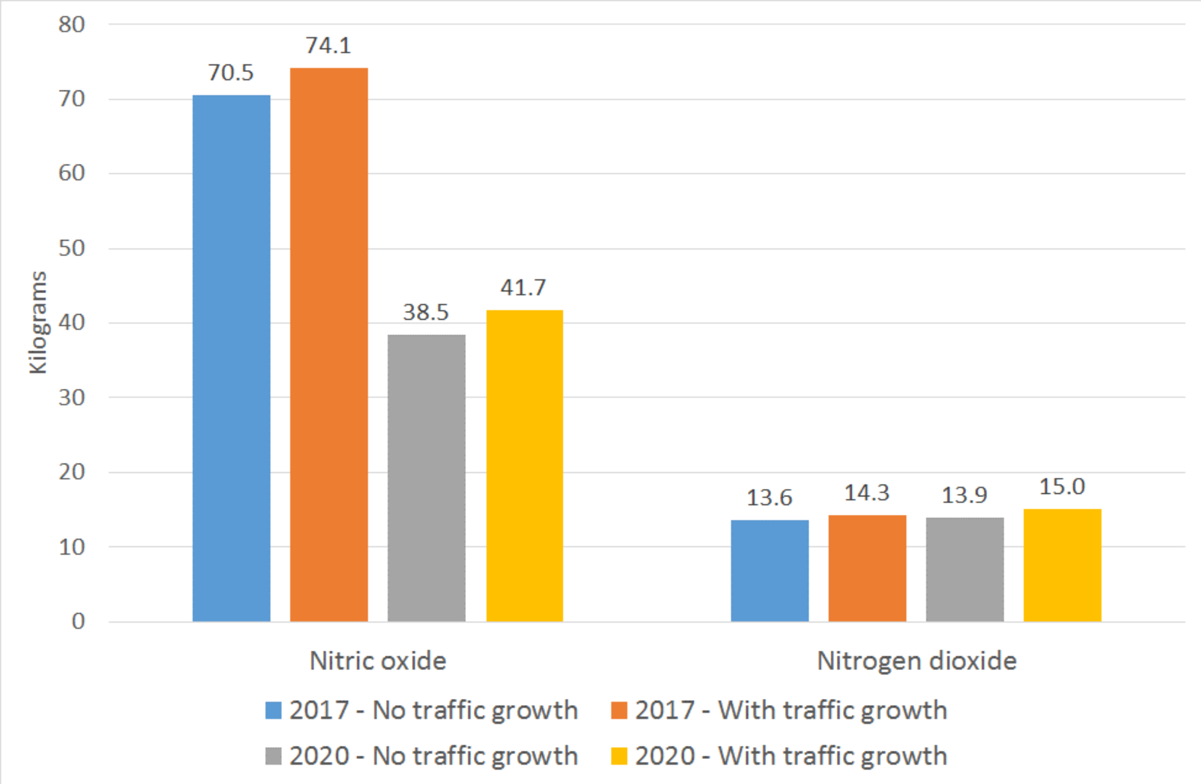

Figure 73: Sensitivity of goods vehicle emissions to assumed traffic growth

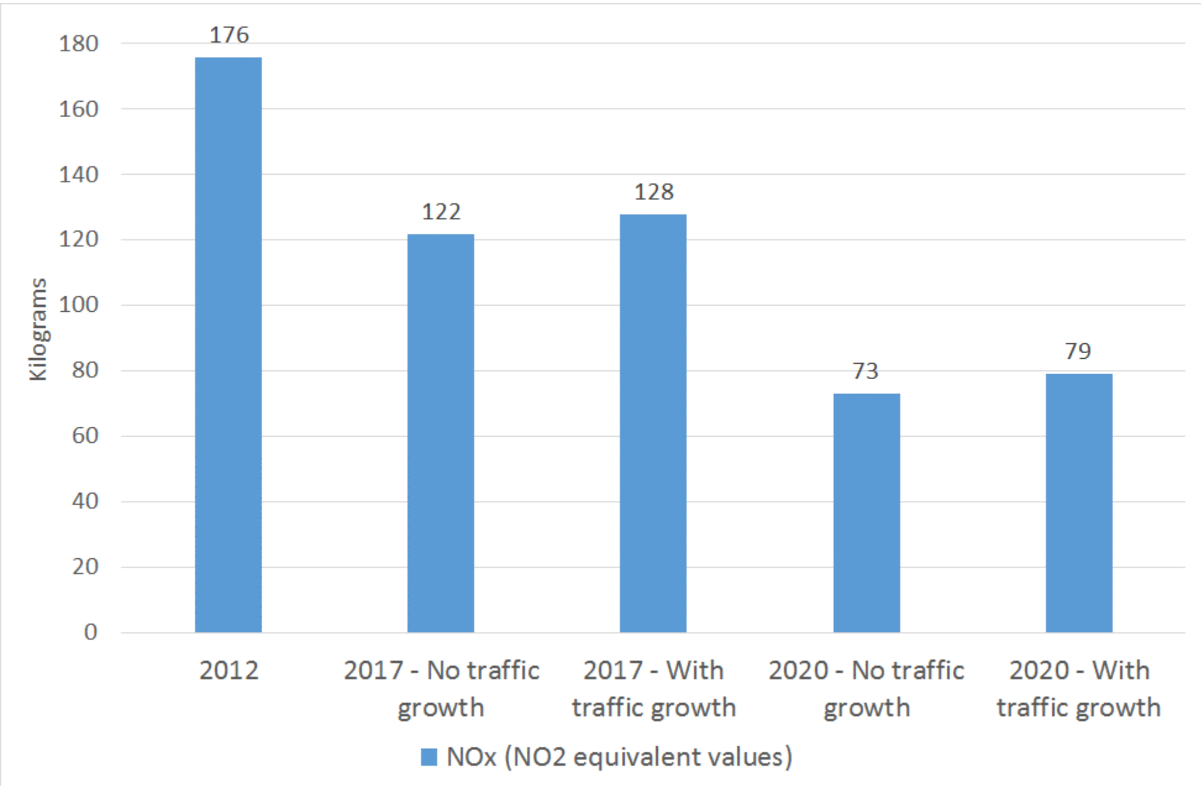

Figure 74: Goods vehicle NO_x emissions (NO_2 equivalent values)

Figure 72 illustrates the assumed evolution of the nitric oxide and nitrogen dioxide components of total NO_x from goods vehicles across the case study areas from 2012 to 2020. The nitric oxide component is assumed to decline from 103.2kg in 2012, to 74.1kg in 2017 (-28% relative to 2012), and finally 41.7kg in 2020 (-60% relative to 2012).

However, the nitrogen dioxide component of total NO_x is observed to decrease from 17.3kg in 2012, to 14.3kg in 2017 (-17% relative to 2012), before increasing to 15.0kg in 2020 (-13% relative to 2012). NO_2 emissions from heavy goods vehicles (N3) are assumed to increase slightly at 2020 due to the previously stated assumption that 50% of emissions of oxides of nitrogen from Euro VI heavy duty engines will be NO_2, and the fact that Euro VI vehicles have a larger market share at 2020 (Figure 71).

Traffic growth assumptions are a potential source of uncertainty in forecasting future emissions. In the base 2017 and 2020 scenarios, a traffic growth rate of 1% per annum compound was assumed from 2012 (the same as light vehicles). Figure 73 presents a comparison of the NO and NO_2 emissions for each scenario reference year, with and without traffic growth. Goods vehicle nitric oxide emissions at 2017 without traffic growth are approximately 4.9% lower than the base scenario at 2017. At 2020, the NO results without traffic growth are approximately 7.7% lower than the base scenario at 2020. For NO_2, the relatively differences at 2017 and 2020 and approximately 4.9% and 7.3% respectively.

Figure 74 presents the aggregate goods vehicle total NO_x emissions across the case study areas by reference year. In this context, NO_x is expressed in terms of NO_2 equivalent values (by mass). The base 2017 scenario goods vehicle total NO_x emissions are approximately 27% lower than 2012; the base 2020 scenario NO_x emissions are approximately 55% lower than 2012.

7.5 Comparison of light vehicle and goods vehicle emissions

Warning. Comparisons between the light vehicle (M1 and N1) and heavy duty goods vehicle (N2 and N3) emissions results should be treated with caution because of the fundamentally different methodologies adopted for the analysis of these two groups of vehicles.

Mean light vehicle emissions have been calculated utilising the journey time data collected in the probe vehicle surveys. Therefore the calculated mean values will be influenced by dynamic variability in journey time, delays, and stops across the multiple probe vehicle survey runs (see Section 6.8).

In contrast, the goods vehicle emissions have been calculated based simply on mean emissions rates, assumed fuel consumption rates, and distance travelled, i.e. the goods vehicle results are insensitive to changes in journey time and traffic congestion. Such differences in methodology may result in systematic inconsistencies between the two sets of results. It should also be remembered that the sample size for heavy duty goods vehicles (N2 and N3) in the 2012 remote sensing surveys was relatively small, and subject to possible sampling bias. The comparison has been included here because the comparison of time trends, if not absolute emission values, may be informative for scenario development and air quality action planning (the above caveats notwithstanding).

Figure 75, Figure 76, and Figure 77 present the comparison of mean emissions of nitric oxide, nitrogen dioxide, and NO_x (NO_2 equivalent values) respectively for light vehicles and goods vehicles, aggregated across all case study areas. It can be seen from Figure 75 that both light vehicles and goods vehicles exhibit a reduction in emissions of nitric oxide with respect to time, but that goods vehicles exhibit a more rapid rate of reduction between 2012 and 2020. Light vehicles exhibit a slower rate of reduction with respect to time, to the extent that whilst calculated nitric oxide emissions from goods vehicles are significantly higher than nitric oxide emissions from light vehicles in 2012, in 2020 nitric oxide emissions from goods vehicles are actually calculated to be lower than those from light vehicles. This effect is due to two main factors. Firstly, the relative change in NO_x type approval limit values for heavy duty vehicles in the transition from Euro V (2.0g NO_x per kW.hr) to Euro VI (0.46g NO_x per kW.hr) is greater than the relative change in NO_x type approval limit values for diesel light duty vehicles in the transition from Euro 5 (180mg NO_x per km) to Euro 6 (80mg NO_x per km). Secondly, the goods vehicle fleet (Figure 64 and Figure 68) tends to exhibit a faster rate of fleet turnover (i.e. the fleet is younger) than, for example, the passenger car fleet (Figure 17). These two factors combined result in newer (and cleaner) goods vehicles entering the fleet at a faster rate than passenger cars over the same time period.

Emissions of primary nitrogen dioxide (Figure 76) are calculated to be lower from the goods vehicle fleet than from the light vehicle fleet. However, they display differing profiles with respect to time. Light vehicle emissions of NO_2 are calculated to increase from 2012 to 2017, before reducing again at 2020 (but not quite down to their previous 2012 levels). In contrast, emissions of NO_2 from goods vehicles are calculated to reduce from 2012 to 2017, but then increase marginally at 2020 (but still 13% below their 2012 values). This effect may be due to the relatively low NO_2 emissions rate observed from heavy goods (N3) vehicles in particular in 2012, and the working assumption that NO_2 will comprise 50% of emissions of oxides of nitrogen from heavy duty vehicles at Euro VI. Adjustments to these working assumptions may lead to differing results.

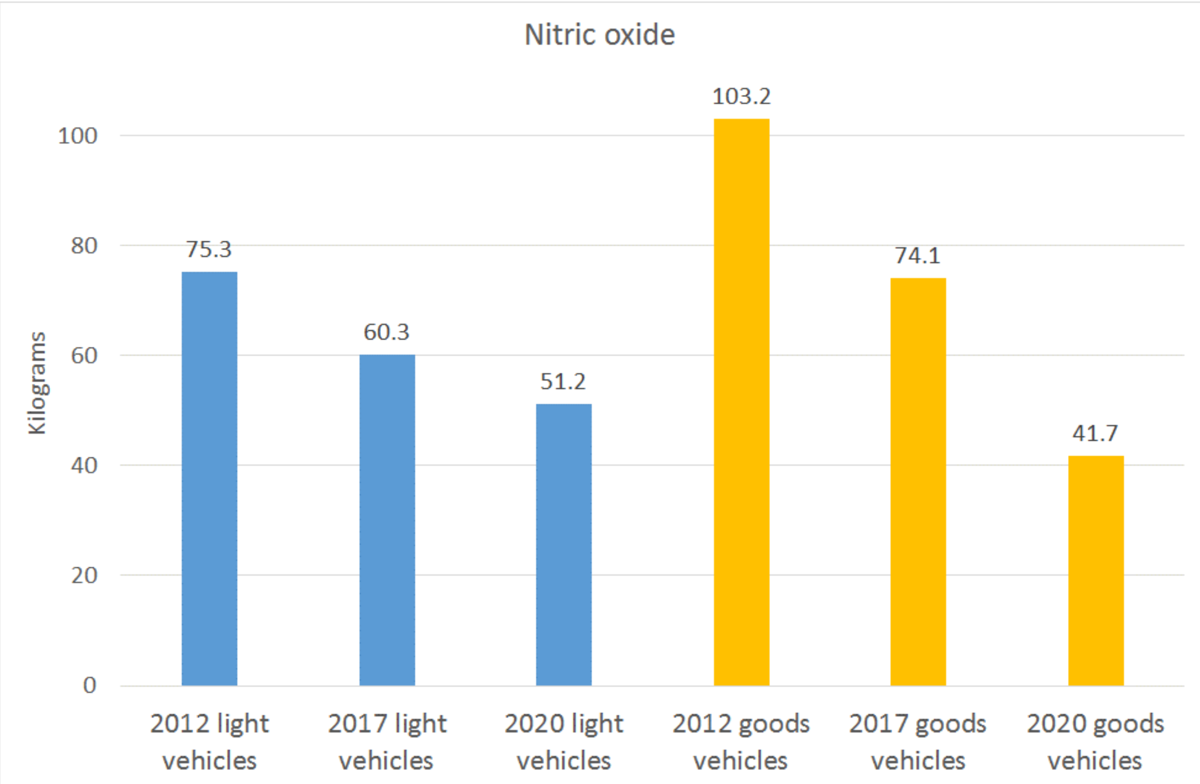

Figure 75: Comparison of NO emissions from light vehicles and goods vehicles

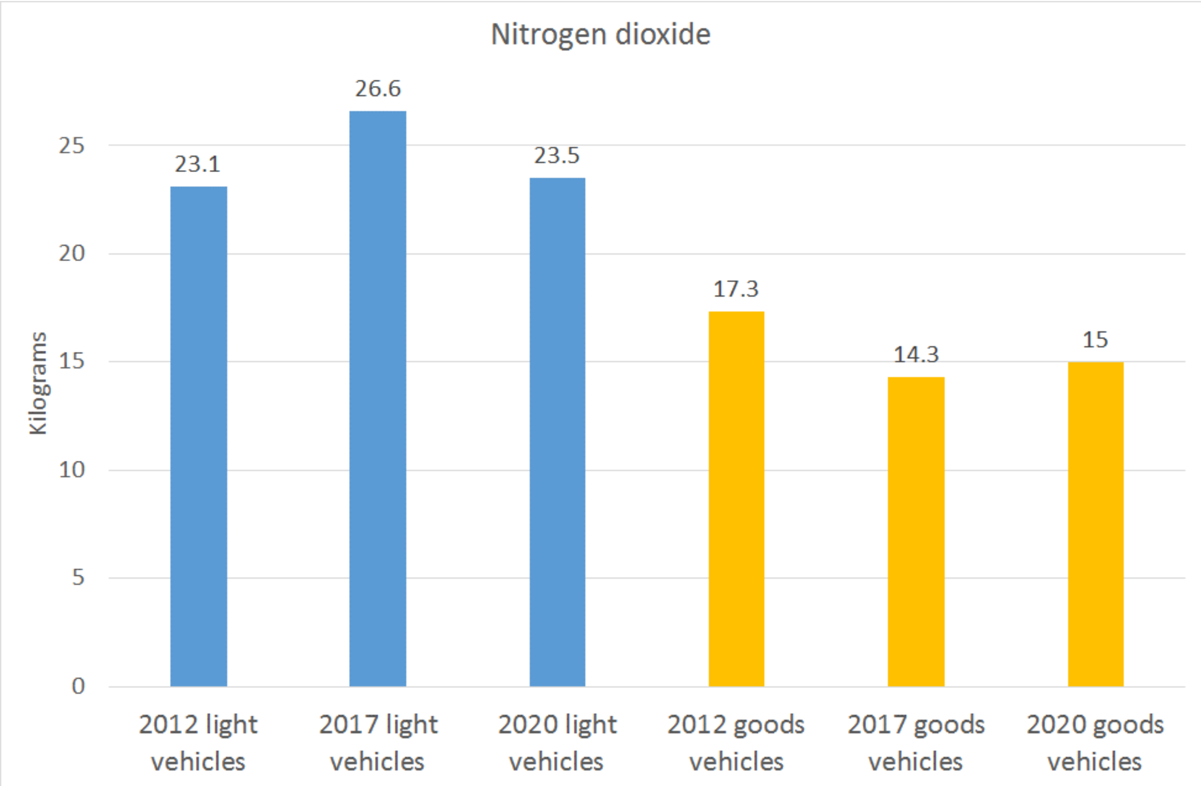

Figure 76: Comparison of NO_2 emissions from light vehicles and goods vehicles

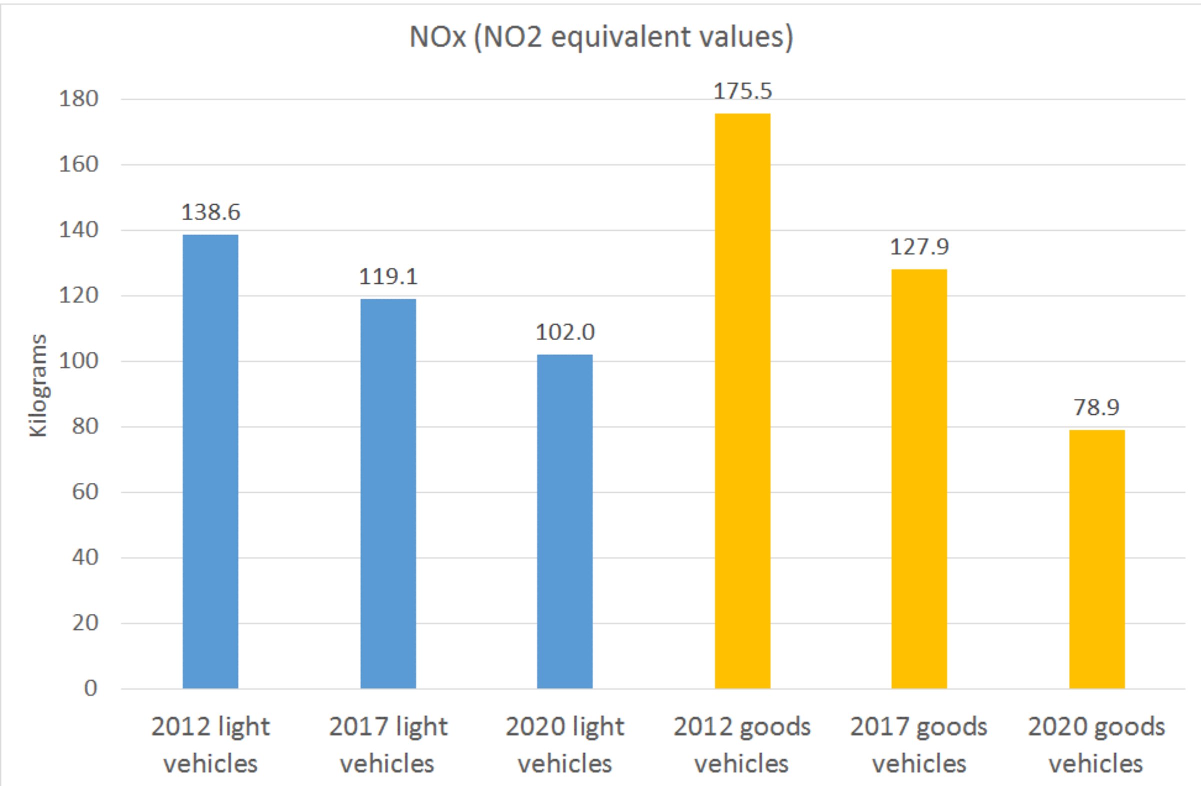

Figure 77: Comparison of NO_x emissions from light vehicles and goods vehicles

Due to the relative dominance of the NO component (by mass), the profile of total NO_x (NO_2 equivalent values) is similar to the NO profile, with calculated total NO_x from goods vehicles (N2 and N3) being significantly higher than light vehicles (M1 and N1) at 2012, but reducing to below the level of light vehicle NO_x emissions by 2020 (Figure 77).

7.6 Summary

Data derived from the 2012 remote sensing surveys for medium and heavy goods vehicles (N2 and N3 respectively) should be treated with some caution because the survey instrumentation would have difficulty collecting data from some heavy vehicle chassis configurations, and because sample sizes are relatively small.

As with light vehicles, the assumed reduction in NO_x emissions from Euro VI vehicles relative to Euro V was based on the pro rata difference between the legislated type approval limit values. The Euro V NO_x emission limit value over the previous European Transient Cycle (ETC) is 2.0 g/kW.hr, whereas the Euro VI NO_x emission limit value over the World Harmonised Transient Cycle (WHTC) is 0.46 g/kW.hr, an assumed reduction of approximately 77%. A small additional adjustment was made to allow for the differences in the two drive cycles at Euro V and Euro VI.

A simplified approach to estimating absolute emissions is adopted for goods vehicles because the probe vehicle data used for light vehicles is not necessarily representative of heavy duty commercial vehicles. The approach adopted utilised observed mean emission rates (g/kg of fuel burned), fuel consumption rates in units of kilograms per km, traffic volume (counts) by vehicle sub-type and time period, and distance travelled (km). Goods vehicle fuel consumption rates were derived from Department for Transport statistics.

The base 2017 scenario goods vehicle total NO_x emissions over all case study areas combined are calculated to be approximately 27% lower than 2012; the base 2020 scenario NO_x emissions are calculated to be approximately 55% lower than 2012. In this context, NO_x is expressed in terms of NO_2 equivalent values (by mass). The relatively faster rate of reduction of goods vehicle NO_x emissions when compared to light vehicle emissions, with respect to time, is due to two factors; (a) the relatively larger assumed step change in NO_x emissions in the transition from Euro V to Euro VI for goods vehicles; and (b) the relatively faster rate of commercial vehicle fleet turnover (i.e. the goods vehicle fleet is younger than the passenger car fleet).

8. TfL bus fleet emissions

8.1 TfL bus fleet characteristics

The bus fleet is unique as it is the only element of the road vehicle fleet in the case study areas which is under direct public influence. Bus service contracts are negotiated between Transport for London and the various bus companies, specifying the types of vehicle technology to be utilised on particular services or groups of services. The characteristics of the bus fleet are therefore strongly influenced / determined by TfL policy. As is to be expected in such an urban area, numerous bus services operate within the case study areas in Ealing. Table 72 lists the main weekday daytime TfL bus services operating in each of the case study areas.

Table 72: TfL bus services operating in case study areas

Case study location	TfL bus services (daytime, weekday)
Acton High Street	70, 207, 266, 427, 440, 607, E3
Horn Lane	260, 266, 440
Haven Green / The Mall	65, 83, 112, 207, 226, 297, 427, 607, E1, E2, E7, E8, E9, E10, E11
A40 Western Avenue	95, 260, 487
Western Road, Southall	105, 195, 482, E5, H32

TfL provided information on the bus vehicle engine and emissions control technology utilised in the existing bus fleet operating in the case study areas in Ealing in 2014. Broad brush estimates of fuel consumption rates were also obtained from TfL (personal communication with TfL, June 21st 2014). A summary is presented in Table 73.

Table 73: Bus fleet composition and assumed fuel consumption rates

Vehicle type	Emission standard	Estimated proportion of fleet (all case study areas combined) %	Assumed fuel consumption rate (litres/km)
Single deck	Euro III	2.1%	0.427
	Euro IV	16.1%	0.370
	Euro V	4.4%	0.355
	Euro VI	1.1%	0.355
	Euro VI hybrid	0.0%	0.315
Double deck	Euro III	5.8%	0.541
	Euro III SCR retrofit	4.9%	0.541
	Euro IV	25.8%	0.516
	Euro V	38.7%	0.504
	Euro VI	0.0%	0.511
	Euro VI hybrid	1.1%	0.316

8.2 TfL bus emissions

As with goods vehicles, sample rates for buses from the 2012 remote sensing surveys were relatively small compared to light vehicles, so results should be treated with some caution, particularly when disaggregated by type, emission standard, and after-treatment technology. However, such disaggregation is necessary to investigate the likely impact of changes in the bus fleet composition over time. Table 74 presents the emission rates of nitric oxide and nitrogen dioxide used in the analysis. Values up to Euro V were observed in the 2012 remote sensing surveys, although some aggregation of categories (for example, single decker and double decker) has been necessary, particularly when observed numbers of single deck vehicles have been very small. Euro VI vehicles, and Euro III vehicles retro-fitted with selective catalytic reduction (SCR) technology, were not observed in the 2012 remote sensing surveys, so expected emissions performance of these buses has been based on the limited amount of TfL test data available in the public domain.

Table 74: Assumed bus NO and NO_2 emission rates

Vehicle type	Emission standard	Assumed NO emissions rate (g/kg of fuel burned)	Assumed NO_2 emissions rate (g/kg of fuel burned)
Single deck	Euro III	22.43	5.57
	Euro IV	28.86	8.38
	Euro V	16.75	4.86
	Euro VI	0.60	0.60
	Euro VI hybrid	0.60	0.60
Double deck	Euro III	22.43	5.57
	Euro III SCR retrofit	2.22	2.55
	Euro IV	28.86	8.38
	Euro V	16.75	4.86
	Euro VI	0.60	0.60
	Euro VI hybrid	0.60	0.60

TfL have stated that the retro-fitting of selective catalytic reduction (SCR) to older Euro III buses is observed to reduce NO_2 emissions by 54.6%, and reduce total NO_x emissions by 88.4%, based on test results from Denis Dart and Volvo double deck vehicles. TfL state that Euro VI buses are expected to have 95% lower NO_x emissions compared to Euro V buses, although 50% of the mass of NO_x is expected to be NO_2 (figures obtained from presentation by TfL at the Air Pollution Research in London seminar, City Hall, London, June 26th 2014). These TfL figures have been utilised to inform the calculation of the emission rates in Table 74, particularly for Euro III SCR retro-fit, and for Euro VI.

In terms of future developments in the TfL bus fleet, the following information is available from TfL:

- All TfL buses are planned to meet a minimum of Euro IV standard for particulate matter and NO_x by 2015;
- SCR systems had been retro-fitted to 1,015 Euro III buses as of May 1st 2014. An additional 400 SCR systems are to be retro-fitted to Euro III buses during 2014;
- The remaining Euro III buses will be replaced with Euro VI buses by 2015;
- TfL have a target to introduce 1,700 hybrid buses (including 600 New Routemasters) by 2016. (As at March 31st 2014, there were 168 New Routemaster hybrids in the TfL fleet, 643 hybrid double deckers, and 33 hybrid/fuel cell/electric single decker vehicles). To put these figures into context, there were 8,765 buses in the TfL fleet in total as at March 31st 2014 (Source: TfL annual statistics, July 2014).

For the purpose of generating future year scenarios, the following **additional scenario assumptions** have been made regarding the future development of the TfL bus fleet in Ealing to 2017 and 2020:

- All TfL buses operating in Ealing will meet a minimum of Euro V standard for NO_x by 2020;
- There will be a 50% reduction in existing Euro IV buses between 2014 and 2017. These buses are assumed to be replaced by Euro V (50%), Euro VI (25%), and Euro VI hybrid (25%).
- There will be a 100% reduction in existing Euro IV buses between 2014 and 2020. These buses are assumed to be replaced by Euro V (50%), Euro VI (25%), and Euro VI hybrid (25%).
- Existing Euro III buses which have been retro-fitted with SCR emissions control technology are assumed to be retained to 2017, but will be replaced by 2020 with Euro VI (50%) and Euro VI hybrid (50%).

As noted in Section 1.2, a simplified approach to estimating absolute emissions is adopted for goods vehicles, utilising observed mean emission rates (g/kg of fuel burned), fuel consumption rates in units of kilograms per km, traffic volume (counts) by vehicle sub-type and time period, and distance travelled (km). Since the available data on the bus fleet mix in Ealing supplied by TfL related to 2014, results have been presented as 2014 rather than 2012. No growth in bus vehicle numbers / frequencies has been assumed in the future year scenarios.

In 2014, 24.6kg of nitric oxide is calculated to be emitted by TfL buses during an average weekday 12 hour period, across all of the case study areas under consideration (Table 75). Approximately 67% of NO from buses is emitted by Euro IV vehicles or earlier. The Haven Green clockwise loop exhibits the highest emissions of any individual case study area due to the large number of bus services converging at this hub (particularly when it is considered that only clockwise traffic movements are included in the tables). Emissions calculated for Acton High Street and Western Road are also significant.

At 2017, total emissions of NO has reduced from 24.6kg to 19.0kg (Table 77), a reduction of over 22%. NO emissions from Euro III (non SCR) buses are removed, and emissions from Euro IV buses are reduced. At 2020 (Table 79), total emissions of NO reduce further to 13.0kg (52.8% of 2014 value), with the largest reductions being attributable to the retirement of the remaining Euro IV vehicles from the fleet (and the assumed improved emissions performance of the Euro V and Euro VI vehicles which replace them).

In 2014, emissions of primary NO_2 from TfL buses across the case study areas totalled 7.4kg during an average weekday 12 hour period (Table 76). Euro IV and earlier buses are calculated to emit 68% of this total. At 2017, total emissions of NO_2 have reduced from 7.4kg to 5.9kg (Table 78), a reduction of just over 20% relative to 2014. At 2020 (Table 80), total emissions of NO_2 decrease further to 3.9kg (53.2% of the 2014 value), due largely to the assumed improved emissions performance of the Euro VI vehicles relative to the Euro IV vehicles which have been replaced.

Figure 78 illustrates the assumed evolution of the nitric oxide and nitrogen dioxide components of total NO_x from TfL buses across the case study areas from 2014 to 2020. The nitric oxide component is assumed to decline from 24.6kg in 2014, to 19.0kg in 2017 (-22.8% relative to 2014), and finally 13.0kg in 2020 (-47.2% relative to 2014). The nitrogen dioxide component of total NO_x is observed to decrease from 7.4kg in 2014, to 5.9kg in 2017 (-20.4% relative to 2012), before further reducing to 3.9kg in 2020 (-46.8% relative to 2014).

Figure 79 presents the aggregate total TfL bus NO_x emissions across the case study areas by reference year. In this context, NO_x is expressed in terms of NO_2 equivalent values (by mass). The base 2017 scenario total bus NO_x emissions are approximately 22.4% lower than 2014; the base 2020 scenario NO_x emissions are approximately 47.1% lower than 2014.

Table 75: Mean NO (grams) in 2014: TfL buses, average weekday (12 hour period)

	AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Single deck												
Euro III	0	0	71	160	71	0	0	0	0	0	0	**302**
Euro IV	222	207	57	1171	56	270	226	692	731	889	889	**5410**
Euro V	186	173	0	0	0	0	0	599	633	0	0	**1590**
Euro VI	0	0	0	4	0	0	0	0	0	0	0	**4**
Euro VI hybrid	0	0	0	0	0	0	0	0	0	0	0	**0**
Double deck												
Euro III	278	259	142	463	141	0	0	0	0	0	0	**1283**
Euro III SCR retro-fit	0	0	0	0	0	49	41	138	146	0	0	**374**
Euro IV	962	896	492	2486	487	0	0	0	0	1834	1834	**8992**
Euro V	1512	1408	567	1590	561	533	446	0	0	0	0	**6617**
Euro VI	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro VI hybrid	0	0	0	3	0	0	0	0	0	0	0	**3**
Total	3160	2943	1330	5877	1317	852	712	1429	1510	2723	2723	**24576**

Table 76: Mean NO_2 (grams) in 2014: TfL buses, average weekday (12 hour period)

	AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Single deck												
Euro III	0	0	18	40	18	0	0	0	0	0	0	**75**
Euro IV	65	60	17	340	16	78	66	201	212	258	258	**1571**
Euro V	54	50	0	0	0	0	0	174	184	0	0	**461**
Euro VI	0	0	0	4	0	0	0	0	0	0	0	**4**
Euro VI hybrid	0	0	0	0	0	0	0	0	0	0	0	**0**
Double deck												
Euro III	69	64	35	115	35	0	0	0	0	0	0	**319**
Euro III SCR retro-fit	0	0	0	0	0	56	47	159	168	0	0	**429**
Euro IV	279	260	143	722	142	0	0	0	0	533	533	**2612**
Euro V	439	408	164	461	163	155	129	0	0	0	0	**1920**
Euro VI	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro VI hybrid	0	0	0	3	0	0	0	0	0	0	0	**3**
Total	905	843	377	1685	373	289	242	533	564	791	791	**7394**

Table 77: Mean NO (grams) in 2017: TfL buses, average weekday (12 hour period)

	AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Single deck												
Euro III	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro IV	111	104	34	586	34	135	113	384	406	427	427	**2760**
Euro V	223	208	6	170	6	45	38	684	723	139	139	**2381**
Euro VI	0	0	2	10	2	1	0	2	2	2	2	**23**
Euro VI hybrid	0	0	0	2	0	0	0	1	1	2	2	**11**
Double deck												
Euro III	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro III SCR retro-fit	0	0	0	0	0	49	41	138	146	0	0	**374**
Euro IV	651	607	333	1527	330	0	0	0	0	892	892	**5234**
Euro V	1705	1588	666	2033	659	533	446	0	0	253	253	**8136**
Euro VI	3	3	2	8	2	0	0	0	0	5	5	**28**
Euro VI hybrid	2	2	1	8	1	0	0	0	0	3	3	**20**
Total	2697	2511	1044	4344	1034	763	638	1210	1279	1723	1723	**18966**

Table 78: Mean NO_2 (grams) in 2017: TfL buses, average weekday (12 hour period)

	AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Single deck												
Euro III	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro IV	32	30	10	170	10	39	33	112	118	124	124	**802**
Euro V	65	60	2	49	2	13	11	199	210	40	40	**691**
Euro VI	0	0	2	10	2	1	0	2	2	2	2	**23**
Euro VI hybrid	0	0	0	2	0	0	0	1	1	2	2	**11**
Double deck												
Euro III	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro III SCR retro-fit	0	0	0	0	0	56	47	159	168	0	0	**429**
Euro IV	189	176	97	444	96	0	0	0	0	259	259	**1520**
Euro V	495	461	193	590	191	155	129	0	0	73	73	**2360**
Euro VI	3	3	2	8	2	0	0	0	0	5	5	**28**
Euro VI hybrid	2	2	1	8	1	0	0	0	0	3	3	**20**
Total	787	733	306	1281	303	264	221	472	499	509	509	**5883**

Table 79: Mean NO (grams) in 2020: TfL buses, average weekday (12 hour period)

	AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Single deck												
Euro III	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro IV	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro V	248	231	13	326	13	75	63	813	859	257	257	**3154**
Euro VI	1	1	2	13	2	2	1	3	3	4	4	**37**
Euro VI hybrid	1	1	0	5	0	1	1	3	3	4	4	**22**
Double deck												
Euro III	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro III SCR retro-fit	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro IV	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro V	1881	1752	765	2455	757	533	446	0	0	506	506	**9601**
Euro VI	7	7	3	16	3	6	5	18	19	10	10	**105**
Euro VI hybrid	4	4	2	13	2	4	3	11	12	6	6	**65**
Total	2142	1995	785	2828	777	621	519	847	895	787	787	**12985**

Table 80: Mean NO_2 (grams) in 2020: TfL buses, average weekday (12 hour period)

	AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB	Total
Single deck												
Euro III	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro IV	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro V	72	67	4	95	4	22	18	236	249	75	75	**915**
Euro VI	1	1	2	13	2	2	1	3	3	4	4	**37**
Euro VI hybrid	1	1	0	5	0	1	1	3	3	4	4	**22**
Double deck												
Euro III	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro III SCR retro-fit	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro IV	0	0	0	0	0	0	0	0	0	0	0	**0**
Euro V	546	508	222	712	220	155	129	0	0	147	147	**2785**
Euro VI	7	7	3	16	3	6	5	18	19	10	10	**105**
Euro VI hybrid	4	4	2	13	2	4	3	11	12	6	6	**65**
Total	631	587	233	854	231	189	158	270	286	245	245	**3930**

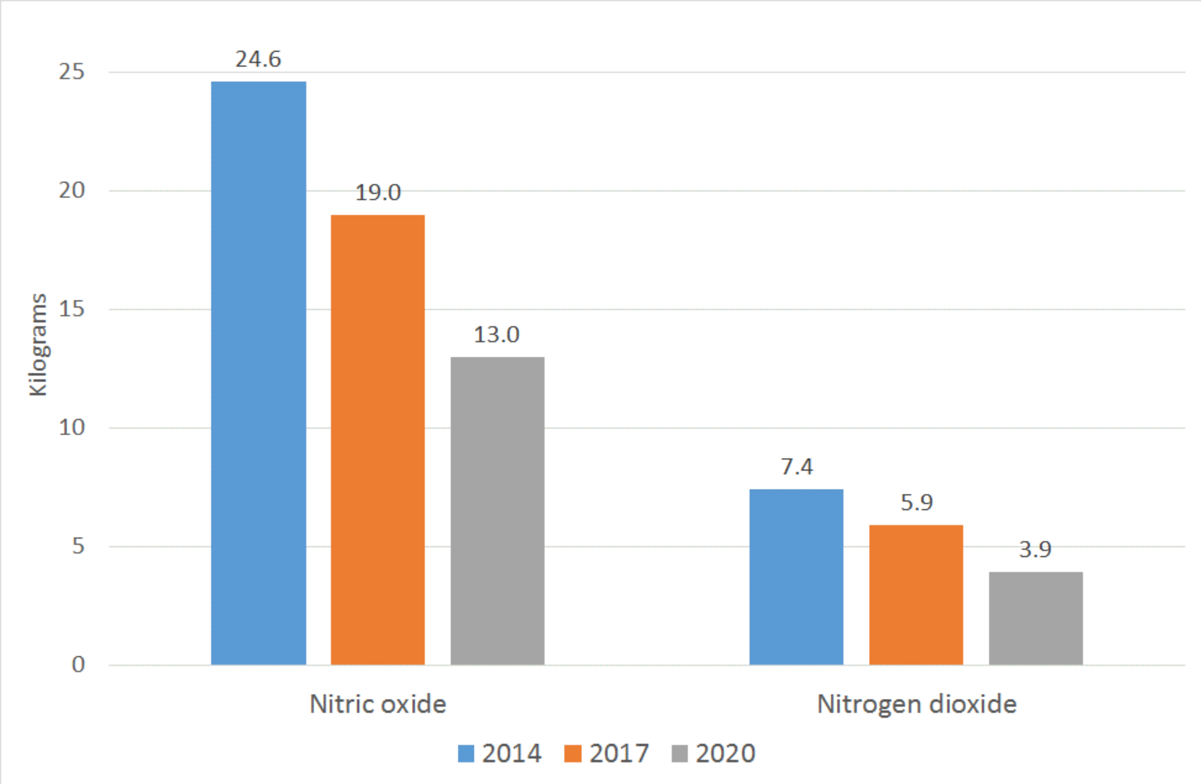

Figure 78: Aggregate emissions of TfL bus NO and NO_2 across case study areas

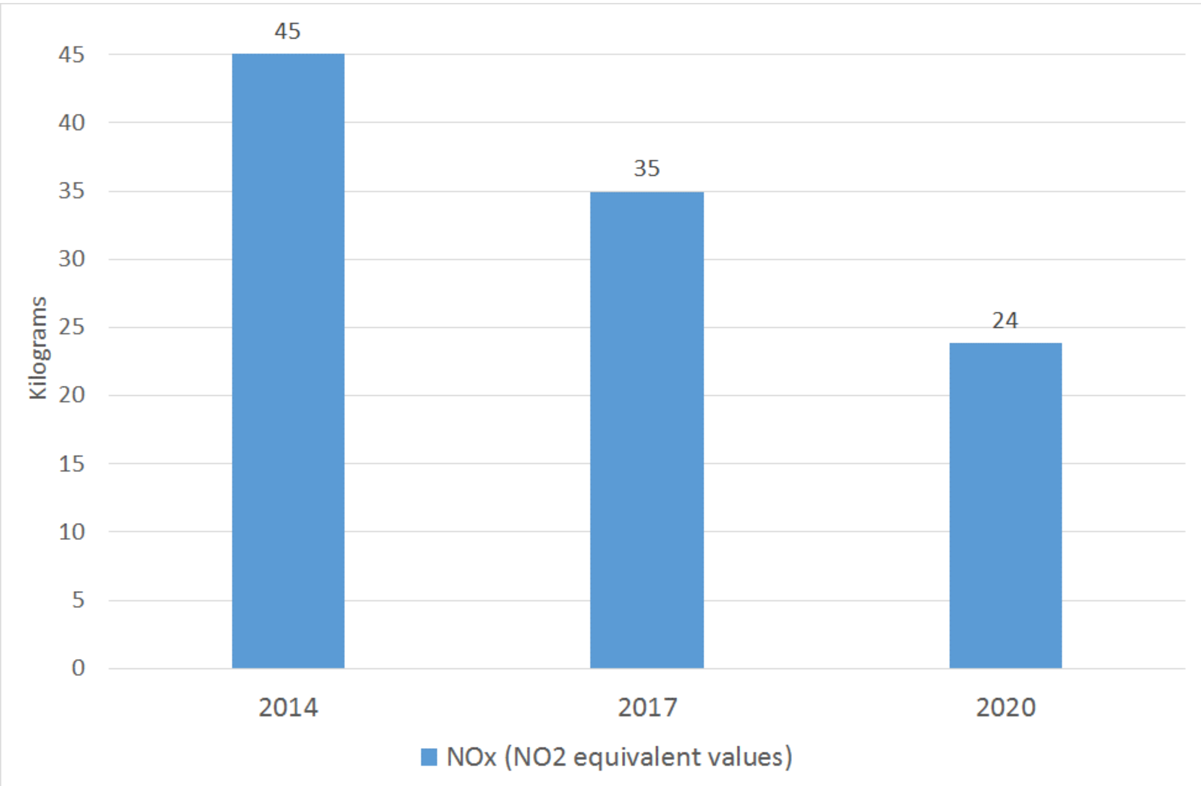

Figure 79: TfL bus NO_x emissions (NO_2 equivalent values)

8.3 Summary

The bus fleet is unique as it is the only element of the road vehicle fleet in the case study areas which is under direct public influence. Bus service contracts are negotiated between Transport for London and the various bus companies, specifying the types of vehicle technology to be utilised on particular services or groups of services. The characteristics of the bus fleet are therefore strongly influenced / determined by TfL policy.

Information on the bus vehicle engine and emissions control technology utilised in the existing bus fleet operating in the case study areas in Ealing in 2014 was obtained from TfL. Broad brush estimates of fuel consumption rates were also obtained from TfL.

As with heavy duty goods vehicles, sample rates for buses from the 2012 remote sensing surveys were relatively small compared to light vehicles, so results should be treated with some caution, particularly when disaggregated by type, emission standard, and after-treatment technology. Euro VI buses, and Euro III buses retro-fitted with selective catalytic reduction (SCR) technology, were not observed in the 2012 remote sensing surveys, so expected emissions performance of these bus types has been based on TfL test result data available in the public domain.

In defining the likely future characteristics of the TfL bus fleet operating in Ealing, reference has been made to existing TfL stated policy, for example that all TfL buses are planned to meet a minimum of Euro IV standard for particulate matter and NO_x by 2015. For the purpose of generating future year scenarios, the following additional scenario assumptions have been made regarding the future development of the TfL bus fleet in Ealing to 2017 and 2020:

- All TfL buses operating in Ealing will meet a minimum of Euro V standard for NO_x by 2020;
- There will be a 50% reduction in existing Euro IV buses between 2014 and 2017. These buses are assumed to be replaced by Euro V (50%), Euro VI (25%), and Euro VI hybrid (25%).
- There will be a 100% reduction in existing Euro IV buses between 2014 and 2020. These buses are assumed to be replaced by Euro V (50%), Euro VI (25%), and Euro VI hybrid (25%).
- Existing Euro III buses which have been retro-fitted with SCR emissions control technology are assumed to be retained to 2017, but will be replaced by 2020 with Euro VI (50%) and Euro VI hybrid (50%).

No growth in bus vehicle numbers / frequencies has been assumed in the future year scenarios. With the above assumptions, at 2017, total NO_x emissions from TfL buses operating in the Ealing case study areas are calculated to reduce by approximately 22% relative to 2014. At 2020, the reduction relative to 2014 is calculated to be approximately 47%.

9. Relationship with diffusion tube NO_2 concentration data

9.1 Aggregate NO_x emissions by case study area

The annual average NO_2 concentrations in the case study areas, as measured using diffusion tubes in 2012, were reported in Section 2. These values are obtained from the '2013 Air Quality Progress Report' for the London Borough of Ealing. Year 2012 values are utilised because they are temporally consistent with the vehicle emissions data collected during the remote sensing surveys in 2012.

Table 81 presents the aggregate mean mass of NO_X (NO_2 equivalent values) in kilograms for an average weekday 12 hour period (0700 to 1900), for each of the case study areas by direction. Values are presented for light vehicles (M1 and N1), heavy vehicles (N2 and N3), and buses (M3) for each of the years and scenarios considered in this analysis. If the results for light vehicles, heavy vehicles, and buses are aggregated for each case study area, it is possible to calculate the absolute and relative differences in NO_x (NO_2 equivalent) emissions for future years and scenarios, relative to the 2012 baseline, and to the 2017 scenario year.

Table 81: Mean NO_x (NO_2 equivalent) emissions (kg). Average weekday (12 hour period)

		AHEB	AHWB	HGEB	HGLP	HGWB	HLNB	HLSB	WAEB	WAWB	WREB	WRWB
Light vehicles (M1 and N1)												
2012		2.86	5.04	1.39	6.56	2.07	10.55	3.86	39.86	50.28	9.49	6.57
2017	1% traffic growth pa	2.37	4.16	1.16	5.48	1.72	8.77	3.25	34.80	44.03	7.87	5.47
2020	1% traffic growth pa	2.01	3.51	0.99	4.68	1.45	7.37	2.78	30.05	37.85	6.63	4.63
2017	No traffic growth	2.26	3.96	1.11	5.22	1.63	8.35	3.10	33.11	41.89	7.48	5.20
2020	No traffic growth	1.86	3.24	0.91	4.33	1.34	6.81	2.56	27.76	34.96	6.12	4.27
2017	Euro 6 diesel sensitivity test	2.43	4.26	1.19	5.61	1.76	8.99	3.33	35.70	45.18	8.05	5.60
2020	Euro 6 diesel sensitivity test	2.16	3.77	1.06	5.02	1.56	7.94	2.98	32.45	40.93	7.13	4.98
2017	Scrappage (10%)	2.25	3.94	1.10	5.20	1.62	8.30	3.08	32.96	41.70	7.44	5.18
2017	Scrappage (20%)	2.12	3.71	1.04	4.92	1.53	7.83	2.90	31.11	39.38	7.02	4.88
2017	Reduce diesel purchases	2.36	4.13	1.15	5.44	1.70	8.71	3.23	34.52	43.69	7.80	5.43
2017	ULEZ	1.09	1.89	0.54	2.54	0.78	4.02	1.51	16.75	21.22	3.58	2.52
2017	Switch off engines	2.29	3.73	1.16	4.78	1.50	6.31	3.08	32.30	42.84	6.34	4.95
Heavy vehicles (N2 and N3)												
2012		2.38	2.64	1.14	2.56	1.15	7.24	4.55	62.57	71.60	9.57	10.26
2017	1% traffic growth pa	1.74	1.92	0.84	1.91	0.85	5.33	3.36	45.53	51.84	7.08	7.51
2020	1% traffic growth pa	1.08	1.19	0.53	1.22	0.54	3.33	2.11	28.06	31.75	4.45	4.67
2017	No traffic growth	1.66	1.83	0.80	1.82	0.81	5.07	3.20	43.32	49.33	6.74	7.15
2020	No traffic growth	1.00	1.10	0.49	1.12	0.50	3.07	1.95	25.92	29.32	4.11	4.31
Buses (M3)												
2012		5.75	5.36	2.42	10.70	2.39	1.60	1.33	2.72	2.88	4.97	4.97
2017		4.92	4.58	1.91	7.94	1.89	1.43	1.20	2.33	2.46	3.15	3.15
2020		3.91	3.65	1.44	5.19	1.42	1.14	0.95	1.57	1.66	1.45	1.45

According to the London Atmospheric Emissions Inventory (LAEI), 43.3% of NO_x emissions in Ealing are attributable to road transport, with 56.7% attributable to non road transport sources. If we assume that the changes in road transport emissions in Ealing from light vehicles, heavy vehicles, and buses, as a result of fleet evolution and the 'what if?' scenario interventions impact on this

43.3% value, we can calculate in a broad brush manner the likely change in overall NO_x emissions by case study area in 2017, and consequently, likely changes in air quality.

To do this, it is necessary to estimate the NO_2 concentration at the diffusion tube which is attributable to the non-road transport sources. In reality, this is a complex issue to resolve for any individual diffusion tube, due to the variation in spatial location of the point, line, and dynamic NO_x sources, and the complexities of weather, atmospheric dispersion and chemistry. However, in this context an estimate was determined by reviewing the 'background' diffusion tube data for Ealing for the 2012 calendar year. Assuming that the annual mean NO_2 measurements at the background diffusion tube sites are measuring NO_2 in the approximate proportions of 43.3% (road transport) and 56.7% (non road transport), an absolute estimate of the non road transport element can be calculated. The median NO_2 concentration at the background diffusion tube sites was observed to be 30.15μg/m^3 (annual mean values). From this, the absolute NO_2 concentration attributable to non road transport sources was calculated as 56.7% × 30.15 μg/m^3 = 17.1 μg/m^3. This value was subtracted from the case study area roadside and kerbside diffusion tube values, before the reduction in road transport related NO_2 emissions (as derived from the previous scenario analysis) was applied.

These differences have been calculated and applied in the following sections to the diffusion tube NO_2 concentrations measured in the case study areas in 2012. This provides an 'indication' of the likely changes in NO_2 concentrations in the case study areas in the future year scenarios.

9.2 Acton High Street diffusion tubes

Figure 80 illustrates the annual mean NO_2 concentrations obtained from diffusion tube measurements in Acton High Street in 2012, and the calculated NO_2 concentrations in 2017 and 2020 assuming (a) no traffic growth, (b) 1% traffic growth per annum, and (c) the reduced Euro 6 efficacy sensitivity test relating to light duty diesel vehicles as discussed in Section 6.9.

It can be seen that at 2012, both diffusion tube locations at 88 High Street and 182 High Street exceeded the 40µg/m^3 annual mean threshold level. At 2017, with 1% per annum assumed traffic growth, both locations are still above the threshold level. At 2020, with the evolution of the vehicle fleet, the 182 High Street site is calculated to be below the 40µg/m^3 annual mean threshold level.

Figure 81 illustrates the calculated impact of the light vehicle scenarios described in Section 6 at year 2017, relative to the 2017 situation with 1% per annum assumed traffic growth. As is to be expected, the ultra-low emission zone light vehicle scenario has the greatest impact on NO_2 concentrations, reducing levels of NO_2 at the 182 High Street site below the 40µg/m^3 annual mean threshold level. Both the light diesel scrappage schemes, and the light vehicle 'switch off engines' scenarios, make a lesser but nonetheless useful contribution to reducing NO_2 concentrations, but neither below the annual mean threshold level. At 88 High Street, NO_2 concentrations at year 2017 remain above the annual mean threshold level, even with the light vehicle ULEZ intervention.

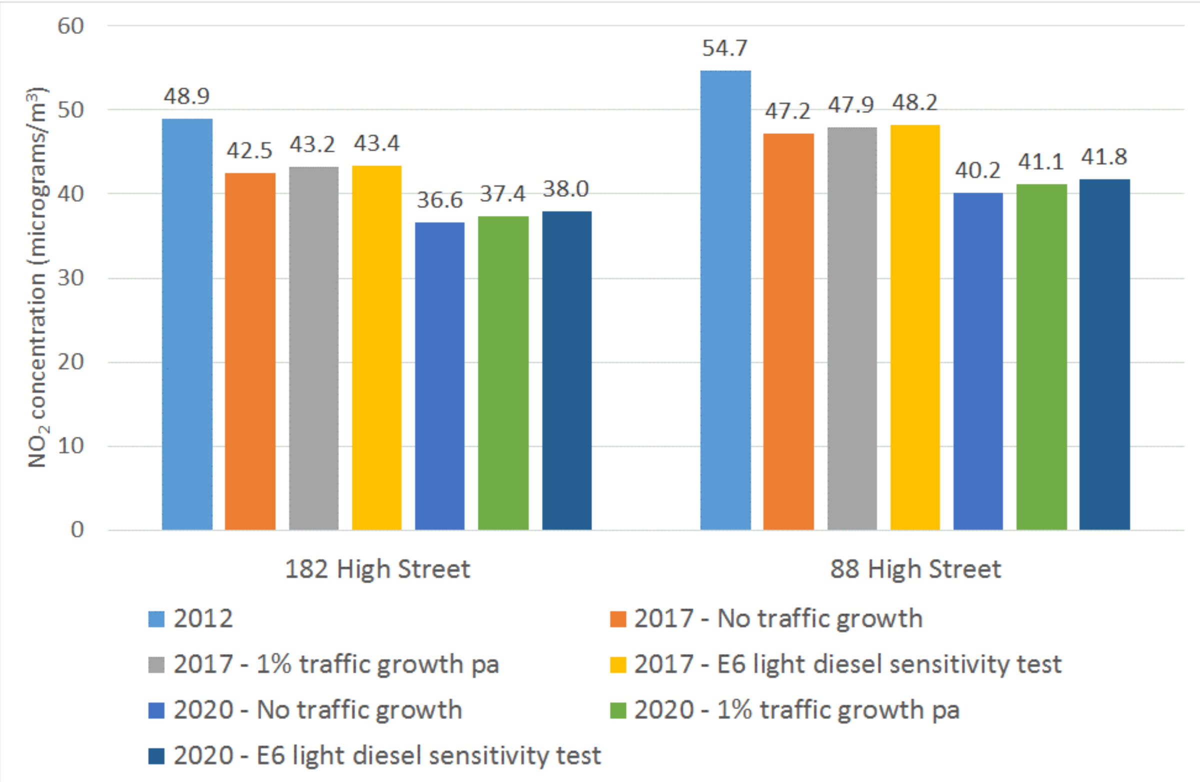

Figure 80: Acton High Street diffusion tube sites - Annual mean NO_2 concentrations

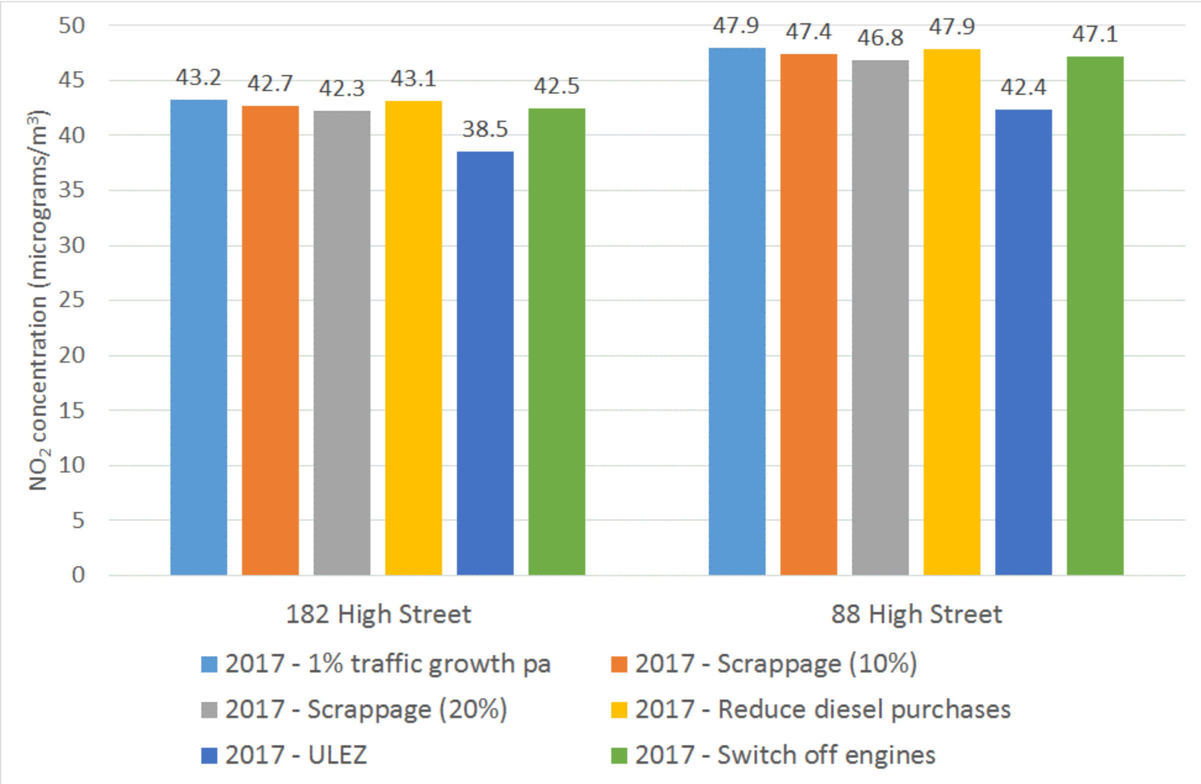

Figure 81: Acton High Street – Light vehicle scenarios - Annual mean NO_2 concentrations

9.3 Horn Lane diffusion tubes

Figure 82 illustrates the annual mean NO_2 concentrations obtained from diffusion tube measurements in Horn Lane in 2012, and the calculated NO_2 concentrations in 2017 and 2020 assuming (a) no traffic growth, (b) 1% traffic growth per annum, and (c) the reduced Euro 6 efficacy sensitivity test relating to light duty diesel vehicles.

It can be seen that at 2012, both of the diffusion tube locations at 156 Horn Lane and at the Horn Lane AQMS exceeded the 40µg/m^3 annual mean threshold level, although at 156 Horn Lane by only a small margin. At 2017, with 1% per annum assumed traffic growth, the diffusion tube at 156 Horn Lane falls below the annual mean threshold level, but the Horn Lane AQMS location remains above the threshold at 47.2 µg/m^3. At 2020, with the evolution of the vehicle fleet, both sites are calculated to be below the 40µg/m^3 annual mean threshold level if Euro 6 is assumed to be effective.

Figure 83 illustrates the calculated impact of the light vehicle scenarios described in Section 6 at year 2017, relative to the 2017 situation with 1% per annum assumed traffic growth. At 156 Horn Lane, all scenarios are well below the 40µg/m^3 annual mean threshold level, with the light vehicle ULEZ performing best. However, it is notable that the 'switch off engines' light vehicle scenario performs better that the light diesel vehicle scrappage intervention. At the Horn Lane AQMS at 2017, all light vehicle scenarios remain above the annual mean threshold level, except for the ULEZ intervention. In interpreting these results, it should be noted that the majority of the benefits of the 'switch off engines' intervention were calculated to be realised on the northbound approach to the junction with the A40 Western Road (see Figure 48 and Table 51 / Table 52), and the greatest impact on NO_2 concentrations would be expected in this geographic location (subject to variation in local atmospheric conditions / wind direction).

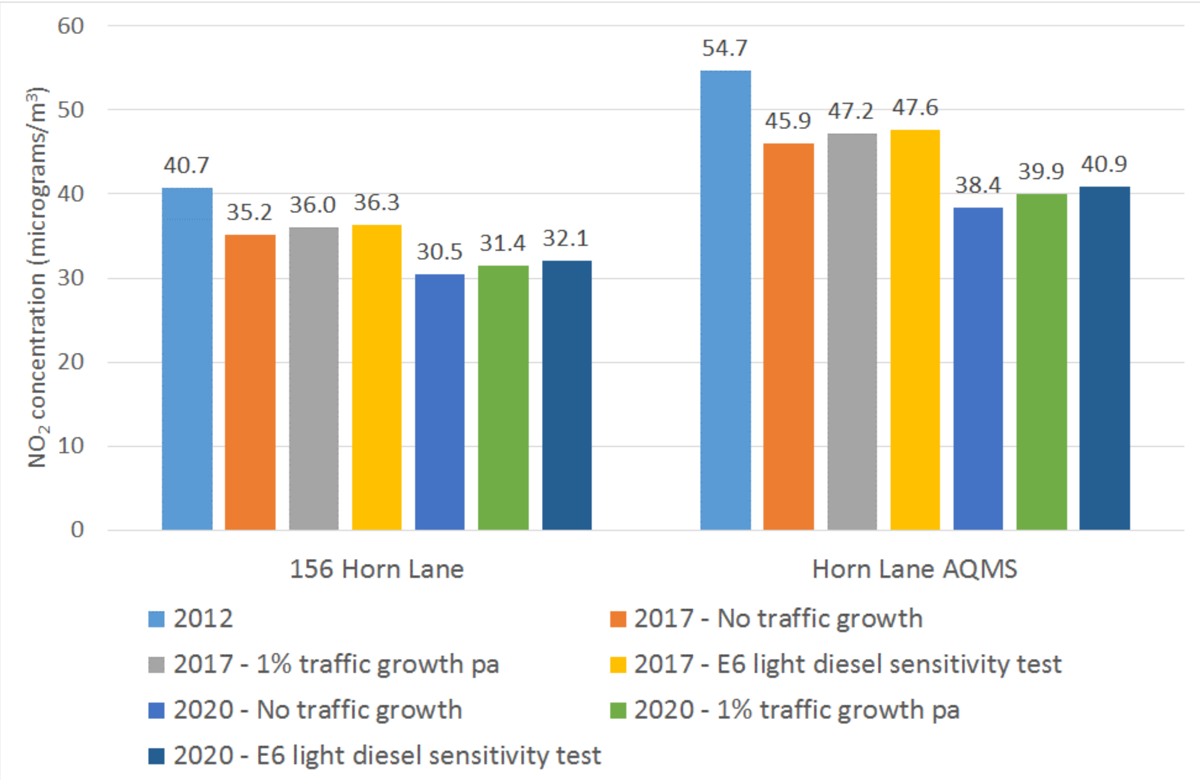

Figure 82: Horn Lane diffusion tube sites – Annual mean NO_2 concentrations

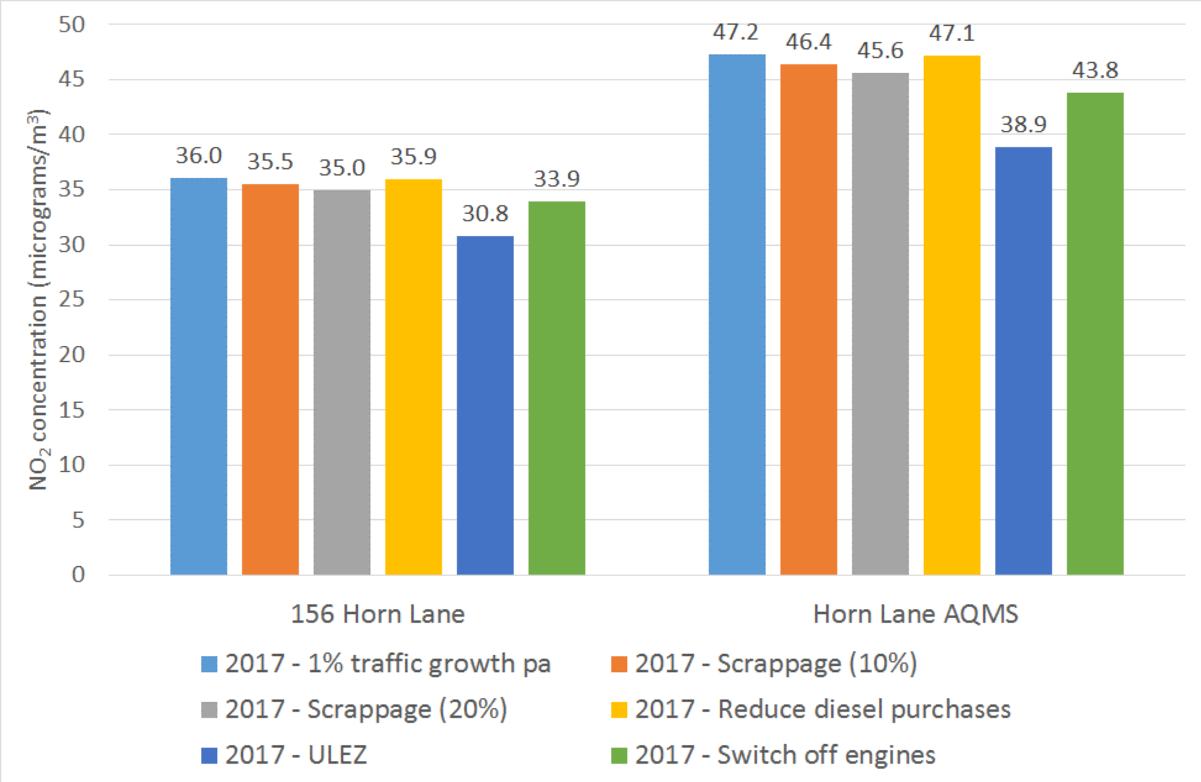

Figure 83: Horn Lane – Light vehicle scenarios – Annual mean NO_2 concentrations

9.4 A40 Western Avenue diffusion tubes

Figure 84 and Figure 85 illustrate the annual mean NO_2 concentrations obtained from a total of four diffusion tube locations on the A40 Western Avenue in 2012, and the calculated NO_2 concentrations in 2017 and 2020 assuming (a) no traffic growth, (b) 1% traffic growth per annum, and (c) the reduced Euro 6 efficacy sensitivity test relating to light duty diesel vehicles.

It can be seen that at 2012, all four diffusion tube locations at Wendover Court, Western Avenue AQMS, 6 Western Avenue, and 98 Western Avenue exceeded the 40µg/m^3 annual mean threshold level. At 2017, with 1% per annum assumed traffic growth, all four locations are still above the threshold level, although only by a small margin at 98 Western Avenue. At 2020, with the evolution of the vehicle fleet, the diffusion tube sites at Wendover Court and 98 Western Avenue fall below the 40µg/m^3 annual mean threshold level assuming 1% traffic growth per annum. However, the measurement sites at Western Avenue AQMS and 6 Western Avenue remain well above the annual mean threshold level.

Figure 86 and Figure 87 illustrate the calculated impact of the light vehicle scenarios described in Section 6 at year 2017, relative to the 2017 situation with 1% per annum assumed traffic growth.

At Wendover Court, no scenario intervention reduces NO_2 concentrations below the 40µg/m^3 annual mean threshold level at 2017, although the ULEZ comes close at 40.8µg/m^3, and the light diesel vehicle scrappage and light vehicle 'switch off engines' interventions have some benefits. At 98 Western Avenue, no light vehicle scenario interventions succeed in reducing NO_2 concentrations below the annual mean threshold level, except for the ULEZ scenario (38.2 µg/m^3).

However, at the Western Avenue AQMS and at 6 Western Avenue, none of the light vehicle scenario interventions at 2017 succeed in reducing NO_2 concentrations below the 40µg/m^3 annual mean threshold level. In interpreting these results, it should be noted that the majority of the benefits of the 'switch off engines' intervention were calculated to be realised on the eastbound and westbound approaches to the signalised junctions Mansfield Road, Horn Lane / Gipsy Corner, and Savoy Circus (see Figure 50 and Table 55 / Table 56), and the greatest impact on NO_2 concentrations would be expected in these geographic locations (subject to variation in local atmospheric conditions / wind direction). This might provide additional NO_2 reduction benefits to diffusion tube locations such as 6 Western Avenue (close to Savoy Circus).

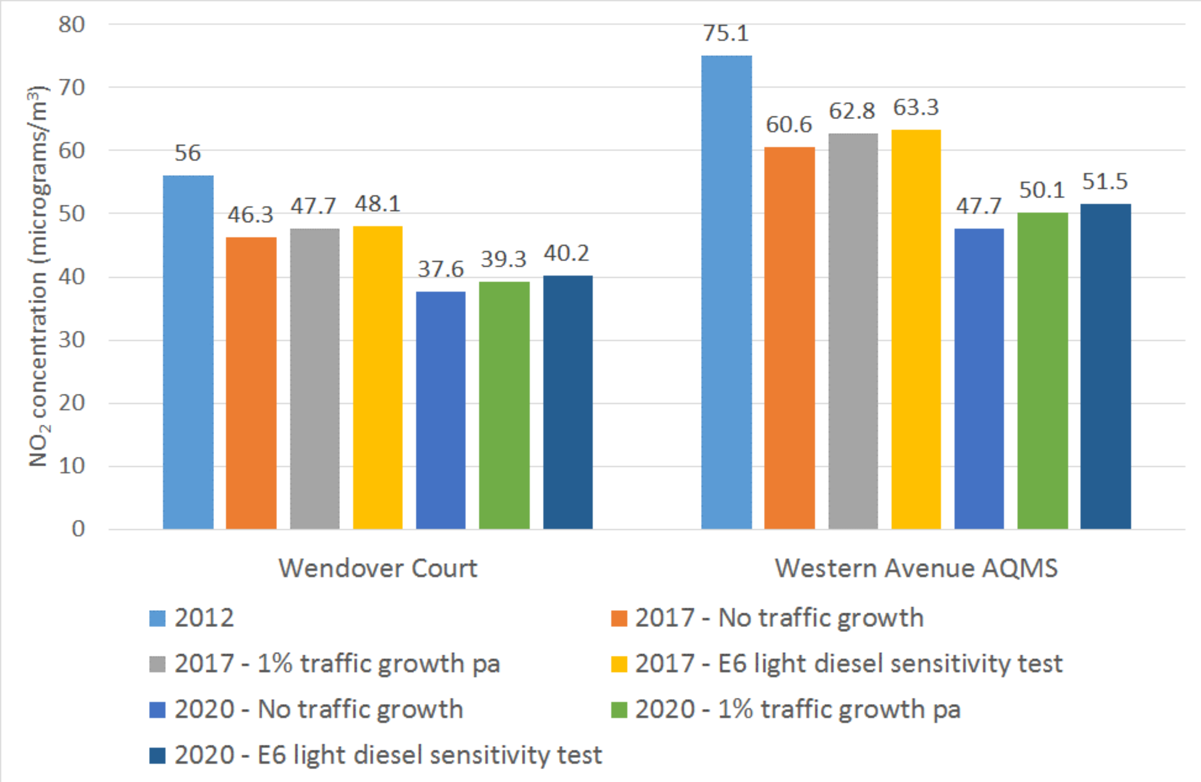

Figure 84: A40 Western Avenue diffusion tube sites (Part I) – Annual mean NO_2 concentrations

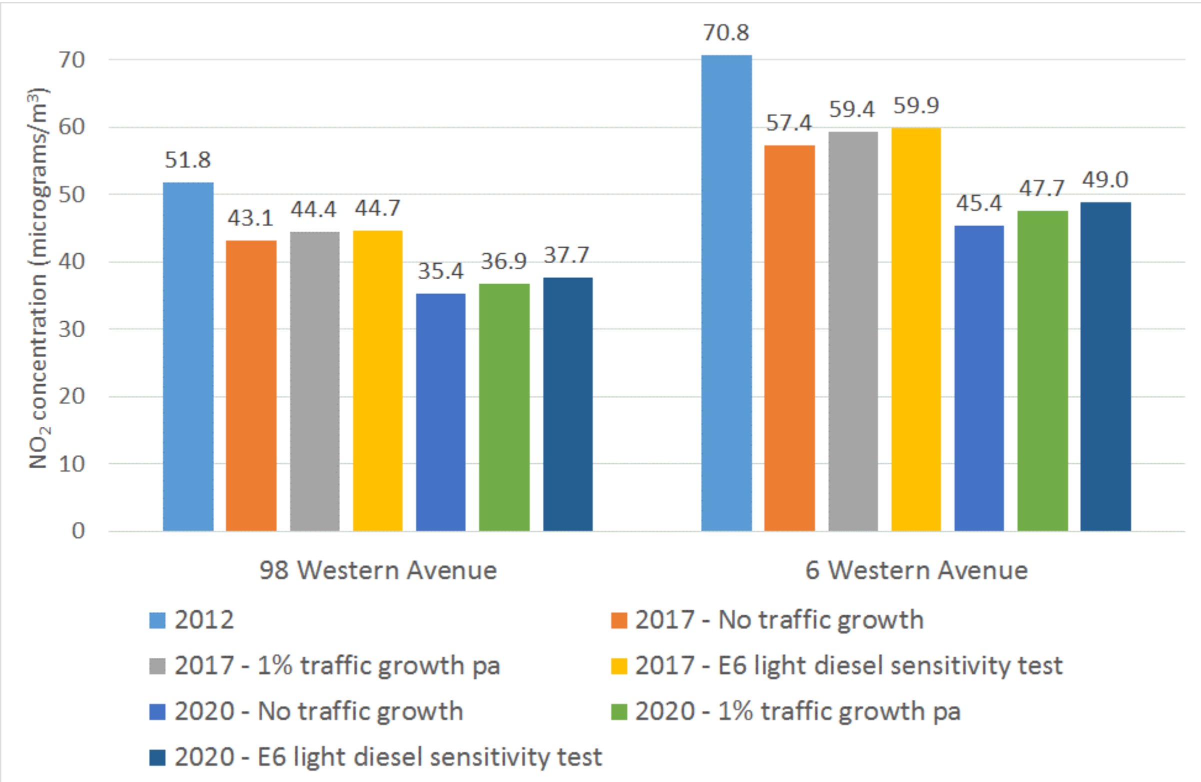

Figure 85: A40 Western Avenue diffusion tube sites (Part II) – Annual mean NO_2 concentrations

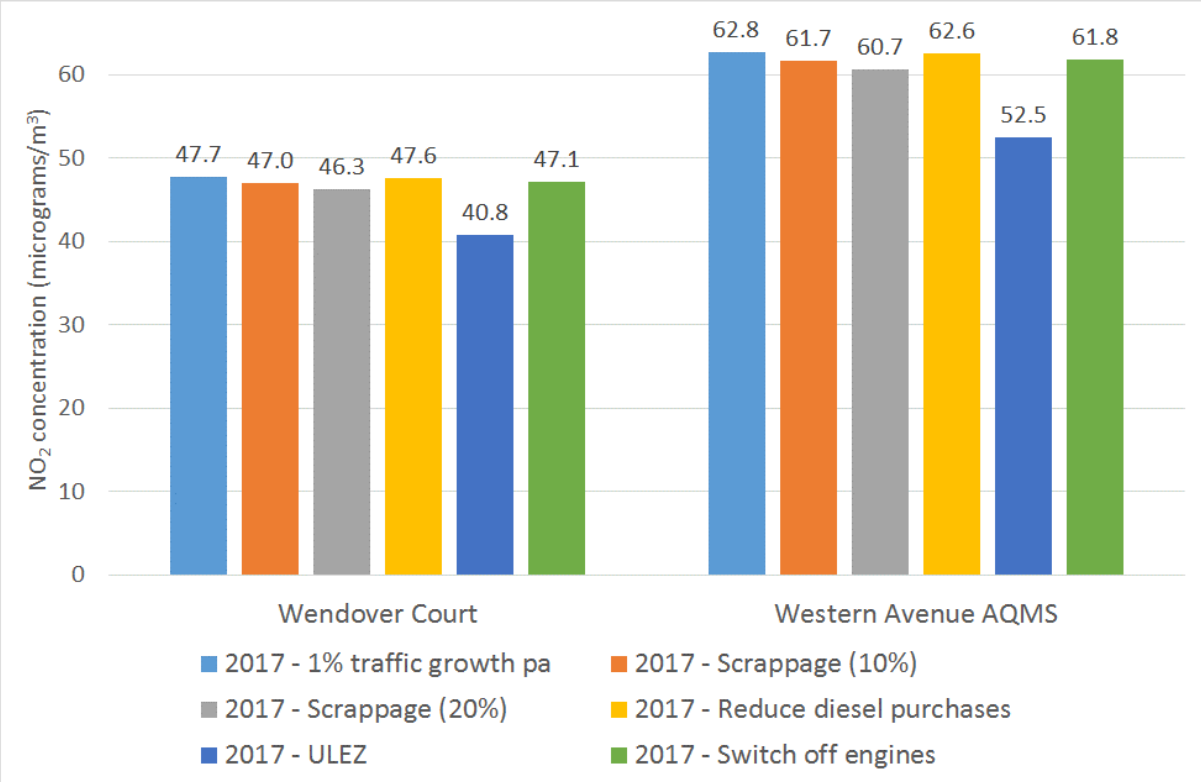

Figure 86: A40 Western Ave (Part I) – Light vehicle scenarios – Annual mean NO_2 concentrations

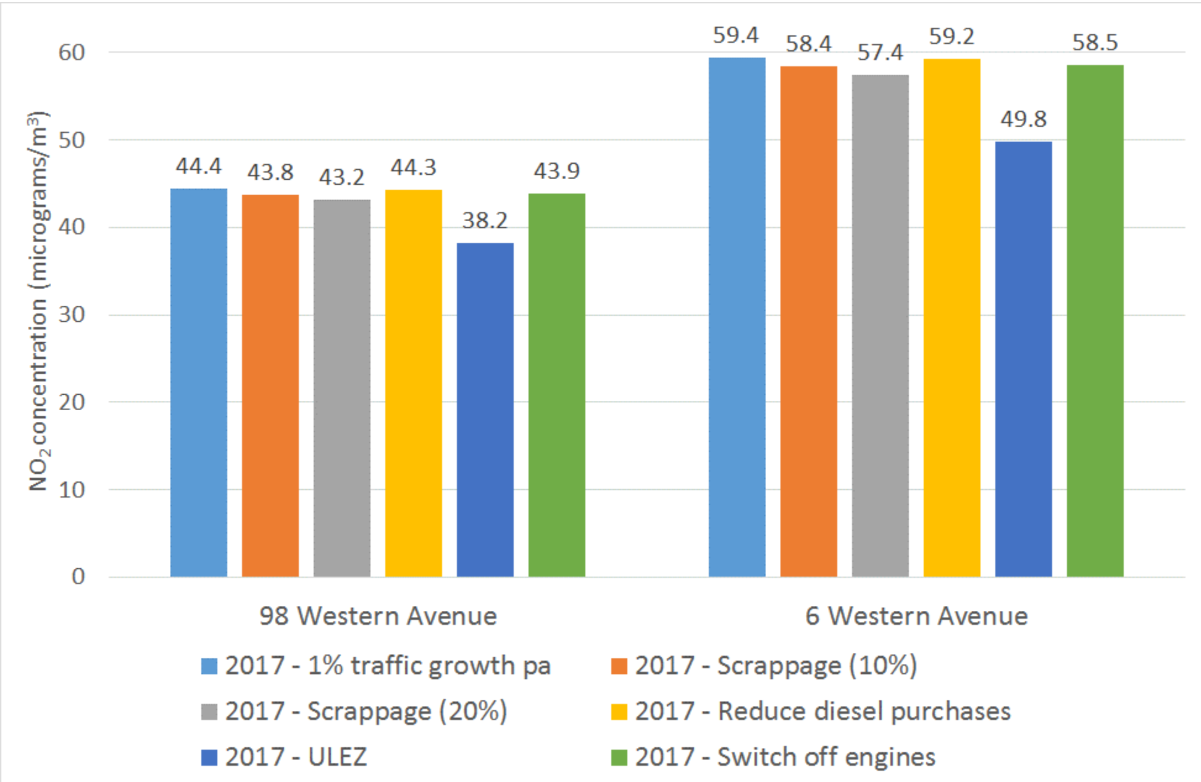

Figure 87: A40 Western Ave (Part II) – Light vehicle scenarios – Annual mean NO_2 concentrations

9.5 Haven Green diffusion tubes

Figure 88 and Figure 89 illustrate the annual mean NO_2 concentrations obtained from four diffusion tube locations within the Haven Green case study area in 2012, and the calculated NO_2 concentrations in 2017 and 2020 assuming (a) no traffic growth, (b) 1% traffic growth per annum, and (c) the reduced Euro 6 efficacy sensitivity test relating to light duty diesel vehicles.

It can be seen that at 2012, all four diffusion tube locations at 8 Spring Bridge Road, Gordon Road, 41-42 Haven Green, and Haven Green Court exceeded the 40µg/m^3 annual mean threshold level. At 2017, with 1% per annum assumed traffic growth, NO_2 concentrations at all diffusion tube locations remain above the annual mean threshold limit value, although at Gordon Road by a small margin. At 8 Spring Bridge Road, NO_2 concentrations are calculated to remain above the annual mean threshold level at 2017, by a wide margin at 55.9µg/m^3.

At 2020, with the evolution of the vehicle fleet, all diffusion tube locations except 8 Spring Bridge Road are calculated to fall below the 40µg/m^3 annual mean threshold level assuming 1% traffic growth per annum.

Figure 90 and Figure 91 illustrate the calculated impact at Haven Green of the light vehicle scenarios described in Section 6 at year 2017, relative to the 2017 situation with 1% per annum assumed traffic growth. At the Gordon Road, only the scrappage scenario (20%), the switch off engines scenario, and the ULEZ scenario are calculated to be below the 40µg/m^3 annual mean threshold level. At Haven Green Court and 41-42 Haven Green, NO_2 concentrations for all light vehicle scenarios are calculated to be above the 40µg/m^3 annual mean threshold level, with the exception of the ULEZ.

However, at 8 Spring Bridge Road, none of the individual light vehicle scenario interventions alone succeed in reducing NO_2 concentrations below the annual mean threshold level at year 2017. Even with the light vehicle ULEZ scenario intervention, the calculated annual mean NO_2 concentration is 48.5µg/m^3.

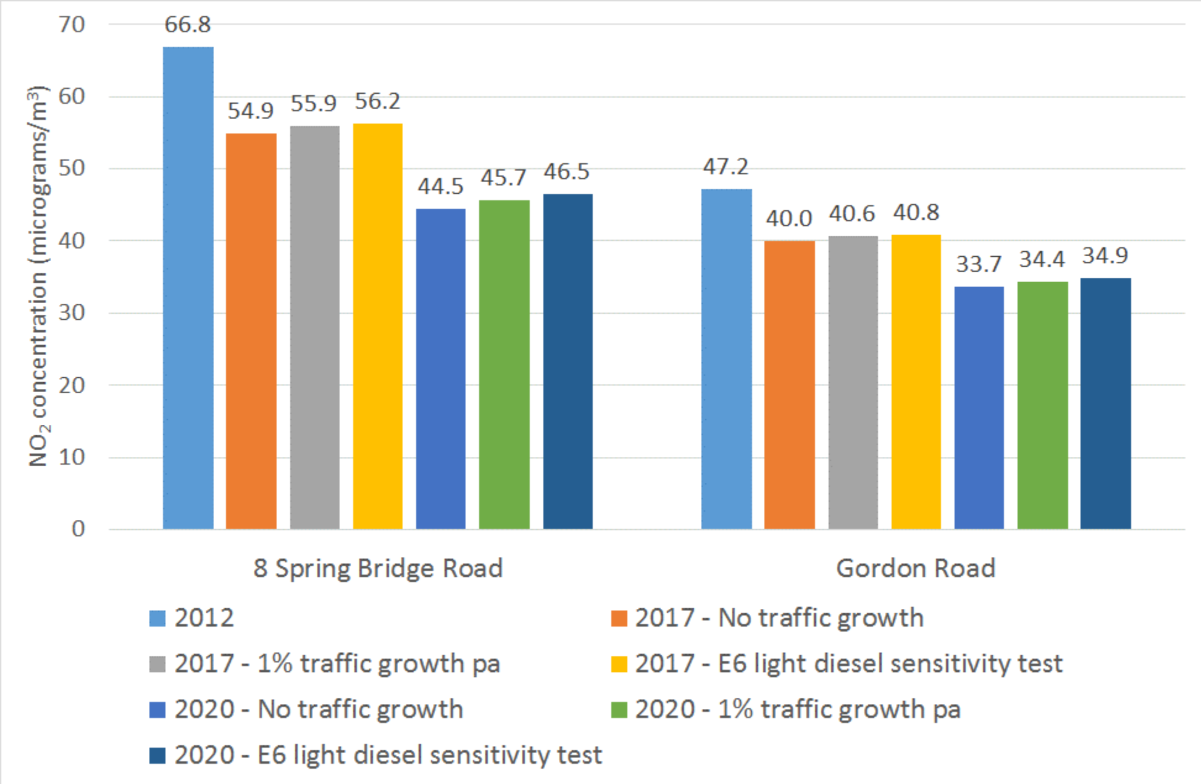

Figure 88: Haven Green diffusion tube sites (Part I) – Annual mean NO_2 concentrations

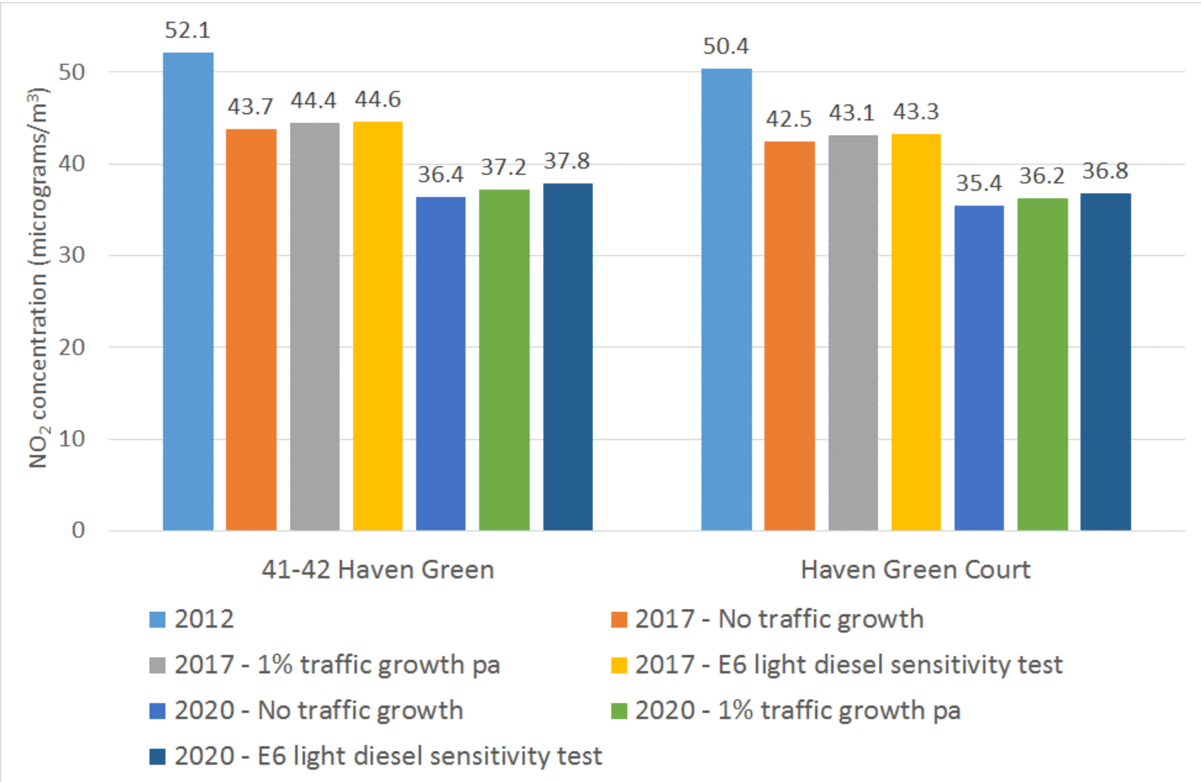

Figure 89: Haven Green diffusion tube sites (Part II) – Annual mean NO_2 concentrations

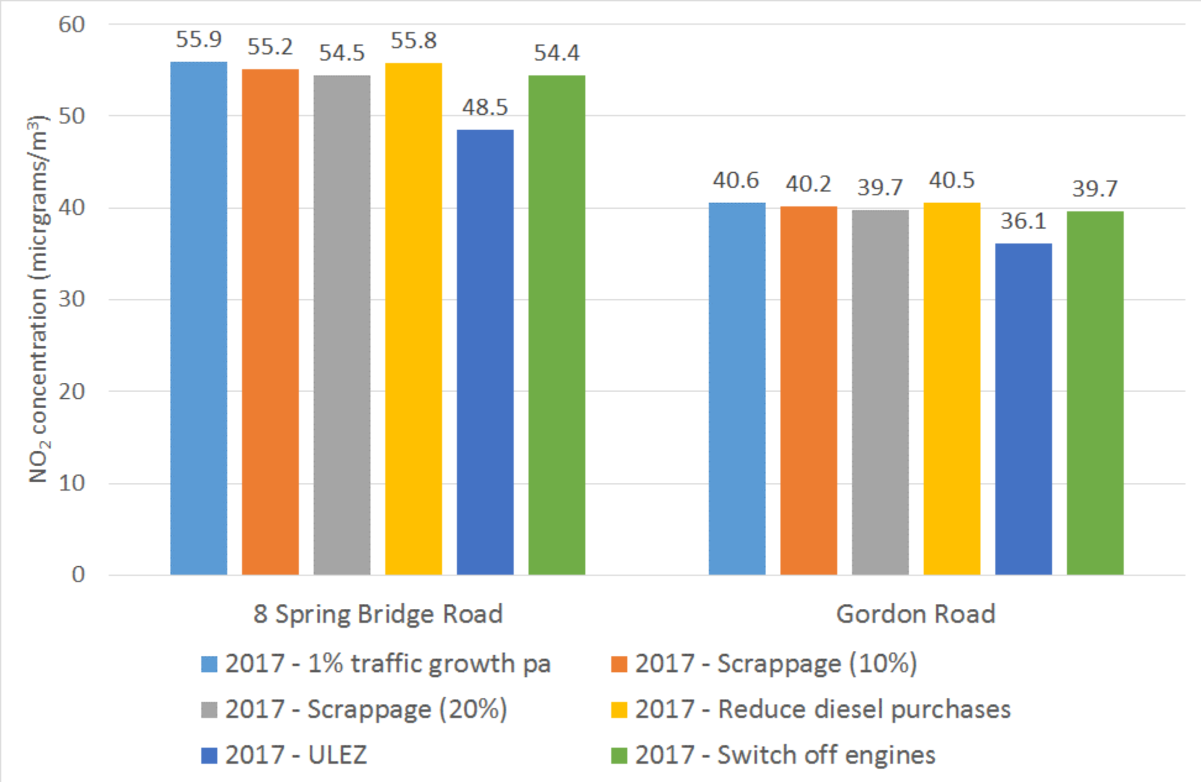

Figure 90: Haven Green (Part I) – Light vehicle scenarios – Annual mean NO_2 concentrations

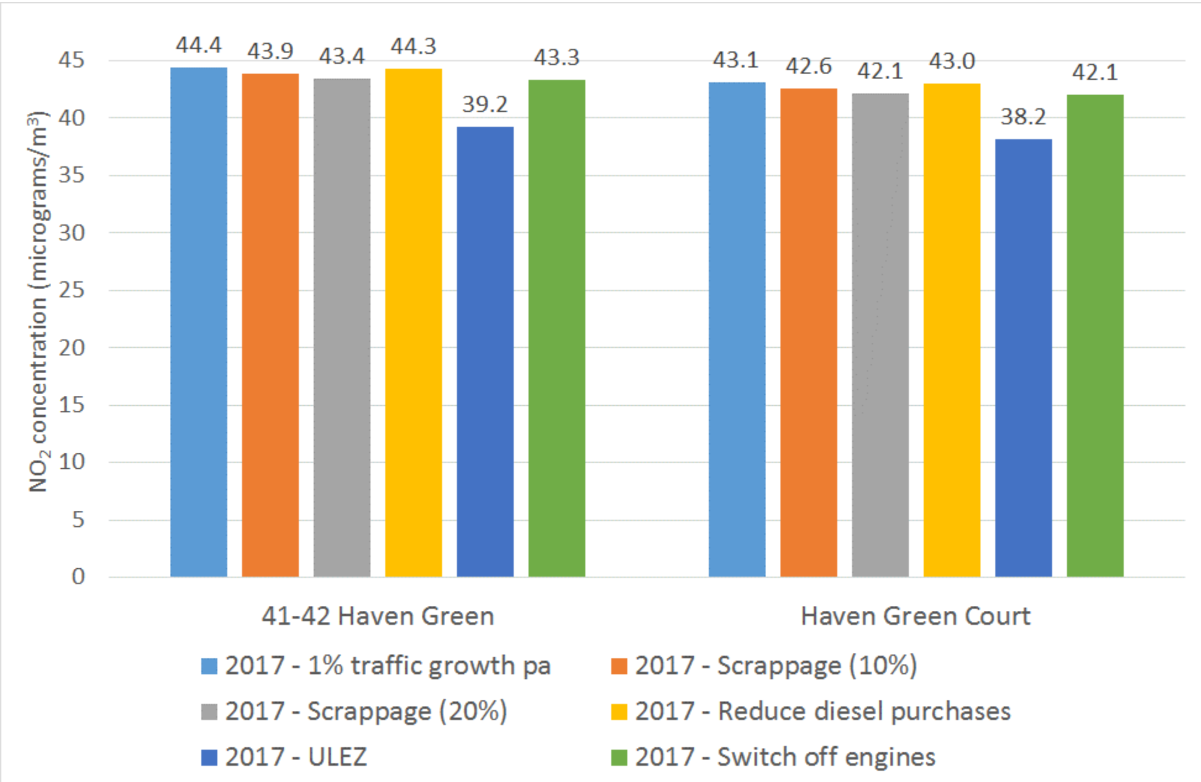

Figure 91: Haven Green (Part II) – Light vehicle scenarios – Annual mean NO_2 concentrations

9.6 Western Road, Southall diffusion tubes

Figure 92 illustrates the annual mean NO_2 concentrations obtained from two diffusion tube measurement locations in Western Road, Southall in 2012, and the calculated NO_2 concentrations in 2017 and 2020 assuming (a) no traffic growth, (b) 1% traffic growth per annum, and (c) the reduced Euro 6 efficacy sensitivity test relating to light duty diesel vehicles as discussed in Section 6.9.

It can be seen that at 2012, both diffusion tube locations at 18 Western Road (41.9µg/m^3) and Featherstone Primary School (42.4µg/m^3) exceeded the 40µg/m^3 annual mean threshold level. At 2017, with 1% per annum assumed traffic growth, both locations are calculated to fall below the threshold level. At 2020, with the evolution of the vehicle fleet, both sites are calculated to have annual mean NO_2 concentrations ≤30µg/m^3.

Figure 93 illustrates the calculated impact of the light vehicle scenarios described in Section 6 at year 2017, relative to the 2017 situation with 1% per annum assumed traffic growth. As is to be expected, the ultra-low emission zone light vehicle scenario has the greatest impact on NO_2 concentrations. The light vehicle 'switch off engines' scenario has the next best reduction in NO_2 concentrations, performing marginally better than the light diesel vehicle scrappage scheme scenarios.

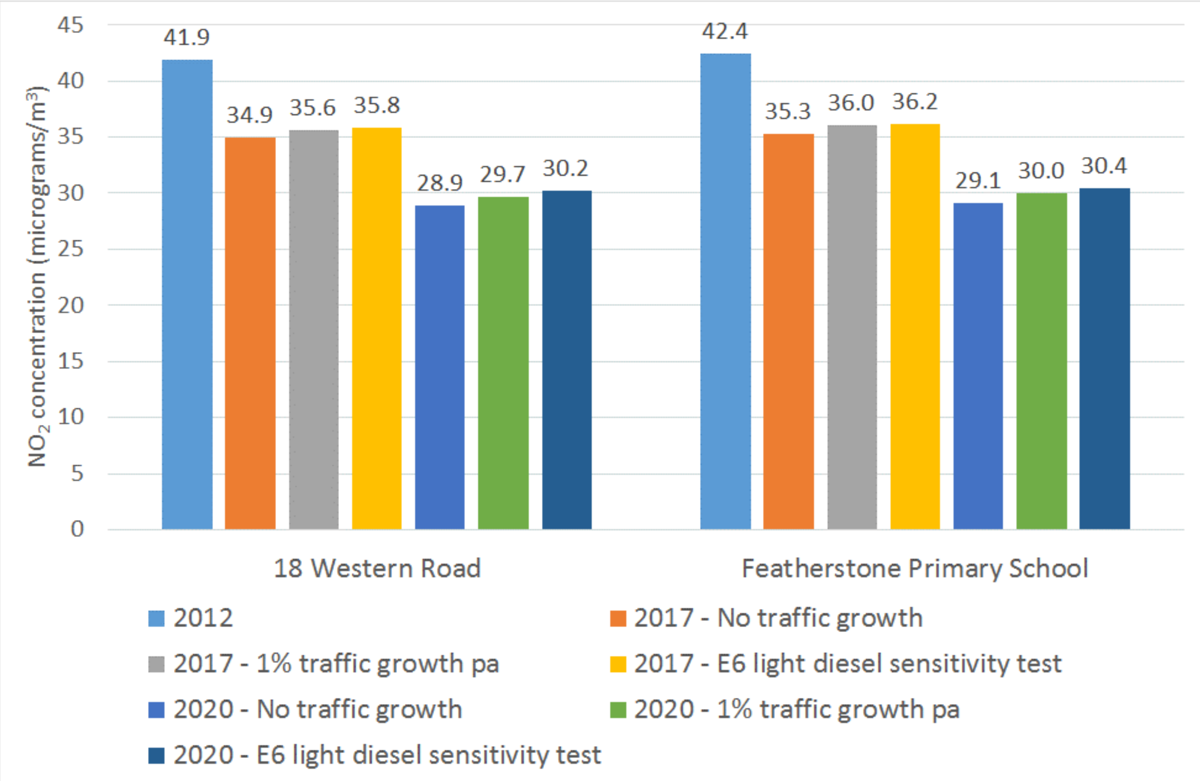

Figure 92: Western Road, Southall diffusion tube sites – Annual mean NO_2 concentrations

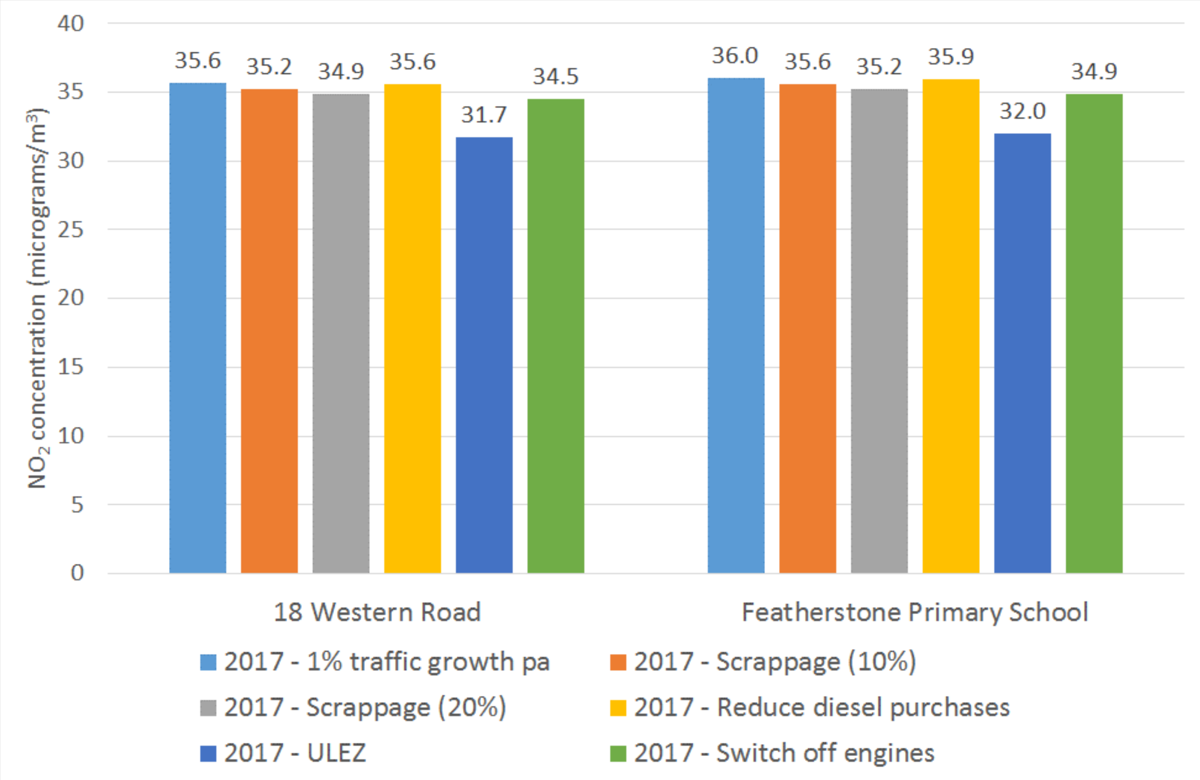

Figure 93: Western Road, Southall – Light vehicle scenarios – Annual mean NO_2 concentrations

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Appendix A

Nitrogen dioxide (NO_2) and nitric oxide (NO) light vehicle emission rates derived from 2012 remote sensing surveys.

Grams of pollutant per kilogram of fuel consumed (g/kg) with respect to engine load power (kW).

Mean nitric oxide (NO) emission rates derived from 2012 remote sensing surveys.

Grams of nitric oxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW).

Diesel cars and vans

	Diesel cars <2.0 litres						Diesel cars > 2.0 litres						Diesel vans (up to 3.5 tonnes)					
kW	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**
<-16					7.07	8.68					4.57					10.53	6.56	6.33
-16 to -12				10.21	9.02	8.75				7.47	4.83	5.12				10.39	7.98	7.29
-12 to -8					7.05											12.19	6.84	6.93
-8 to -4			13.46	8.76	6.59	7.61				6.48	5.79	6.30				11.99	7.51	7.13
-4 to 0				10.56	6.67	8.38				7.04	4.71	5.89				12.24	7.09	8.00
0 to 4				10.05	7.47	7.16				9.34	5.32	5.93				11.53	7.13	8.81
4 to 8				10.89	6.47	7.35				8.00	5.50	5.96				11.98	7.49	7.81
8 to 12			10.97	11.51	6.82	8.52				9.48	5.14	5.43				12.38	7.89	8.32
12 to 16				11.80	7.30	9.90				9.85	6.24	6.32				12.71	8.20	9.09
16 to 20				11.97	8.56	9.14				10.15	6.98	7.70				13.01	8.23	8.86
20 to 24				14.75	9.57	11.98				9.73	8.36	9.49				14.56	9.56	10.29
24 to 28				15.07	9.24	10.43					7.84	10.00				14.60	8.73	9.18
28 to 32					10.91	13.67					10.33					11.30	9.45	11.27
32 to 36			15.33		11.94											15.88	10.13	11.04
36 to 40					12.99					12.86							10.53	13.06
40 to 44				16.65		15.60					10.78	11.22					13.30	12.31
44 to 48					15.36											14.48		
48 to 52																	13.45	14.76
>= 52																		
Total	7.89	11.37	13.68	11.69	7.76	8.84	6.71	8.18	11.29	9.38	6.32	6.69	9.29	12.79	12.79	12.54	8.07	8.81

Mean nitric oxide (NO) emission rates derived from 2012 remote sensing surveys.

Grams of nitric oxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW).

Diesel taxis

kW	Taxi FX Euro 2	Metrocab Euro 2	Taxi TX1 Euro 2	Metrocab Euro 3	Taxi TXII Euro 3	Taxi Vito 111 Euro 4	Taxi TX4 Euro 4	Taxi Vito 113 Euro 5	Taxi TX4 Euro 5
<-16			22.40		8.32		7.10		
-16 to -12	21.32		23.16				7.91		
-12 to -8					9.32	10.59			
-8 to -4			23.53		8.26		8.00	6.89	
-4 to 0	24.82		22.89		8.30		8.94		
0 to 4	22.09		23.09		9.25	10.03	9.21		
4 to 8	18.14		20.55		9.16	10.75	8.72		
8 to 12	13.79		17.08		9.50	10.29	8.30	7.94	
12 to 16	11.51		14.23		10.26	11.46	8.45	8.21	
16 to 20			11.97		11.75	11.36	9.13		
20 to 24			11.41		12.47	12.56	9.72		
24 to 28			12.57				10.14		
28 to 32									
32 to 36	12.21							10.78	
36 to 40					13.55	14.55			
40 to 44			14.38				12.30		
44 to 48									
48 to 52									
>= 52									
Total	17.23	31.10	17.77	9.74	9.84	11.19	8.87	8.53	12.82

Mean nitric oxide (NO) emission rates derived from 2012 remote sensing surveys.

Grams of nitric oxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW).

Petrol cars

	Petrol cars <1.4 litres						Petrol cars 1.4 to 2.0 litres						Petrol cars >2.0 litres					
kW	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**
<-16					0.58				8.15	1.79	1.67					2.35		
-16 to -12			5.14	1.44		1.22			8.04		2.28	0.93					0.90	
-12 to -8					1.48			9.52		1.90	1.82				3.56	1.84		
-8 to -4				2.74	1.00	1.54			7.26	2.76	2.16							
-4 to 0			5.43	2.64	1.18	1.12			9.60	2.52	1.72	0.96				1.85	1.36	
0 to 4			5.10	2.54	1.44	0.80		11.62	8.48	3.10	1.81	0.35			7.34	2.65	0.95	
4 to 8			6.47	2.65	2.06	0.75		11.58	8.84	3.66	2.09	0.60			4.47	2.16	0.71	
8 to 12			8.02	3.41	2.08	0.87			10.11	2.95	2.51	0.58			8.30	1.94	0.54	
12 to 16			7.65	4.73	3.20	1.87			9.75	3.33	2.33	0.90			6.09	4.18	0.33	
16 to 20				2.09	3.62	0.82			11.70	2.99	3.02	2.01				1.85	1.50	
20 to 24				2.34	1.67				9.27	5.46	3.71					4.09	0.74	
24 to 28					4.18					4.91	2.60						2.15	
28 to 32								14.17		2.51	4.13							
32 to 36			7.22												7.70			
36 to 40				3.00		2.06			12.26			1.75				2.52		
40 to 44					4.38					3.15	2.88						1.64	
44 to 48																		
48 to 52																		
>= 52																		
Total	19.69	13.72	6.37	2.91	2.02	1.09	20.75	12.01	9.42	3.21	2.30	0.89	16.37	7.05	6.10	2.55	0.97	0.64

Mean nitrogen dioxide (NO_2) emission rates derived from 2012 remote sensing surveys.

Grams of nitrogen dioxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW).

Diesel cars and vans

	Diesel cars <2.0 litres						Diesel cars > 2.0 litres						Diesel vans (up to 3.5 tonnes)					
kW	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**
<-16					3.73	4.71					5.35					3.07	4.54	4.60
-16 to -12				4.00	4.76	4.17				3.77	5.72	5.97				3.68	4.87	3.95
-12 to -8					3.88											2.38	4.66	5.13
-8 to -4			2.09	4.15	3.44	3.86				3.70	5.48	6.49				2.99	4.72	3.79
-4 to 0				3.37	3.12	3.77				4.46	5.60	4.95				2.98	5.23	4.28
0 to 4				2.77	3.23	3.50				3.59	5.91	4.88				2.65	4.78	4.35
4 to 8				2.51	3.14	3.44				4.33	5.78	4.53				2.59	4.44	3.91
8 to 12			1.78	2.81	3.59	3.36				3.68	5.12	4.12				2.51	4.58	4.05
12 to 16				2.41	3.62	3.26				3.26	4.87	3.79				2.55	4.39	4.24
16 to 20				3.27	3.89	3.73				3.59	5.58	4.01				2.29	4.03	4.05
20 to 24				1.91	3.44	4.80				4.62	5.91	4.64				2.43	4.06	4.44
24 to 28				2.98	4.05	4.57					5.35	3.59				2.14	3.56	3.51
28 to 32					4.92	4.37					6.09					2.62	4.61	4.35
32 to 36			1.53		5.14											3.22	5.38	4.08
36 to 40					3.67					4.68							4.85	5.55
40 to 44				3.58		4.43					6.65	5.59					6.79	5.10
44 to 48					5.52											2.12		
48 to 52																	6.53	5.55
>52																		
Total	1.91	3.26	1.82	2.86	3.59	3.66	2.15	2.22	1.74	4.00	5.55	4.53	0.00	2.40	1.81	2.61	4.56	4.21

Mean nitrogen dioxide (NO_2) emission rates derived from 2012 remote sensing surveys.

Grams of nitrogen dioxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW).

Diesel taxis

kW	Taxi FX Euro 2	Metrocab Euro 2	Taxi TX1 Euro 2	Metrocab Euro 3	Taxi TXII Euro 3	Taxi Vito 111 Euro 4	Taxi TX4 Euro 4	Taxi Vito 113 Euro 5	Taxi TX4 Euro 5
<-16			2.72		3.15		1.92		
-16 to -12	1.82		2.97				2.27		
-12 to -8					1.99	4.39			
-8 to -4			2.83		2.55		2.17	7.82	
-4 to 0	1.52		2.48		2.21		2.24		
0 to 4	1.59		2.45		2.29	3.83	2.28		
4 to 8	1.19		2.11		2.06	3.53	2.18		
8 to 12	0.79		1.43		1.58	3.04	1.53	7.57	
12 to 16	0.62		1.02		1.38	3.00	1.30	7.36	
16 to 20			0.77		1.59	3.77	1.14		
20 to 24			0.74		1.59	4.09	1.25		
24 to 28							1.15		
28 to 32							1.20		
32 to 36	0.59							7.06	
36 to 40			0.96		1.79	2.63			
40 to 44							1.01		
44 to 48									
48 to 52									
>52									
Total	1.11	3.46	1.64	0.95	1.82	3.49	1.68	7.46	4.72

Mean nitrogen dioxide (NO_2) emission rates derived from 2012 remote sensing surveys.

Grams of nitrogen dioxide per kilogram of fuel consumed (g/kg) with respect to engine load (kW).

Petrol cars

	Petrol cars <1.4 litres						Petrol cars 1.4 to 2.0 litres						Petrol cars >2.0 litres					
kW	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Pre Euro**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**
<-16					0.13				0.10	0.27	0.15					0.00		
-16 to -12			0.16	0.00		0.08			0.15		0.00	0.00					0.00	
-12 to -8					0.00			0.30		0.18	0.00				0.15	0.03		
-8 to -4				0.00	0.07	0.00			0.03	0.00	0.14							
-4 to 0			0.19	0.13	0.09	0.20			0.14	0.18	0.10	0.01				0.02	0.14	
0 to 4			0.14	0.10	0.13	0.25		0.08	0.17	0.14	0.19	0.17			0.13	0.17	0.55	
4 to 8			0.00	0.14	0.07	0.16		0.12	0.29	0.05	0.03	0.31			0.13	0.12	0.02	
8 to 12			0.30	0.13	0.18	0.19			0.41	0.04	0.17	0.13			0.00	0.01	0.05	
12 to 16			0.05	0.06	0.14	0.00			0.12	0.14	0.19	0.27			0.00	0.30	0.00	
16 to 20				0.10	0.11	0.21			0.07	0.00	0.12	0.00				0.00	0.18	
20 to 24				0.20	0.07				0.00	0.08	0.18					0.03	0.05	
24 to 28					0.19					0.21	0.12						0.10	
28 to 32								0.13		0.00	0.23							
32 to 36			0.16												0.22			
36 to 40				0.08		0.45			0.13			0.41				0.00		
40 to 44					0.31					0.05	0.03						0.12	
44 to 48																		
48 to 52																		
>52																		
Total	0.22	0.27	0.12	0.09	0.12	0.17	0.18	0.15	0.21	0.09	0.13	0.19	0.13	0.19	0.10	0.06	0.09	0.00

Appendix B

Note on nitrogen dioxide (NO_2) concentrations at the 182-215 Windmill Lane, Greenford UB6 9DW Borough Specific Focus Area.

Windmill Lane, Greenford NO_2 concentrations

182-215 Windmill Lane, Greenford UB6 9DW is identified by the London Borough of Ealing as a Borough Specific Focus Area for air quality. Historically, there have been concerns regarding the levels of NO_2 monitored at the Windmill Lane roadside diffusion tube monitoring site (currently located at 205 Windmill Lane. The concentration of bus operations in the immediate vicinity of Otter Road and Windmill Lane has been of specific concern. Windmill Lane is one-way northbound from the junction of Otter Road (see Figure B1 below).

Whilst Windmill Lane is not currently a bus route 'per se', local services which start / terminate at Greenford (such as E1, E2, E3, E11) utilise the Otter Road / Windmill Lane one way loop as a turning point. Bus stands in Windmill Lane (stand Z1) and Otter Road (stands Z2 and Z3) are used for bus layover for local services (Figures B2 and B3 below). Until recently (June 2011), service E5 routed via Otter Road, but this service was re-routed towards Perivale to run direct from Greenford Road into Ruislip Road East (instead of serving Otter Road) by introducing a 'buses only' right turn from Greenford Road into Ruislip Road East (Transport for London, 2014). This reduced the number of buses on Otter Road by about five per hour during daytime weekdays.

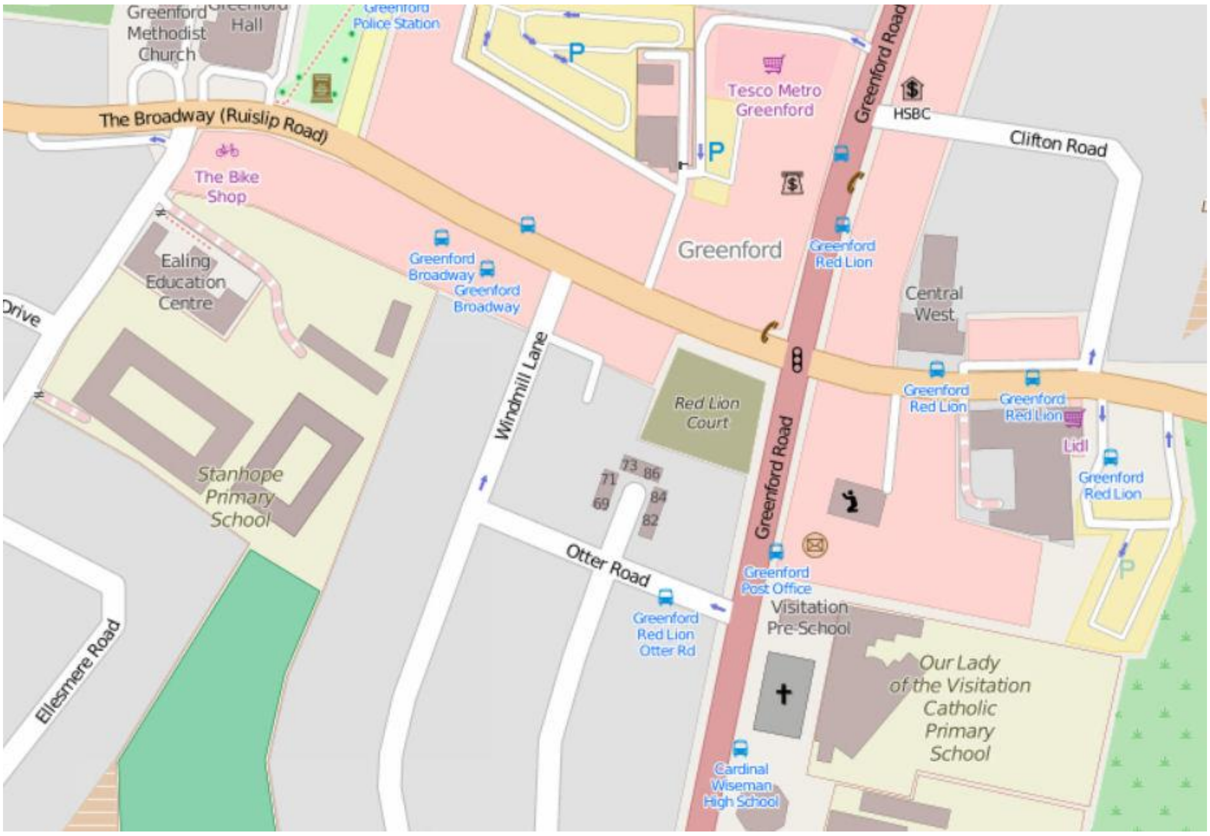

Figure B1: Windmill Lane, Greenford. One way section from Otter Road. © OpenStreetMap contributors

With reference to Figure B4 below, observed NO_2 concentrations at the diffusion tube at 205 Windmill Lane were above the annual mean threshold level of 40µg/m^3 in 2009, 2010, and 2011, although there was a decrease from 2010 to 2011 (possibly related to the removal of bus service E5 from Otter Road / Windmill Lane in June 2011). In 2012, the annual mean NO_2 concentration fell below the 40µg/m^3 threshold to **37.9µg/m^3**, and it reduced again in 2013 to **33.2 µg/m^3**. Whilst this trend will need to continue to be monitored, it would appear that the introduction of newer, cleaner buses on the services in question may be having some beneficial effect on local concentrations of NO_2. Transport for London have supplied information regarding the Euro standard and technologies of buses currently operating on routes E1, E2, E3, and E11. These are presented in Table B1 below.

Figure B2: Bus stands in Windmill Lane (stand Z1) and Otter Road (stands Z2 and Z3). © TfL

Figure B3: Buses (services E11 & E3) on stand Z1 at Windmill Lane, and on stand Z2 (service E3) on Otter Road. © Google Earth

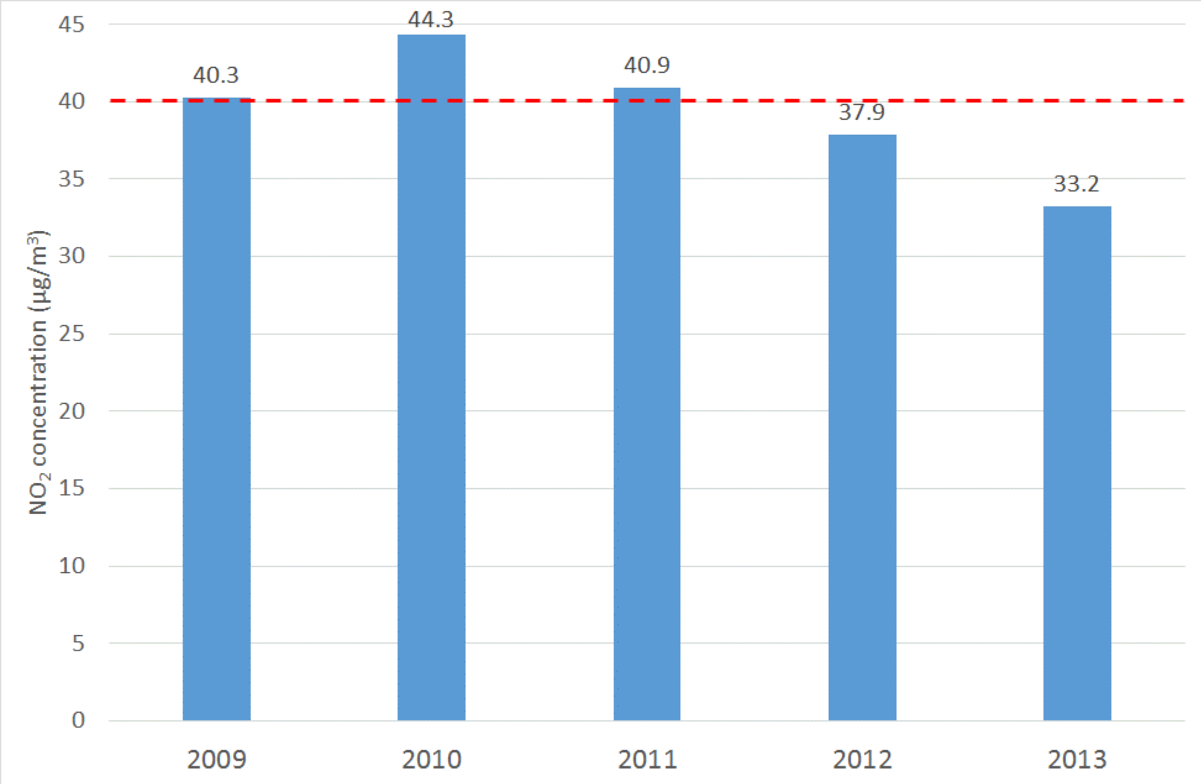

Figure B4: Diffusion tube at 205 Windmill Lane, Greenford. Annual mean NO_2 concentration (µg/m^3)

Table B1: TfL buses operating on Otter Road / Windmill Lane (as at Jun 2014)

Service	Type	Year	Engine	Implemented from	Number of vehicles	Daytime weekday frequency
E1	Double deck	2014	Euro 6 hybrid diesel	June 2013	7	Every 6 – 10 minutes
E2	Double deck	2010	Euro 4 diesel	May 2011	15	Every 6 – 10 minutes
E3	Double deck	2010	Euro 5 diesel	June 2013	26	Every 5 – 7 minutes
E11	Single deck	2007	Euro 4 diesel	May 2012	5	Every 20 minutes

For the purpose of this analysis, we assume consistent future year scenario interventions for buses at Windmill Lane as we have adopted for the other case study areas described in Section 8.

- All TfL buses operating in Ealing will meet a minimum of Euro V standard for NO_x by 2020;
- There will be a 50% reduction in existing Euro IV buses between 2014 and 2017. These buses are assumed to be replaced by Euro V (50%), Euro VI (25%), and Euro VI hybrid (25%).
- There will be a 100% reduction in existing Euro IV buses between 2014 and 2020. These buses are assumed to be replaced by Euro V (50%), Euro VI (25%), and Euro VI hybrid (25%).
- Existing Euro III buses which have been retro-fitted with SCR emissions control technology are assumed to be retained to 2017, but will be replaced by 2020 with Euro VI (50%) and Euro VI hybrid (50%).

Following these criteria, the main impact on the bus fleet operating at Windmill Lane is to remove 50% of the Euro 4 buses by 2017, and the removal of 100% of the Euro 4 buses by 2020, to be replaced by newer technologies as described above, i.e. fleet changes to services E2 and E11. If this is done, the impact on local NO_2 concentrations at Windmill Lane is calculated to be as illustrated in Figure B5 below. As a result of the assumed changes in future bus fleet technologies only, it is estimated that annual mean NO_2 concentrations at Windmill Lane will reduce to **29.7µg/m³** in 2017, and further reduce to **26.1µg/m³** by 2020. This assumes that road transport has a 43.3% share of NO_x emissions in Ealing, that road transport NO_x emissions are dominated by bus exhaust emissions locally at Windmill Lane, and that there are no changes in other sources of local NO_x pollution.

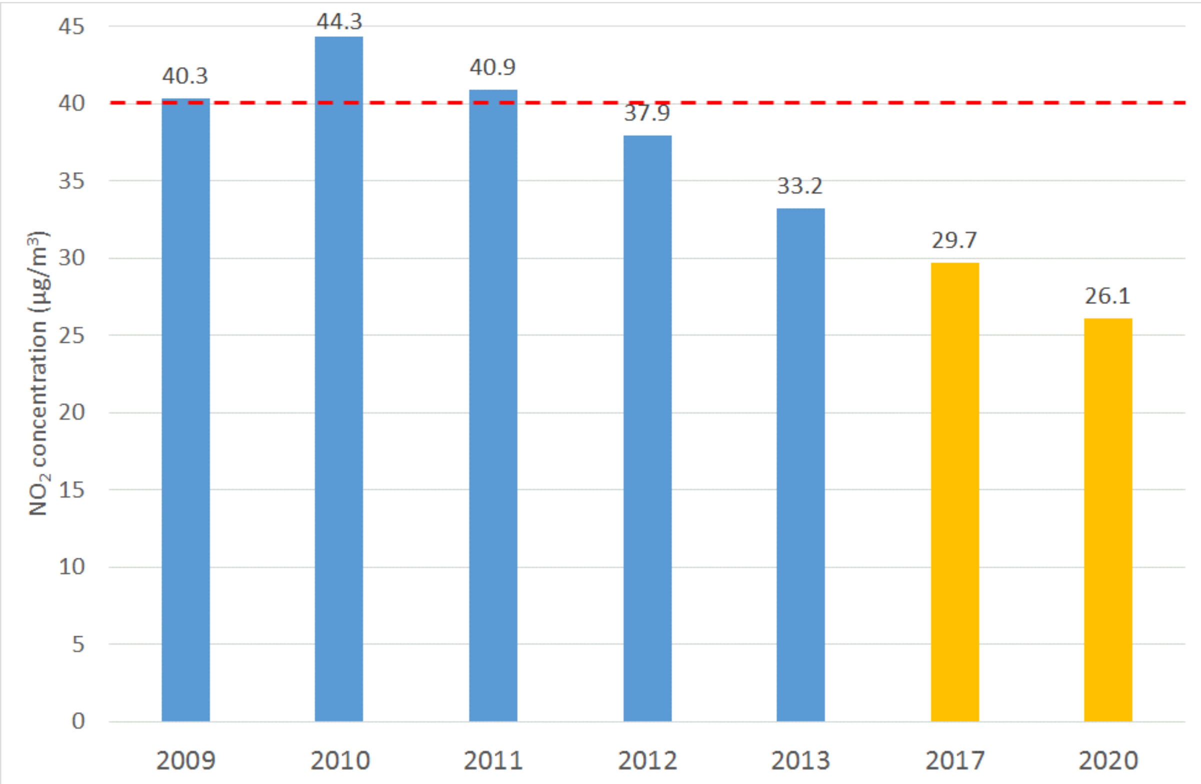

Figure B5: Diffusion tube at 205 Windmill Lane, Greenford. Future year bus scenarios. Annual mean NO_2 concentration (µg/m³)