BRADFORD LOW EMISSION ZONE FEASIBILITY STUDY

Report prepared by
Bradford Environmental Health Service,
Directorate of Environment and Sport

November 2014

Contents

Acknowledgements

Leeds City Council – modelling work and partnership working on joint Leeds/Bradford CBA and HIA

Low Emission Strategies Ltd -Technical support

Bradford Institute of Health Research (NHS Bradford) - HIA

Public Health England - HIA

AEA Ricardo - CBA

1. Introduction

1.1 This report outlines the assessment areas and outputs of the Bradford Low Emission Zone Feasibility Study. The study has been carried out following a recommendation by DEFRA that local authorities who will have Air Quality Management Areas beyond 2015 should examine the feasibility of Low Emission Zones (LEZ) to help accelerate a reduction in road transport emissions. The Study has been funded by DEFRA and has been undertaken in partnership with local health professionals and Leeds City Council. The outputs are to be extrapolated to other West Yorkshire Local Authorities as part of the West Yorkshire Low Emission Strategy Project (WYLES).

1.2 It is important to note that the study does not represent the development of a plan to implement Low Emission Zones in Bradford. The study aims to show the relative impact of several intervention scenarios beyond the 'business as usual' case and discusses the impact that these scenarios may have on projected air quality concentrations, health of the local population and the costs and benefits associated with each intervention measure. The costs of enforcing LEZ are also discussed.

1.3 It is acknowledged that further analysis of selected scenarios will be required in order to progress the concept of LEZ in Bradford beyond this initial feasibility Study.

2. Background

2.1 The City of Bradford Metropolitan District Council (CBMDC), along with all other Local Authorities, has a duty to review and assess air quality in the District and pursue the achievement of air quality objectives, as part of the requirements of the Environment Act 1995[1]. Monitoring and modelling has shown that concentrations of nitrogen dioxide (NO_2) exceed government air quality objective in the vicinity of the urban road network. Road transport emissions of oxides of nitrogen (NOx) are the major cause of elevated NO2 concentrations. Four Air Quality Management Areas (AQMA) have been designated (see appendix 1) where public exposure is a concern and there is a possibility that other AQMA may be required. Monitoring data, collected by the authority for those areas, shows that concentrations of NO_2 have not reduced in line with expectations, in part due to the increase in diesel passenger vehicle numbers over the last decade.

2.2 Many urban zones across the UK are experiencing similar problems and Bradford is classified by DEFRA, in its reporting under the EU Air Quality Directive[2], to be part of the West Yorkshire Zone which has the 4th most significant NO_2 concentration issues after London, West Midlands and Greater Manchester. DEFRA predicts that areas of Bradford and West Yorkshire will not meet the binding EU Limit Value for NO_2 until beyond 2030[3]. On the 20th February 2014, the European Commission commenced infraction proceedings against the Government for failing to meet the EU Limit Value and significant annual fines are expected.

[1] http://www.legislation.gov.uk/ukpga/1995/25/contents
[2] http://ec.europa.eu/environment/air/quality/legislation/directive.htm
[3] http://uk-air.defra.gov.uk/data/gis-mapping

Under the reserve powers of the Localism Act 2011[4] the Government can transfer EU fines to any public authority whose "act or omission" has contributed to the breach.

2.3 No areas within the Bradford District are likely to exceed the EU Limit Value for Particulate Matter (PM_{10}); however, there are areas, near to major roads, experiencing concentrations of fine particulates ($PM_{2.5}$) which exceed the World Health Organisation (WHO) Target Level. Road transport emissions are the most significant source of fine particulates in the urban area[5]. The WHO classifies diesel exhaust emissions as carcinogenic[6]. Research by Public Health England[7] shows that PM2.5 concentrations are estimated to cause 222 adult deaths a year in Bradford, representing 5.3% of total mortality. In recognition of the significant public health burden poor air quality contributes, the Public Health Outcomes Framework tasks Local Authority Public Health Departments with reporting to indicator 3.01 – the fraction of all cause adult mortality attributable to anthropogenic particulate air pollution. Health research carried out through The Born in Bradford Programme has provided evidence that road transport emissions of both NO_x and $PM_{2.5}$ have a significant effect on birth weights and incidence of strokes and heart attacks[8] within the Bradford population.

2.4 CBMDC was awarded funding from DEFRA (2011/12) to develop an innovative Low Emission Strategy (LES) to reduce road transport emissions across the District. The LES was formally adopted on the 5th November 2013 and demonstrates how the Council will use municipal powers to influence emission reductions. The Bradford LES has inspired other councils to develop similar strategies and was recognised by a City of London Sustainable Cities Award 2014. Bradford MDC now chairs and manages the development of a DEFRA funded Low Emission Strategy for West Yorkshire (WYLES), including a project board representing all the five West Yorkshire Local Authorities, METRO, Local Transport Plan (LTP) Board and Public Health England.

2.5 An integral element of the Bradford LES is the requirement to undertake a study regarding the feasibility of Low Emission Zones (LEZ) in Bradford. Bradford MDC has taken an innovative partnership approach to the LEZ Study with joint working with local health professionals, including Public Health, NHS Bradford and Bradford Health Observatory, and with Leeds City Council, strengthening local and regional capacity and capability in road transport emission evaluation and health impact assessment. Approaches taken by the Bradford Leeds LEZ Study are now being extrapolated to West Yorkshire through the WYLES Project.

3. Low Emission Zone Study

3.1 The study has identified the existing emissions from transport in Bradford by using the number plate data from the Automatic Number Plate Recognition cameras which cover all major transport routes in the City. The number plate data (for all routes from three representative days) has been analysed to establish the existing local fleet emission profile.

[4] http://www.legislation.gov.uk/ukpga/2011/20/contents/enacted
[5] Defra Source Apportionment 2012
[6] http://www.iarc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf
[7] Estimating Local Mortality Burdens associated with Particulate Air Pollution, PHE, 2014
[8] http://www.borninbradford.nhs.uk/

Each vehicle type has a distinct emissions profile dictated by the relevant emissions factors, for example an older larger diesel vehicle will emit more pollution than a small modern petrol vehicle.

3.2 This dataset allows for the emissions from alternative 'Low Emission Zone' scenarios to be studied by altering the fleet characteristics and calculating the emissions relevant to those changes in the fleet profile. This study looks at the changes in emissions and subsequent improvements in air quality that could be realised and the health impact and cost associated with those changes.

3.3 The LEZ Study has been carried out in 3 phases:

i) Assessment of baseline road transport emissions in 2012, 2016 and 2021 and the changes in emissions and concentrations of NO_x, NO_2, Particulate Matter and CO_2, resulting from LEZ intervention scenarios applied to the areas bounded by the Inner Ring Road, Outer Ring Road and across the Bradford Urban District. (See Map 1 and 2)

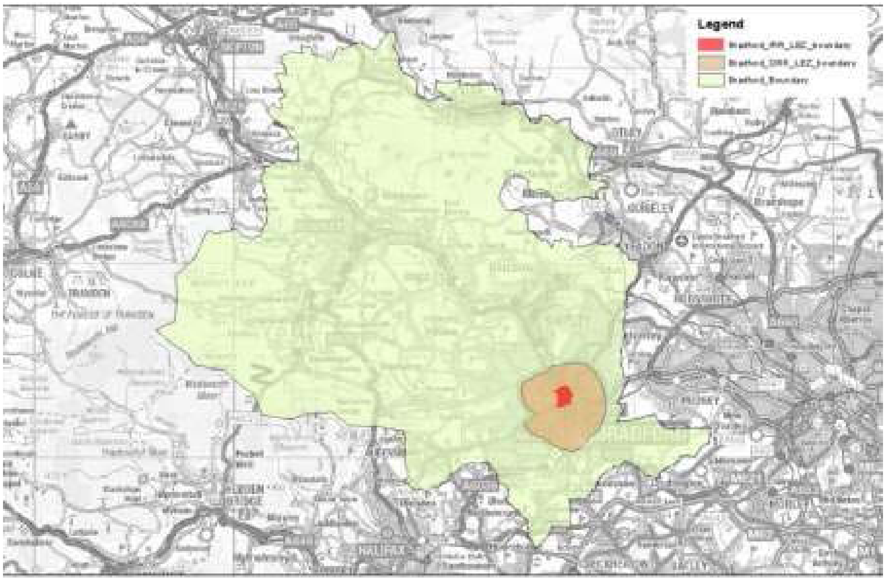
ii) Assessment of the impact of road transport emissions on health, including deprivation correlation, and the anticipated effects of introducing selected LEZ intervention scenarios.

iii) Economic assessment of the costs and benefits of introducing selected LEZ intervention scenarios, including enforcement scenarios, within the Inner or Outer Ring Road.

3.4 In addition to the baseline assessments, the LEZ intervention scenarios selected were:

- The Emissions Assessment Methodology & Results can be found in Appendix 2
- The Health Impact Assessment can be found in Appendix 3
- The Cost Benefit Analysis can be found in Appendix 4

Map 1 - LEZ Study Boundaries: Inner & Outer Ring Roads and District



Map 2 – Modelled Road Links: Inner, Outer Ring Roads and Bradford District

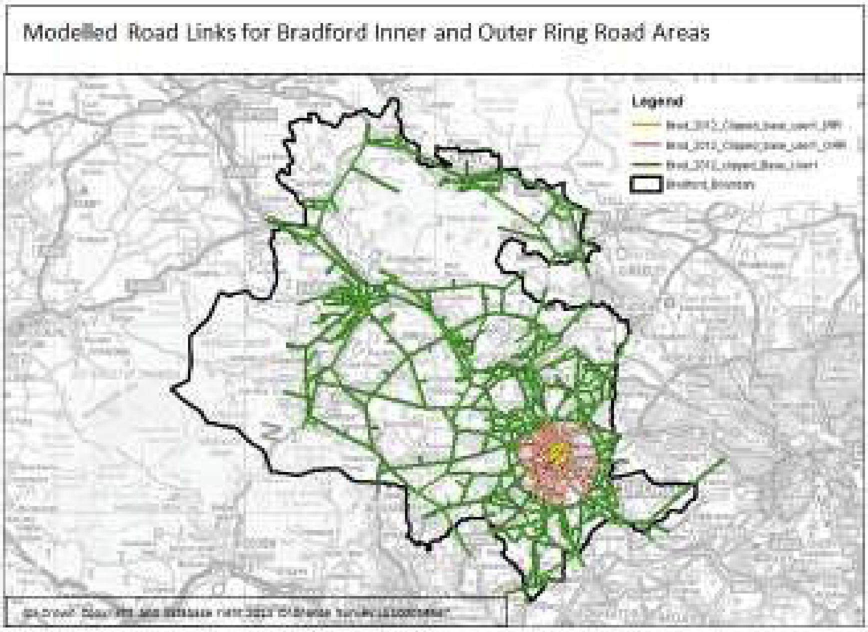


Table 1 – Modelled LEZ Scenarios

SCENARIO NAME	DESCRIPTION
2012 base	Existing fleet mix
2016 base	Projected fleet mix do minimum
2016 fuel split	Projected fleet but with the petrol/diesel mix for cars and N1 vans returned to Year 2000 ratios
2016 all buses Euro VI	Projected fleet but all buses (including Euro IV and Euro V) become Euro VI buses
2016 all HGV Euro VI	Projected fleet but all HGV (including Euro IV and Euro V) become Euro VI
2016 all bus and HGVs Euro VI	Projected fleet but all buses and HGVs (including Euro IV and Euro V) become Euro VI
2016 All vans Euro 6	Projected fleet but all vans replaced with Euro 6
2016 E2&E3 retrofit	Projected fleet but with Euro II and Euro III buses retrofitted with "non TFL DPF and SCR" technology
2016 all Pre Euro IV buses Euro VI	Projected fleet but all buses older than Euro IV are replaced with an Euro VI
2016 all Pre Euro IV HGV Euro VI	Projected fleet but all HGV older than Euro IV are replaced with an Euro VI
2016 Pre Euro IV bus and HGVs to Euro VI	Projected fleet but all buses and HGVs older than Euro 4 are replaced with Euro VI
2016 10% reduction in car use	Projected fleet with 10 % reduction in car use resulting from measures to promote walking and cycling
2021 base	Projected fleet mix do minimum
2021 fuel split	Projected fleet but with the petrol/diesel mix for cars and N1 vans returned to year 2000 ratios
2021 All buses to Euro VI	Projected fleet but with all buses (including Euro IV and Euro V) become Euro VI buses
2021 All HGVs to Euro VI	Projected fleet but with all HGVs (including Euro IV and Euro V) become Euro VI
2021 All bus and HGVs to Euro VI	Projected fleet but with all buses and HGVs (including Euro V) become Euro VI
2021 All vans to Euro 6	Projected fleet but all vans replaced with Euro 6
2021 All pre Euro V buses to Euro VI	Projected fleet but with all buses older than Euro V are replaced with Euro VI buses
2021 All pre Euro V HGV to Euro VI	Projected fleet but all HGVs older than Euro V are replaced with Euro VI
2021 All pre Euro V bus and HGVs to Euro VI	Projected Leeds fleet but All Pre Euro V buses and HGVs become Euro VI
2021 10% reduction in car use	Projected fleet with 10 % reduction in car use resulting from measures to promote walking and cycling

3.5 The LEZ Study has incorporated the most up-to-date information available, applying best practice tools and techniques at each stage of assessment. It is acknowledged that there are gaps in both local and national data, emission factors and costs, therefore assumptions and caveats are clearly stated.

3.6 A key issue has been the comparison of the emission profile of the Bradford vehicle fleet (using ANPR) in relation to the national fleet composition. The Study has shown that the Bradford fleet emission profile is older than national assumptions and that future projections that are only possible using national projections, are likely to overestimate the benefits of natural fleet turnover. Additionally, emission factors for certain vehicle types, including natural gas vehicles, are not available and, therefore, the Euro VI Standard represents both diesel and gas vehicles, even though test data indicates that Euro VI gas vehicles will be cleaner than Euro VI diesel vehicles[9].

3.7 It should be noted that LEZ intervention scenarios selected for evaluation do not represent an exhaustive list. The selections were made based on their anticipated capability to impact on emissions and then promote discussion on potential adjustments and combination of measures that may be required. Additionally, as modelling outputs have been produced, the data has been used to continually inform the implementation of the Bradford LES and development of the WYLES.

4. Assessment of Emissions and Concentrations

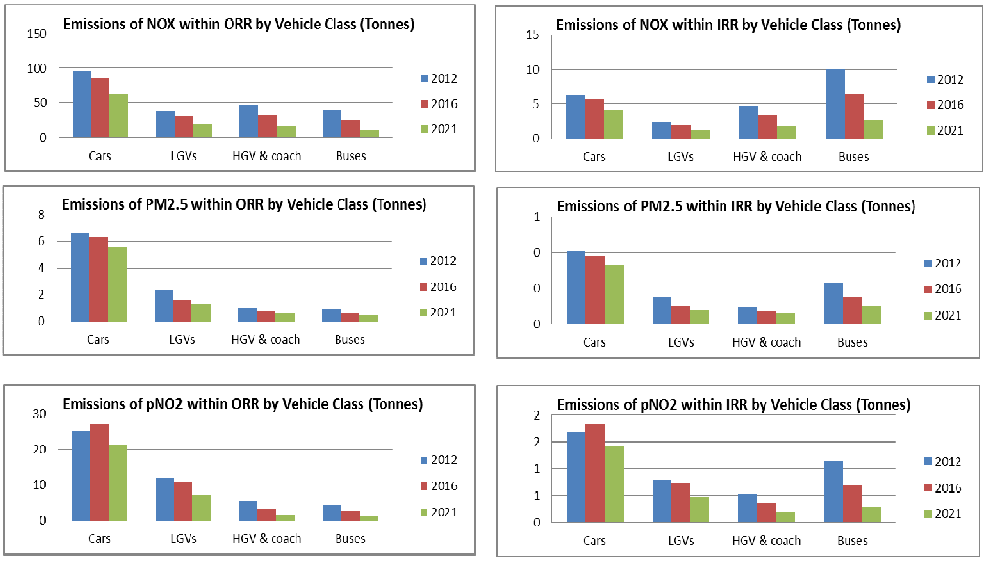
4.1 The assessment of the Bradford local fleet showed that buses contribute 43% of road transport NO_x emissions within the Inner Ring Road and 18% in the Outer Ring Road area. The review of ANPR data for 2012 showed that buses in Bradford were markedly older than in Leeds with 49% being Euro III or older compared with 32% in Leeds.

4.2 The modelling shows that emissions are expected to improve over time as older, more polluting vehicles are replaced with cleaner models. However, natural replacement will not be sufficient alone to meet the EU Limit Value for NO_2. Some caution is needed here as several previous studies[10] have indicated significant improvements in air quality over time that have not materialised. This is partly due to the failure of European Emission Standards to deliver emission benefits in real-world driving and also due to the increased take up of diesel passenger vehicles. While the Study has used ANPR data to gain an accurate picture of baseline conditions, future projections use National Atmospheric Emissions Inventory (NAEI) data regarding fleet emission profile which may prove unrealistic. For example the Study assumes that 64% of all HGVs (28 – 34t articulated class) will be Euro VI in 2016 whereas there was 0% in 2012. (See Table 2).

4.3 Tables 2 and 3 below depict the emissions by vehicle class for the chosen base years for the areas bounded by both the Inner and Outer Ring Roads. Total transport based emissions of NOx, $PM_{2.5}$ and primary NO_2 are forecast to reduce from all vehicle classes between 2012 and 2021. However, primary NO_2 emissions from cars are forecast to increase between 2012 than 2016, before reducing to levels below the existing by 2021.

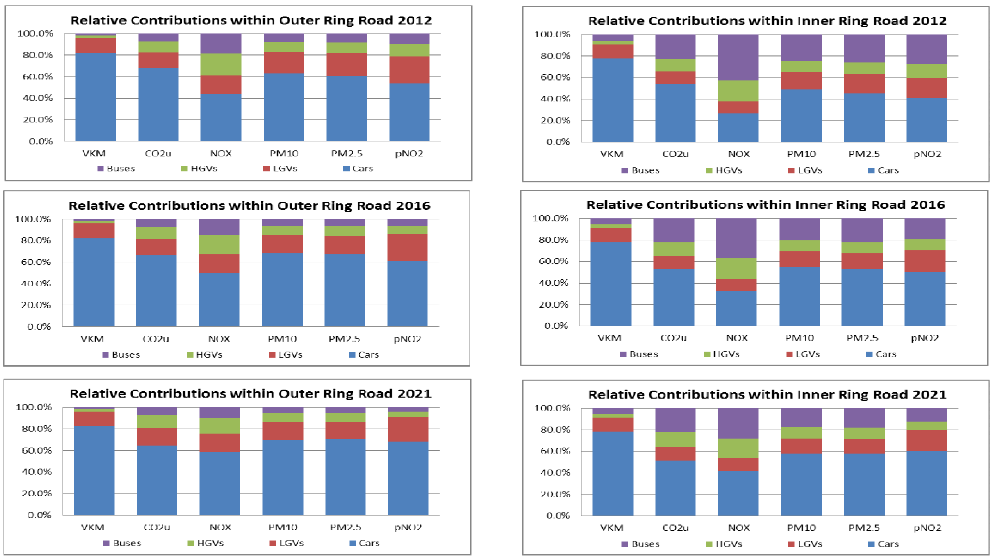
[9] Scania 2014, VTT (Finland), TNO (Netherlands)
[10] Bradford MDC LAQM Review and Assessment

Table 2 - How total emissions from each vehicle class are projected to change with time within the modelled LEZ boundaries (NAEI Projections)



Note: pNO2 = primary NO2

Table 3 - How the proportion of the total emissions is projected to vary over time compared to the mileage driven by that vehicle class in LEZ boundaries



Note: VKM = vehicle km.

4.4 Tables 4 and 5 below show the baseline emissions for 2012, 2016 and 2021, and the changes in NO_x arising from each LEZ intervention scenario for each projected baseline year. Using NO_x to NO_2 calculations, it has been shown that none of the LEZ intervention scenarios applied alone would enable the Government Objective for NO_2 to be met in the AQMAs for any of the projected years.

Table 4 - Changes in NO_x Emissions within Inner Ring Road (Tonnes) per Scenario

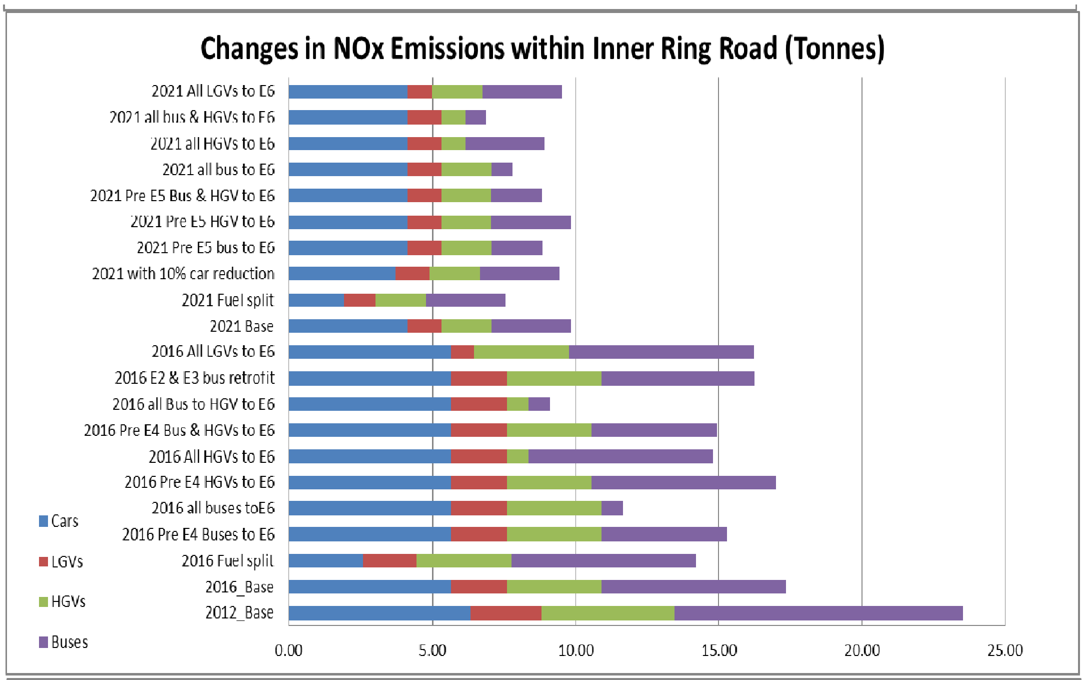
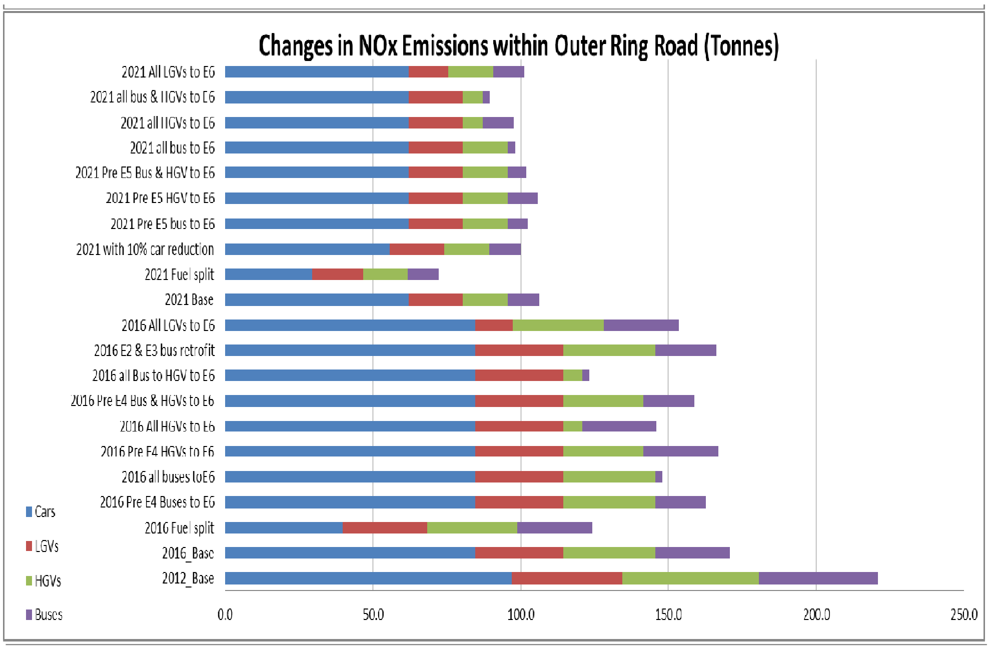


Table 5 - Changes in NO_x Emissions within Outer Ring Road (Tonnes) per Scenario



4.5 The findings indicate that significant emission reductions could be made by:

- Improving bus and HGV emissions towards Euro VI within the Inner and Outer Ring Road areas
- Reversal of the increase in diesel passenger cars to year 2000 ratio (20% of the fleet or less)

- Reducing the number of passenger cars overall by 10% - modal shift to public transport, walking and cycling

4.6 It can be seen that emission reductions in the 2016 are proportionately greater than in the 2021 when the business as usual scenario assumes a much cleaner vehicle fleet in total. The cumulative benefits of reducing emissions at the earliest opportunity are discussed in later sections. However, it should also be recognised that if vehicle operators are required to improve emissions, they are likely to take action in years prior to any target date, therefore providing benefits in the preceding years. It is apparent that a combination of intervention measures would need to be pursued in order to meet Government Objective Levels for NO_2 and also the EU Limit Value.

4.7 Generally, the LEZ scenarios modelled show corresponding reductions in particulate matter along with NO_x reductions and do not increase CO_2 emissions. The 10% reduction in car journeys does appear to have significant benefits in improving CO_2 emissions. However, the year 2000 fuel split scenario shows that there will be a marginal increase in CO_2. This should not be considered significant as medium and long term aims to reduce CO_2 emissions from road transport will not be based on a diesel vehicle strategy. Indeed, it has been shown in countries such as Japan that a petrol/hybrid/electric strategy for passenger and light goods vehicles could have significant potential to both reduce air pollutant and CO_2 emissions.

4.8 Table 6 shows the emission reductions of NO_x projected for the Outer Ring Road area for each scenario and also the emission reductions required to meet the Government Objective in the AQMAs. It should be noted that the emission reduction per scenario represents the total reduction in tonnes within the study area, whereas the tonnage reduction required in the AQMAs to meet the Government Objective represents the specific amount required at the location adjacent to the monitoring site.

4.9 It should be noted that the emissions modelling study uses traffic flows based on the Bradford Saturn model (2011 outputs) and does not take account of increases in concentrations that may result from non-compliant vehicles skirting / avoiding LEZ boundary areas. Further assessment would be required in terms of traffic modelling, to ascertain the likely effects on vehicle movements and resulting concentrations, should LEZ boundaries be considered.

Table 6 - Emission reductions of NOx provided by Bradford ORR scenarios compared with required reductions in AQMAs

Scenario	Emission reduction, tonnes	
	2016	2021
2016 fuel split	46.4	
2016 all buses Euro VI	22.8	
2016 all HGV Euro VI	24.7	
2016 all bus and HGVs Euro VI	47.5	
2016 All vans Euro 6	17.3	
2016 Euro II &Euro III retrofit	4.4	
2016 all Pre Euro IV buses Euro VI	8.3	
2016 all Pre Euro IV HGV Euro VI	3.8	
2016 Pre Euro IV bus and HGVs to Euro VI	12.1	
2016 10% reduction in car traffic	8.5	
2021 fuel split		33.8
2021 All buses to Euro VI		8.0
2021 All HGVs to Euro VI		8.6
2021 All bus and HGVs to Euro VI		16.6
2021 All vans to Euro 6		4.9
2021 All pre Euro V buses to Euro VI		4.0
2021 All pre Euro V HGV to Euro VI		0.2
2021 All pre Euro V bus and HGVs to Euro VI		4.3
2021 10% reduction in car traffic		6.2
Required reductions of NOx (tonnes) in AQMA		
Manningham Lane	107	44
Shipley Airedale Road 1	104	40
Shipley Airedale Road 2	78	14
Shipley Airedale Road 3	72	9

Note – AQMA are designated where both pollution levels are likely to exceed Government Objectives and there is relevant exposure i.e. homes and schools. The Government Objective for NO_2 is 40 ug/m^3. The EU Limit Value for NO_2 is 40 ug/m^3. However, the Limit Value applies to any location where the public has access. Therefore, the area that exceeds the EU Limit Value in Bradford is much greater than the areas of the AQMA.

5. Health Impact Assessment

5.1 The Health Impact Assessment (HIA) was carried out as a joint exercise between Public Health England, NHS Bradford, Bradford MDC and Leeds City Council. The HIA is a way of gauging the positive and negative health impacts of projects and policies with the aim of identifying areas in Leeds and Bradford that would be most affected by reductions in road pollution and specific health benefits. The HIA focuses specifically on NO_2 and $PM_{2.5}$ and maps concentration changes against Local Super Output Area (LSOA) data allowing quantification of the impacts on health of the local population. It is acknowledged that, while our understanding of the health effects caused by air pollution is increasing, it is probable that current methodologies are likely to under estimate all impacts[11]. Certain health issues, including cancer, are not quantified as part of this study.

5.2 The HIA process has enabled effective partnership working to develop between health and air quality professionals. Collaboration will continue as a result of this study, potentially identifying new sources of funding for pollution prevention work. It is proposed that Health Economists will look at the outputs of the LEZ Study in more detail, funded by AHSN (NHS) in partnership with the Bradford Health Observatory. This study will provide more detailed costings for the impacts of air pollution on health and allow cost and benefit calculations for LEZ interventions to be compared more accurately with other health interventions (e.g. cancer drugs) through the use of QALYs (quality adjusted life years).

5.3 The LEZ Study HIA has been peer reviewed by CREAL (Centre for Research in Environmental Epidemiology), Barcelona, who support the findings.

5.4 The HIA Study has quantified the health effects across the Bradford District arising from concentration changes in $PM_{2.5}$ and NO_2 for future years with selected LEZ intervention scenarios compared with the 2012 baseline. The HIA outputs for each scenario can be seen in Table 7. While not all LEZ scenarios were selected for assessment, the findings give an indicative picture of the likely benefits arising from non-selected scenarios.

5.5 The 10% reduction in car journey scenario (through an increase in cycling and walking) also offers significant health benefits arising from active travel that have not been quantified as part of this study. This measure could play a significant role in reducing obesity levels and improving mental well being.

5.6 The HIA Study also looked at the relationship between pollution levels and deprivation. It was found that a significant correlation exists between high pollution levels and areas with deprived populations. The reduction of pollution levels through improvements in road transport emissions, as a passive intervention, can be seen as an effective mechanism for improving the health of some of the most deprived residents in the District and thereby reducing health inequalities in Bradford.

[11] Takenoue 2009

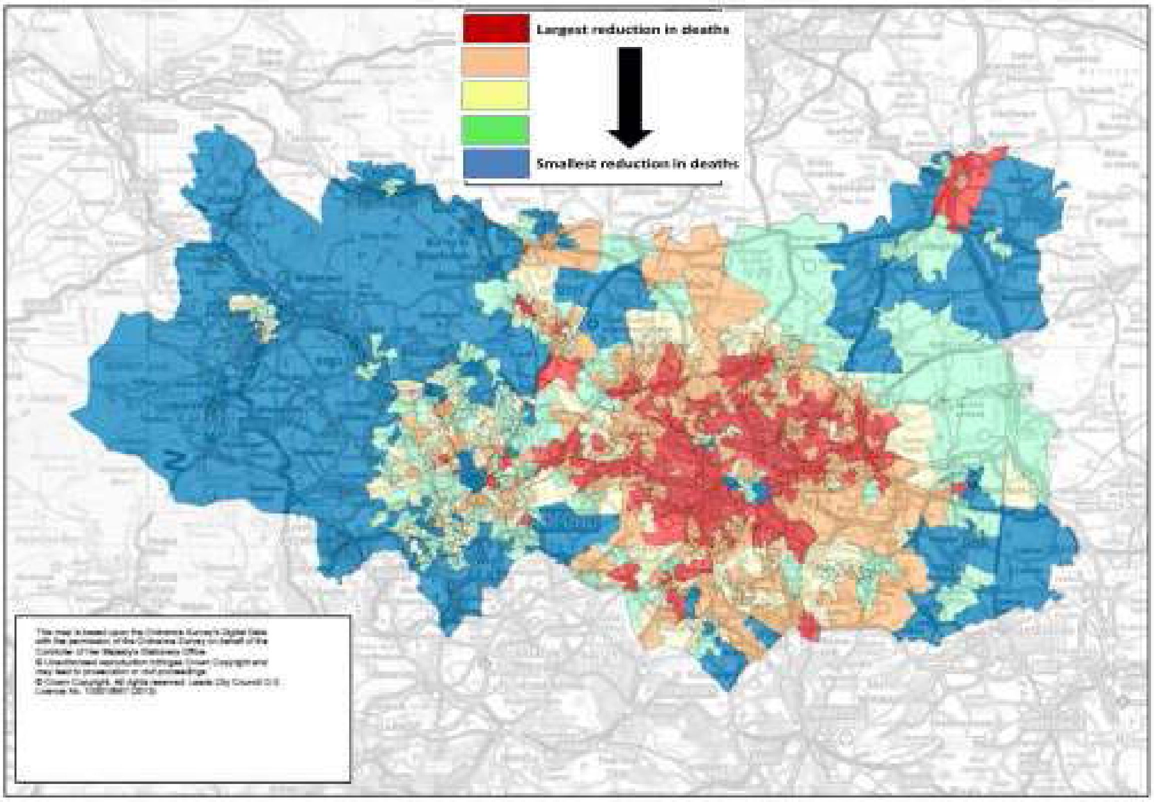
Table 7 - Health Impact Assessment: Summary of Impacts of Key Interventions in Bradford

Baseline Scenario 2012 (approximate deaths attributable to air pollution - PM 2.5)	222 (74 - 407)			
Scenario	**Pre- Euro IV buses & HGVs upgraded to Euro VI by 2016**	**Pre-Euro V buses upgraded to Euro VI by 2021**	**Year 2000 ratio of petrol to diesel met by 2021**	**10% reduction in journeys and increase in speed by 2021**
Approximate reduction in deaths attributable to PM2.5 (annual)	2 (0-2.3)	3 (0.3-5)	3 (0.3-5)	3 (0.3-5)
Approximate reduction in cardiopulmonary deaths attributable to PM2.5 (annual)	1 (0-2)	2 (1-3)	2 (1-3)	2 (1-3)
Approximate reduction in coronary events attributable to PM2.5 (annual)	24 (0-53)	45 (0-99)	45 (0-100)	45 (0-99)
Approximate reduction in low birth weight babies (<2500g) attributable to PM2.5 (annual)	2 (1-4)	3 (1-6)	3 (1-6)	4 (1-7)
Approximate reduction in low birth weight babies (<2500g) attributable to NO2 (annual)	8 (0-17)	18 (0-38)	21 (0-45)	17 (0-36)
Approximate reduction in children developing asthma attributable to NO2 by age 18	82 (18-152)	181 (40-335)	212 (47-393)	173 (38-320)
Approximate reduction in pre term births attributable to PM2.5	0.4 (0.4-0.4)	0.7 (0.6-0.7)	0.7 (0.6-0.7)	0.7 (0.6-0.7)
Annual years of life gained for newborns (all birth combined)	42	64	6	76

Numbers in brackets are 95% confidence intervals. All estimates are number of deaths per year apart from childhood asthma which is prevalence by age 18 years

**Cardiopulmonary deaths are a subset of all deaths so (to avoid double counting) should not be added together to calculate total deaths*

Map 3 - Reduction in deaths due to falling PM2.5 due to upgrading buses to Euro 6 by 2021 (Scenario 2).



6. Cost Benefit Analysis

6.1 An economic assessment of the costs and benefits (CBA) of the LEZ intervention scenarios has been carried out by Ricardo-AEA in accordance with Government best practice, including:

- Assessment of the damage costs[12] saved and abatement costs[13] saved for each LEZ intervention scenario.
- Assessment of the costs associated with introducing LEZ intervention scenarios.
- Assessment of the costs of enforcing LEZ scenarios.

6.2 The aim of the CBA is to look at the cost-effectiveness of potential LEZ intervention scenarios.

6.3 A key issue with this type of CBA is that those who benefit from improvements in air quality are not necessarily the same as those who may incur costs from introducing measures. Additionally, while it is acknowledged that the introduction of low emission measures will have a much wider benefit across the Bradford District, the CBA only looks at benefits within

[12] Costs to health and environment per tonne of pollutant
[13] Cost to Government per unit of pollutant abated to meet binding EU Limit Value

the inner and outer ring road. The CBA does not look at productivity and, therefore, it is recognised that true benefits will be underestimated.

6.4 Further work is required to understand the benefits that a transition to low emission fuels and technologies may bring to the local economy. Also, Bradford NHS (AHSN) is in the process of commissioning a further study to look at the local economic impacts associated with LEZ intervention scenarios which will provide further detail of the health economic costs of introducing measures.

6.5 It should be noted that opportunities for funding, while not considered as part of the assessment, can influence options for taking forward intervention scenarios (see paragraph 5.6)

6.6 DEFRA has developed estimates of the unit costs for emission abatement using a marginal abatement cost curve (MACC) to estimate the potential supply of abatement at a national scale. The MACC reflects the abatement potential and cost for a range of different abatement technologies. Wider impacts on society are incorporated, including: impacts on other pollutants; energy and fuel impacts, and health impacts (damage costs). The abatement represented by the national average compliance gap is compared against the MACC to estimate an indicative unit cost of abatement. It is only indicative because both the gap and the abatement potential from different technologies will vary between areas. DEFRA guidance recommends that if there is no clear rationale to use a particular measure the recommended default value is £29,150 per tonne of NO_x (a lower figure is used for the Euro II & III bus retrofit scenario as the national MACC assumes that these measures will be implemented anyway).

6.7 The abatement cost methodology is applicable while nitrogen dioxide concentrations at relevant receptors throughout the area remain above the Limit Value. Table 8 shows the abatement costs avoided for each of the emission reduction measures applied to the Bradford Outer Ring Road area and represents the emission reduction for each measure compared with the 2016 or 2021 base case.

6.8 It should be noted that Government Guidance has dictated the use of abatement costs methodology for the LEZ cost benefit assessment (in line with HM treasury green book guidance[14]). The abatement costs saved will not necessarily be realised by Bradford Council, instead they are indicative of the societal savings associated with meeting the cost of meeting the NO2 objectives. They are also a useful method to provide comparison of the efficacy of the different scenarios.

[14] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/197893/pu1500-air-quality-greenbook-supp2013.pdf

Table 8 - Abatement costs avoided in the Bradford Outer Ring Road area

Scenario	Emission reduction, tonnes		Unit abatement cost, £(2015)	Abatement cost saved, £(2015)
	2016	2021		
2016 fuel split	**46.4**		29,150	1,306,821
2016 all buses Euro VI	22.8		29,150	642,145
2016 all HGV Euro VI	24.7		29,150	695,657
2016 all bus and HGVs Euro VI	47.5		29,150	1,337,802
2016 All vans Euro 6	17.3		29,150	487,242
2016 Euro II &Euro III retrofit	4.4		7,257	30,851
2016 all Pre Euro IV buses Euro VI	8.3		29,150	233,763
2016 all Pre Euro IV HGV Euro VI	3.8		29,150	107,024
2016 Pre Euro IV bus and HGVs to Euro VI	12.1		29,150	340,787
2016 10% reduction in cars	8.5		29,150	238,399
2021 fuel split		33.8	29,150	801,518
2021 All buses to Euro VI		8	29,150	189,708
2021 All HGVs to Euro VI		8.6	29,150	203,936
2021 All bus and HGVs to Euro VI		16.6	29,150	393,645
2021 All vans to Euro 6		4.9	29,150	116,196
2021 All pre Euro V buses to Euro VI		4	29,150	94,854
2021 All pre Euro V HGV to Euro VI		0.2	29,150	4,743
2021 All pre Euro V bus and HGVs to Euro VI		4.3	29,150	101,968
2021 10% reduction in cars		6.2	29,150	147,099
2016-2021 fuel split	240.6		29,150	6,267,872
2016-2021 all buses Euro VI	92.4		29,150	2,438,139
2016-2021 all HGVs Euro VI	99.9		29,150	2,636,347
2016-2021 all buses and HGVs Euro VI	192.3		29,150	5,074,487
2016-2021 all vans Euro 6	66.6		29,150	1,762,756
2016-2021 10% reduction in cars	44.0		29,150	1,146,194

6.9 The costs for introducing measures have been assessed and may include:

- additional capital expenditure
- additional operational costs
- additional maintenance costs

6.10 Table 9 provides a summary of the costs of implementing the LEZ intervention measures in Bradford. The table shows the cost of the measures for implementation in 2016 and 2021 (net present value, base 2015). The costs for the HGV measures include the cost of enforcement of the LEZ.

6.11 In general, the cost per tonne abated is lower for implementation in 2016 than in 2021 for comparable measures. It is thus most cost effective to implement measures as soon as possible: cost effectiveness is reduced if implementation is delayed.

6.12 It shows the unit abatement cost applied in each case and the net present value (base year 2015) of the abatement cost avoided by the measure. A discount rate of 3.5% was applied to future year abatement costs avoided. The table shows the value of the national abatement costs avoided by the measures for single years, 2016 or 2021. It also shows the value of the costs avoided over the period 2016-2021 for five measures.

6.13 It can be seen that the ‘year 2000 fuel split’ and ‘all bus and HGV to Euro VI’ options provide the largest abatement cost avoided in the Bradford Outer Ring Road Area. The Euro II and Euro III retrofit options provide the smallest cost avoided.

6.14 The Euro VI bus options include a compressed natural gas (CNG) bus scenario.

6.15 The most cost effective option in Bradford would be to implement Low Emission Zones requiring bus operators to meet the Euro VI standard by converting to compressed natural gas (CNG) buses within the Outer Ring Road areas. This is provided that it is practical to replace existing non-compliant buses with buses running on CNG. CNG buses are potentially less expensive to run than diesel buses because fuel costs are lower. *[It should be noted that the abatement costs avoided were calculated on the basis of the default value of £29,150 per tonne of oxides of nitrogen emitted. DEFRA abatement cost guidance recommends that sensitivity analysis is carried out to reflect the uncertainty in the abatement costs. If the default value of £29,150 is used then it is suggested that a range of £28,000 - £73,000 is appropriate. If the higher value of the range is used the measure to replace pre Euro IV buses in Bradford becomes attractive].*

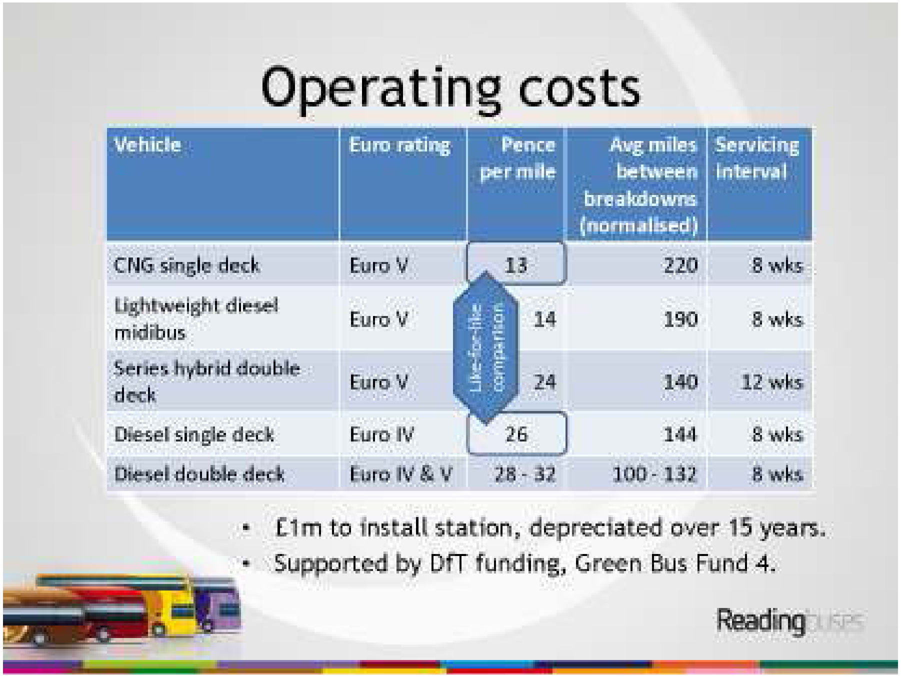
Table 9 - Costs of measures per tonne of oxides of nitrogen (NOx) abated

Measure	Discounted cost, £million 2015		Discounted emission reduction, tonnes 2015			Cost per tonne abated, £	
	2016 implementation	2021 implementation	2016-2021	2021 onwards	2016-onwards	2016 implementation	2021 implementation
Fuel split	19.3	20.7	215	199	415	46,000	104,000
All buses Euro VI	11.9	3.8	84	21	103	116,000	185,000
All buses Euro VI (CNG scenario)	**0.2**	**0.3**	**84**	**21**	**103**	**2,000**	**15,000**
All HGV Euro VI	7.4[+]	1.9[+]	90	21	110	67,000	92,000
All bus and HGV Euro VI	18.9[+]	5.6[+]	174	41	216	87,000	136,000
Pre Euro IV buses to Euro VI	1.0		21		21	49,000	
Pre Euro IV buses to Euro VI (CNG scenario)	**0.2**		**21**		**21**	**10,000**	
Pre Euro IV HGV to Euro VI	0.8[+]	-	7		7	117,000	
Pre Euro IV bus and HGV to Euro VI	1.8[+]	-	27		27	66,000	
All vans Euro 6	31	10	61	14	75	411,000	729,000
Euro II and Euro III bus retrofit	0.9	-	3		3	262,000	
Pre Euro V buses to Euro VI		1.2		9	9		140,000
Pre Euro V buses to Euro VI (CNG scenario)		0.3		9	9		35,000
Pre Euro V HGV to Euro VI		0.5[+]		0	0		Indeterminate
Pre Euro V bus and HGV to Euro VI		1.7		9	9		198,000
Promotion of walking and cycling(TravelSmart)	1.4		10		10	143,000	

Measure	Cost per tonne abated , £ 2016 implementation
All buses Euro VI (CNG scenario)	**2,000**
Pre Euro IV buses to Euro VI (CNG scenario)	**10,000**
Fuel split	**46,000**
Pre Euro IV buses to Euro VI	**49,000**
Pre Euro IV bus and HGV to Euro VI	**66,000**
All HGV Euro VI	**67,000**
All bus and HGV Euro VI	**87,000**
All buses Euro VI	**116,000**
Pre Euro IV HGV to Euro VI	**117,000**
Promotion of walking and cycling (TravelSmart)	**143,000**
Euro II and Euro III bus retrofit	**262,000**
All vans Euro 6	**411,000**

[+] *Includes cost of HGV LEZ enforcement*

6.16 As part of this study, bus operators using CNG buses were contacted to obtain further information regarding operational costs. Information provided by Reading Buses is shown below.



Operating costs

Vehicle	Euro rating	Pence per mile	Avg miles between breakdowns (normalised)	Servicing interval
CNG single deck	Euro V	13	220	8 wks
Lightweight diesel midibus	Euro V	14	190	8 wks
Series hybrid double deck	Euro V	24	140	12 wks
Diesel single deck	Euro IV	26	144	8 wks
Diesel double deck	Euro IV & V	28 - 32	100 - 132	8 wks

Like-for-like comparison

- £1m to install station, depreciated over 15 years.
- Supported by DfT funding, Green Bus Fund 4.

Reading buses

6.17 It can be seen from the all the assessments that diesel cars are a key contributor to NO_2 issues across Bradford and measures to control or limit their use could have significant benefits. However, this is a complex issue depending on how the 'year 2000 fuel split' is formulated into a policy. The initial cost figures shown in Table 9 assume that all diesel drivers in Bradford would switch to a petrol car and the costs only take account of operational costs. It is recognised that diesel cars cost more to buy and maintain than petrol cars[15] and that unless a motorist travels more than 11,000 a year then it is likely that a petrol car will be the cheapest option. Further analysis is being carried out to look at the costs of measures that may discourage the use of certain diesel vehicles in Bradford, incorporating wider considerations than just fuel costs. It should be noted that the development of policies to limit/control the use of diesel cars will require analysis of the financial complexities that go beyond the remit of this study and the costs for introducing measures depend on the assumptions made in the analysis.

6.18 The cost of the 10% vehicle reduction through promotion of walking and cycling is based on the costs of national programmes such as Cycling Demonstration Towns (CDT) and Sustainable Travel Towns (STT) where a cost of £30 and £46.93 is applied per person, respectively. The cost of TravelSmart[16] is estimated at £25 per person giving an overall cost for Bradford of £1.4m. It was estimated that 10.8% of the population would take up the

[15] http://www.which.co.uk/cars/driving/driver-tools/petrol-vs-diesel/choosing-between-petrol-and-diesel/
[16] TravelSmart is

offer of TravelSmart personal support. The costs for the TravelSmart programme are less than the total damage and abatement costs avoided (63% of the costs avoided for Bradford) calculated for a 10% reduction in car traffic. The TravelSmart programme would thus be cost neutral with respect to air quality benefits if it achieved a 6.3% reduction in car traffic in Bradford.

6.19 Interventions to promote walking and cycling will have significant additional benefits to air quality improvements including improved health resulting from greater levels of activity and reduction in congestion. A University of Sheffield health, economic and modelling report[17] estimated the cost of intervention per Quality-Adjusted Life Year (QALY) saved resulting from greater levels of physical activity for each intervention. These were £5000, £900 and £300-2500 per QALY for CDT, STT and TravelSmart interventions respectively. The report assumes a "value" of £20,000 per QALY: on this basis the benefits of the walking and cycling measures are substantially greater than the cost of the intervention.

6.20 It should be noted that the feasibility of introducing measures can be influenced by funding opportunities that are not accounted for in the CBA. For example, the Euro II and III bus retrofit option appears to be one of the least cost effective measures to introduce, however, introduction of this measure is already underway in Bradford. Bradford MDC was successful in an application to the DfT Clean Vehicle Technology Fund (CVTF) 2014/15 and secured £394,000 to work in partnership with First Bus and Transdev (who are providing match funding) to retrofit 25 Euro III buses with selective catalytic reduction and particle traps (SCRT). This project will see a reduction in NO_x emissions of 118 tonnes in the urban area.

6.21 Other funding streams will be identified that may assist in introducing low emission measures in Bradford, including:

- £30m OLEV (2015-2020) funding to create 2 to 4 'Low Emission Cities'
- £30m OLEV (2015 to 2020) funding for low emission buses, including gas buses and infrastructure.

6.22 The CBA has looked at the costs and implications for enforcing selected intervention scenarios. Parking Enforcement in Bradford and the police currently use both manual and camera methods for enforcing vehicle offences aimed at parking restrictions and improving road safety. Vehicle emissions in Bradford are not controlled other than for MOT provisions.

6.23 For bus measures, enforcement could be provided through a LEZ whereby the Traffic Commissioner only issues licences for compliant vehicles. Alternatively, bus emission standards could be included within Quality Contracts or Bus Partnerships. These issues are currently under discussion between the West Yorkshire Combined Authority (WYCA) and the Association of Bus Operators in West Yorkshire (ABOWY). There is currently a draft emission standard for buses prepared last year by WYCA that states that all buses should be a Euro III

[17] Walking and cycling: local measures to promote walking and cycling as forms of travel or recreation: Health economic and modelling report. University of Sheffield, 2012.
https://www.nice.org.uk/guidance/ph41/resources/economic-modelling-report2

Standard within 3 years subject to commercial viability. While it is acknowledged that this draft standard will not enable air quality improvements in Bradford it also recognises, and is prepared to be informed by the LEZ Feasibility Study.

6.24 The HGV intervention options (and perhaps the year 200 fuel split – discouraging diesel cars) will most likely require ANPR systems for enforcement and these costs have been factored into the cost per tonne of NO_x abated in the CBA.

6.25 The cost of installing and operating ANPR systems depends to a considerable extent on the existing infrastructure. Start-up costs include the costs of the cameras, site preparation, signage, mounting structures and associated civil engineering, security provision, back office accommodation and equipment, and back office training. Operating costs include maintenance of the cameras and back office staff, accommodation and supervision costs. The existing infrastructure already covers some of these aspects.

6.26 CBMDC has estimated an installation cost of £10,000 per camera and operating costs associated with two full time staff equivalents, approximately £80,000 per year. The net present value (base 2015) of installing and operating 15 cameras in Bradford over the period 2016-2021 is estimated on this basis to be £571,000. Discussions with parking enforcement indicate that cost neutrality may be achieved based on the set amount of the Fixed Penalty Notice (FPN) that would be issued to non-compliant vehicles. Manual enforcement options and issues around identification of certain vehicle types, according to their emissions, are discussed in the CBA.

6.27 *It should be noted that during the course of the LEZ Study, CBMDC, in partnership with the Road Haulage Association (RHA), undertook a survey of all 'O' licence operators registered in Bradford. From a 28% response, hauliers indicated that their fleets were already Euro IV compliant and that LEZ controls, if reasonable and advertised well in advance, should not be problematic. Many hauliers were looking at natural gas and biomethane options but recognised that a lack of infrastructure was a main barrier for uptake.*

6.28 Incentives and disincentives to discourage the use of certain diesel cars in the urban area will require further consideration, including national measures such as Vehicle Excise Duty (VED) which provide advantages for diesel vehicles over petrol vehicles based on CO_2 emissions. Green parking permits, differential parking rates and mileage allowances are some of the measures that could help reverse the dieselisation of the passenger car fleet if combined with public awareness campaigns.

6.29 *It should also be noted that as part of the ongoing Low Emission Strategy work, an assessment of the Bradford Council Fleet emission profile and options for accelerating the uptake of low emission vehicles has been carried out. Some of the options for LEZ interventions, particularly HGV and LGV measures will require some consideration in terms of potential compliance.*

7. Conclusions

7.1 The following conclusions can be drawn from the study:

i. There is currently a substantial health burden related to the emissions from vehicles in the Bradford District.

ii. The health burden is born disproportionately by the most deprived in Bradford and contributes to health inequalities.

iii. LEZ interventions represent a passive intervention to improve health and reduce health inequalities.

iv. Passenger cars, in particular, the proportion of diesel cars, are the most significant contributor to elevated levels of NOx within the Bradford outer ring road.

v. Within the inner ring road buses are the most significant single contributor of NOx.

vi. From the vehicle km driven by each vehicle type buses and HGVs provide a disproportionate contribution to NO2 concentrations.

vii. From the scenarios modelled, measures to accelerate improvement in bus and HGV emissions and measures to reduce the proportion of diesel cars appear to give the best improvements in air quality.

viii. A 10% reduction in passenger car traffic gives significant improvements in air quality and the health and well being benefits in up taking active travel will also be significant for the individual.

ix. No single intervention scenario will be sufficient to meet the NO2 objective in the AQMAs in Bradford.

x. Grant funding can significantly improve the cost effectiveness of measures, BDMCD are already working with local bus operators through a £394,000 DfT grant to retrofit local buses.

xi. The study indicates that improving bus emissions, particularly through the uptake of gas bus technology, and measures to discourage diesel car use and older HGVs may be the most cost effective options.

xii. The study includes the operational, capital and maintenance cost of options, further work may be required to understand the wider consequential impacts of interventions, for example on the price of distribution and goods, bus fares and the second hand car market.

xiii. The national fleet projections over optimistically predicted the current Bradford fleet.

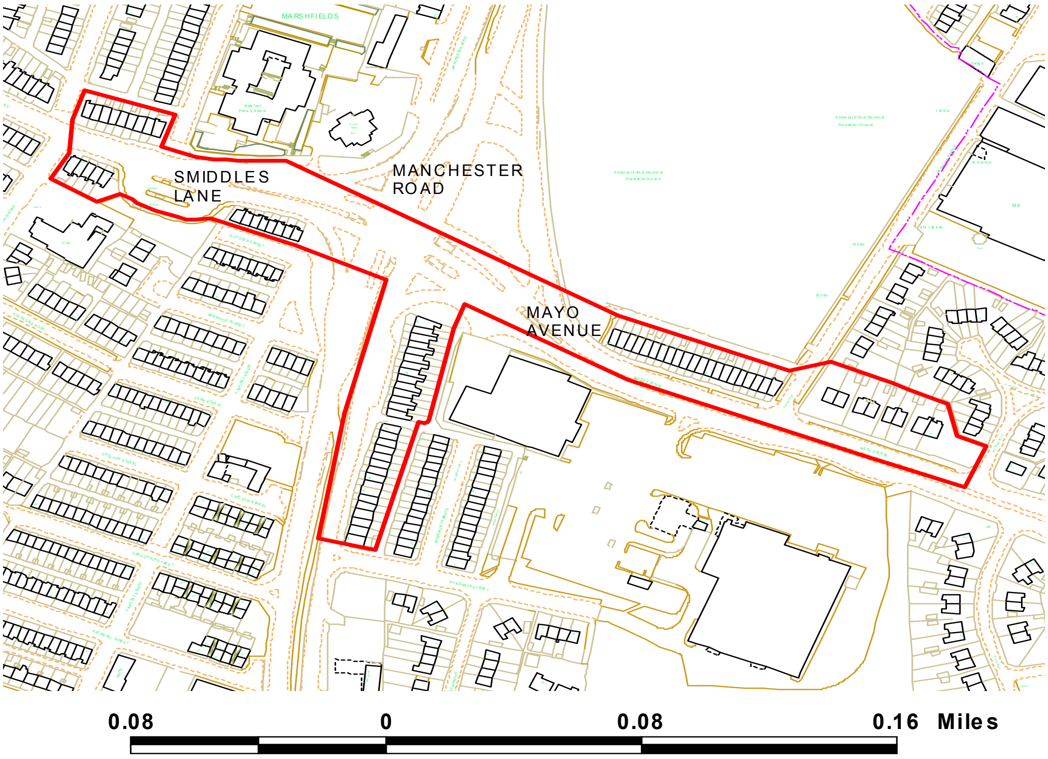
xiv. The forward projections for fleet improvements are optimistic and the ‘do nothing’ scenario may require significant interventions to achieve it in Bradford.

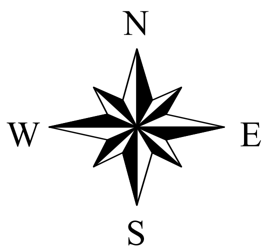
xv. While this Study provides an indication of the feasibility of introducing Low Emission Zones type measures, further work will be required to develop identified possibilities into worked through policy measures.

APPENDIX 1 – CBMDC AIR QUALITY MANAGEMENT AREAS

The City of Bradford Metropolitan District Council Air Quality Management Order (No.1), 2006

The Area surrounded by the red line has been designated as an Air Quality Management Area.





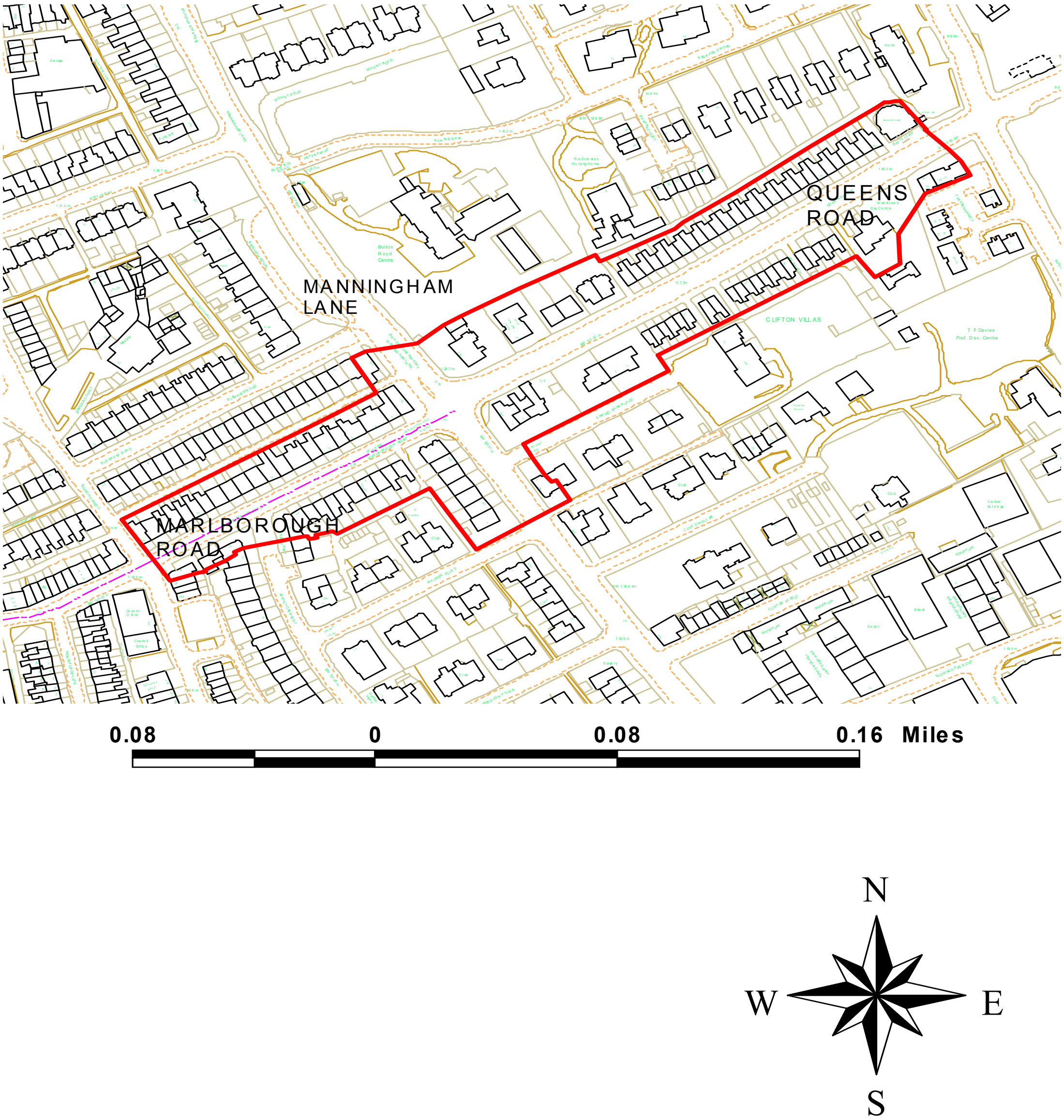
The following properties are located within the **Bradford Metropolitan District Council Air Quality Management Order (No.1), 2006**

8-24 Smiddles Lane, Marshfields, Bradford, BD5 9NS (evens)

35-41 Smiddles Lane, Marshfields, Bradford, BD5 9NS (odds)
1 Dovesdale Road, Marshfields, Bradford, BD5 9QB
4-18 Scholes Street, Marshfields, Bradford, BD5 9PT (evens)
751-809 Manchester Road, Bradford, BD5 8LN (odds)
41-97 Mayo Avenue, West Bowling, Bradford, BD5 8HR

The City of Bradford Metropolitan District Council Air Quality Management Order (No.2), 2006

The Area surrounded by the red line has been designated as an Air Quality Management Area.

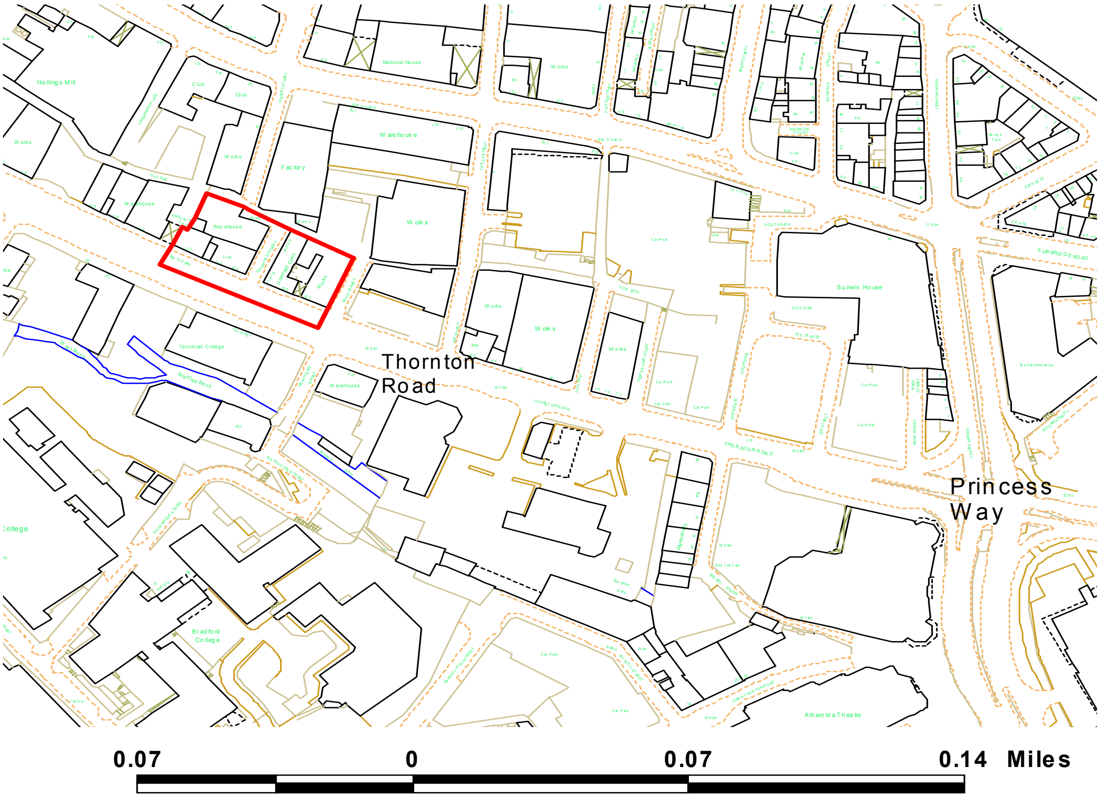


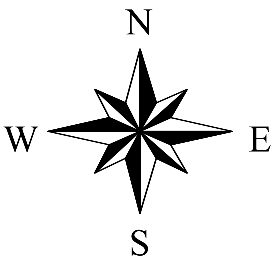
The following properties are located within the **City of Bradford Metropolitan District Council Air Quality Management Order (No.2), 2006**

2-40 Marlborough Road, Manningham, Bradford, BD8 7LE (evens)
1-31 Marlborough Road, Manningham, Bradford, BD8 7LE (odds)
3 Apsley Villas, Manningham, Bradford, BD8 7LE
2 Walmer Villas, Manningham, Bradford, BD8 7ET
251-263 Manningham Lane, Bradford, BD8 7EP (odds)
282-288 Manningham Lane, Bradford, BD8 7BU (evens)
1, 2,3,5,7,9,11 Spring Bank Place, Manningham, Bradford, BD8 7BX
Flats 1-12 Daleside House, Manningham, Bradford, BD8 7BS
Queens House, Manningham, Bradford, BD8 7BS
1-65 Queens Road, Manningham, Bradford, BD8 7BS (odds)
2-42 Queens Road, Manningham, Bradford, BD8 7BT (evens)
Waddiloves Day Centre, Manningham, Bradford
6-20 Twickenham Court, Manningham, Bradford, BD8 7BL (evens)

The City of Bradford Metropolitan District Council Air Quality Management Order (No.3), 2006

The Area surrounded by the red line has been designated as an Air Quality Management Area.



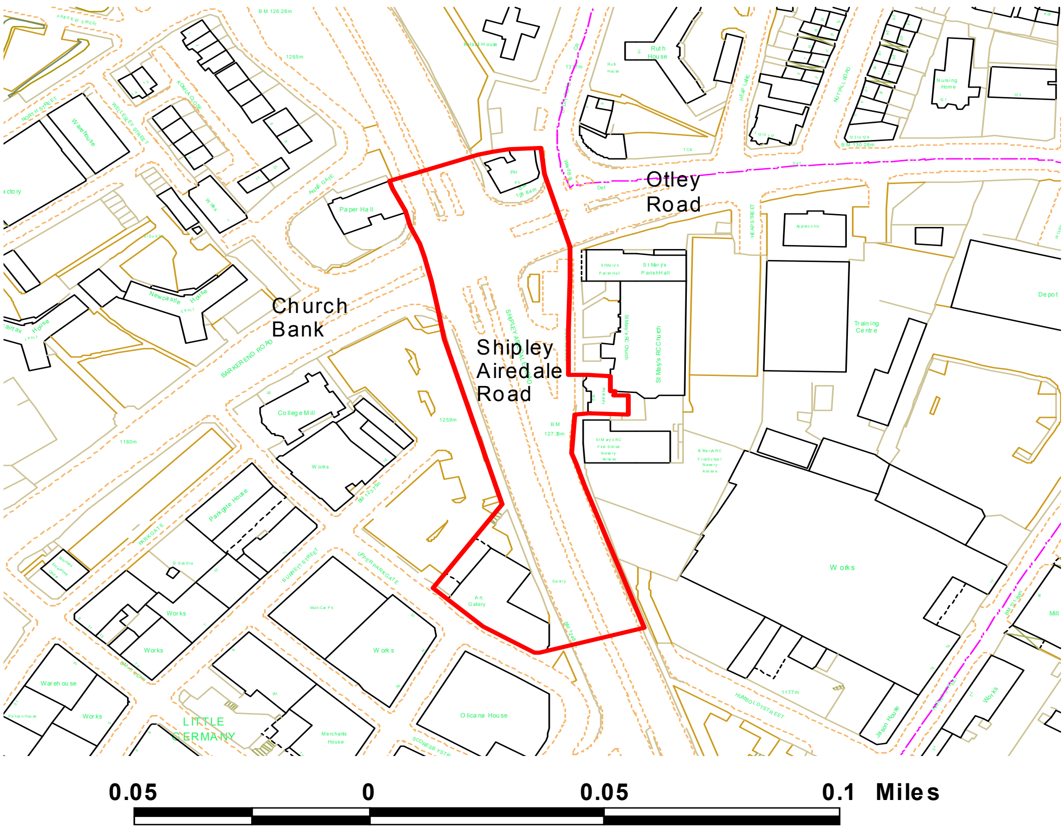


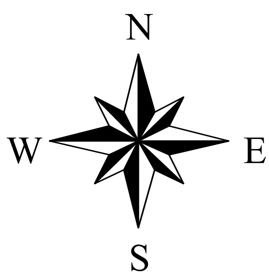
The following properties are located within the **City of Bradford Metropolitan District Council Air Quality Management Order (No.3), 2006**

Flats 1-39 Holmfield Court, Thornton Road, Bradford, BD1 2DW
102-112 Thornton Road, Bradford, BD1 2DX (evens)

The City of Bradford Metropolitan District Council Air Quality Management Order (No.4), 2006

The Area surrounded by the red line has been designated as an Air Quality Management Area.





The following properties are located within the **City of Bradford Metropolitan District Council Air Quality Management (No.4) Order, 2006**

The Cock & Bottle Inn, Barkerend Road, BD3 9AA
Apartments 1-33 Treadwell Mills, Upper Parkgate, Little Germany, BD1 5DW
St Mary's Presbytery, Barkerend, Bradford, BD1 5EE

APPENDIX 2 – EMISSIONS ASSESSMENT AND RESULTS

EMISSIONS and CONCENTRATION ASSESSMENT

METHODOLOGY

Emission Modelling

Traffic Flows

A SATURN traffic model covering the Bradford District and validated against traffic count data has been used to provide the traffic flows for the existing and future base years. The model provided speed and volumes data for three different time periods throughout the day (1 x AM peak hour, 1 x PM peak hour and a typical daytime Inter-peak hour).

Traffic Fleet

The SATURN model did not include separate vehicle user classes for Bus, Cars, LGVS or HGVs and therefore these needed to be estimated against detailed traffic counts on selected locations in order to provide a suitable user class assignment matrix.

Automatic Number Plate Recognition (ANPR) cameras were taken from key radial routes outside the inner ring road to capture the registration details of all inbound vehicles over three consecutive typical working days.

The data was processed to give details of each vehicle's class, type, engine size, fuel type and weight and date of registration. The date of first registration was then used to estimate the most likely Euro standard of the engine in order to complete a Bradford's specific vehicle hierarchy of the fleet most likely to be affected by any proposed LEZ interventions.

Calculating the Emissions from the Road Transport Network

The traffic flows and speed data for each road link was entered in to **S**imple **E**missions **M**odelling **Frame**work (SEMFrame) developed by Dr. Paul Goodman whilst at Leeds University's Institute for Transport Studies. SEMFrame has since become the frontend of the wider ***P***latform for ***I***ntegrated ***T***raffic, ***H***ealth and ***E***mission ***M***odelling (PITHEM) concept of Dr Anil Namdeo at Newcastle University's School of Civil Engineering and Geosciences.

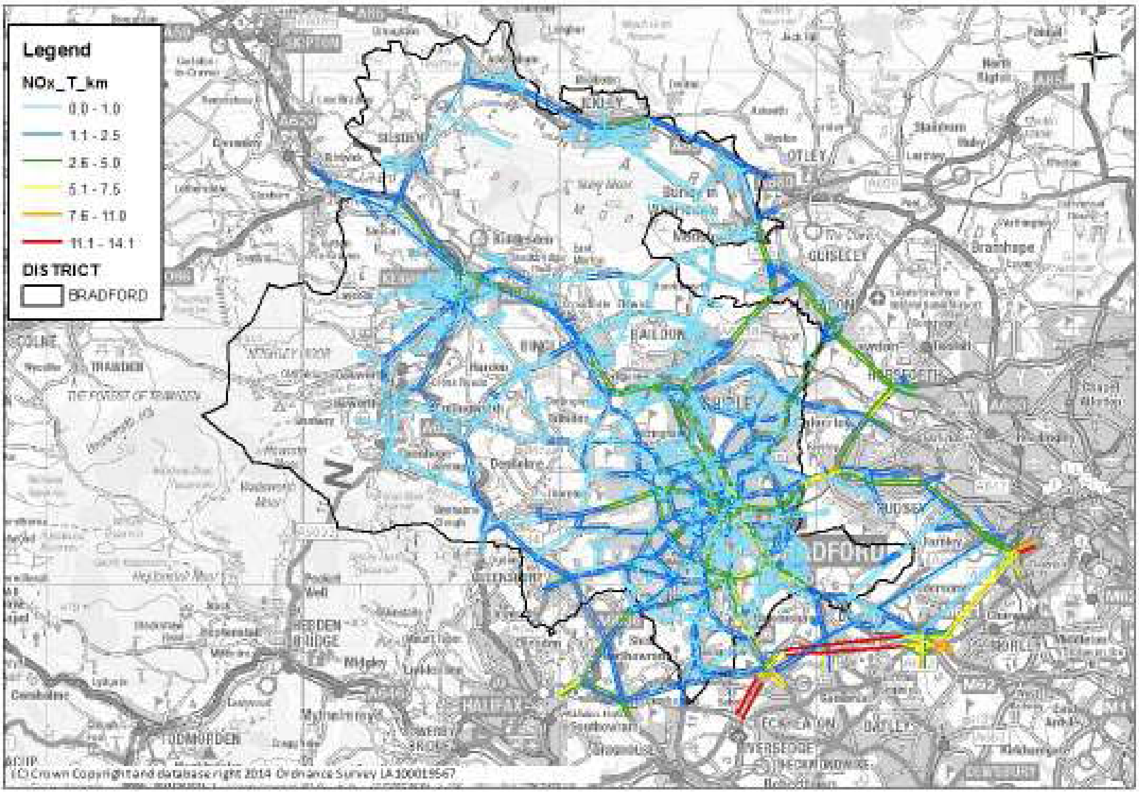
PITHEM takes the link-based period output networks from a suitable macroscopic traffic model such as SATURN and calculates the traffic Vehicle Kilometres Travelled (VKM) for each vehicle user class. Suitable speed-based emissions factors and scaling factors are then applied to produce total annual emissions by each user class on each modelled road link.

For the purpose of this exercise the UK National Atmospheric Emission Inventory's (NAEI) Emission Factor Toolkit v 5.2 (EFT) emission factors set for the relevant year. However the standard UK average urban fleet hierarchy was adjusted to reflect the local fleet hierarchy collected by the ANPR cameras.

PITHEM was used to calculate the annual emission for each link and total emissions for the whole network for each vehicle user class for Total Oxides of Nitrogen (NOx), primary Nitrogen Dioxide (pNO_2), ultimate Carbon Dioxide uCO_2 and particulate matter smaller than 2.5 microns in diameter ($PM_{2.5}$)

Figure 1 below shows the SATURN network indicating the calculated annual NOx emission rates using PITHEM. It should be noted that although the SATURN network is represented in a schematic way using, the distances used within the emission calculations are the actual link lengths contained within the modelled link length and capacity data.

Figure 1



Modelling the Intervention Scenarios

Base Year and Business as usual scenarios

A validated output for The SATURN traffic assignment model already existed for the year 2011. This was considered suitable as representing the existing base year scenario of 2012 as:-

- ANPR data was collected towards the back end of 2011 and early 2012.
- Suitable meteorological data existed for 2011
- The modelled road network had not changed between 2011 and 2012
- There was very little - if any – traffic growth noted between 2011 and 2012.
- Monitored air quality data existed for 2011 and 2012 for validation purposes

The Business as Usual years chosen were 2016 and 2021, giving a 10 year horizon with a mid-point trend point. Due to the timescales likely to be involved in the process required to adopt any Low Emission Zone Intervention, it is not expected that any noticeable impact would be achieved prior to 2016.

The average UK urban vehicle fleet hierarchy for 2012 was adjusted using the data collected from the ANPR cameras to more accurately reflect the local traffic fleet mix already accessing the central area of Bradford and which would most likely be affected by any future intervention.

The adjusted local fleet hierarchy was then projected forward for the 2016 and 2021 business as usual years using the percentage changes applied to the national fleet projections contained within the NAEI EFT.

Intervention Scenarios

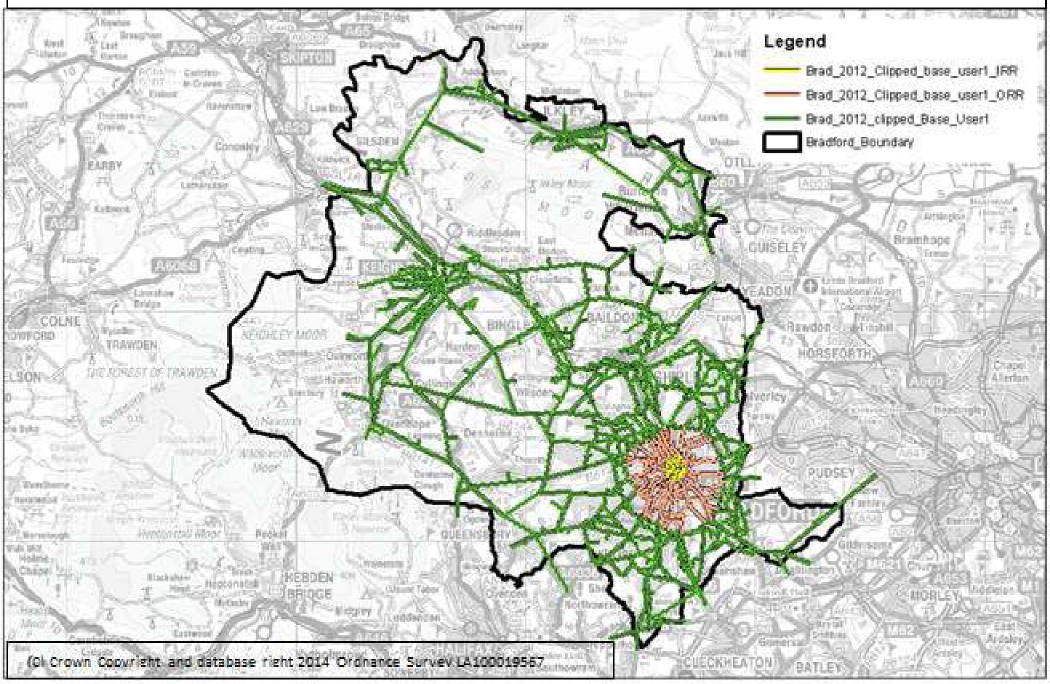
Each intervention scenario was modelled by changing the adjusted local fleet hierarchy to reflect the required intervention. Table 1 below shows the variance in the age profile for the 28T to 34T HGV articulated vehicle class between the UK and local fleet hierarchy in 2012, the projected 2016 business as usual and the changes to represent an intervention scenario which replaces all Pre-Euro 4 HGVs with Euro 6 diesel or Gas.

Table 1

Proportion of HGV ARTICs within the 28t to 34t weight class	NAEI UK 2012 percentage	Bradford Local Fleet 2012 percentage	NAEI UK Projected 2016 Percentage split	Projected Bradford 2016 percentage split	2016 scenario, All Pre-Euro 4 HGVs replaced with Euro 6
Pre-Euro	0.0%	0.0%	0.0%	0.0%	0.0%
Euro_I	0.0%	0.0%	0.0%	0.0%	0.0%
Euro_II	0.9%	3.0%	0.0%	0.0%	0.0%
Euro_III	14.4%	19.2%	1.6%	2.2%	0.0%
Euro_IV	19.9%	31.3%	3.6%	5.7%	5.7%
Euro_V_EGR	16.2%	11.6%	7.7%	7.0%	7.0%
Euro_V_SCR	48.7%	34.8%	23.1%	21.1%	21.1%
Euro_VI	0.0%	0.0%	64.0%	64.0%	66.2%

It is anticipated that the geographical enforcement boundary of any future intervention would be based on either the Inner or Outer Ring Roads. Consequently the Modelled road links within these two areas were isolated and the total annual emissions within each area were calculated for each user class. Figure 2 depicts the two areas for which the changes in emission totals were assessed for the Economic Impact Assessment.

Modelled Road Links for Bradford Inner and Outer Ring Road Areas



Calculation of Pollutant Concentrations

The total annual emission networks calculated in PITHEM were post-processed to produce link based emission rates. The resulting emission rates were then imported in to the AIRVIRO air pollution dispersion modelling package to create line source based emission databases.

AIRVIRO was then set up to calculate the average hourly concentrations of both NOx and $PM_{2.5}$ over a $250m^2$ grid by applying sequential hourly meteorological data for the full 2011 calendar year using the Gaussian dispersion model. The data was then post processed to calculate the estimated annual average concentration for each pollutant.

The NOx concentration calculated over the 250m grids for the existing 2012 base year, were converted to estimated annual average NO_2 levels using the Defra NOx to NO2 Calculator v3.2. Although a full validation exercise was not undertaken, the base year 2012 concentrations for both the resultant NO2 and PM2.5 values were then compared to monitored data as both spot levels and grid average values.

The differences between the monitored and modelled concentrations were found to be consistent with the contribution expected from the un-modelled sources contained within the LAQM 1km grid background concentration maps over which LEZ interventions would have no influence, such as industrial and domestic emissions and secondary suspension sources.

CAVEATS AND ASSUMPTIONS

Vehicle fleet hierarchy

Profiling the Existing Fleet

The ANPR cameras, collected data over consecutive dates on a typical midweek for inbound traffic flows. The site locations were chosen to ensure a representative sample was collected and the data normalised. So if the same vehicle was registered by the cameras more than once a day then the characteristics of that vehicle were included more than once when creating the representative fleet hierarchy.

The ANPR Cameras were located between the Inner and outer ring roads. There may be a different total fleet mix in the Bradford area as a whole, however those vehicles may not operate within the city centre area and therefore it is assumed they would not be affected by any proposed LEZ interventions. This may not be the case for certain vehicle that are based within the Outer Ring Road but only travel away from the city centre, particularly HGV movements from local depots etc.

The Euro standard data to be returned with vehicle data was not comprehensive and in many cases related to the date the vehicle model was first introduced rather than engine type. A decision was taken to base the Euro standard of the vehicles based on the date of first registration against the dates that the new engine Euro standards came in to force for each vehicle type. It is recognised that there may be some irregularities where some vehicle manufacturers were meeting certain Euro standards prior to the introduction date whilst certain vehicles may have been allowed derogation to enter in to the fleet whist still only meeting the previous standard.

Projecting the future Local Vehicle Fleet

Although the ANPR data collection has suggested difference in the age and weight distribution of the local fleet compared to the UK national fleet for the 2012 time period, the only way to predict the future change in the vehicle hierarchy was to base the proportional changes on the project UK national fleet changes. This has resulted in the local fleet tending more towards the national fleet in future years, particularly the introduction of new Euro standards, which may well be over estimating the benefits of the 2016 and 2021 Business as usual scenarios.

A knock on effect of the possible over prediction of the benefits of the business as usual scenarios is inevitably the potential under-estimation of the additional benefits modelled for the interventions which involve replacing older vehicles with newer ones for the same base years.

Vehicle based emission Calculations

Vehicle based emissions have been calculated using the emission factors contained within the Emission Factor Toolkit 5.2. These are average speed based emission rates factors for different vehicle types and have been applied to the traffic data modelled by the SATURN traffic assignment model. The SATURN model has predicted average link speeds for eight different time periods.

The time periods modelled within SATURN include different hours within the peak, inter-peak and off-peak periods and should produce more realistic results than an average 24 hour link speed. However it is expected that there will still be some weakness in the estimates due to:-

- The averaging out of the speeds over a whole link, especially the longer links.
- Inherent weakness in the nature of the emission factors and modelled traffic data
- The SATURN network only covering major routes, especially beyond the Outer Ring Road.

Estimating Changes in Emissions for Different Intervention Scenarios

In addition to any weakness resulting from the forward projection of the local fleet hierarchy, there are potential weaknesses due to all interventions had to be applied across the entire urban road network rather.

No attempt has been made of the potential for vehicles either re-routing around the modelled LEZ areas or vehicles based and operating outside the potential LEZ areas not being affected in anyway.

Conversely, Motorway fleet characteristics were not changed in any of the intervention models, and remained set to the projected average UK national fleet, which may have underestimated some changes on the motorway network especially the M606.

In view of the inability to re-model the behaviour change brought about by any given intervention, the modelled road links within the two potential LEZ boundaries were isolated and total emission by each vehicle class calculated for each scenario. This action has hopefully limited any discrepancies to the modelled benefits to expected rate of compliance within the zones themselves.

Converting the Road Based Annual Emissions in to Annual Concentrations

Methodology

The emissions calculated from the modelled traffic network were entered in to the Airviro Dispersion model as an annual average hourly emission. Sequential hourly data for 2011 was then applied with a 250m square calculation grid covering the whole district and post processed to create annual average concentrations.

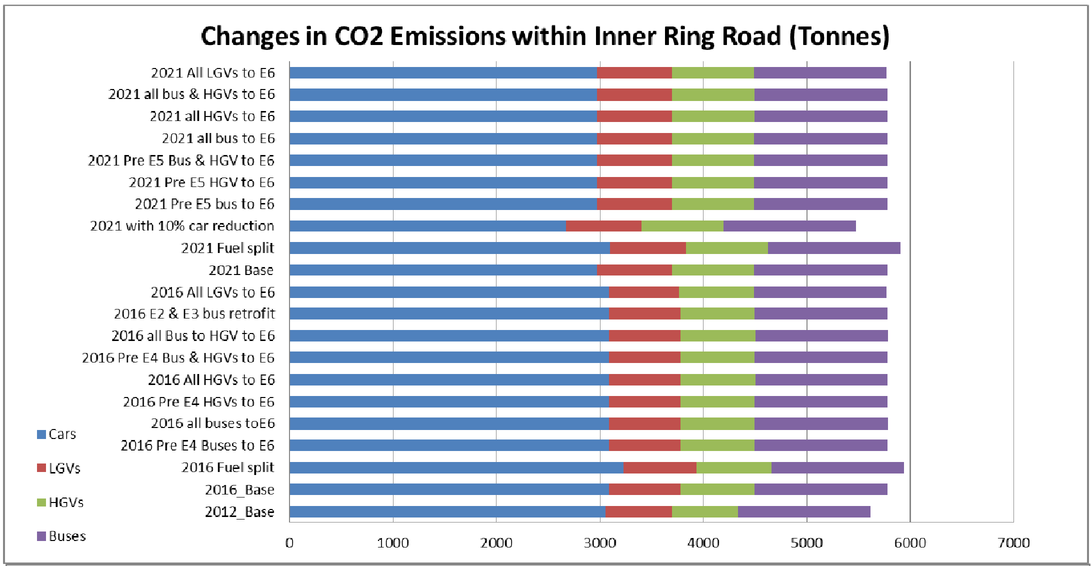
The modelling might have might have been more accurate if the emissions were entered in to the dispersion model with a diurnal profile rather than a straight forward annual average. However the method used was chosen to enable the different scenarios to be modelled and compared on a like for like basis much quicker than would otherwise have been the case.

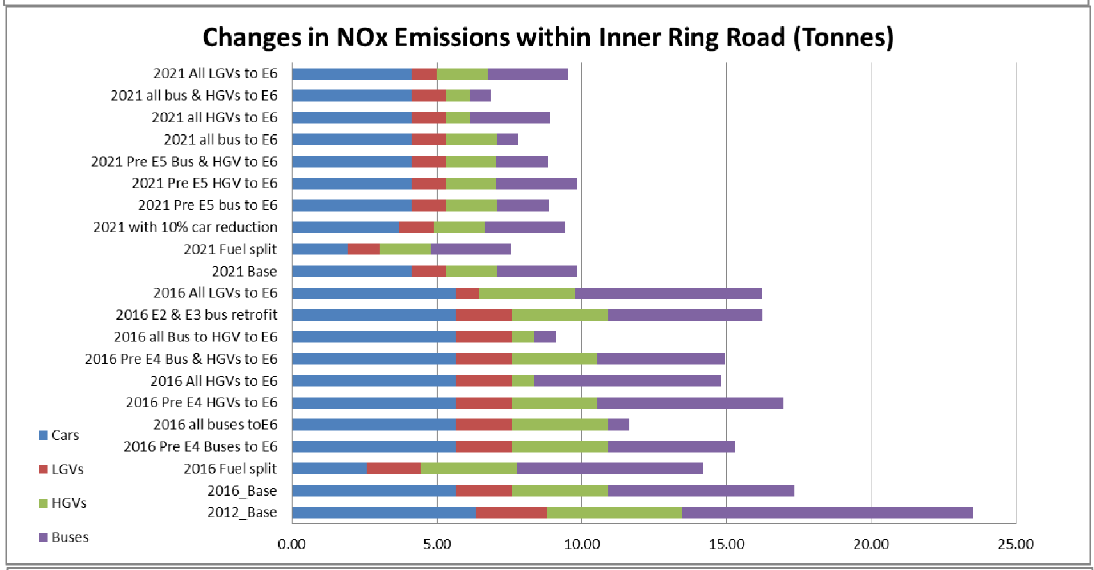
Although the modelling techniques have been very useful for comparing large networks with multiple variations of interventions, the SATURN network base is not a detailed spatially correct representation of the traffic network. This effect is much more pronounced on the periphery of the network.

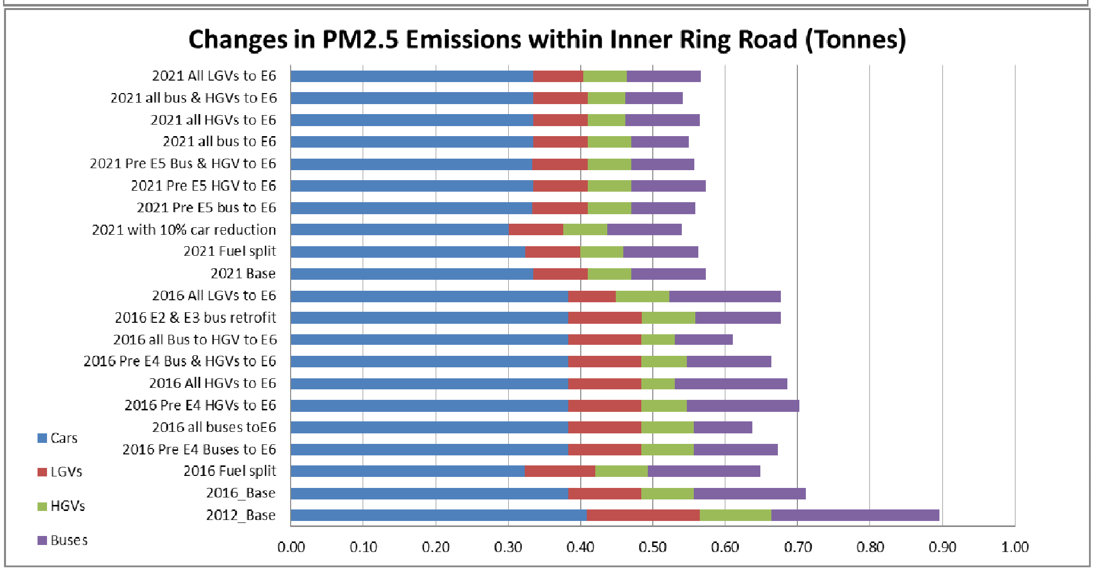
The result of the spatial inaccuracy of certain parts of the model will have some bearing on the overall accuracy of the resulting concentration levels at any given point. The grid averages, should be more representative within the central areas where more of the road network is modelled within any given grid. Although the grid average values on the periphery of the modelled network may be subject discrepancies due the lower density of road links which may also be contained within the wrong dispersion grid.

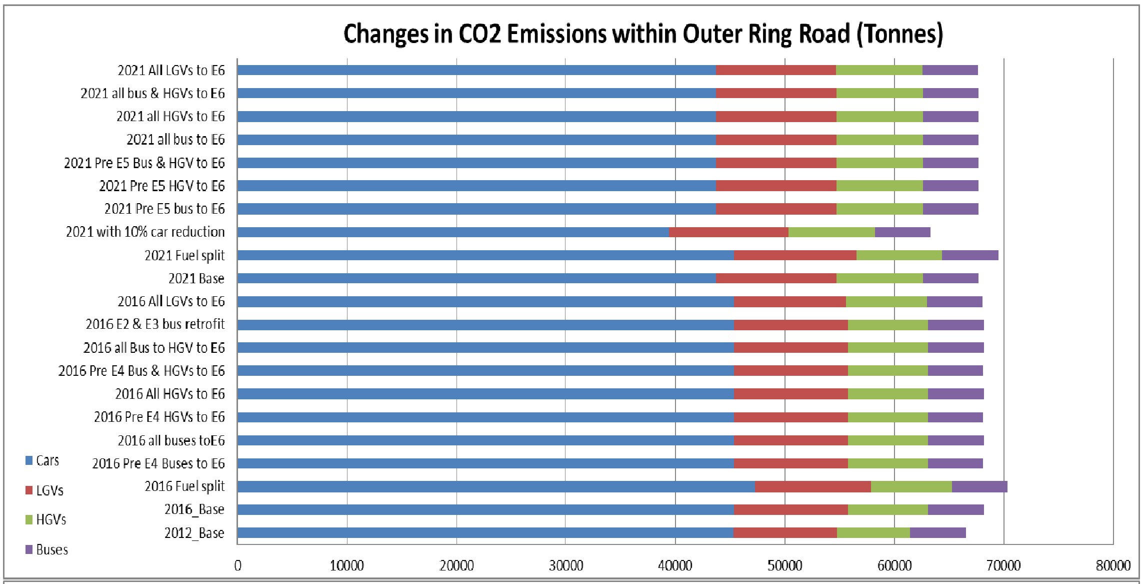
Modelling Outputs

Emission and concentration modelling outputs are provided below:

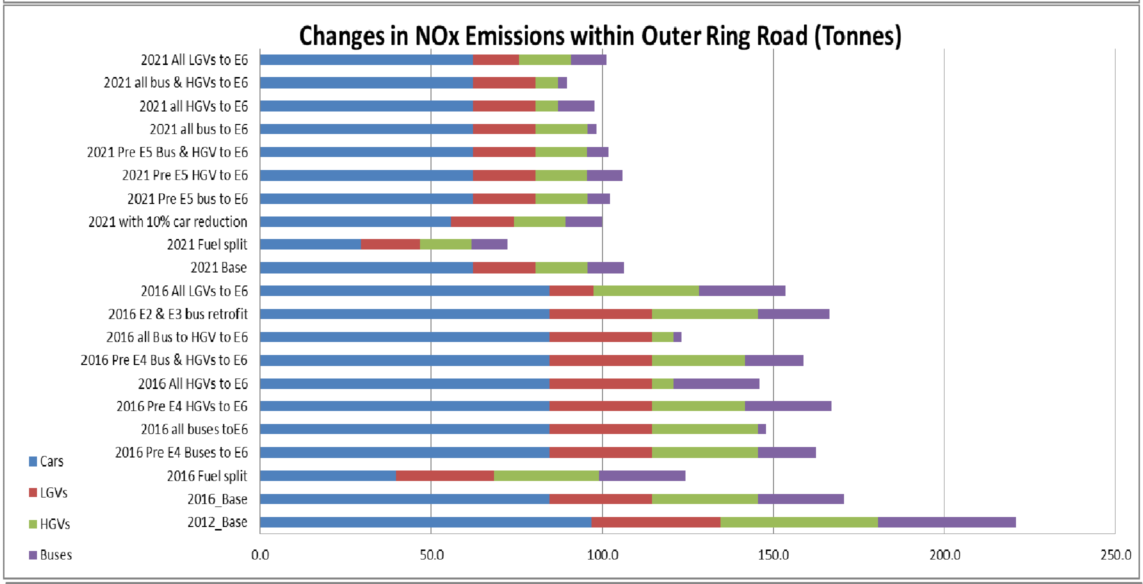

Changes in CO2 Emissions within Inner Ring Road (Tonnes)
2021 All LGVs to E6
2021 all bus & HGVs to E6
2021 all HGVs to E6
2021 all bus to E6
2021 Pre E5 Bus & HGV to E6
2021 Pre E5 HGV to E6
2021 Pre E5 bus to E6
2021 with 10% car reduction
2021 Fuel split
2021 Base
2016 All LGVs to E6
2016 E2 & E3 bus retrofit
2016 all Bus to HGV to E6
2016 Pre E4 Bus & HGVs to E6
2016 All HGVs to E6
2016 Pre E4 HGVs to E6
2016 all buses toE6
2016 Pre E4 Buses to E6
2016 Fuel split
2016_Base
2012_Base
Cars
LGVs
HGVs
Buses
0
1000
2000
3000
4000
5000
6000
7000


Changes in NOx Emissions within Inner Ring Road (Tonnes)
2021 All LGVs to E6
2021 all bus & HGVs to E6
2021 all HGVs to E6
2021 all bus to E6
2021 Pre E5 Bus & HGV to E6
2021 Pre E5 HGV to E6
2021 Pre E5 bus to E6
2021 with 10% car reduction
2021 Fuel split
2021 Base
2016 All LGVs to E6
2016 E2 & E3 bus retrofit
2016 all Bus to HGV to E6
2016 Pre E4 Bus & HGVs to E6
2016 All HGVs to E6
2016 Pre E4 HGVs to E6
2016 all buses toE6
2016 Pre E4 Buses to E6
2016 Fuel split
2016_Base
2012_Base
Cars
LGVs
HGVs
Buses
0.00
5.00
10.00
15.00
20.00
25.00

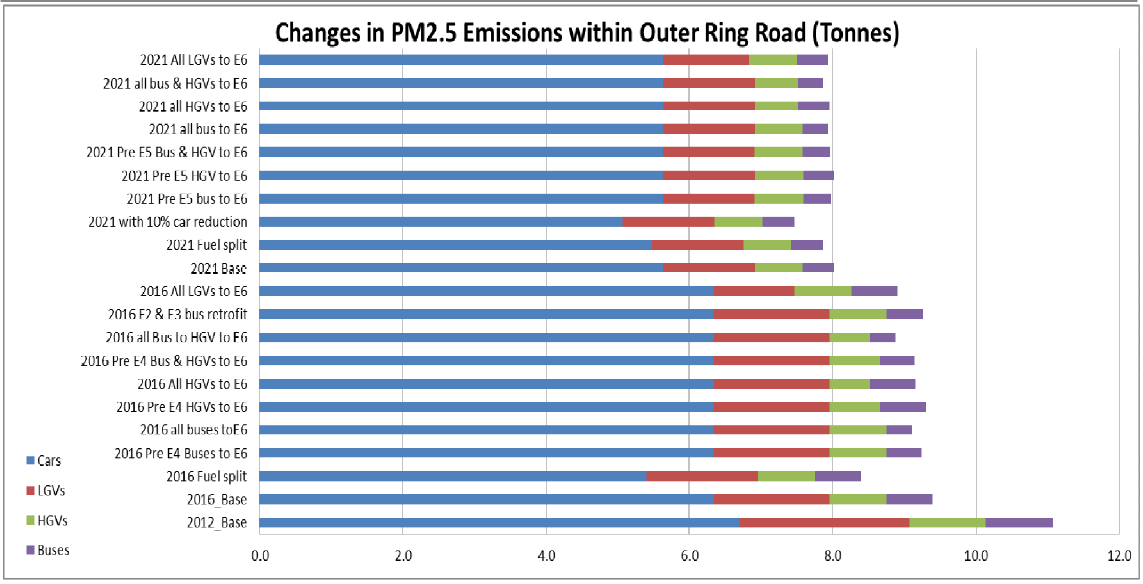

Changes in PM2.5 Emissions within Inner Ring Road (Tonnes)
2021 All LGVs to E6
2021 all bus & HGVs to E6
2021 all HGVs to E6
2021 all bus to E6
2021 Pre E5 Bus & HGV to E6
2021 Pre E5 HGV to E6
2021 Pre E5 bus to E6
2021 with 10% car reduction
2021 Fuel split
2021 Base
2016 All LGVs to E6
2016 E2 & E3 bus retrofit
2016 all Bus to HGV to E6
2016 Pre E4 Bus & HGVs to E6
2016 All HGVs to E6
2016 Pre E4 HGVs to E6
2016 all buses toE6
2016 Pre E4 Buses to E6
2016 Fuel split
2016_Base
2012_Base
Cars
LGVs
HGVs
Buses
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00



Changes in CO2 Emissions within Outer Ring Road (Tonnes)
2021 All LGVs to E6
2021 all bus & HGVs to E6
2021 all HGVs to E6
2021 all bus to E6
2021 Pre E5 Bus & HGV to E6
2021 Pre E5 HGV to E6
2021 Pre E5 bus to E6
2021 with 10% car reduction
2021 Fuel split
2021 Base
2016 All LGVs to E6
2016 E2 & E3 bus retrofit
2016 all Bus to HGV to E6
2016 Pre E4 Bus & HGVs to E6
2016 All HGVs to E6
2016 Pre E4 HGVs to E6
2016 all buses toE6
2016 Pre E4 Buses to E6
2016 Fuel split
2016_Base
2012_Base
Cars
LGVs
HGVs
Buses
0
10000
20000
30000
40000
50000
60000
70000
80000

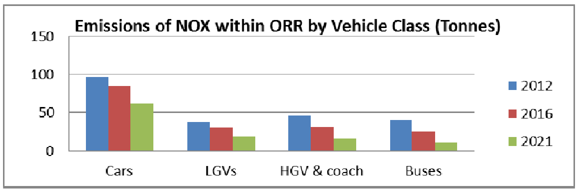


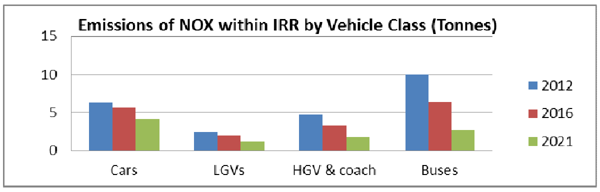
Changes in NOx Emissions within Outer Ring Road (Tonnes)
2021 All LGVs to E6
2021 all bus & HGVs to E6
2021 all HGVs to E6
2021 all bus to E6
2021 Pre E5 Bus & HGV to E6
2021 Pre E5 HGV to E6
2021 Pre E5 bus to E6
2021 with 10% car reduction
2021 Fuel split
2021 Base
2016 All LGVs to E6
2016 E2 & E3 bus retrofit
2016 all Bus to HGV to E6
2016 Pre E4 Bus & HGVs to E6
2016 All HGVs to E6
2016 Pre E4 HGVs to E6
2016 all buses toE6
2016 Pre E4 Buses to E6
2016 Fuel split
2016_Base
2012_Base
Cars
LGVs
HGVs
Buses
0.0
50.0
100.0
150.0
200.0
250.0

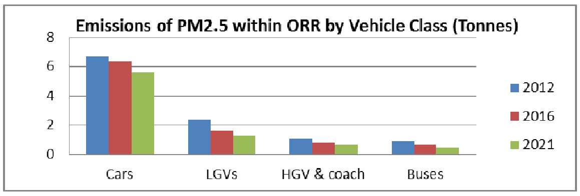


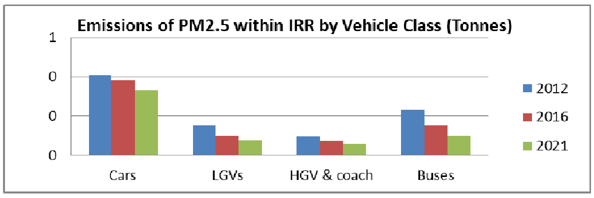
Changes in PM2.5 Emissions within Outer Ring Road (Tonnes)
2021 All LGVs to E6
2021 all bus & HGVs to E6
2021 all HGVs to E6
2021 all bus to E6
2021 Pre E5 Bus & HGV to E6
2021 Pre E5 HGV to E6
2021 Pre E5 bus to E6
2021 with 10% car reduction
2021 Fuel split
2021 Base
2016 All LGVs to E6
2016 E2 & E3 bus retrofit
2016 all Bus to HGV to E6
2016 Pre E4 Bus & HGVs to E6
2016 All HGVs to E6
2016 Pre E4 HGVs to E6
2016 all buses toE6
2016 Pre E4 Buses to E6
2016 Fuel split
2016_Base
2012_Base
Cars
LGVs
HGVs
Buses
0.0
2.0
4.0
6.0
8.0
10.0
12.0

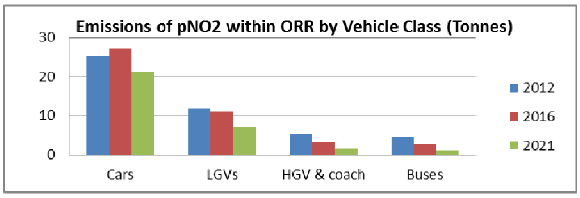
How total emissions from each vehicle class change are projected to change with time within the modelled two LEZ boundaries (business as usual)

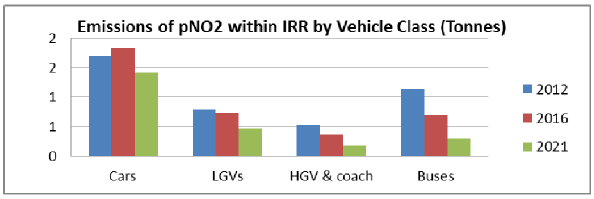




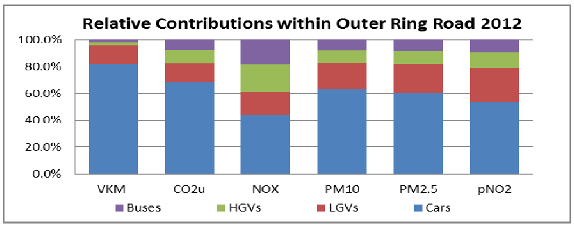


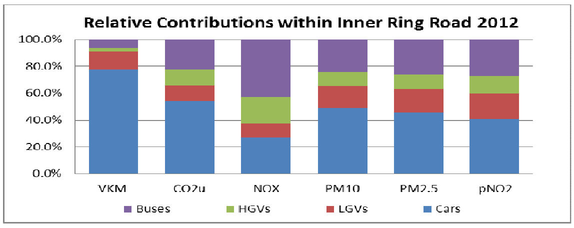


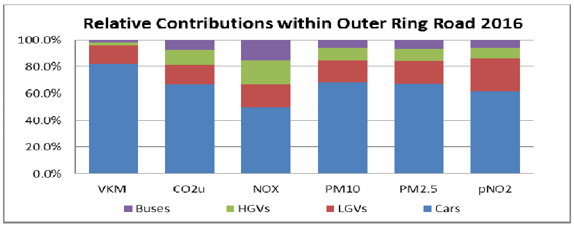


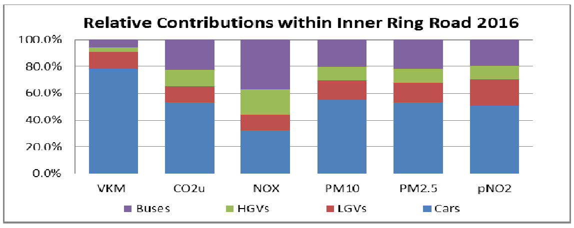


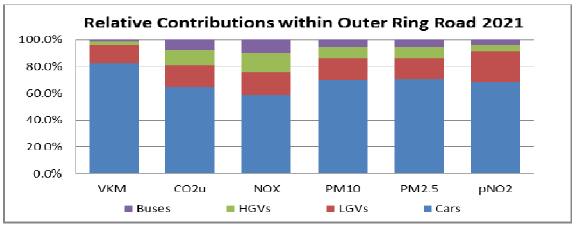
How the proportion of the total emissions is projected to vary over time when compared to the Mileage driven by that vehicle class with LEZ boundaries

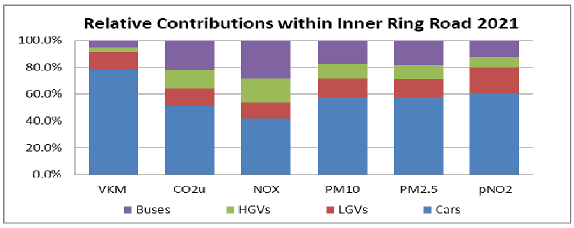






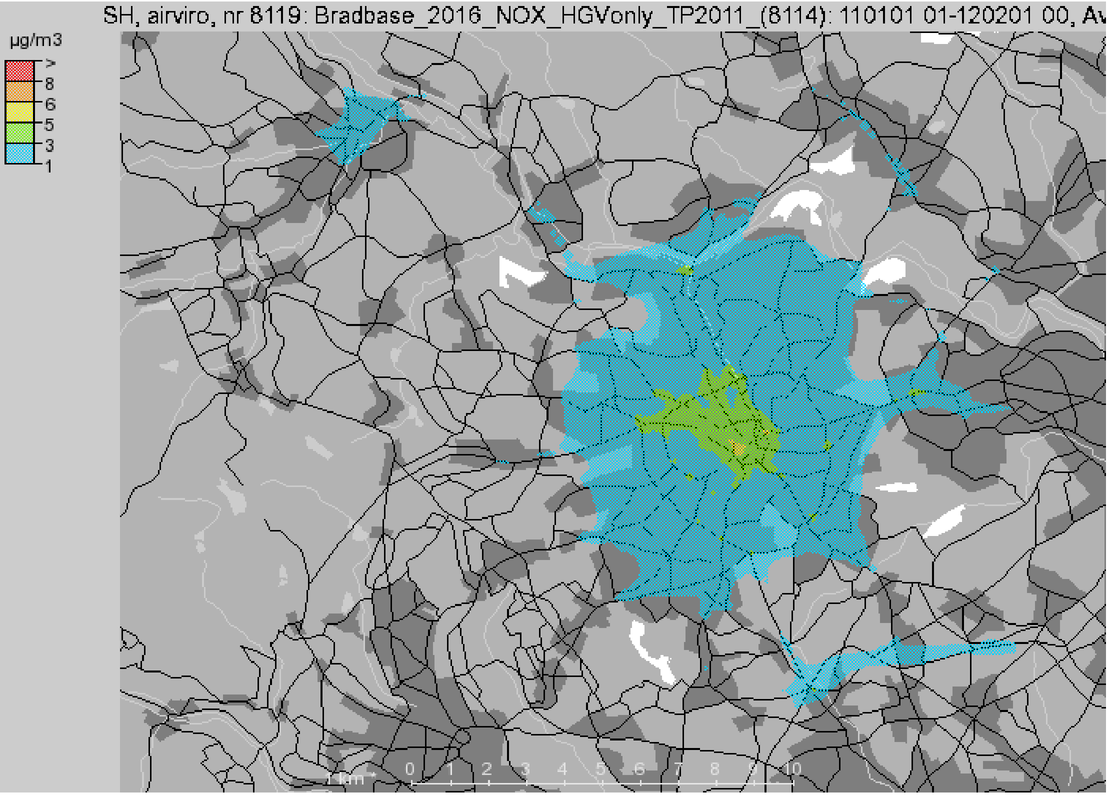




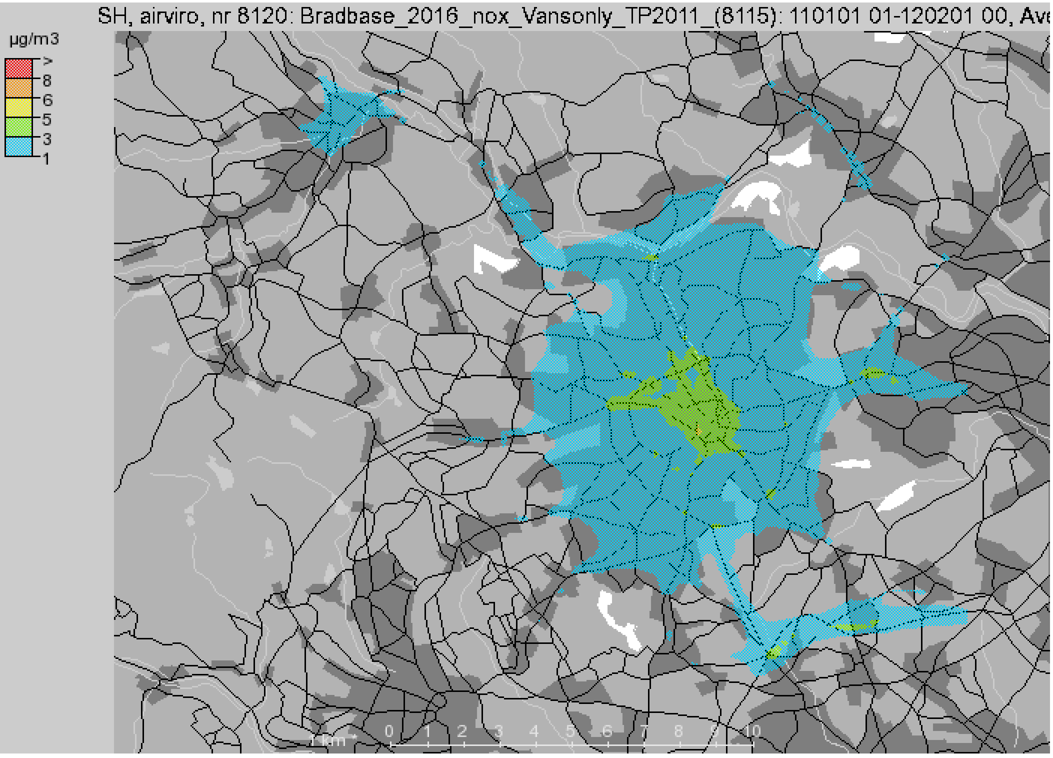


2016 individual contributions from bus, car, HGV and Vans for NOX only

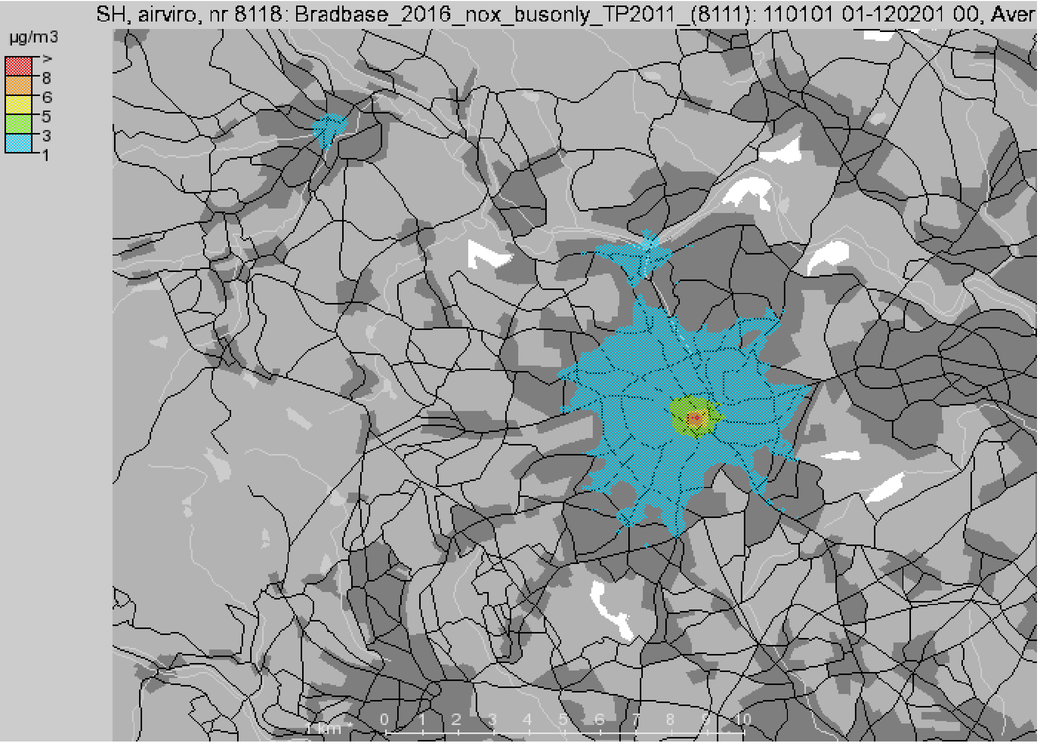
Estimated Contribution to NOx contributions attributable to HGVs Only



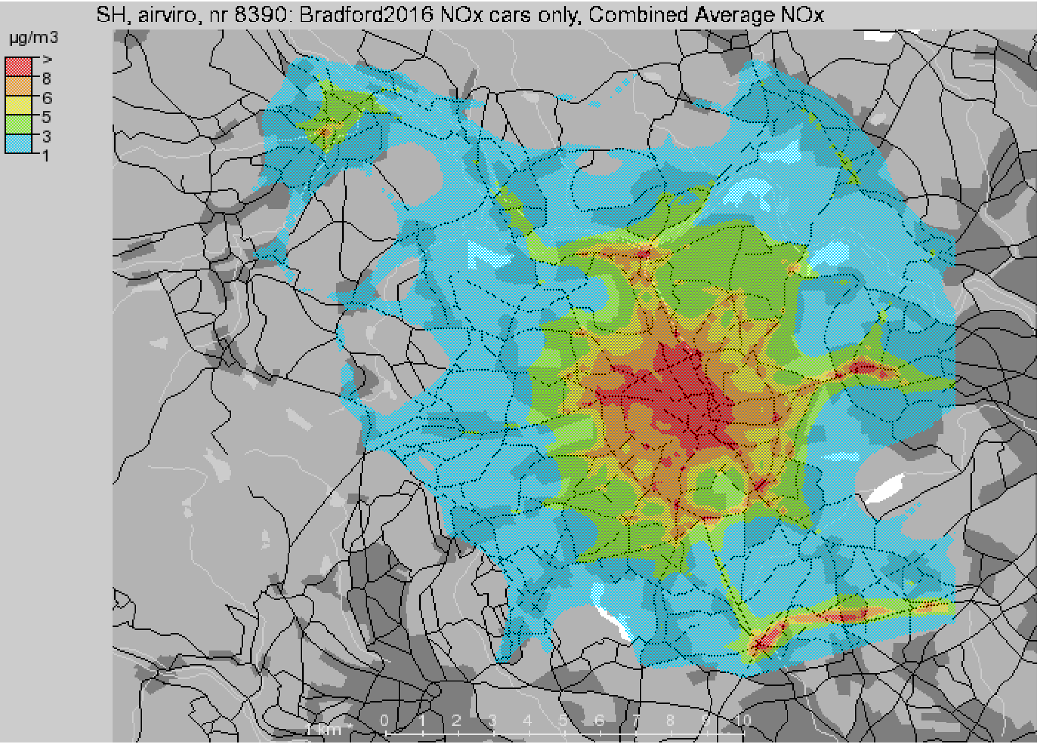
Estimated Contribution to NOx contributions attributable to LGVs Only



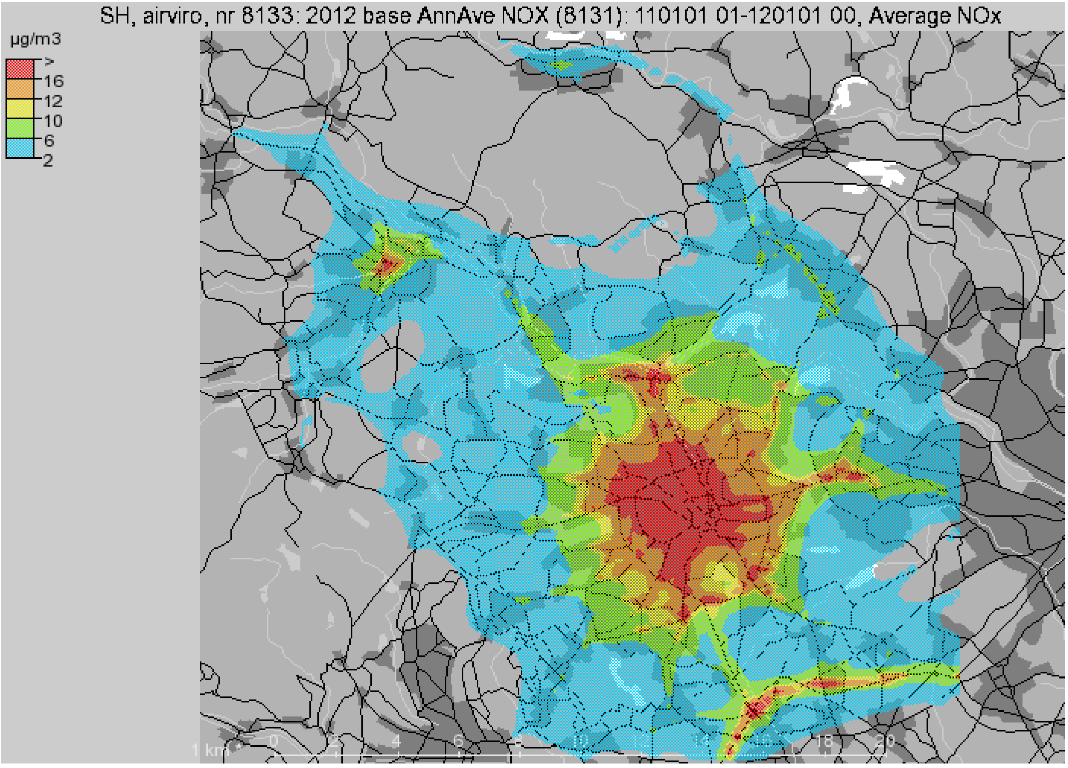
Estimated Contribution to NOx contributions attributable to Buses Only



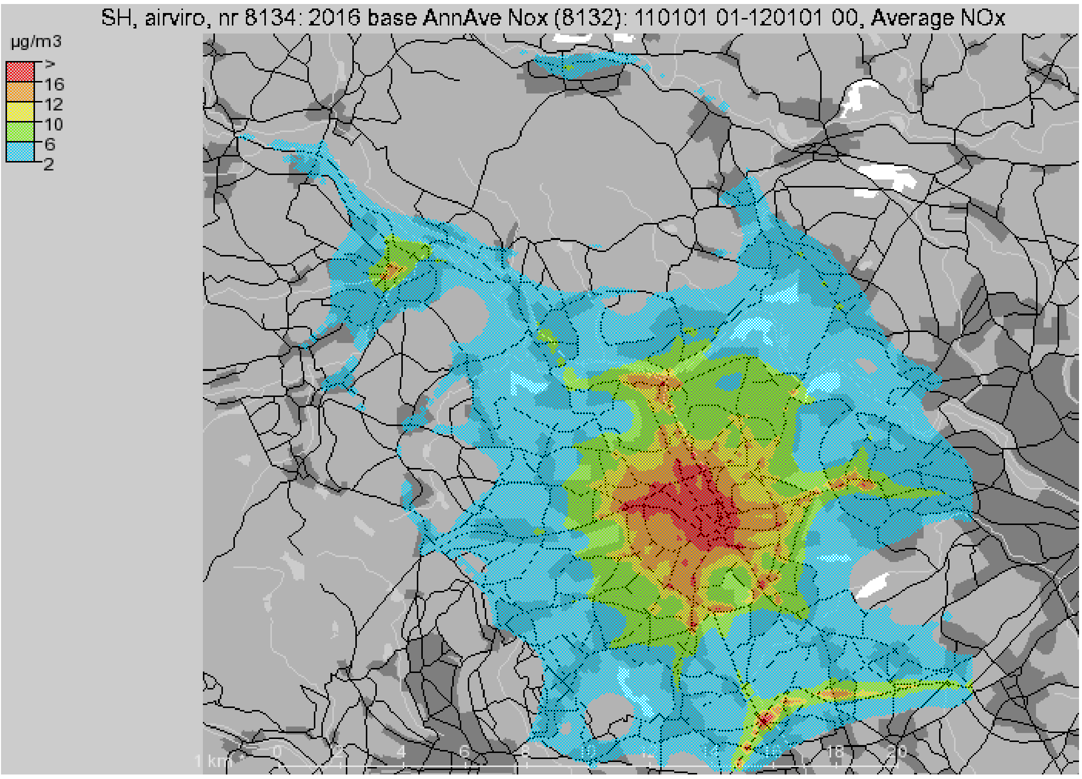
Estimated Contribution to NOx contributions attributable to Cars Only



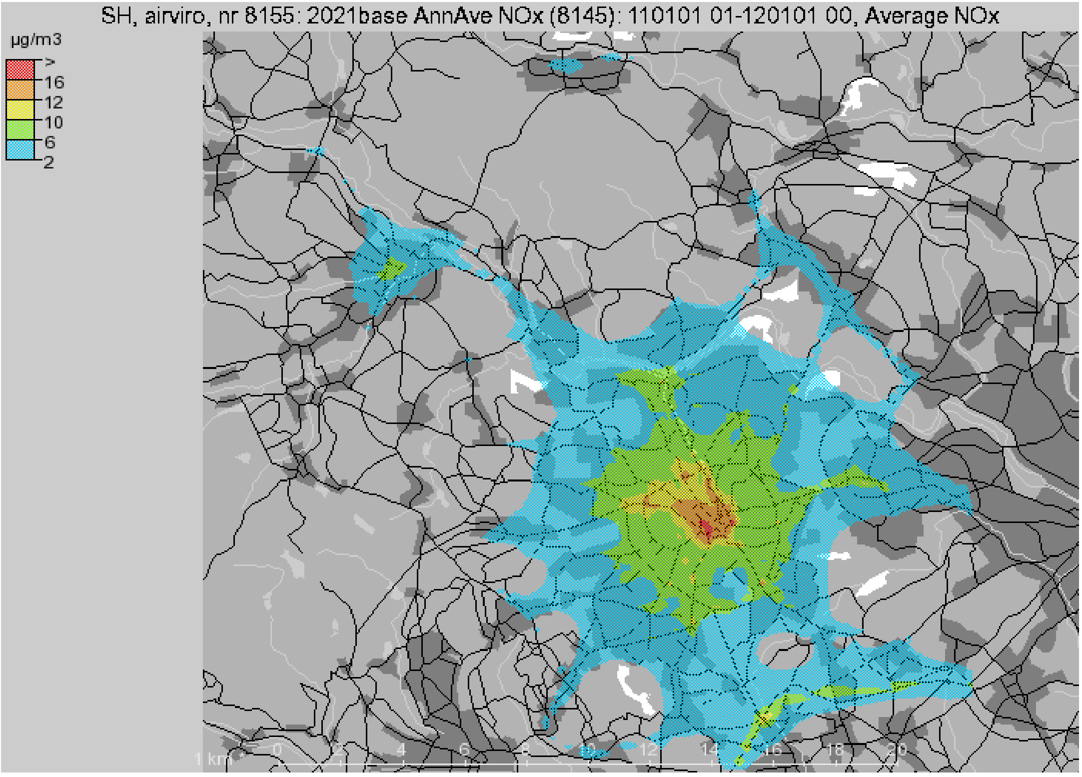
Total estimated Annual Average NOx for 2012 base year – All vehicle sources



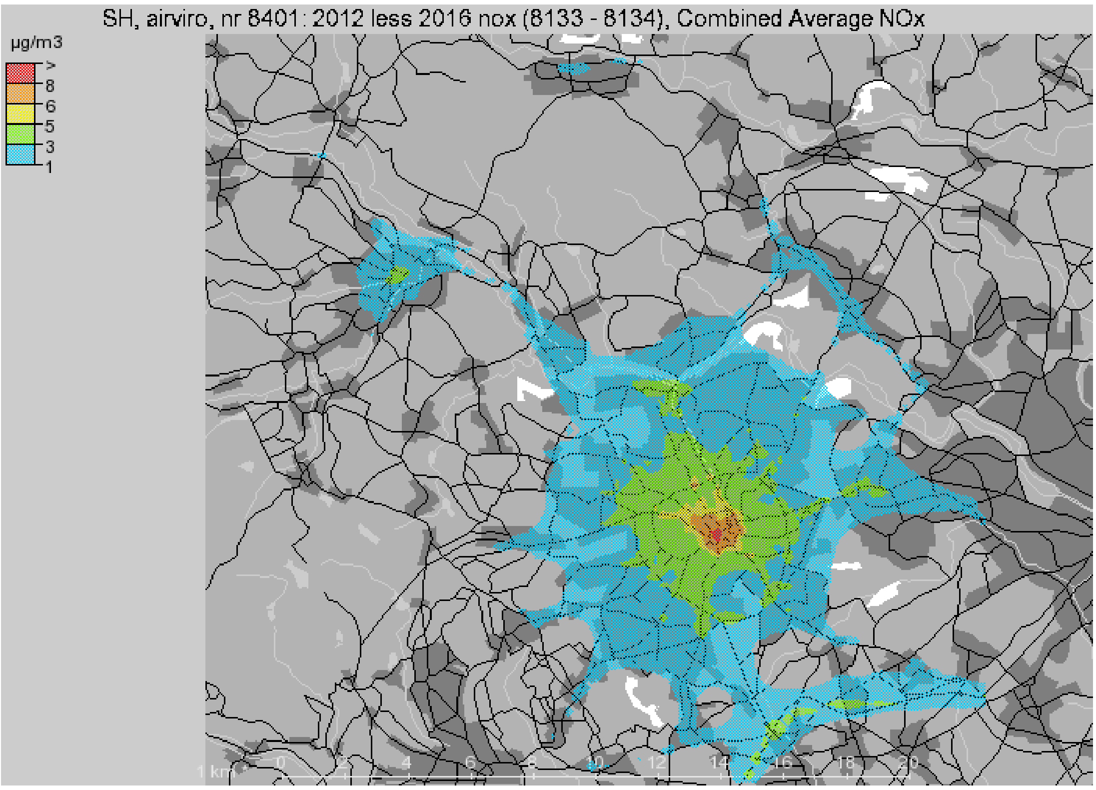
Total estimated Annual Average NOx for 2016 base year – All vehicle sources



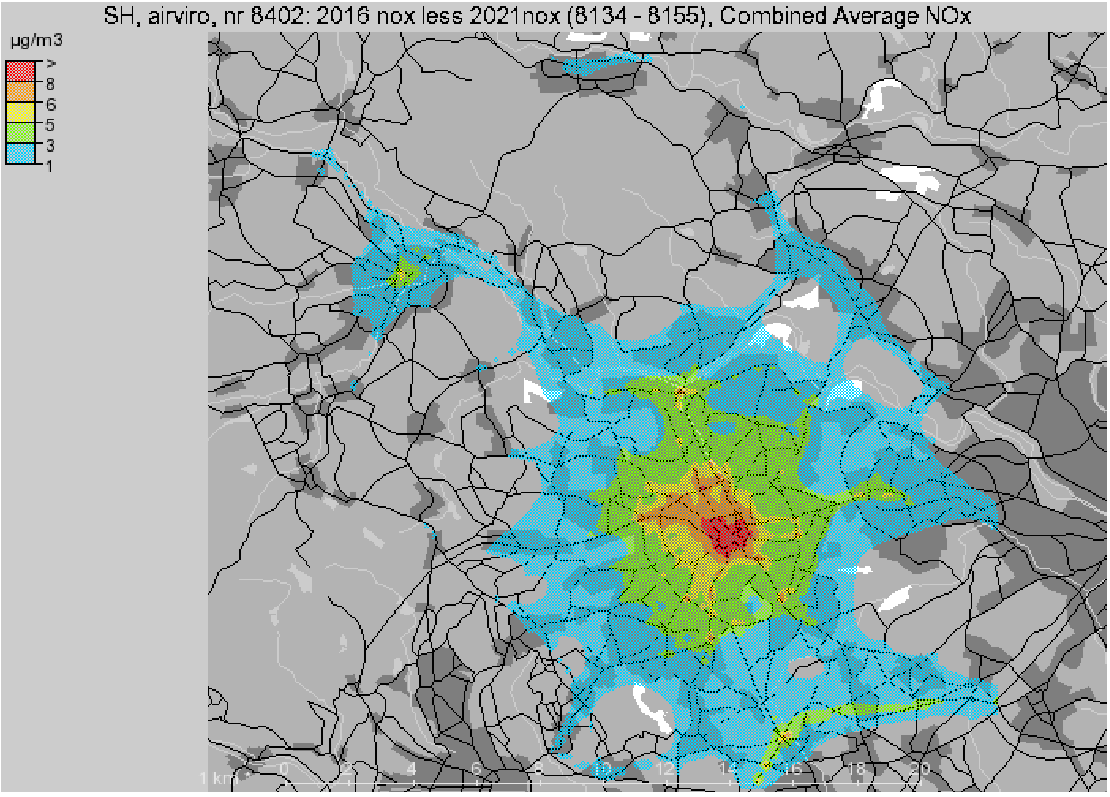
Total estimated Annual Average NOx for 2021 base year – All vehicle sources



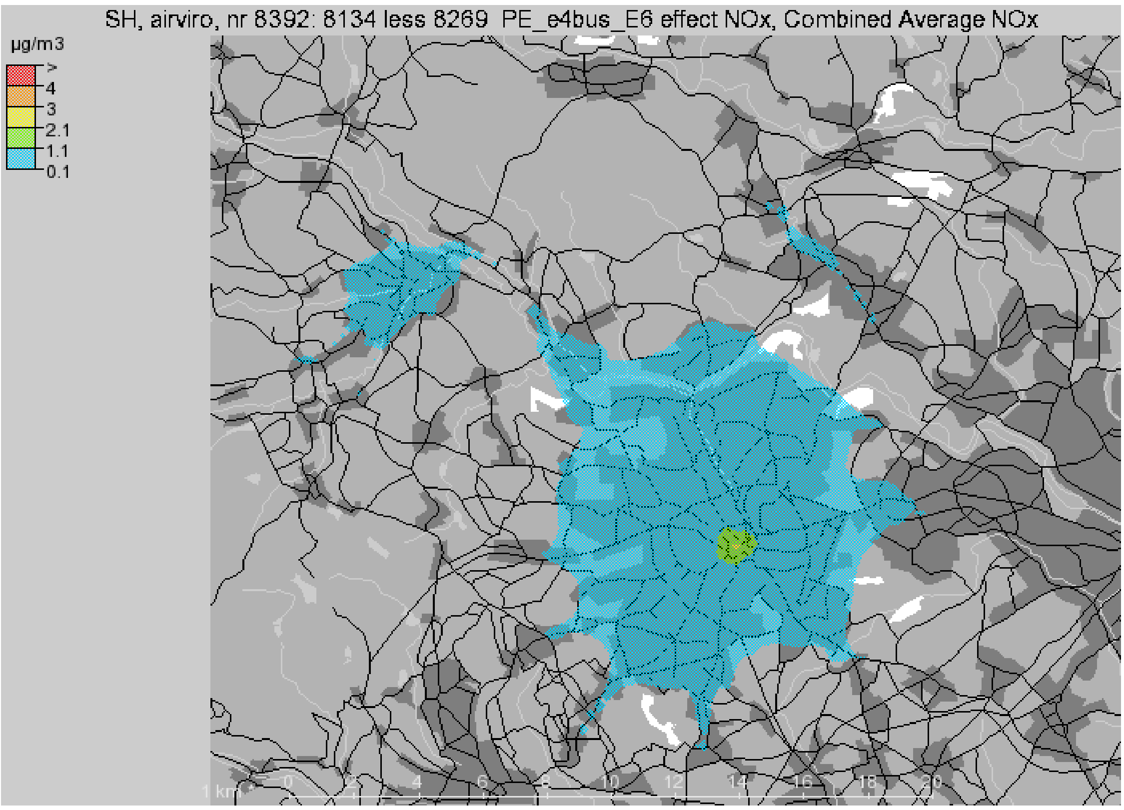
The Expected improvement between base years– i.e. green means expected fall of 3-5ug 2012 base concentrations less 2016



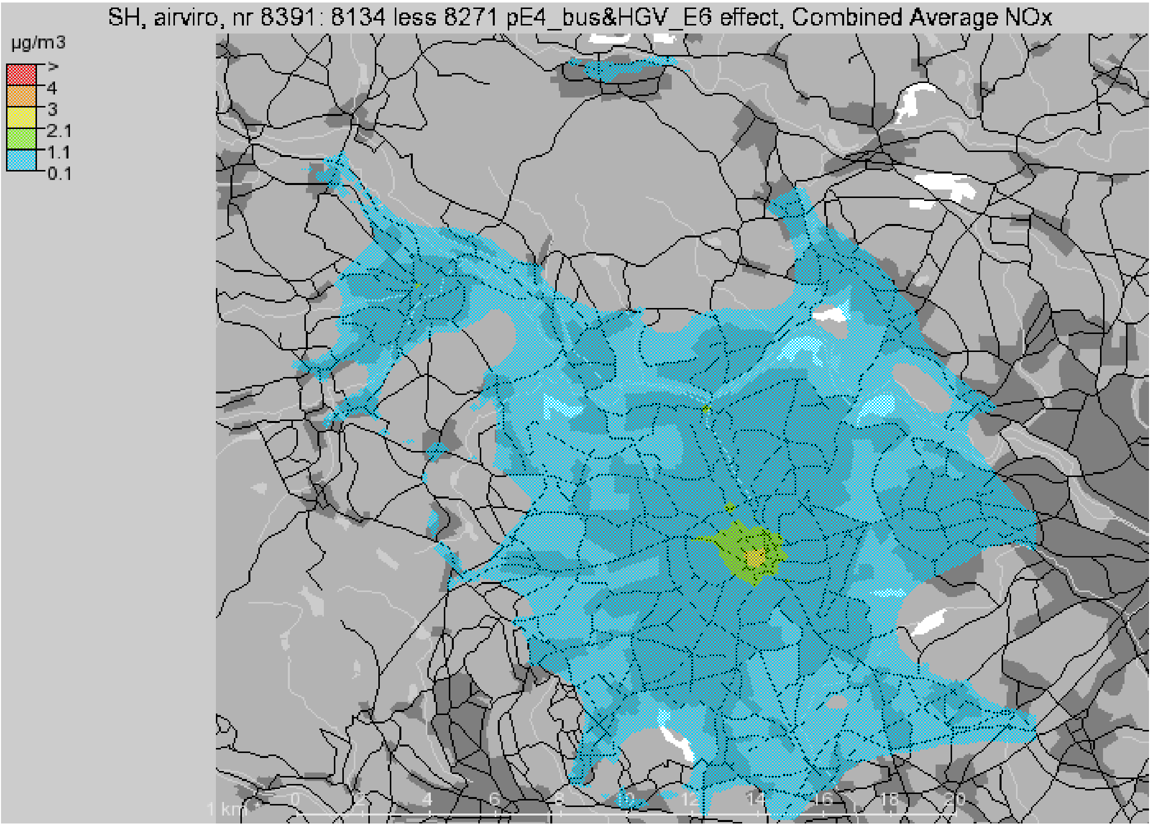
2012 base concentrations less 2016



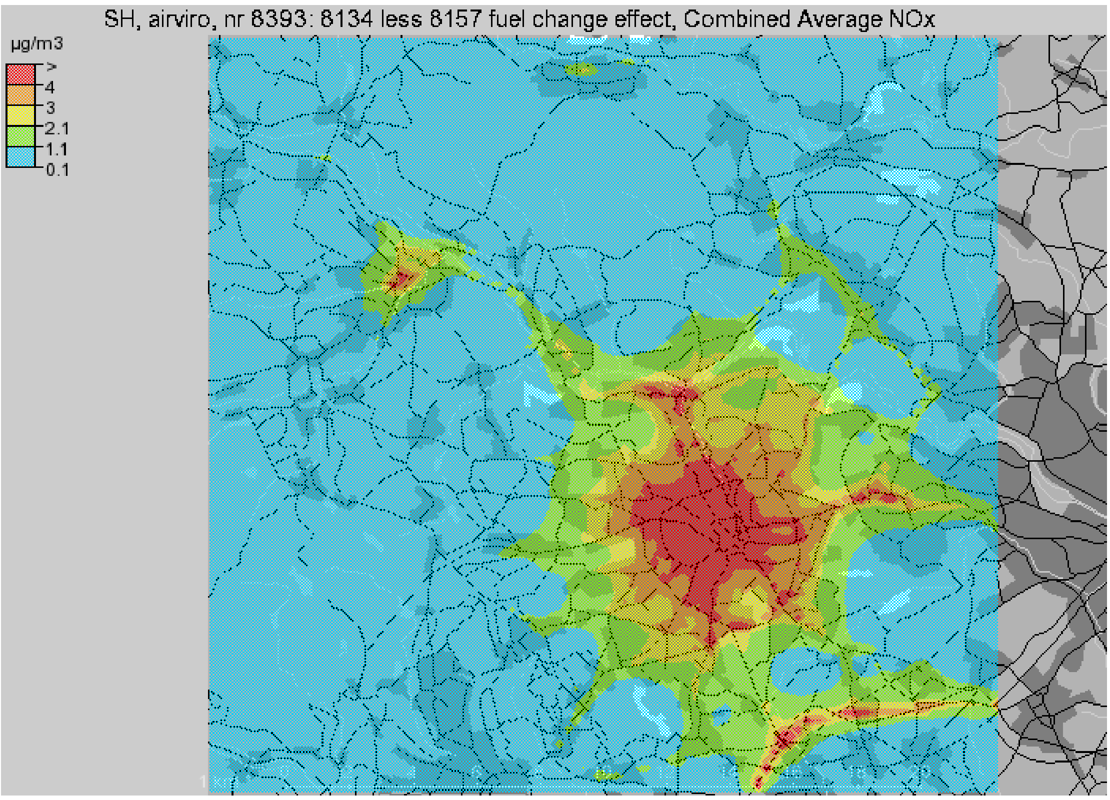
Additional Improvement in NOx predicted in 2016 by replacing all Pre Euro 4 buses with E6



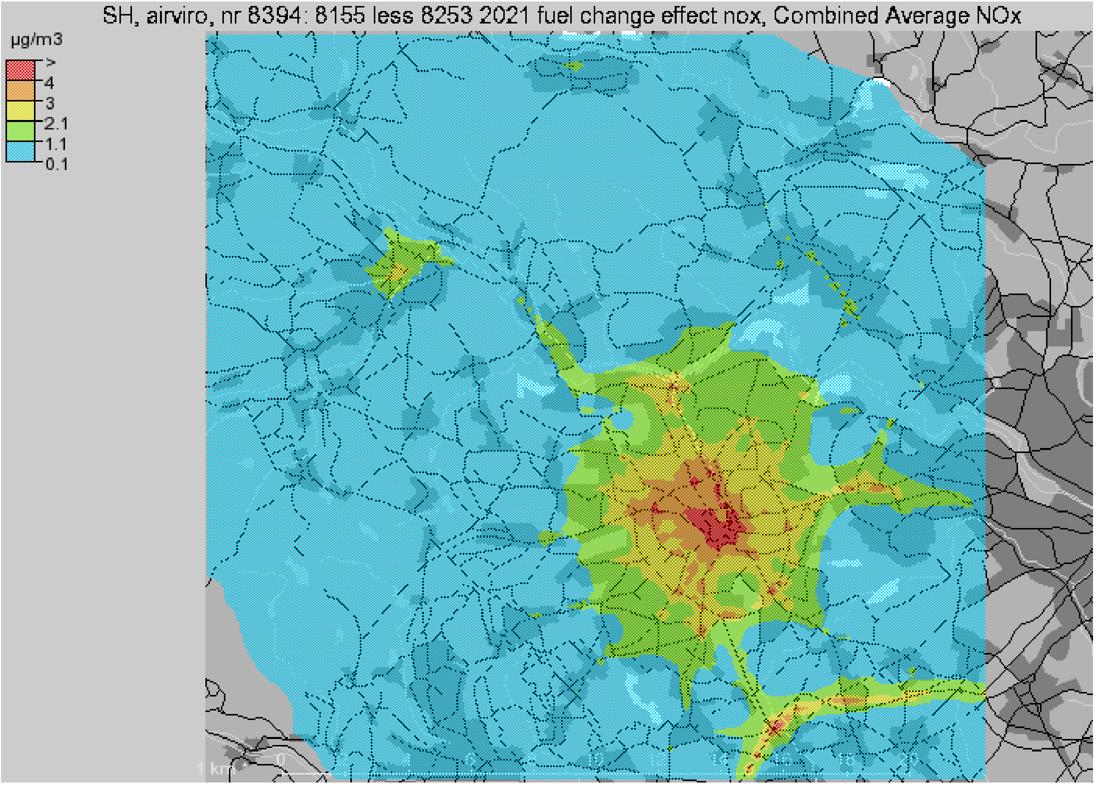
Additional Improvement predicted in 2016 by replacing all Pre Euro 4 buses and HGVs with E6



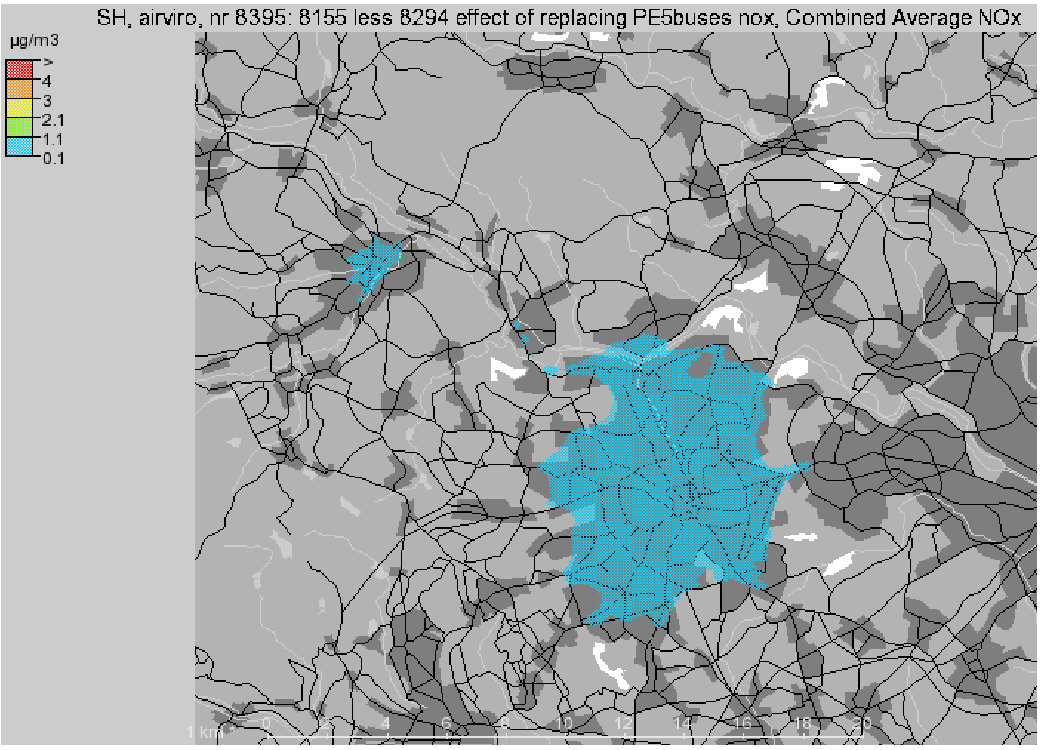
Additional Improvement over the base year predicted in 2016 by reverting to 89% petrol / diesel split for cars and class 1 vans (based on Year 2000 data)



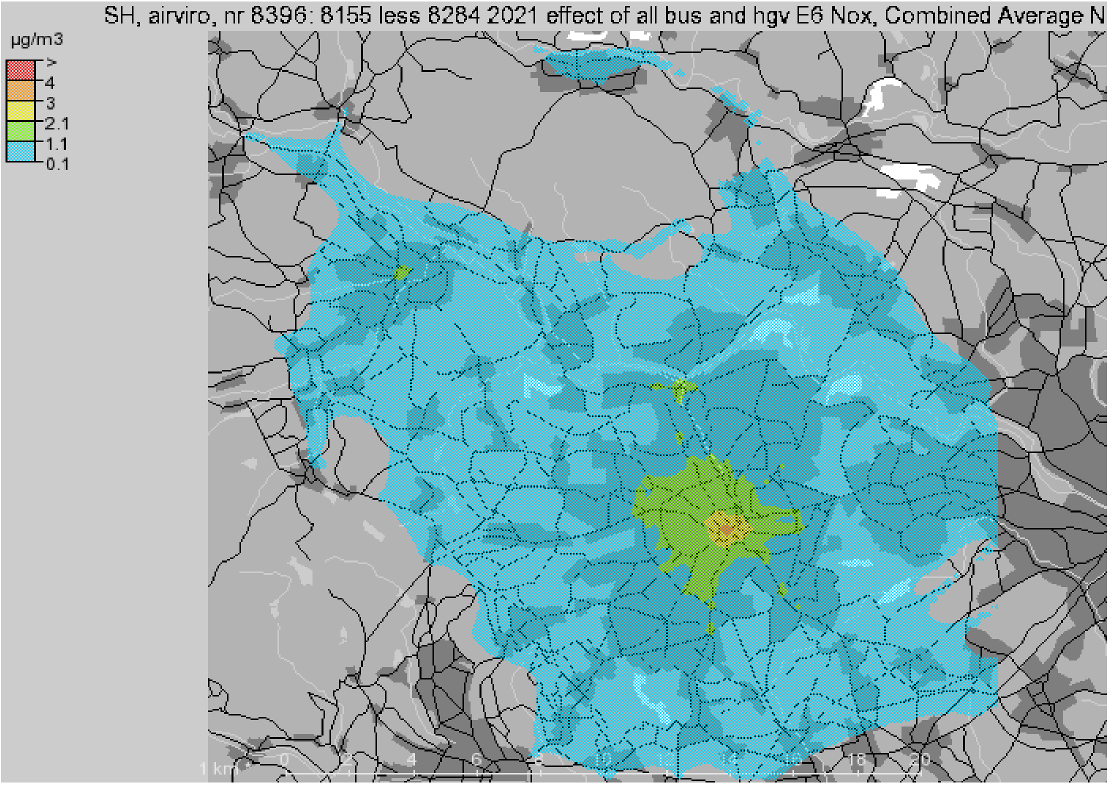
Additional Improvement over the base year predicted in 2021 by reverting to 89% petrol / diesel split for cars and class 1 vans (based on Year 2000 data)



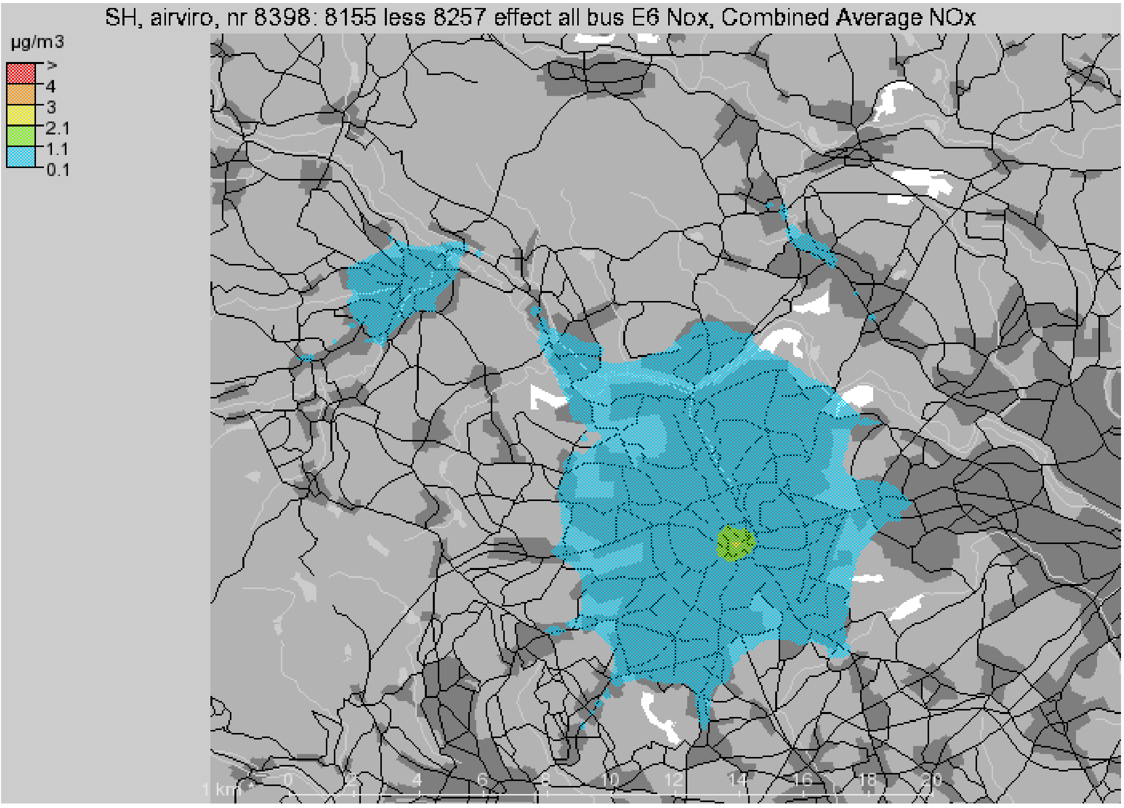
Additional Improvement predicted in 2021 by replacing all Pre Euro 5 buses with E6



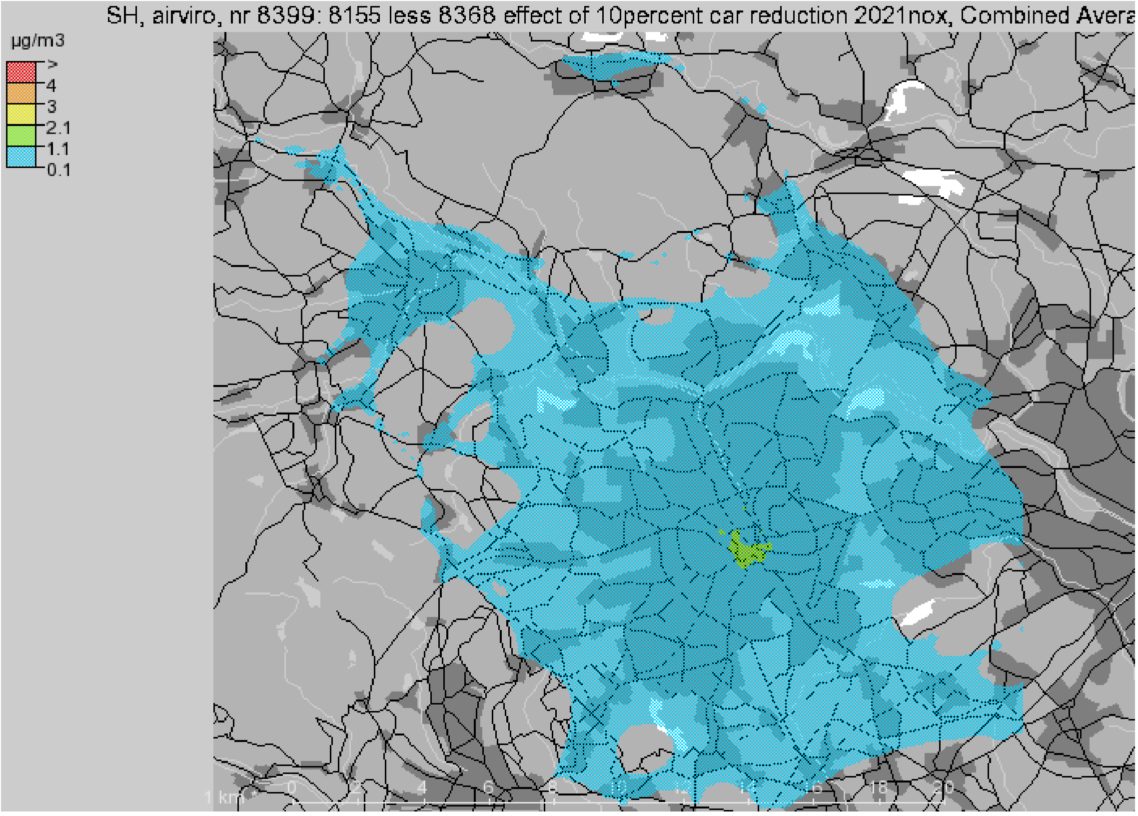
Additional Improvement predicted in 2021 by all buses and HGVs complying with E6



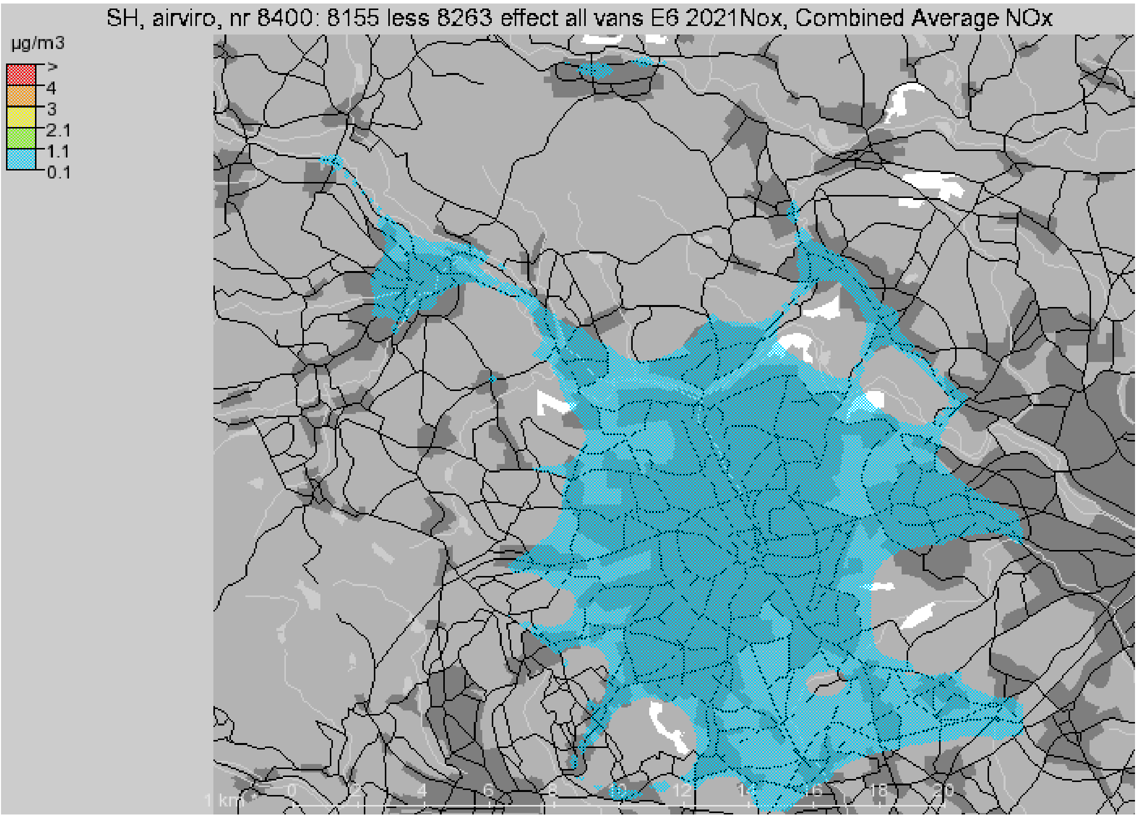
Additional Improvement predicted in 2021 by all buses complying with E6



Additional Improvement predicted in 2021 by reducing predicted car journeys by 10%

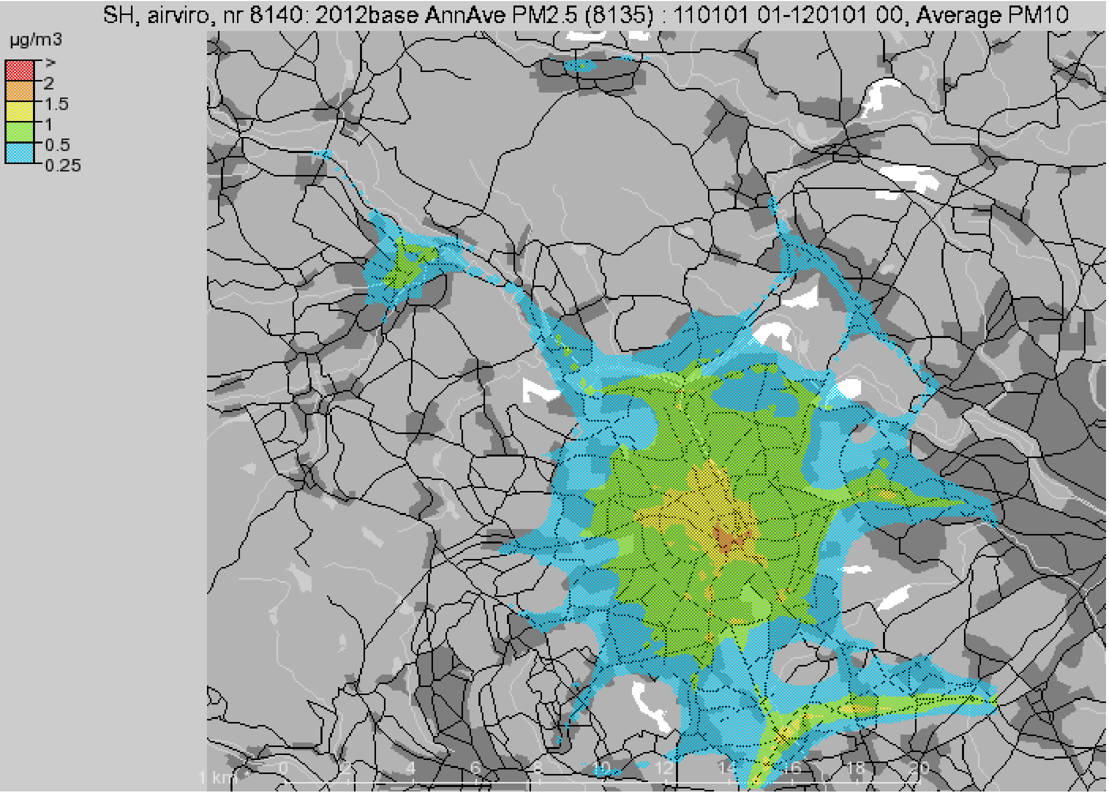


Additional Improvement predicted in 2021 by all LGVs complying with E6

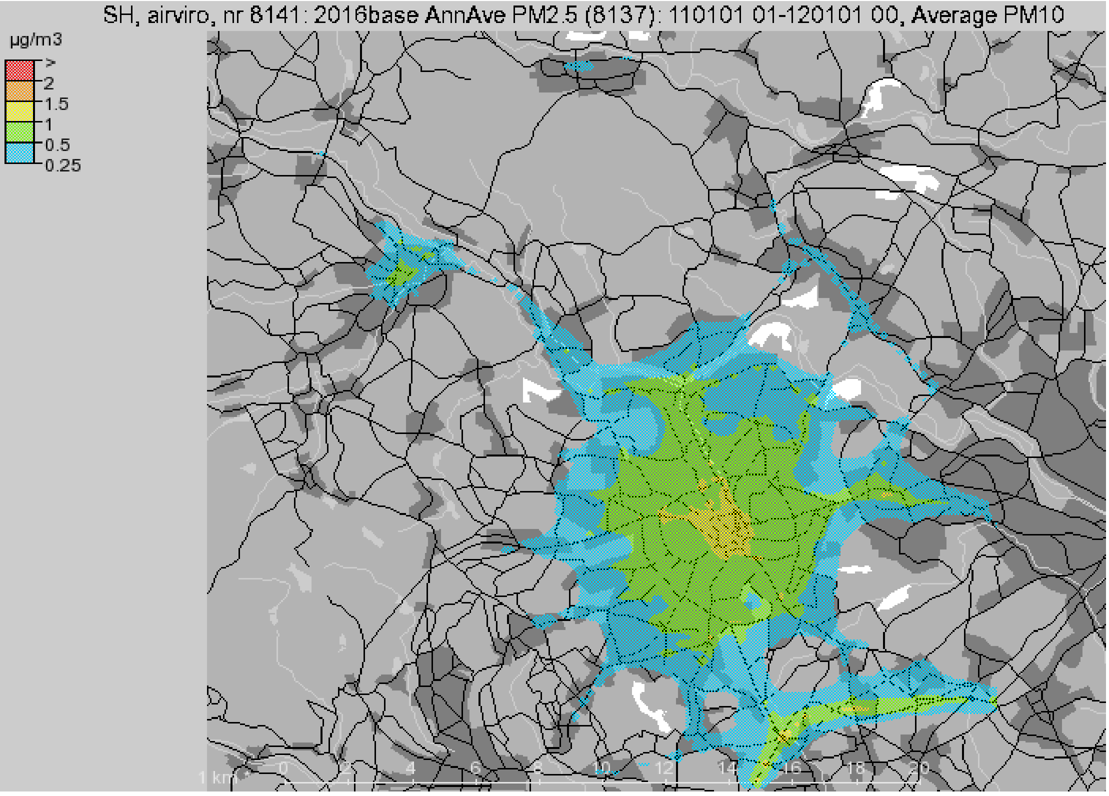


PM2.5

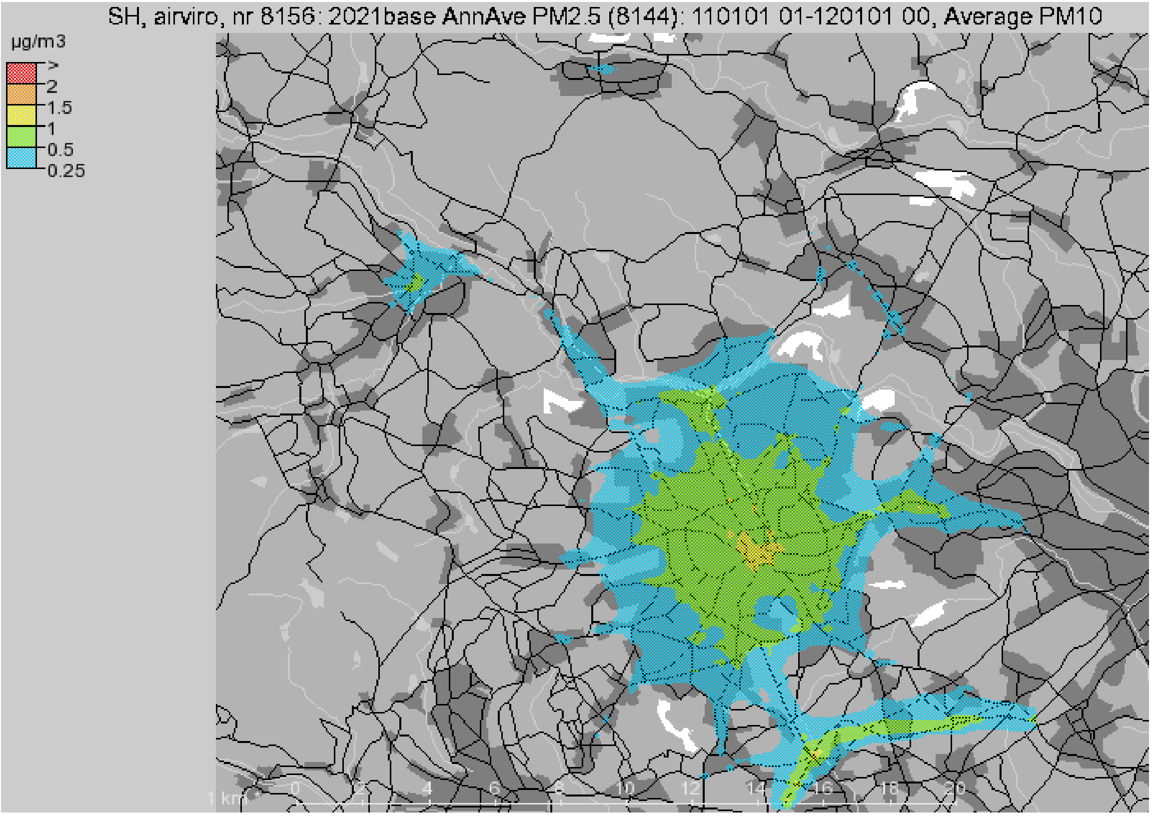
Total estimated Annual Average PM2.5 for 2012 base year – All vehicle sources



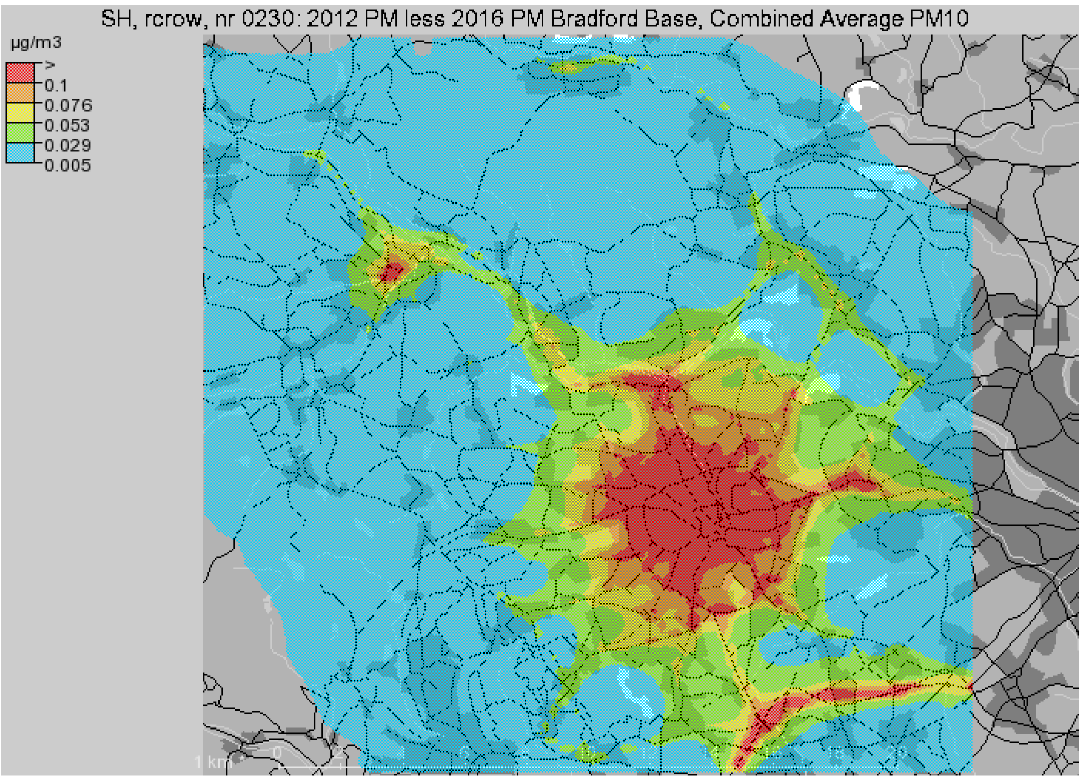
Total estimated Annual Average PM2.5 for 2016 base year – All vehicle sources



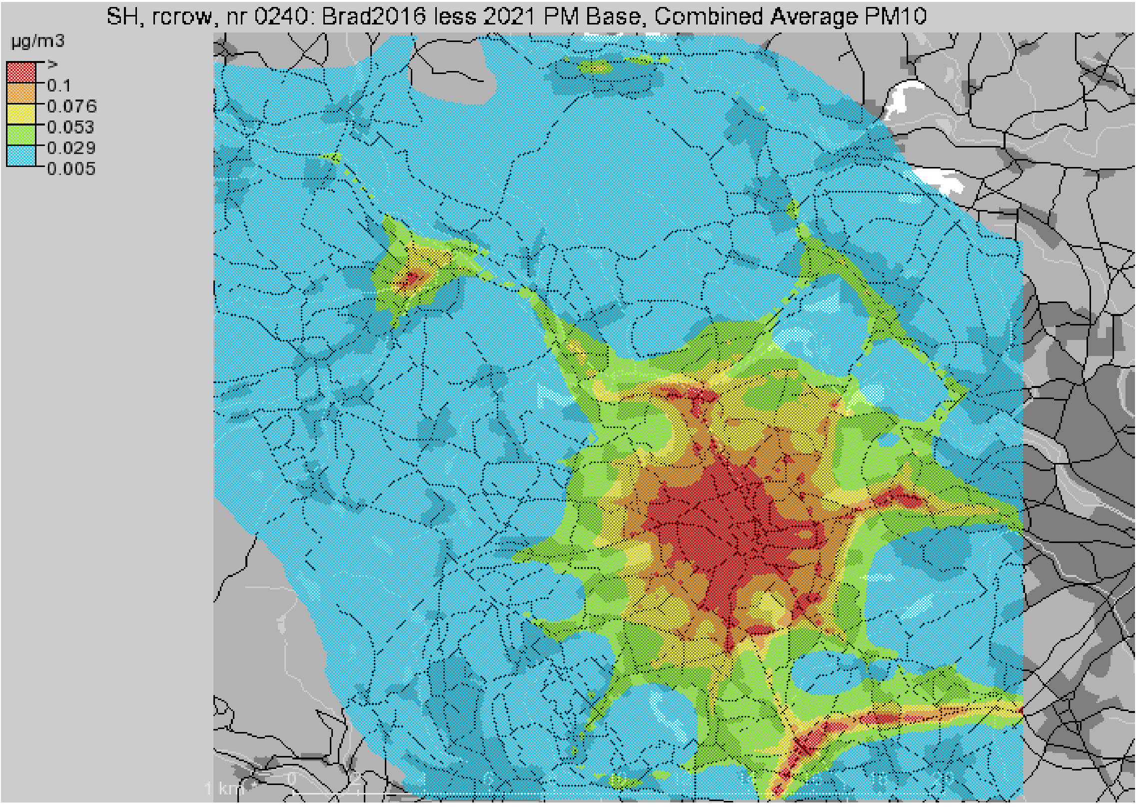
Total estimated Annual Average PM2.5 for 2021 base year – All vehicle sources



The Expected improvement between base years– i.e. green means expected fall of 0.03 and 0.05ug 2016 base year prediction subtracted from 2012 base year

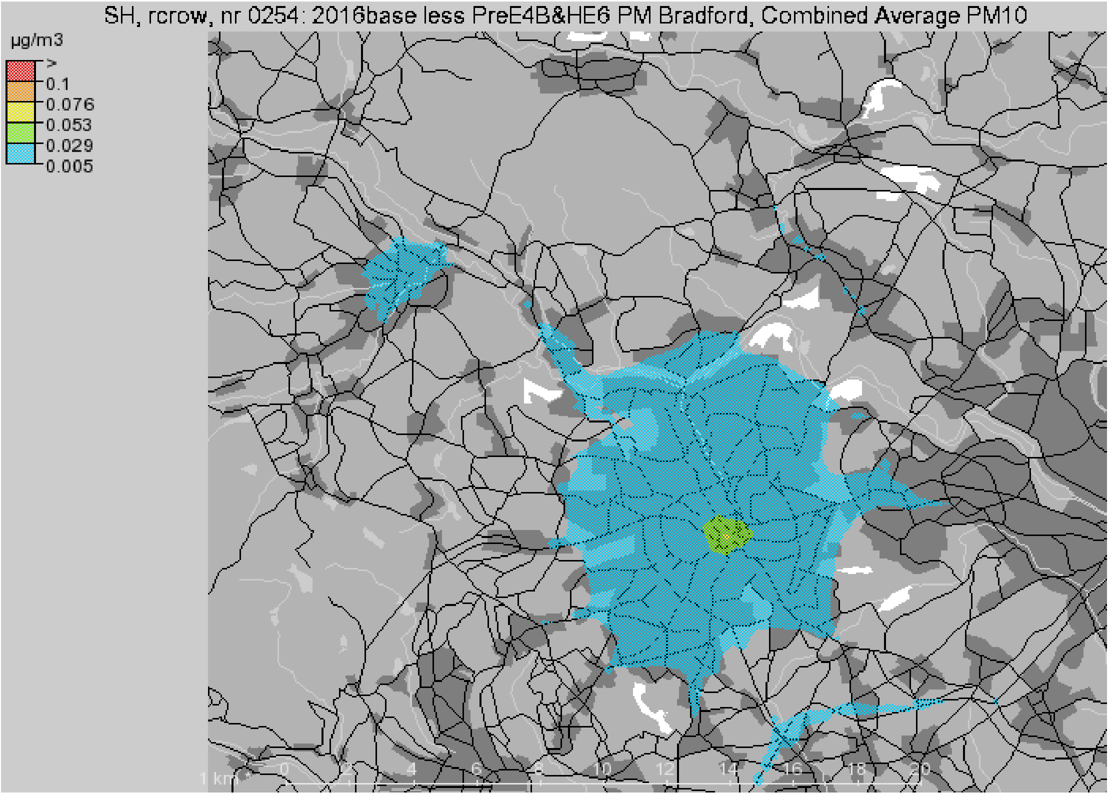


2021 base year prediction subtracted from 2016 base year

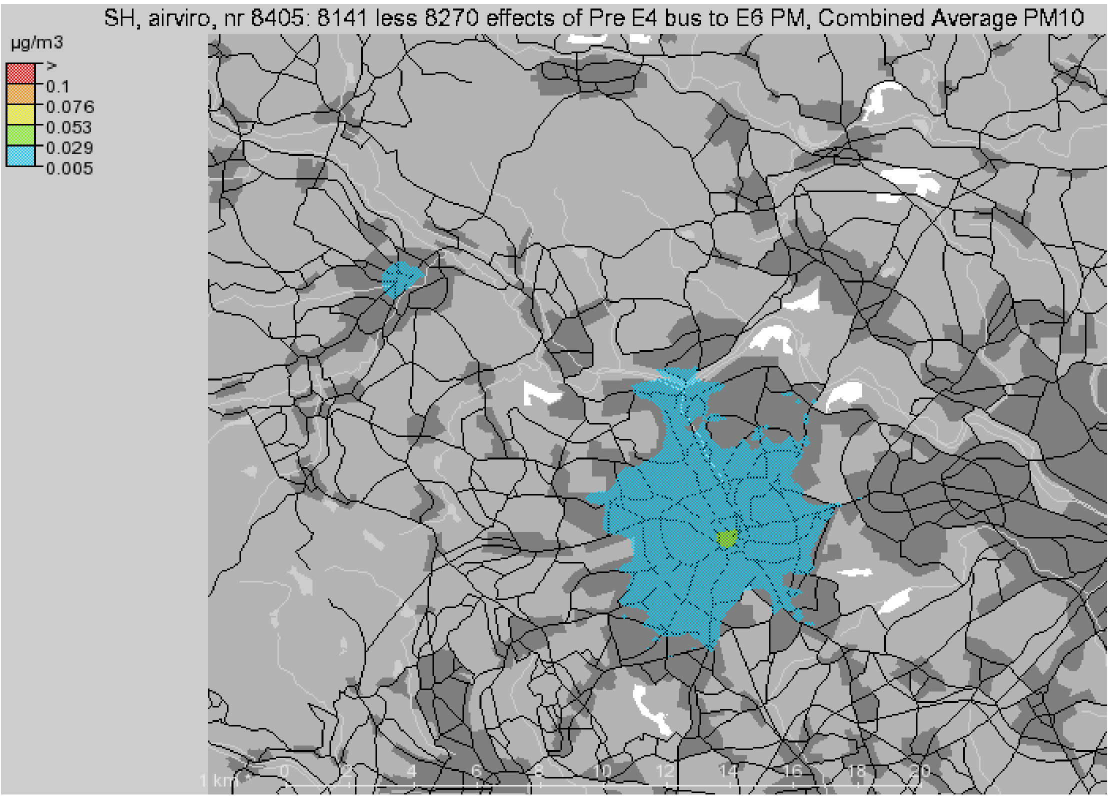


NOTE – unlike NOx biggest reduction occurs between 2012 and 2016 not 2016 to 2021

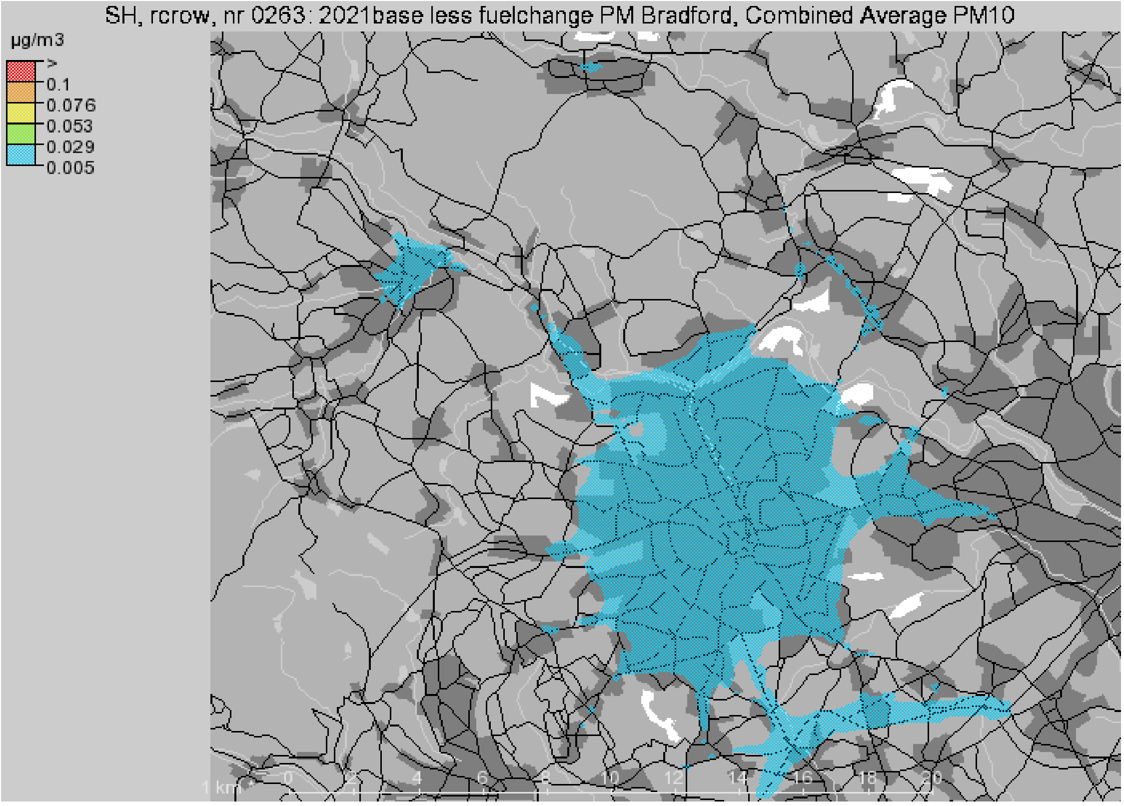
Additional Improvement over the base year predicted in 2016 through all Pre Euro 4 buses and HGVs replaced with Euro 6



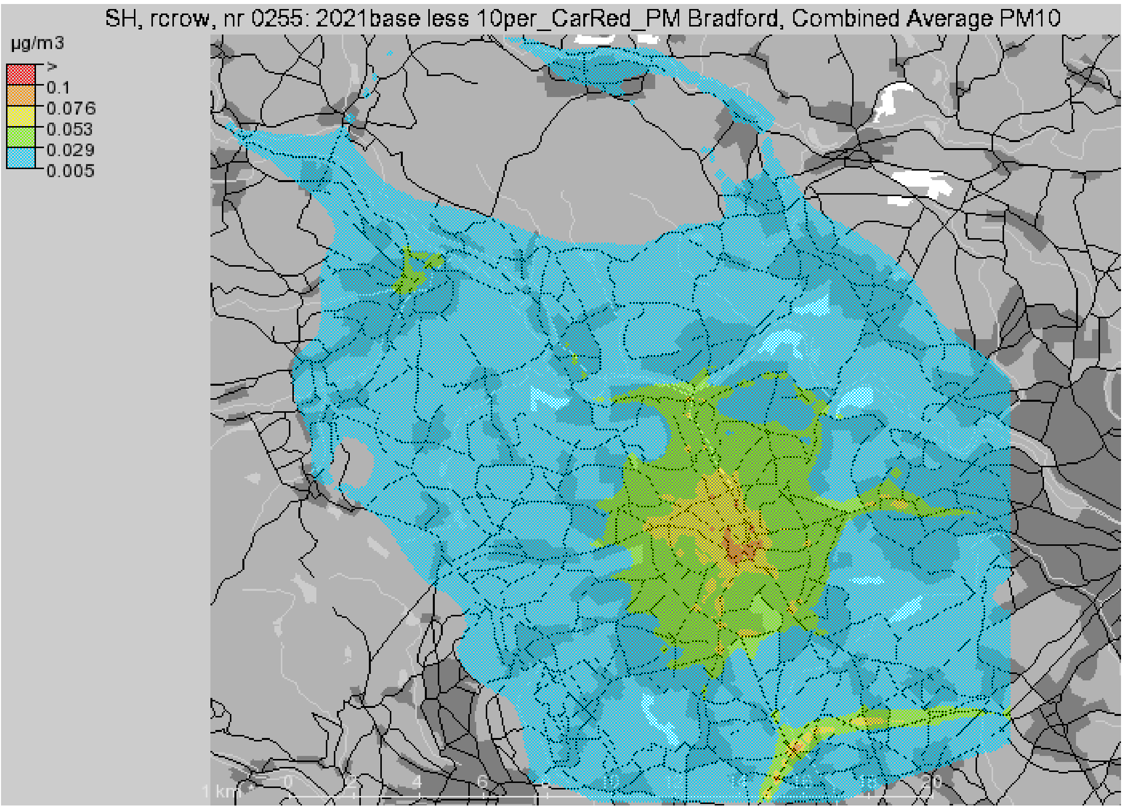
Additional Improvement over the base year predicted in 2016 through all Pre Euro 4 buses replaced with Euro 6



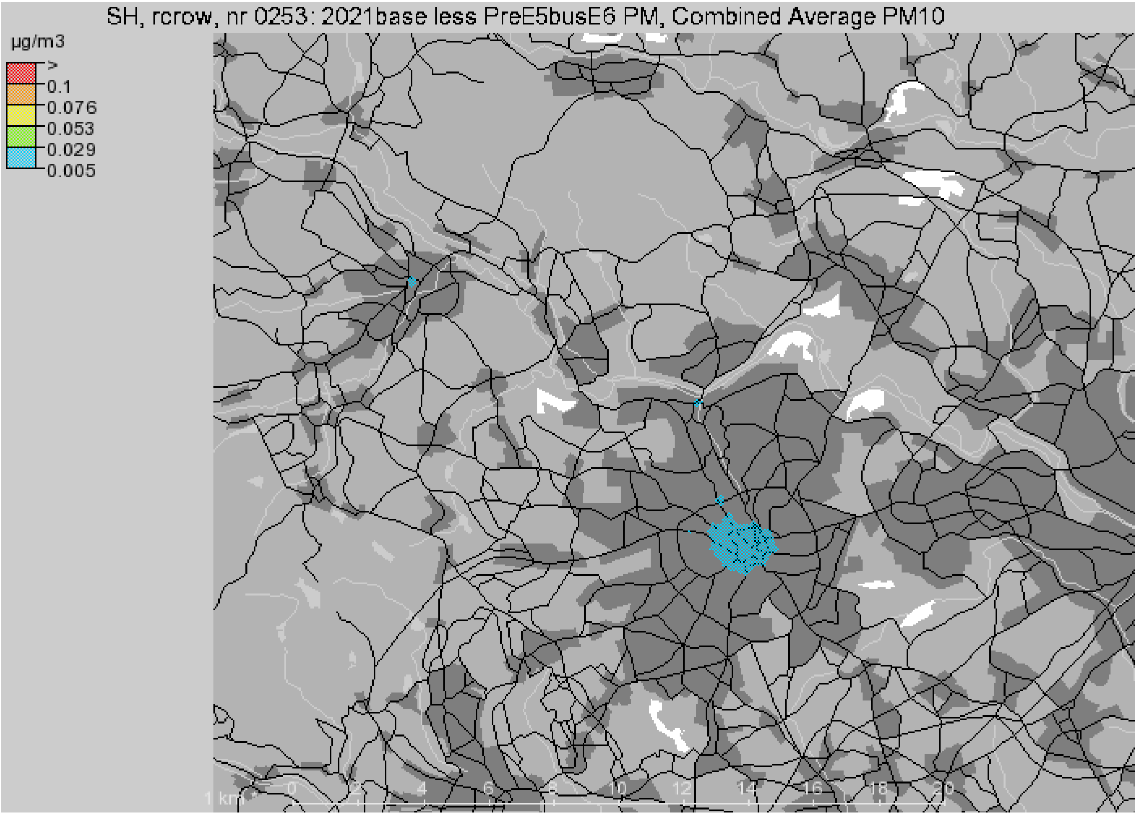
Additional Improvement over the base year predicted in 2021 by reverting to 89% petrol / diesel split for cars and class 1 vans (based on Year 2000 data)



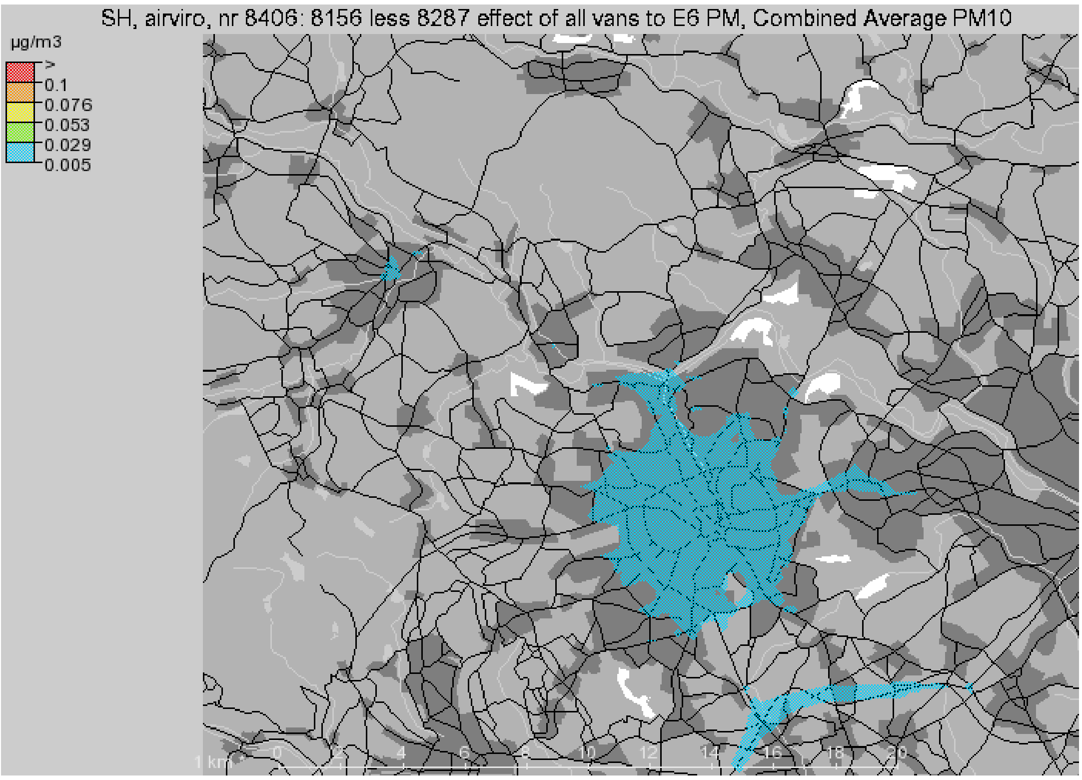
Additional Improvement predicted in 2021 by reducing predicted car journeys by 10%



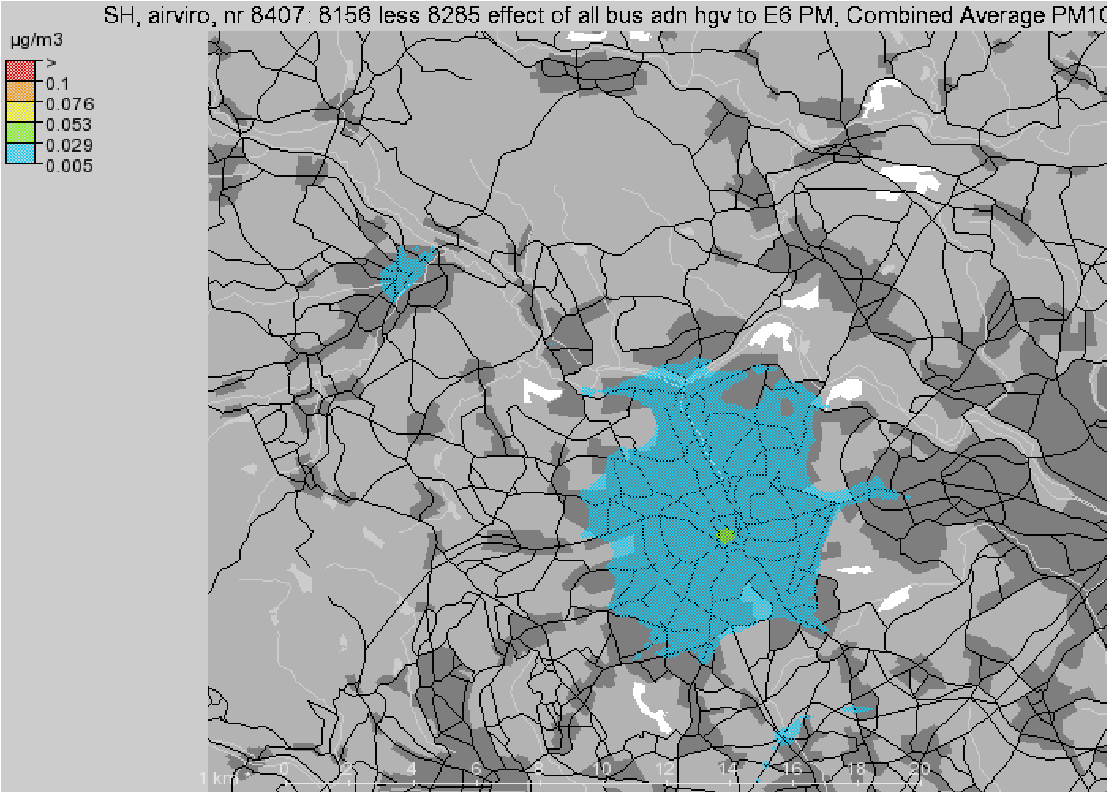
Additional Improvement over the base year predicted in 2021 through all Pre Euro 5 buses replaced with Euro 6



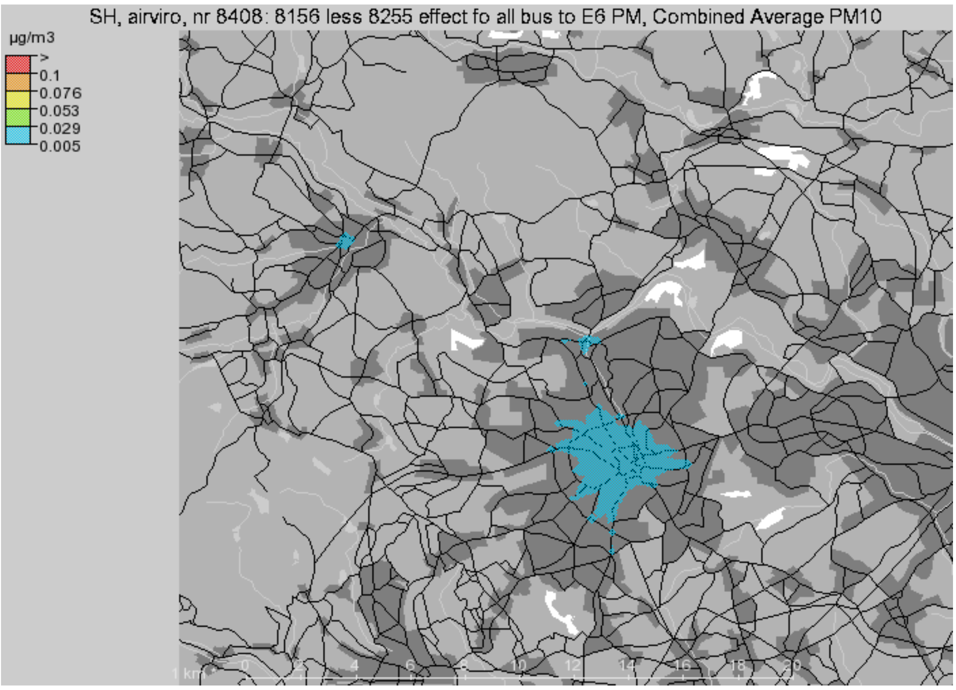
Additional Improvement over the base year predicted in 2021 through all LGVs complying with Euro 6



Additional Improvement over the base year predicted in 2021 through all Bus and HGVs complying with Euro 6



Additional Improvement over the base year predicted in 2021 through all Buses complying with Euro 6



APPENDIX 3 – HEALTH IMPACT ASSESSMENT

PUBLIC HEALTH ENGLAND, LEEDS CITY COUNCIL, BRADFORD METROPOLITAN DISTRICT COUNCIL

West Yorkshire Low Emission Zone feasibility study

Health impact assessment methodology and preliminary findings (Leeds and Bradford)

Duncan Cooper (West Yorkshire Health Protection Team, Public Health England)
Richard Crowther (Leeds City Council)
Richard Dixon (Leeds City Council)
Sally Jones (Bradford Metropolitan District Council)
Dave Cherry (Leeds City Council)
Andrew Whittles (Low Emission Strategies Ltd)
Mike Gent (West Yorkshire Health Protection Team, Public Health England)

April 2014

Summary

Background

- Air pollution is a key determinant of health. The burden due to fine particulate matter alone has been estimated to be 29,000 deaths per year in the UK.
- In 2011 Bradford and Leeds Councils were awarded grants by the Department for Environment, Food and Rural Affairs (DEFRA) to undertake a Low Emission Zone (LEZ) feasibility study. This work will explore the costs and benefits of measures to improve air quality.
- As part of the work a health impact assessment (HIA) has been carried out in collaboration between Leeds and Bradford Councils and Public Health England. Health Impact Assessments gauge the potential positive and negative health impacts of projects or policies.
- The aim of this HIA is to identify areas in Leeds and Bradford that would be most affected by reductions in road pollution, and identify specific health benefits.

Low emission zone feasibility study

- A pollution model was used to look at current air pollution and to predict future changes in air quality under four scenarios:

1. *Scenario 1: 2016 emissions given pre Euro 4 Buses and HGVs upgraded to Euro 6*
2. *Scenario 2: 2021 emissions given all buses and HGVs are upgraded to Euro 6*
3. *Scenario 3: 2021 emissions given year 2000 petrol to diesel split is achieved*
4. *Scenario 4: 2021 emissions given a 10% reduction in car and small vehicle journeys*

- Changes in fine particulate matter (PM2.5) and oxides of nitrogen (NOx) were assessed separately.

Main findings

- Deprived inner city areas and areas adjacent to major roads are currently the most likely to be affected by poor air quality and to suffer adverse health effects.
- There are an estimated 350 deaths per year in Leeds and 222 in Bradford District attributable to fine particulate air pollution (PM2.5).
- All four of the low emission zone scenarios show improvements in air quality in most parts of Leeds and Bradford. Health benefits are predicted to be greatest in inner city and deprived areas but also occur in the wider population due to commuting and travel within the Districts.
- Our scenarios predicted a fall of between 15 and 19 deaths per year in Leeds and Bradford combined. However, a larger group of people would experience health benefits. We predict a fall in premature and low birth weight babies and childhood asthma, and fewer hospital admissions for heart and respiratory problems.
- Improvements in health are most likely to occur when policies to improve air quality span local authorities and also encourage:
  - increased active travel (walking, cycling and public transport),
  - community safety strategies such as traffic calming in residential areas, and
  - increased creation and use of urban green space.
- In combination these policies could lead to cleaner air as well as improvements in physical and mental health, reduced obesity rates and improved safety.

Recommendations

- The methods developed here should be considered for investigating the impact of a low emission zone across West Yorkshire.
- The results should be summarised alongside other work packages within the LEZ feasibility study, and presented to:
  - Elected members in Leeds and Bradford Districts,
  - The West Yorkshire Local Transport Plan board,
  - Joint Health and Well Being Boards of both Districts, to inform the Joint Strategic Needs Assessment.
- The development of a LEZ should be placed within the context of a wider package of public health and environmental policy (including a modal shift towards safe active travel and increased physical activity).

CONTENTS

1. Introduction

1.1 Health effects of air pollution

Air pollution is a key determinant of health. This has been recognised within the Department of Health's Public Health Outcome Framework (DH, 2012) which contains a specific indicator related to air pollution ('fraction of mortality attributable to particulate air pollution'). Air pollution is, however, a determinant of many other indicators within the framework, including low birth weight and premature mortality for cardiovascular disease, respiratory diseases and cancer. A causal link between road pollution and poor health has been demonstrated for various road pollutants, the most significant of which are particulate matter and nitrogen dioxide. Long term exposure to these pollutants, and short term peaks, can trigger hospital admissions or deaths for people with cardiovascular or respiratory disease (Table 1). The burden due to particulate matter alone has been estimated to be 29,000 deaths per year in the UK (COMEAP, 2010), and nearly 2,600 deaths in Yorkshire (Table 2).

Table1. Main health effects of vehicle pollutants

Pollutant	Effects
Particulate matter	Short term: Increased GP consultations, cardiopulmonary deaths hospital admissions, and wheeze symptoms in asthmatics. Long term: Increased lung cancer and cardiopulmonary deaths and risk of preterm birth. Weaker evidence regarding a link between particulate matter and childhood leukaemia and childhood type II diabetes
Oxides of Nitrogen (NOx)	Short term: Inflammation of the airways, increased incidence of shortness of breath and wheeze symptoms. Long term: Affects the lung function, increased mortality and hospital admissions for those with respiratory disease, increased risk of low birth weight
Ozone	Short term: Impact on hospital admissions, asthma attacks, breathing difficulties and COPD admissions
Carbon monoxide	Short term: Effect on hospital admission for heart attacks
Benzene and 1,3-butadiene	Exposure linked to leukaemia and lymphomas.
Polycyclic aromatic hydrocarbons (PAHs)	Linked to lung cancer.

1.2 Low emission zone feasibility study

In 2011 Bradford Metropolitan District Council (BMDC) and Leeds City Council (LCC) were awarded grants by the Department for Environment, Food and Rural Affairs (DEFRA) to undertake a Low Emission Zone (LEZ) feasibility study. The work has focussed on the benefits of low emission strategies that could result from cleaner bus, freight taxi and private care fleets. Population level behavioural change is also relevant to this work, including reduced congestion and increased uptake of active travel and public transport. The outcome of the feasibility study will inform low emissions strategy in both Districts and address the priorities of the West Yorkshire Local Transport Plan (2011-2026); *to reduce carbon emissions and to improve the quality of life of the population.*

Table 2. Estimated fraction of mortality and annual number of deaths attributable to particulate air pollution (2010)

Area	Fraction of deaths	Total deaths (≥25yrs)	Deaths attributable to PM2.5	Associated life years lost
Bradford	5.3%	4,233	222	2,318
Calderdale	5.0%	1,843	93	1,018
Kirklees	5.4%	3,629	196	2,051
Leeds	5.5%	6,347	350	3,825
Wakefield	5.7%	3,147	178	1,878
West Yorkshire	5.4%	19,199	1,039	11,090
Yorkshire and Humber	5.3%	48,534	2,567	26,636
England	**5.6%**	**458,743**	**25,002**	**264,749**

Source: PHOF (Public Health England, 2014)

The early stages of the feasibility study assessed local air quality concluding that national air quality objectives for carbon monoxide (CO), benzene, 1,3-butadiene, lead and sulphur dioxide (SO_2) were not likely to be exceeded at any locations in Leeds or Bradford. It was decided, therefore, that no further action for these pollutants was required. Further assessment considered that air quality objectives may be exceeded for nitrogen dioxide (NO_2) and particulate matter (PM10/PM2.5) in some areas (Table 3). In fact six Air Quality Management Areas (AQMAs) have been declared in Leeds and four in Bradford (all monitoring average annual NO_2). Particulates and NOx remain of concern locally.

Table 3. National air quality objectives and European Directive and target values for the protection of human health (DEFRA, 2007)

Pollutant	Objective	Measured as	Date to be achieved by and	European obligations

			maintained thereafter	
PM2.5 UK (except Scotland)	25 µg.m3	Annual mean	2020	25 µg.m3
PM10	40 µg.m3	Annual Mean	31 Dec 2004	40 µg.m3
PM2.5 UK (except Scotland)	25 µg.m3	Annual mean	2020	25 µg.m3
PM2.5 (urban areas)	Target of 15% reduction in concentrations at urban background	3 year mean	Between 2010 and 2020	Target of 15% reduction in concentrations at urban background
Nitrogen dioxide (NO_2) (UK)	200µg.m-3 not to be exceeded more than 18 times per year	1 hour mean	31 Dec 2005	200µg.m-3 not to be exceeded more than 18 times per year
Nitrogen dioxide (NO_2) (UK)	40µg.m-3	Annual mean	31 Dec 2005	40µg.m-3

1.3 Health Impact Assessment

Health Impact Assessment is a tool for systematically assessing the potential positive and negative health impacts of projects, programmes and policies. The desired outcome is to improve the quality of public policy decisions by making recommendations that enhance the predicted positive health impacts and minimise the negative impacts.

Conducting a HIA is a key aspect of the Leeds and Bradford LEZ feasibility study. Consequently a HIA baseline assessment was undertaken by a collaborative group from Bradford and Leeds councils and Primary Care Trusts, and the Health Protection Agency in 2012 (Fielding, 2012). This work outlined the health effects of pollution, provided an overview of the health and socio-economic profile of Bradford and Leeds and described current baseline levels of air quality. A follow up workshop in May 2013 discussed LEZ scenarios in more detail and some methodological considerations for estimating the health effects of changes in emissions (Humphreys, 2013).

2 Aims

This document describes a continuation of the HIA process described above. The work has been carried out by a collaborative group drawn from the West Yorkshire Health Protection Team (Public Health England Yorkshire and Humber), Bradford Metropolitan District Council and Leeds City Council. The aims of the work are to:

1. Describe a developmental methodology to quantify the impact of low emission zone scenarios.

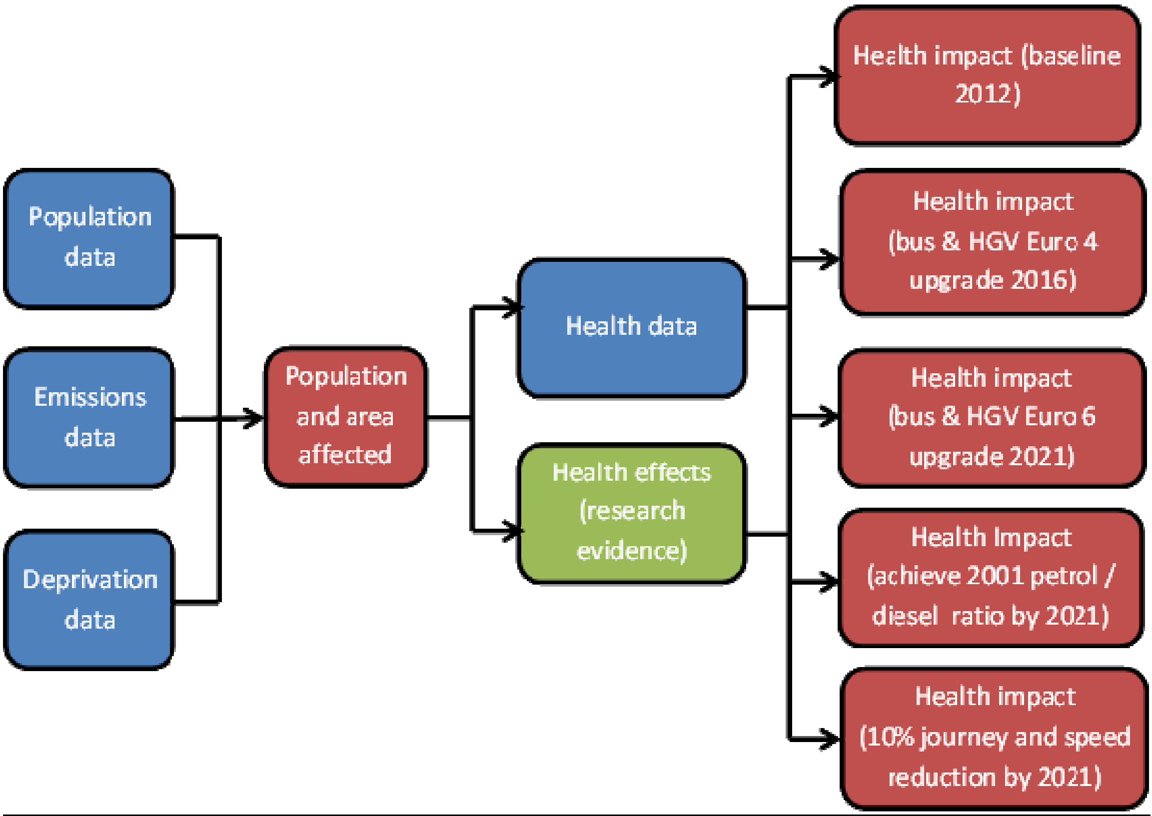
2. Describe the locations and populations most affected by changes in particulate matter (PM2.5) and oxides of nitrogen (NOx) from road sources.
3. Quantify the health impact of changes in particulate matter (PM2.5) and nitrogen oxides (NOx) from road sources.

3 Method

3.1 Analytical model

To determine the populations most affected by projected changes in emissions and the estimated health impact an analytical model was developed (Figure 1). The model uses data from the LEZ source apportionment work and demographic data from the Office for National Statistics to describe the population and areas most affected by pollutants. It then adds small area health data (from Local Authorities) and research evidence about the health effects of pollutants to estimate the health impact of various emission scenarios.

Figure 1. Analysis of emissions, population and health data to assess impact



3.2 Low emission zone source apportionment

The source apportionment work is described in detail elsewhere (Crowther, 2013). In short, automatic number place recognition cameras (ANPR) in Leeds and Bradford were used to take a representative sample of vehicles entering Leeds and Bradford, from which a localised fleet profile was produced. The SATURN traffic modelling was then used to generate average annual daily traffic flows (by vehicle class) for the years 2011, 2016 and 2021. These two sets of information were combined in the PITHEM emissions calculation tool (Platform for Integrated Health and Traffic Emissions Model) using speed related emissions factors to create fleet weighted traffic emissions for each road link. The resulting model output calculates the proportion of the total exhaust emissions by each vehicle type either by:

1. The urban district network as a whole (excluding the motorway network)
2. The area within the outer ring roads of Leeds and Bradford
3. The area within the inner ring roads of Leeds and Bradford

The local feet age and fuel splits were then projected forward using a UK based projections to create an expected business as usual scenario. In addition various interventions (theoretical and more realistic) were modelled to assess the emission benefits which might be achieved for each modelled year. The emissions from these scenarios were input to an Air Quality Dispersion model (using a 250m grid) to assess the spatial distribution of the change in pollutant concentrations.

For the purpose of the HIA the 2012 baseline scenario and four future scenarios were selected for PM2.5 and NOx making 10 in total (Table 4). The models used for the health impact analysis are based on emission from road sources only. NOx is calculated because it is a measure of all NO, NO_2 and N_2O emissions from exhausts and is the pollutant that Euro standards are based on.

These scenarios represent realistic LEZ options (given the work already underway to upgrade bus fleets) as well as aspirational targets (e.g. a 10% reduction in journeys). They also cover passive compliance on the part of the general public (e.g. travelling on cleaner buses) as well as interventions that require active participation (e.g. making fewer car journeys).

Separate models for PM2.5 and NOx were run for Leeds and Bradford Districts separately. As the two model's geographical extent (a square grid) overlapped some grid squares had two possible emission values. Where this occurred the emission value of the grid point's home District was preferred.

Table 4. Low emission zone scenarios used for Health Impact Assessment

Scenario	Description
Particulate matter (2.5 um)	
PM2.5 baseline 2012	PM2.5 2012 baseline scenario. This is the do nothing scenario for 2012, i.e. modelled on existing emissions from fleet
1. PM2.5 given pre Euro 4 Buses and HGVs upgraded to Euro 6 by 2016	PM2.5 in 2016 given all Pre Euro4 buses and Pre Euro4 HGV upgraded to Euro 6. This option more accurately reflects the suggestion of DEFRA that such a scenario might enable West Yorkshire to meet the EU Air Quality Directive.
2. PM2.5 given all buses and HGVs are upgraded to Euro 6 by 2021	PM2.5 in 2021 if all buses and HGVs meet the Euro 6 standard. This scenario could be considered to also represent the use of gas buses
3. PM2.5 given year 2000 petrol to diesel split is achieved 2021	PM2.5 in 2021 assuming that the ratio of petrol to diesel was the same as in year 2000 for cars and car based vans (which is 80% petrol).
4. PM2.5 given a 10% reduction in car and small vehicle journeys 2021	PM2.5 given 10% less car journeys and 10% increased peak speeds
Oxides of Nitrogen (NOx)	
NOx baseline 2012	NOx 2012 baseline scenario. This is the do nothing scenario for 2012, i.e. modelled on existing emissions from fleet

1. NOx given pre Euro 4 Buses and HGVs upgraded to Euro 6 by 2016	NOx in 2016 given all Pre Euro4 buses and HGVs are upgraded to Euro 6 standard. This is option more accurately reflects the suggestion of DEFRA that such a scenario might enable West Yorkshire to meet the EU Air Quality Directive.
2. NOx given all buses and HGVs are upgraded to Euro 6 by 2021	NOx in 2021 if all buses and HGVs meet Euro 6 standard. This scenario could be considered to also represent the use of gas buses
3. NOx given year 2000 petrol to diesel split is achieved by 2021	NOX in 2021 assuming that the ratio of petrol to diesel was the same as in year 2000 for cars and car based vans (which is 80% petrol)
4. NOx given a 10% reduction in car and small vehicle journeys by 2021	NOX given 10% less car journeys and 10% increased peak speeds

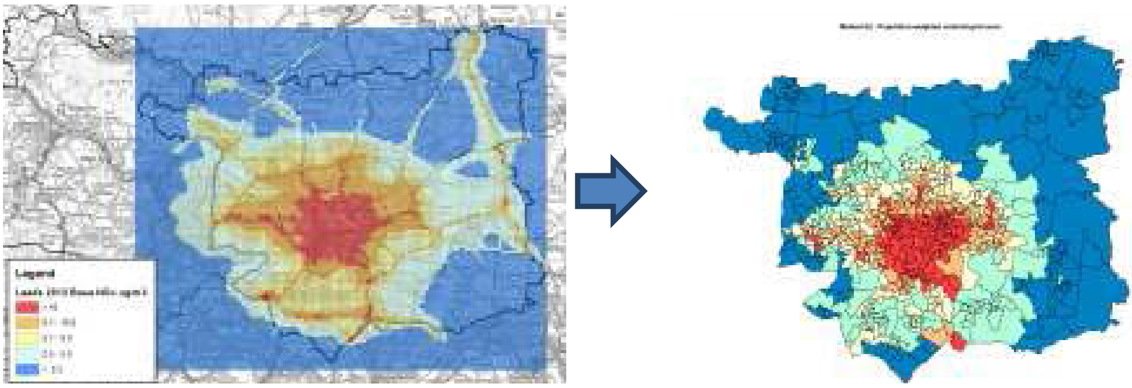
3.3 Linking emissions data to Lower Super Output Areas

Pollutant concentrations were estimated for 250m grid points where as population and health data are available by Lower Super Output Areas (LSOAs), which are administrative areas. Therefore a method was developed to ensure that each LSOA in Leeds and Bradford had an associated pollutant value that corresponded to the population located in that area. This method ignored the spatial relationships between the majority of grid locations and LSOAs to take a single grid score based on the population weighted centroid of the LSOA (Figure 2). This meant that in rural areas (where the majority of the population is located in the high concentration part of the LSOA, near a main road or within a village) the centroid emission was allocated to the LSOA. This method was preferable (on eye-balling) to an alternative method where the average of all grid pollutant values in a LSOA was linked to that LSOA. The averaging method produced spurious results due to the boundary effect of pulling in values from unpopulated gird squares.

Figure 2 Transposition of grid emission values to Lower Super Output area

Baseline emissions from vehicle sources

Emissions transposed to LSOA boundaries



3.4 Calculating changes in emissions

LSOA population data was linked to the LSOA emissions database described above. The range in estimated emissions by LSOA was inspected and the following ranges were derived to classify LSOA baseline emission values as low, medium or high. These ranges were derived from local emission estimates (rather than legal limits or health thresholds) to apportion 5-10% of the population into a high local emission category.

Ranges of 2012 baseline emission value:

PM2.5
Low: 0-0.8 ug/m3 annual average (c74% of population)
Medium: 0.8-1.5 ug/m3 annual average (c20% of population)
High: >1.5 ug/m3 annual average (c6% of population)

NOx
Low: 0-10 ug/m3 annual average (c52% of population)
Medium: 10-20 ug/m3 annual average (c38% of population)
Higher: >20 ug/m3 annual average (c10% of population)

The Index of Multiple Deprivation score (IMD) was linked to LSOA and classified by national deprivation quintile. Each range of IMD scores therefore represented 20% of the national population although in Leeds and Bradford 35% of the population fall into this most deprived 20% of the country.

The population of each deprivation quintile was then stratified by emission category (low, medium and high) to provide a description of 2012 baseline emission levels across the deprivation profile.

A reduction in emissions was calculated for each LSOA by subtracting the emission estimates for a given future scenario from the baseline 2012 value. A three way stratification of emission reduction for each of the future scenarios was derived as follows:

Range of emission reduction for 2016 and 2021**:**

PM2.5
Low impact: 0-0.5ug/m3 annual average
Medium impact: 0.5-1ug/m3 annual average
High impact: >1ug/m3 annual averages

NOx
Low impact: 0-10ug/m3 annul average
Medium impact: 10-15ug/m3 annul average
High impact: >15ug/m3 annual average

3.5 the quantifiable health effects of air pollution

Pubmed was used to search for systematic reviews and meta-analysis where the health effects of PM2.5 or NOx/NO_2 was quantified and generalisable to predominantly urban populations in developed nations. Robust evidence was found for the long term effects of PM2.5 on mortality (all-cause, cardiovascular and respiratory), coronary events (hospital admissions plus deaths), low birth weight (<2500g at birth) and pre term birth (<37 weeks gestation), and for the long term effects of NO_2 on the development of asthma and wheezing, and low birth weight. Low birth weight and preterm birth babies have a greater risk of neonatal complications including breathing problems, respiratory infections and hypothermia, and impaired neurodevelopment.

These meta-analysis combined results from case-control, cohort and cross-sectional studies with adjustment for socio-demographic, lifestyle and pre-existing medical factors. There was insufficient evidence to quantify the long-term exposure to NO_2 to mortality or hospital admissions. Although robust estimates of the short term effects of PM2.5 and NO_2 have been quantified by COMEAP we did not extrapolate these findings to our pollutant models which produced annual average rather than short-term concentrations. The studies used, with the estimated health effects (expressed as coefficients), are listed in Table 4.

Table 4. Evidence used for the quantification of the long term health effects of PM2.5 and NOx

Effects	Quantification coefficient
Deaths from all causes (COMEAP, 2010)	**Total burden of PM2.5 is 29,000 deaths per year** (majority from cardiovascular or respiratory deaths) **All-cause mortality: 1.06 increase (95% CI 1.02-1.11) per 10 µg/m3 increase in PM2.5** **Life expectancy increase of 20 days from birth per 1 µg/m3 reduction in PM2.5** Methodology for calculation of local impact on deaths available in HPA Chemical Hazards and Poisons report (2011).
Deaths from cardiovascular and respiratory diseases (COMEAP, 2009)	**Cardiopulmonary mortality: 1.09 increase (95% CI 1.03-1.16) per 10 µg/m3 increase in PM2.5** **Lung cancer mortality: 1.08 increase (95% CI 1.01-1.16) per 10 µg/m3 increase in PM2.5** COMEAP recommend use of these estimates for use in health impact assessment and assessing policy interventions designed to reduce levels of air pollutants. Coefficients refer to annual average concentration.
Coronary events (Cesaroni, BMJ, 2014) Includes myocardial infarction / ischaemic heart disease at hospital discharge, and as a cause of death.	**Coronary events: 1.19 increase (95% CI 1.00-1.42) per 5ug/m3 increase in PM2.5 (if exposure below 15ug/m3)** From a 10 cohort (5 European countries) study, the most similar cohorts to Leeds/Bradford were German and Danish, with comparable smoking and BMI rates and positive associations between coronary events and PM2.5. A significant effect below annual PM2.5 concentrations of 15mg/m3 equates to the range of PM2.5 estimated for Leeds/Bradford.
Low birth weight (<2500g) (Pedreson, Lancet, 2013) Low birth weight defined as weight less than 2,500g among births after 37 coronary events weeks gestation.	**Low birth weight: 1.18 (95% CI 1.06-1.33) per 5 ug/m3 increase in PM2.5** **Population attributable risk: 22% reduction in LBW for reduction in PM2.5 of 10ug/m3 (annual)** **Low birth weight: 1.09 (1-1.09) per increase of 10ug/m3 in NO_2** Study of 14 European cohorts including Bradford. Sensitivity analysis showed adjustments for smoking, ethnicity and low education (all relevant local factors) did not alter the significance or strength of the results.
Childhood asthma development and **wheeze** symptoms (Takenoue, Paediatrics Int, 2012)	**Asthma development (0-18yrs): 1.135 (1.03-1.25) for 10 p.p.b increase in NO2 (18.8 mg/m3) (SRC, 2014)** **Wheeze symptoms (0-18yrs): 1.05 (1.02-1.085) for 10 p.p.b increase in NO2 (18.8 mg/m3)** Meta-analysis of 12 papers (mostly US and European) where a lag between NO2 exposure and symptoms were studied for 3-18yr olds. Paper also showed correlation with PM10 or SO2.
Preterm birth (<37 weeks gestation)	**Preterm birth: 1.15 (1.14-1.16) per 10 µg/m3 increase in PM2.5**

3.6 Calculating the health impact of pollutants

Data were collected for all-cause mortality, COPD mortality and CVD mortality for both Bradford (2007-2011) and Leeds (2008-2013) by LSOA. Data about CVD hospital admissions (2008-2013) were only available for Bradford LSOAs, and data about childhood asthma prevalence (0-18 years, 2014) were only available for Leeds LSOAs. District wide low birth weight prevalence values (2011) were used for analysis in both Districts (7.2% for Leeds, 9.1% for Bradford), and for preterm births (as LSOA level data were not available.

Estimated reduction in health events per year were calculated from local health data, changes in emissions, and attributable fractions (COMEAP, 2012) or each LSOA using the following formula:

All deaths:

[deaths per year] x [PM2.5 reduction / 10mg/u3] X [OR-1/OR]

Cardiopulmonary deaths:

[CVD deaths per year] x [PM2.5 reduction / 10mg/u3] X [OR-1/OR]

Coronary events in Bradford due to PM2.5:

[CVD hospital admissions and deaths] X [PM2.5 reduction for given scenario/5ug-m3] X [OR-1/OR]

Low birth weight due to PM2.5:

[births x LBW district prevalence] X [pop weighted PM2.5 reduction / 5ug-m3] x [OR-1/OR]

Low birth weight due to NO_2:

[births x LBW prevalence] X [pop weighted NOx reduction / 10ug-m3] x [OR-1/OR] X [NO_2 /NOx ratio of 50%]

Asthma development in Leeds due to NOx (lifetime prevalence by age 18). This figure refers to reduction in prevalence at age 18 rather than annual events as per the estimates above.

[population 0-19yrs X LSOA prevalence] x [pop weighted NOx reduction / 18mg/u3] X [OR-1/OR] X [NO_2 /NOx ratio of 50%]

LSOA events were summed to calculate district totals and mapped by LSOA.

4. Results

4.1 Emission estimates for Leeds and Bradford

Initial findings from the LEZ source apportionment work for Leeds and Bradford are described in detail in the baseline assessment (Crowther, 2013; Fielding 2012). In summary, approximately 7% of total ambient PM2.5 in Leeds was directly from road sources, ranging from 2% to 22% by grid square. In contrast 39% of Leeds and 30% of Bradford Districts NOx emissions were directly from road sources, with these values reaching up to 70% in urban areas. Buses alone accounted for 43% and 41% of NOx emissions within the Leeds and Bradford ring roads.

In Bradford District the highest concentrations of PM2.5 and NOx were estimated to be within the inner ring road and its surrounding area, along the M606 corridor, and in Shipley, Saltaire and Keighley (Figures 3-5). In Leeds the highest concentrations were estimated to be in the city centre, the areas surrounding the M1, M62 and M606 motorways, and around Stanningley by-pass.

Figure 3. Leeds and Bradford Districts

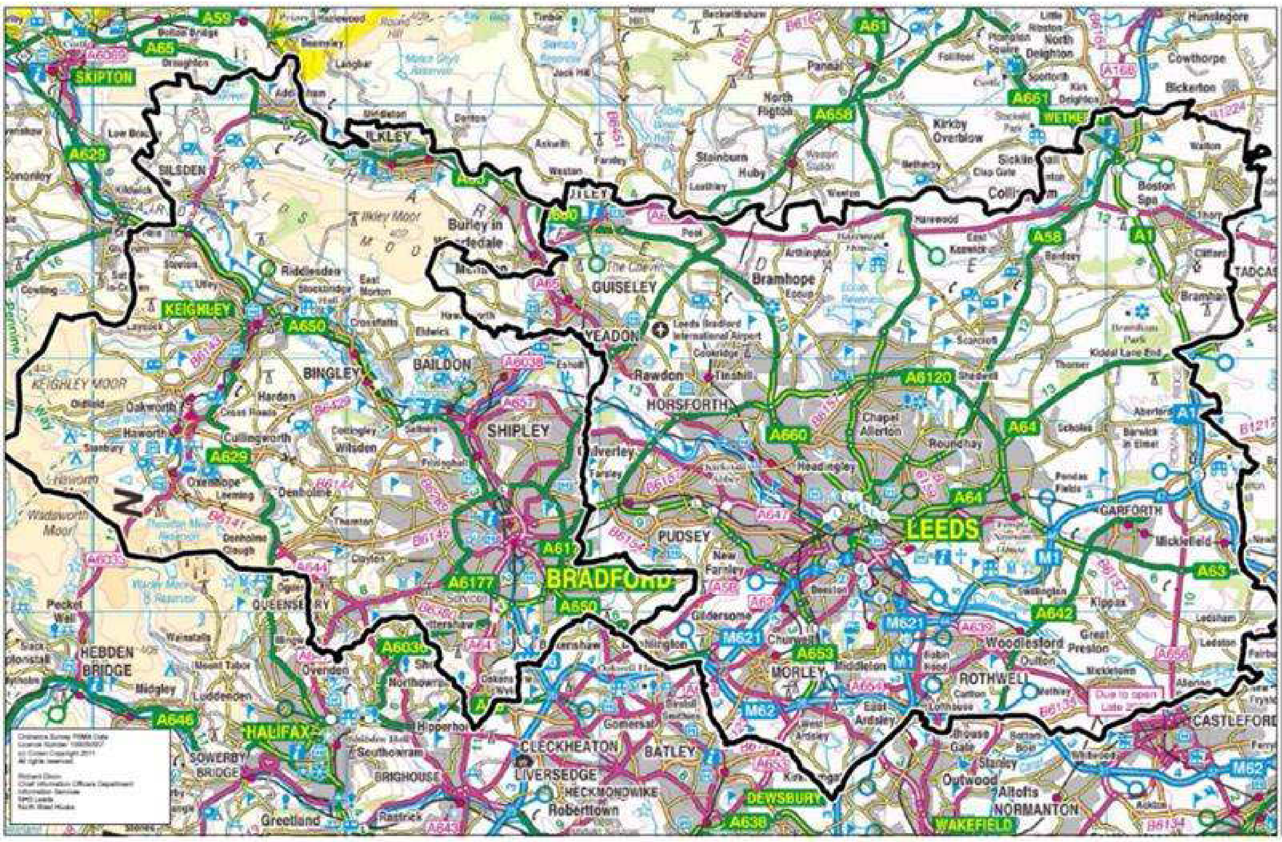


Figure 4. Estimated concentration of PM2.5 in Leeds and Bradford

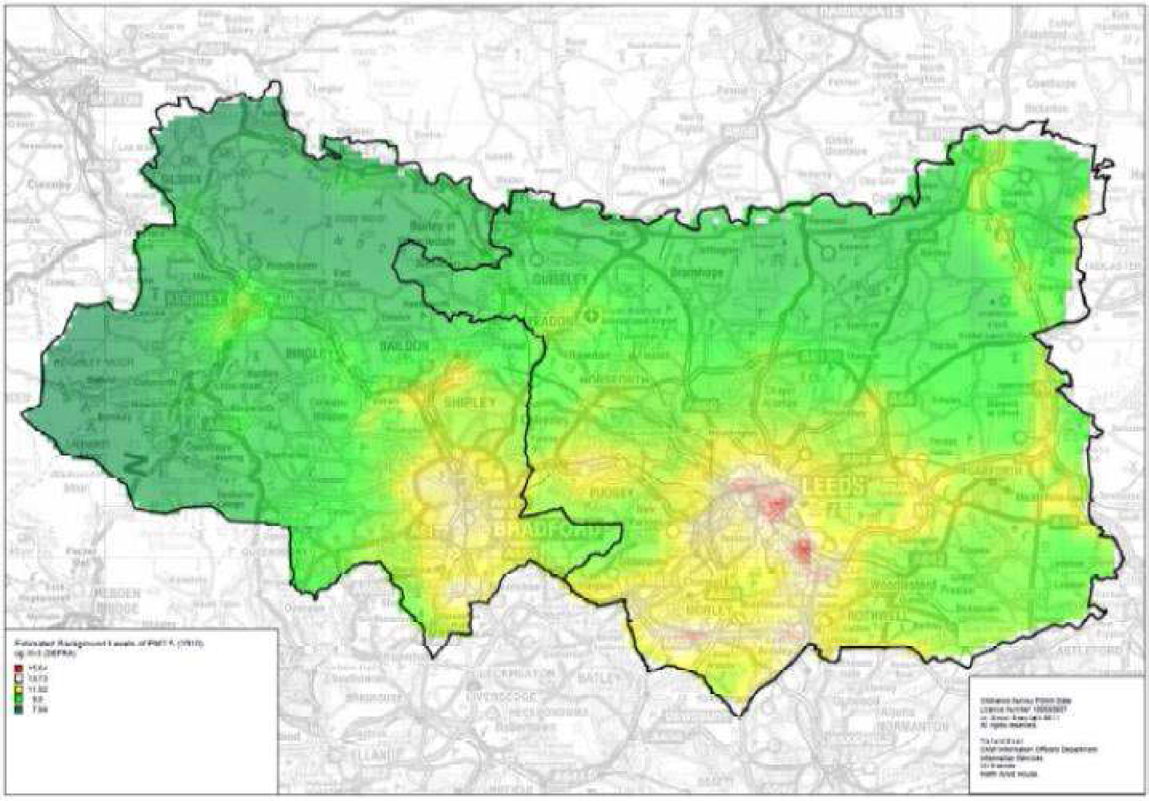
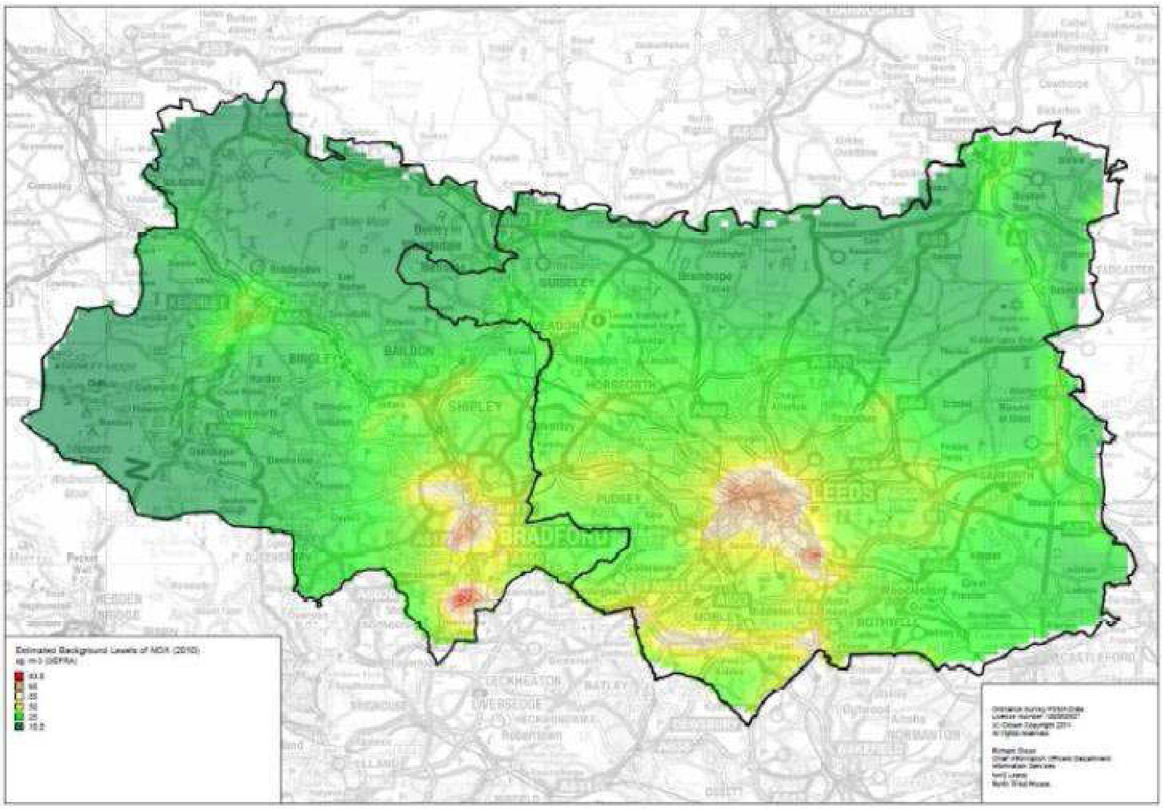


Figure 5. Estimated concentration of NOx in Leeds and Bradford



4.2 Current exposure to road pollution (2012 baseline)

current Particulate matter exposure (PM2.5)

The population of Leeds and Bradford were classified by deprivation and pollutant exposure. In total 45,000 people in deprived areas also live in the areas of highest PM2.5 concentrations. The proportion of the population living in high PM2.5 areas increased from 0% in the least deprived to 10% in the most deprived areas (Table 5). **This distinct gradient (Figure 6) represents an inequality in exposure to harmful road pollutants, with adverse health effects therefore more likely in poorer areas.**

Table 5. Leeds and Bradford population by deprivation quintile and PM2.5 emissions

Population in each deprivation and PM2.5 emission category

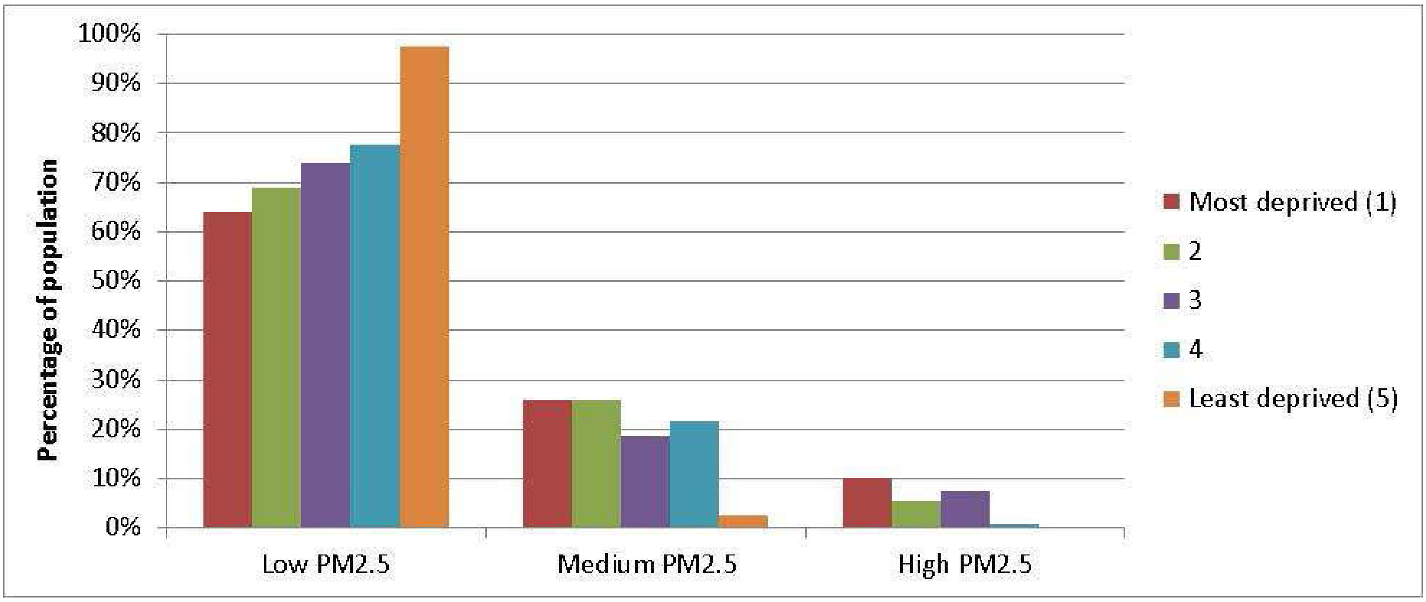
Quintile	Low PM2.5	Medium PM2.5	High PM2.5	Total
Most deprived (1)	287,790	116,807	**45,017**	449,614
2	171,772	64,353	13,465	249,590
3	169,479	43,016	17,113	229,608
4	149,558	41,217	1,661	192,436
Least deprived (5)	145,258	3,571	0	148,829
Total	923,857	268,964	77,256	1,270,077

Low: 0-0.8 ug/m3 annual average, Medium: 0.8-1.5 ug/m3, High: >1.5 ug/m3

Percentage of population in each category

Quintile	Low PM2.5	Medium PM2.5	High PM2.5
Most deprived (1)	64%	26%	**10%**
2	69%	26%	**5%**
3	74%	19%	**7%**
4	78%	21%	**1%**
Least deprived (5)	98%	2%	**0%**
Total	73%	21%	6%

Figure 6. Percentage of population by deprivation quintile and PM2.5 emissions category



current Oxides of Nitrogen exposure (NOX)

In total 88,000 people (7% of the total population) live in deprived areas that also had the highest local NOx concentrations (Table 6). **The proportion of the population living in high**

NOx areas increased from 0% in the least deprived areas to 19% in the most deprived areas (Figure 7). This gradient was more pronounced for NOx than for PM25, again representing more harmful exposures in poorer areas.

Table 6. Leeds and Bradford population by deprivation quintile and NOx emissions

Population in each deprivation and NOx emission category

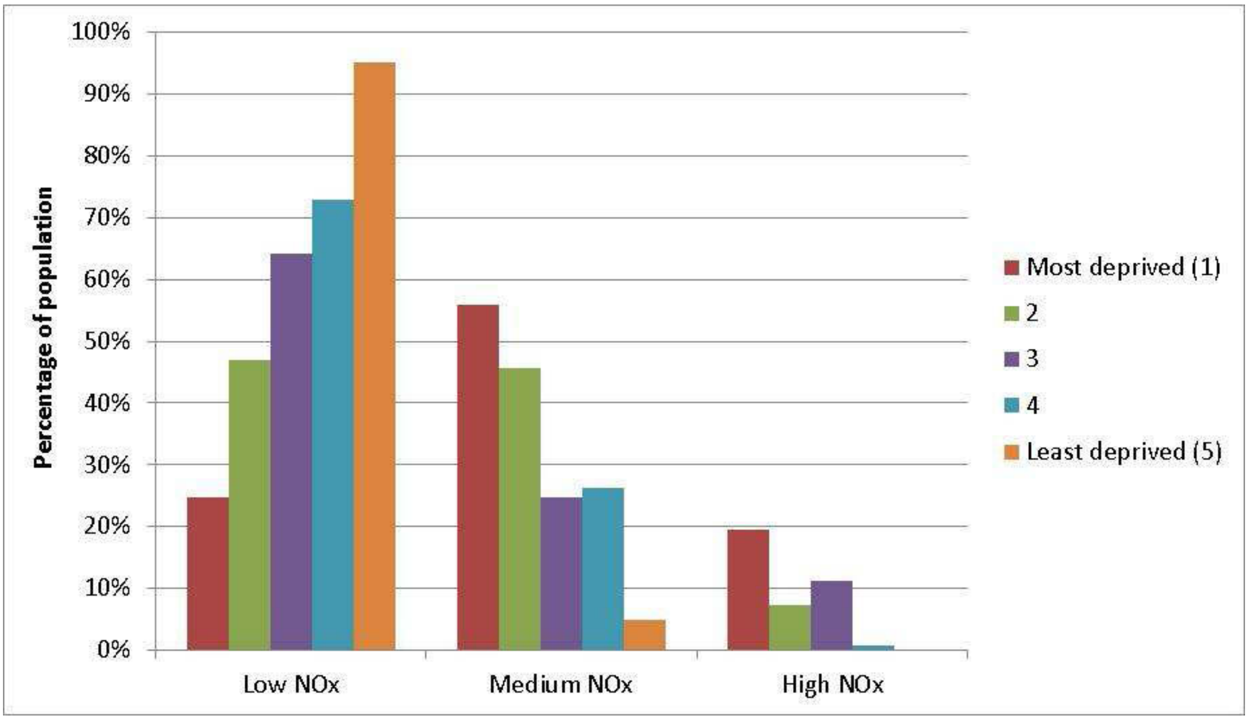
Quintile	Low NOx	Medium NOx	High NOx	Total
Most deprived (1)	111,014	250,955	87,645	449,614
2	117,419	113,968	18,203	249,590
3	147,170	56,669	25,769	229,608
4	140,108	50,663	1,665	192,436
Least deprived (5)	141,569	7,260	0	148,829
Total	657,280	479,515	133,282	1,270,077

Low: 0-10 ug/m3 annual average, Medium: 10-20 ug/m3, Higher: >20 ug/m3

Percentage of population in each category

Quintile	Low NOx	Medium NOx	High NOx
Most deprived (1)	25%	56%	**19%**
2	47%	46%	**7%**
3	64%	25%	**11%**
4	73%	26%	**1%**
Least deprived (5)	95%	5%	**0%**
Total	52%	38%	10%

Figure 7. Percentage of population by deprivation quintile and NOx emissions category



4.3 Reduction IN road pollution (future emission scenarios)

Four future emission scenarios were modelled separately PM2.5 and NOx:

Scenario 1: 2016 emissions given pre Euro 4 Buses and HGVs upgraded to Euro 6

Scenario 2: 2021 emissions given all buses and HGVs meet Euro 6

Scenario 3: 2021 emissions given year 2000 petrol to diesel split is achieved

Scenario 4: 2021 emissions given a 10% reduction in car and small vehicle journeys

Results of the impact of changes in emission under **Scenario 2** are presented below, with results for all 4 scenarios contained within Appendix 1.

Reductions in particulate matter

In Leeds and Bradford 127,000 of the deprived population live in areas of medium PM2.5 reduction and 21,000 in areas with the highest reduction (high impact areas) (Table 7). Between 4% and 5% of deprivation quintiles 1-3 live in high impact areas (i.e. areas of the biggest reduction in PM2.5) compared to 0% in the least deprived areas. **Reductions in PM2.5, therefore, appear to be greatest in the most deprived areas** although medium level reductions in PM2.5 were observed in all areas. This goes some way to addressing the inequalities in exposure, with the largest health gains likely to be in poorer areas (Figure 8).

Table 7. Reduction in PM2.5 exposure: Assuming all buses and HGVs are upgraded to Euro 6 by 2021 (Scenario 2)

Percentage of population in each deprivation and PM2.5 emission reduction category (impact)

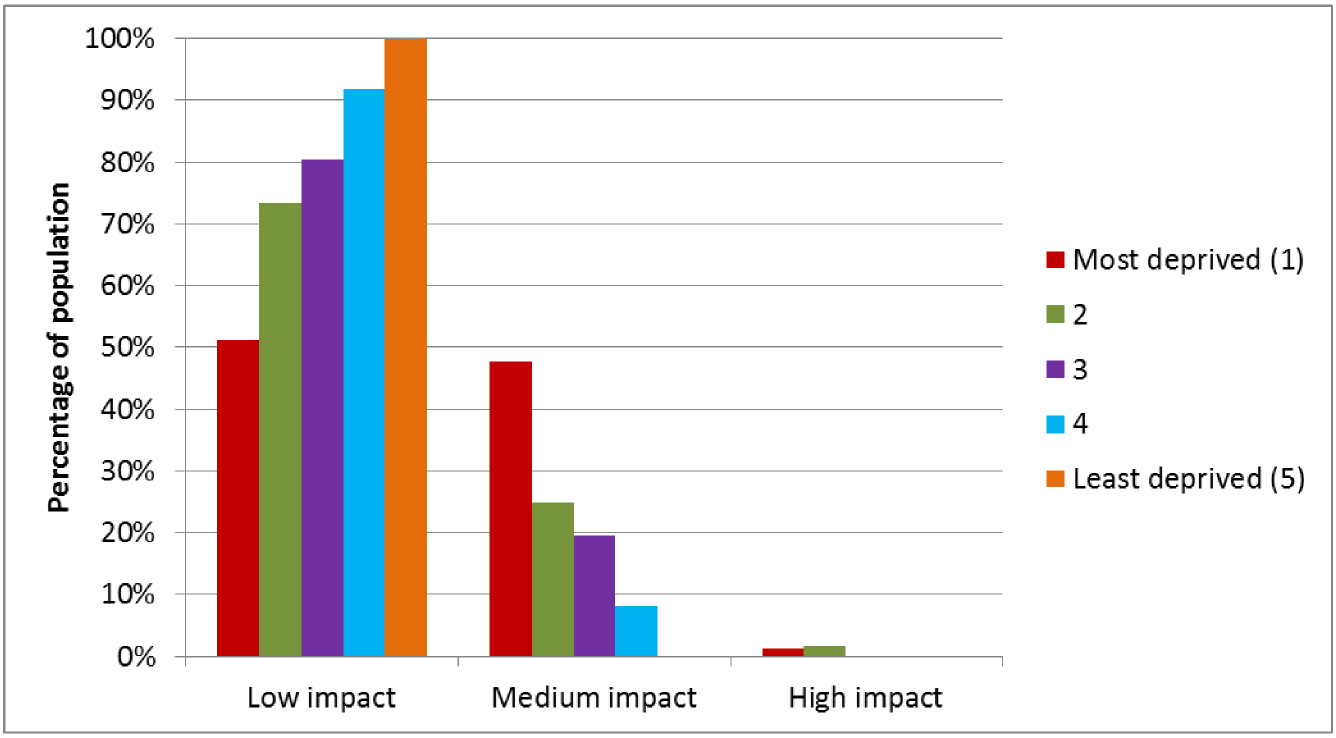
Quintile	Low impact	Medium impact	High impact	Total
Most deprived (1)	301997	127020	20597	449614
2	184244	56483	8863	249590
3	181878	36793	10937	229608
4	156776	35660		192436
Least deprived (5)	146968	1861		148829
Total	**971863**	**257817**	**40397**	**1270077**

Low impact: 0-0.5ug/m3 annual average, Medium impact: 0.5-1ug/m3, High impact: >1ug/m3

Percentage of population in each category

Quintile	Low impact	Medium impact	High impact
Most deprived (1)	67%	28%	**5%**
2	74%	23%	**4%**
3	79%	16%	**5%**
4	81%	19%	**0%**
Least deprived (5)	99%	1%	**0%**
Total	77%	20%	**3%**

Figure 8. Percentage of population by deprivation quintile and PM2.5 reduction category (impact)



Reductions in Oxides of Nitrogen

In Leeds and Bradford 117,000 of the deprived population live in areas of medium NOx reduction and 30,000 in areas with the highest NOx reduction (Table 8). Similar to PM2.5, the largest projected reductions in NOx appeared to be in deprivation quintiles 1-3 (Figure 9). Deprived areas were more likely to experience high reductions in NOx (again addressing current inequalities in exposure), although most areas saw medium level reductions in NOx.

Table 8. Reduction in NOx exposure: Assuming all buses and HGVs are upgraded to Euro 6 by 2021 (Scenario 2)

Percentage of population in each deprivation and NOx emission reduction category (impact)

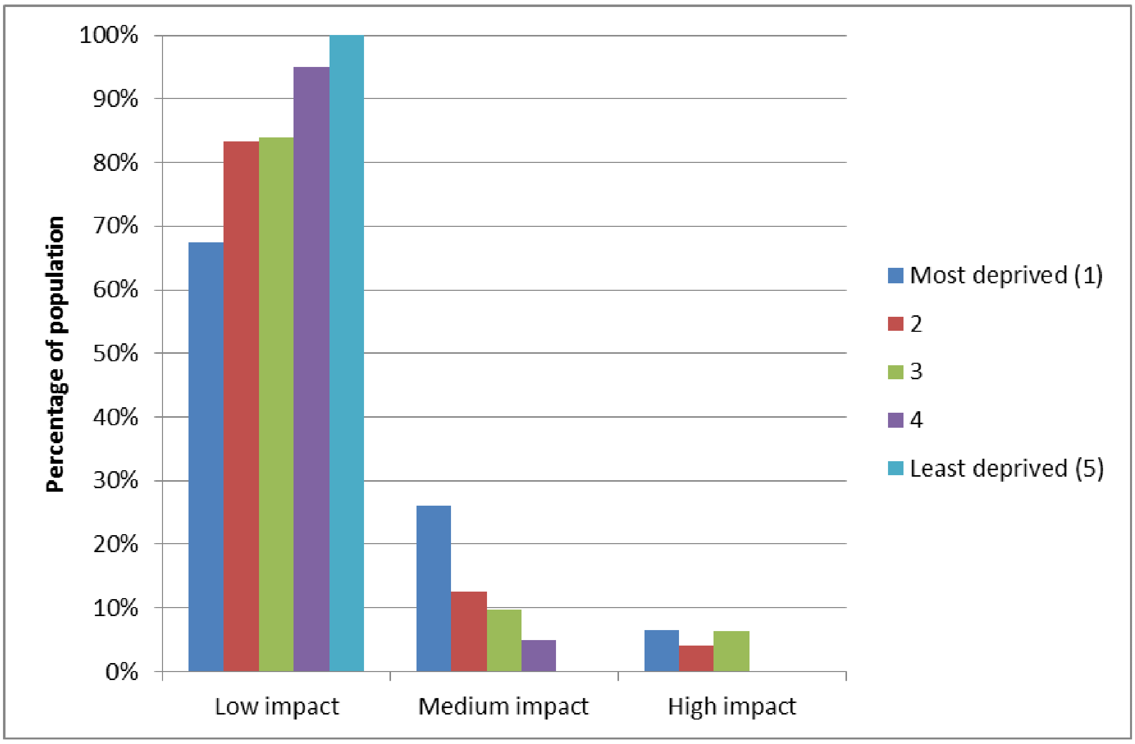
Quintile	Low impact	Medium impact	High impact	Total
Most deprived (1)	303078	116864	29672	449614
2	208096	31261	10233	249590
3	192811	22492	14305	229608
4	182818	9618		192436
Least deprived (5)	148829			148829
Total	**1035632**	**180235**	**54210**	**1270077**

Low impact: 0-10ug/m3 annual average, Medium impact: 10-15ug/m3, High impact: >15ug/m3

Percentage of population in each category

Quintile	Low impact	Medium impact	High impact
Most deprived (1)	67%	26%	7%
2	83%	13%	4%
3	84%	10%	6%
4	95%	5%	0%
Least deprived (5)	100%	0%	0%
Total	82%	14%	4%

Figure 9. Percentage of population by deprivation quintile and oxides of nitrogen reduction category (impact)



4.4 Comparing the impact of different LEZ scenarios

When looking across the four scenarios the impact of PM2.5 reductions were similar for the three 2021 scenarios. 4-5% of the deprived quintile live in high impact areas, and 28-29% in medium impact areas (Table 9). Reductions in NOx appear to have had the greatest impact for Scenario 3 (achieving a year 2000 petrol/diesel split by 2021) with 43% of the deprived population in high or medium impact areas.

Table 9. Summary of reductions in pollutants in deprived areas (against LEZ scenarios).

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	All Pre Euro 4 buses and HGV	All buses and HGVs meet	Year 2000 ratio of petrol to	10% reduction in number of

	upgraded to Euro 6 by 2016	Euro 6 standard by 2021	diesel met by 2021	journeys & increase in speed by 2021
PM2.5				
% of most deprived quintile in **high** impact areas	2%	**5%**	**4%**	**5%**
% of most deprived quintile in **medium** impact areas	24%	**28%**	**28%**	**28%**
NOx				
% of most deprived quintile in **high** impact areas	0%	7%	**9%**	4%
% of most deprived quintile in **medium** impact areas	1%	26%	**33%**	23%

4.5 Health impact of changes in particulate matter and nitrogen oxides

As described in the methods section the health impact of falls in emissions were estimated for all LEZ scenarios. These figures provide approximations of the number of deaths or health events avoided as a result of falling pollution levels. **Approximately 350 deaths per year in Leeds and 222 deaths per year in Bradford are currently attributable to particulate air** pollution (Table 10). It is unlikely that air pollution is the sole cause of a death or health event which will also be influenced by genetic and behavioural factors. Therefore air pollution is a contributory factor to many deaths with an estimated effect equivalent to 572 deaths in Leeds and Bradford.

Table 10. Estimated annual deaths attributable to air pollution and annual reduction in deaths and health events as a result of LEZ scenarios (Leeds and Bradford Districts)

Estimated annual deaths attributable to air pollution and estimated annual reduction in health events as a result of various emissions scenarios												
Baseline scenario (2012)	**Total**	**Leeds**	**Bradford**									
Approximate deaths attributable to air pollution (PM2.5)	572 (191-1049)	350 (117-642)	222 (74-407)									
Scenario	**Scenario 1: All Pre Euro4 buses and HGV upgraded to Euro 6 by 2016**			**Scenario 2: All buses and HGVs upgraded to Euro 6 standard by 2021**			**Scenario 3: Year 2000 ratio of petrol to diesel met by 2021**			**Scenario 4: 10% reduction in number of journeys & increase in speed by 2021**		
	Total	Leeds	Bradford	Total	Leeds	Bradford	Total	Leeds	Bradford	Total	Leeds	Bradford
Approximate reduction in deaths attributable to PM2.5 (annual)	16 (2-29)	14 (2-26)	2 (0.2-3)	19 (2-35)	16 (2-30)	3 (0.3-5)	19 (2-35)	16 (2-29)	3 (0.3-5)	20 (2-36)	17 (2-31)	3 (0.3-5)
Approximate reduction in cardiopulmonary deaths attributable to PM2.5 (annnual)*	8 (3-14)	7 (2-13)	1 (0-2)	10 (3-17)	8 (3-15)	2 (1-3)	10 (3-17)	8 (3-14)	2 (1-3)	10 (3-18)	8 (3-15)	2 (1-3)
Approxiamte reduction in coronary events attributable to PM2.5 (annual)	-	-	24 (0-53)	-	-	45 (0-99)	-	-	45 (0-100)	-	-	45 (0-99)
Approximate reduction in low birth weight babies (<2500g) attributable to PM2.5 (annual)	12 (4-22)	10 (3-18)	2 (1-4)	14 (5-26)	11 (4-20)	3 (1-6)	14 (5-26)	11 (4-20)	3 (1-6)	15 (5-28)	12 (4-21)	4 (1-7)
Approximate reduction in low birth weight babies (<2500g) attributable to NO_2 (annual)	19 (0-40)	11 (0-23)	8 (0-17)	40 (0-84)	22 (0-46)	18 (0-38)	44 (0-93)	23 (0-49)	21 (0-45)	37 (0-79)	20 (0-42)	17 (0-36)
Approximate reduction in children developing asthma attributable to NO_2 by age 18	254 (56-470)	172 (38-318)	82 (18-152)	525 (117-971)	344 (76-637)	181 (40-335)	580 (129-1075)	368 (82-682)	212 (47-393)	494 (110-914)	321 (71-594)	173 (38-320)
Approximate reduction in pre term births attributable to PM2.5	3.2 (3-3.4)	2.8 (2.6-3)	0.4 (0.4-0.4)	3.9 (3.7-4.2)	3.3 (3-3.5)	0.7 (0.6-0.7)	3.9 (3.7-4.2)	3.2 (3-3.4)	0.7 (0.6-0.7)	4.1 (3.8-4.3)	3.4 (3.2-3.6)	0.7 (0.6-0.7)
Annual years of life gained for newborns (all birth combined)	267	224	42	324	260	64	323	257	66	346	270	76

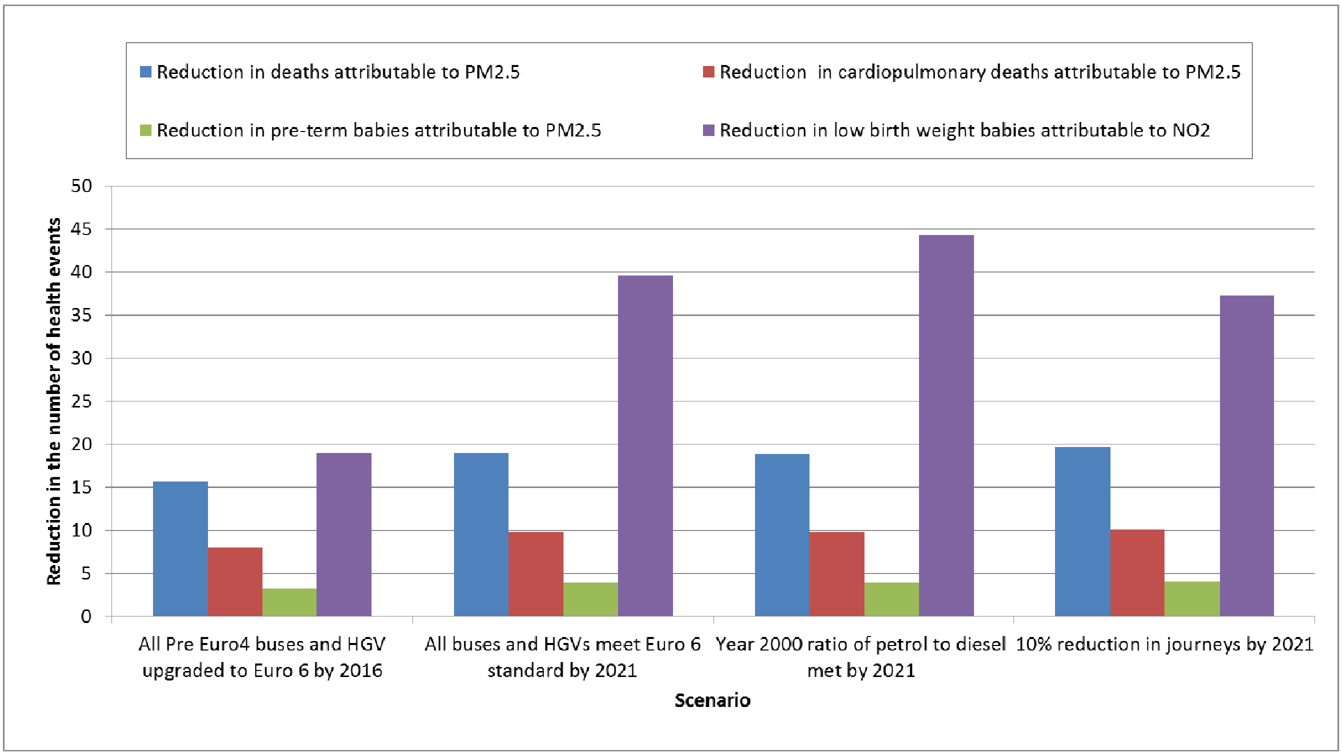
Numbers in brackets are 95% confidence intervals. All estimates are number of deaths per year apart from childhood asthma which is prevalence by age 18 years.
**Cardiopulmonary deaths are a subset of all deaths so (to avoid double counting) should not be added together to calculate total deaths*

Estimated reductions in deaths due to PM2.5 were in the range of 16-20 per year across the four scenarios, of which between 8 and 10 were cardiopulmonary deaths. There were an estimated 12-15 fewer low birth weight babies, and 3-4 fewer preterm babies per year. Scenarios 2-4 produced similar results (Figure 10). There were a range of 24-45 less coronary events per year in Bradford across the four scenarios.

Reductions in health events due to PM2.5 were more modest for Bradford than Leeds. The smaller reductions for Bradford are thought to be due to a number of factors including:

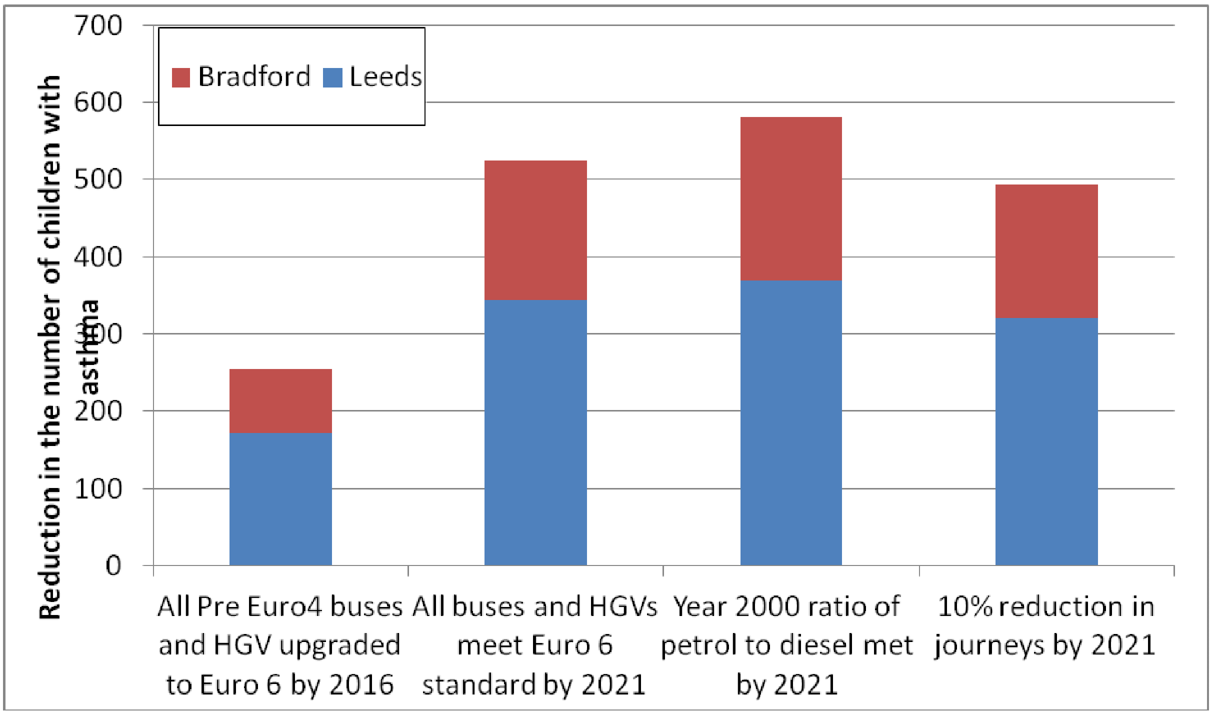
- Bradford's smaller population size.
- A tendency to more edge of town deprivation in Bradford (with low associated pollution) compared to a larger inner city concentration of deprivation in Leeds (where pollution is higher – Figures 4 and 5).
- Higher baseline PM2.5 values and larger reductions in PM2.5 in the Leeds models effecting fleet composition and future growth in km travelled.

Figure 10. Estimated annual reduction in all deaths, cardiopulmonary deaths and low birth weight babies given various LEZ scenarios (Leeds and Bradford combined)



Estimated reductions in low birth weight babies due to NO_2 were in the range of 19-44 per year across the four scenarios, with a range of 254 to 580 less children developing asthma (Figure 11). Scenario 3 (year 2000 petrol to diesel ratio) produced the largest estimated reductions in low birth weight and asthma. Reductions in NOx emissions were more comparable between the Leeds and Bradford models (than PM2.5) leading to equivalent health gains in the two Districts.

Figure 11. Estimated reduction in the number of children and young people (0-18yrs) developing asthma due to long term exposure to NO_2 (Leeds and Bradford Districts)



The estimated reduction in mortality and coronary events due to falls in PM2.5 were modest (Table 11), and similar across the four scenarios (<0.5%). Larger estimated reductions were observed for low birth weight babies (1.2-2.9% for NO_2) and childhood asthma prevalence (1-2.3%).

Table 11. Estimated percentage reduction in health events due to LEZ scenarios

Scenario	All Pre Euro4 buses and HGV upgraded to Euro 6 by 2016	All buses and HGVs meet Euro 6 standard by 2021	Year 2000 ratio of petrol to diesel met by 2021	10% reduction in journeys by 2021
Reduction in deaths attributable to PM2.5	0.1%	0.2%	0.2%	0.2%
Reduction in cardiopulmonary deaths attributable to PM2.5	0.2%	0.3%	0.2%	0.3%
Reduction in low birth weight babies attributable to NO_2	1.2%	2.6%	2.9%	2.4%
Reduction in pre-term babies attributable to PM2.5	0.3%	0.4%	0.4%	0.4%
Reduction in children developing asthma attributable to NO_2	1.0%	2.0%	2.3%	1.9%
Reduction in coronary events attributable to PM2.5 (Bradford only)	0.2%	0.4%	0.4%	0.4%

Figure 12 shows the most deprived areas in Leeds in a ring around the city centre with large areas of deprivation also to the east (Seacroft) and south of the city centre (Middleton). Similarly, deprived parts of Bradford surround much of the city centre with other notable pockets of deprivation in Shipley, Keighley, to the south of the city centre in the Buttershaw and Holmewood estates, and along the eastern edge of the District.

The maps in Figure 13-15 show the areas in which projected falls in pollution would have the largest health benefit (areas shown in red). Although it was possible to quantify the estimated reduction in deaths in each LSOA these figures are subject to large uncertainty at such a local level so are not presented. The maps should be used to assess the parts of Leeds and Bradford where low emission strategies can have the largest beneficial impact.

Within Leeds the impact of reduced mortality was highest in central deprived areas as well as along arterial roads running West and North West from the city centre, along northern parts of the outer ring road, and just south of Wetherby (A58 / A1(M) junction) (Figure 13).

Estimated reductions in mortality were lower in Bradford (due to reasons previously described) but were concentrated in areas adjacent to the city centre. The estimated reduction in childhood asthma (due to 10% less car journeys) showed a similar pattern (Figure 14).

Figure 15 shows the reduction in coronary deaths and hospital admissions in Bradford with the highest impact in a ring of deprived areas around the outer ring road and also extending west along the Thornton Road, Allerton Road and Toller Lane areas, and in central Keighley and Shipley.

Figure 12. Deprivation in Leeds and Bradford (blue area are the least deprived, red areas the most deprived)

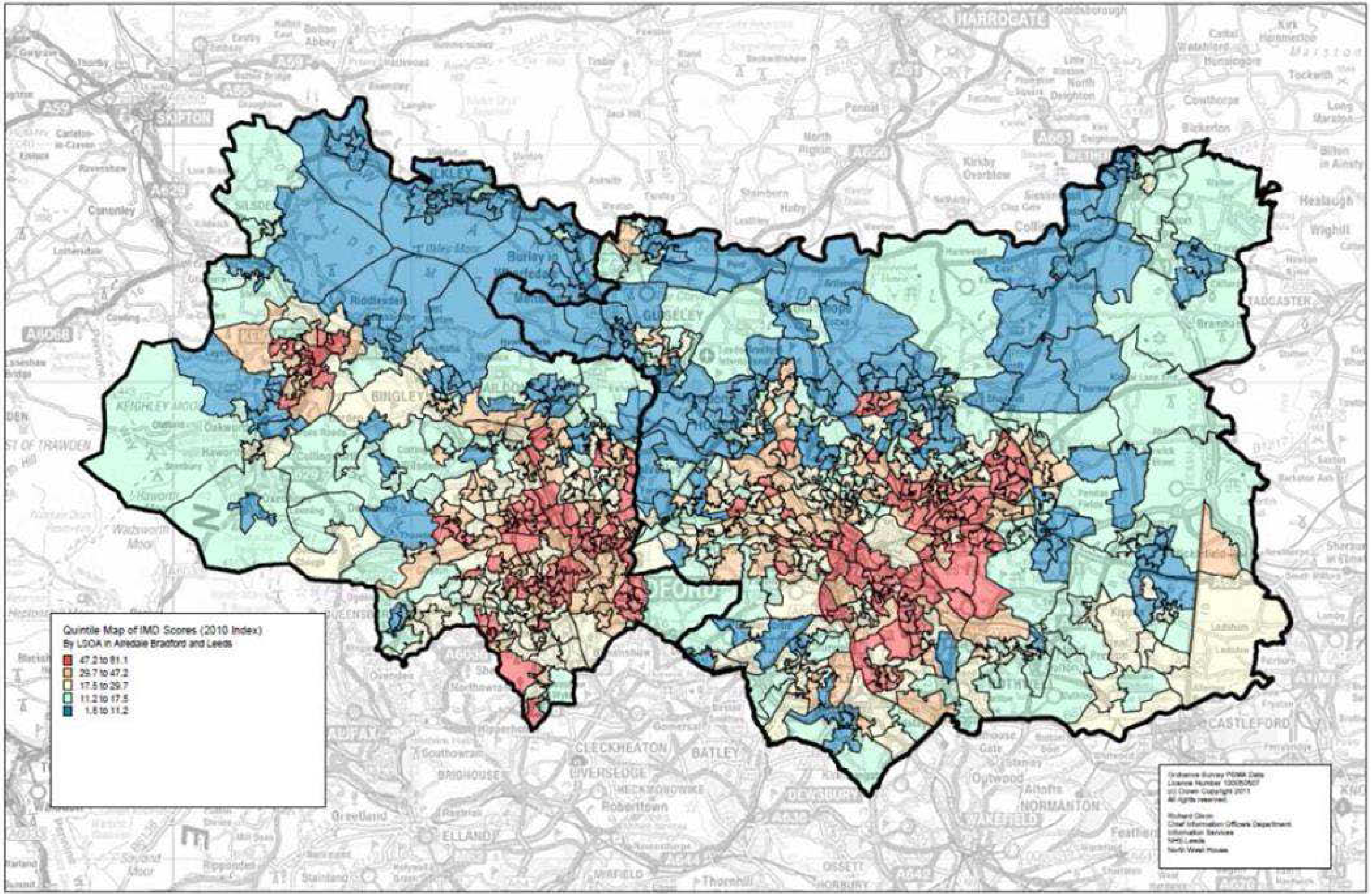


Figure 13. Reduction in deaths due to falling PM2.5 due to upgrading buses to Euro 6 by 2021 (Scenario 2).

Areas with the largest predicted health benefit are shown in red.

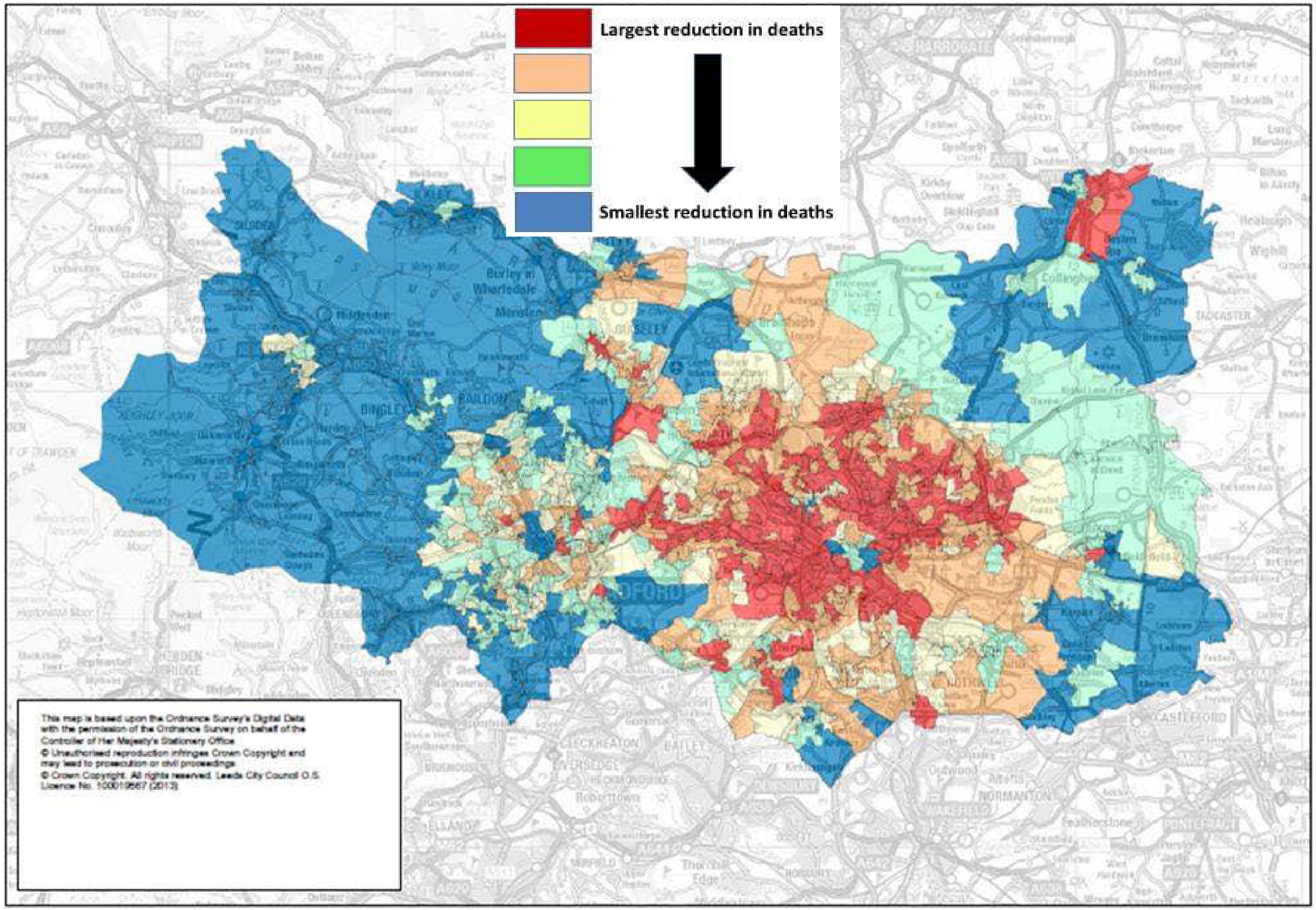


Figure 14. Reduction in children with asthma due to falling NOx given a 10% reduction in journeys by 2021 (Scenario 4)

Areas with the largest predicted health benefit are shown in red.

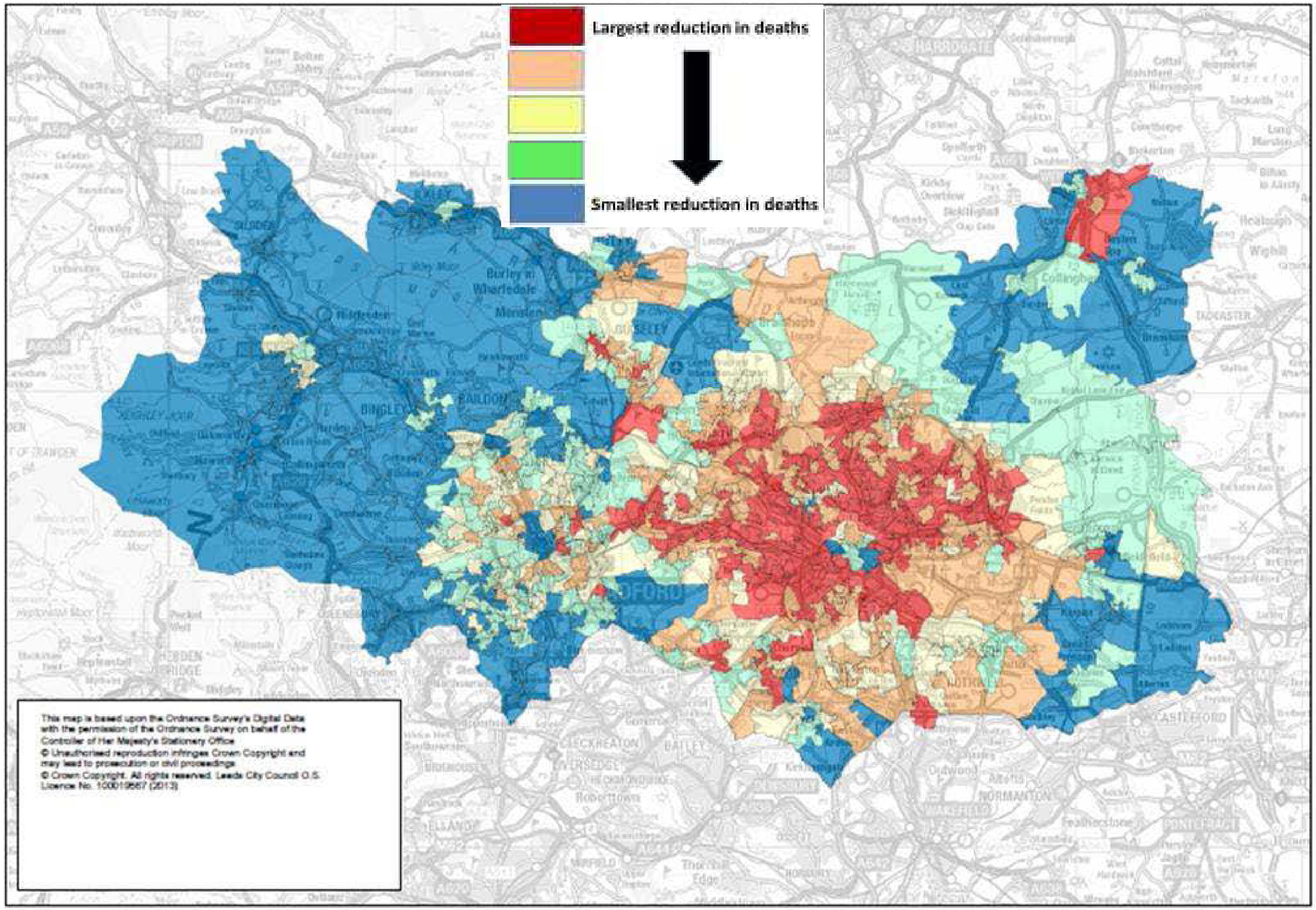
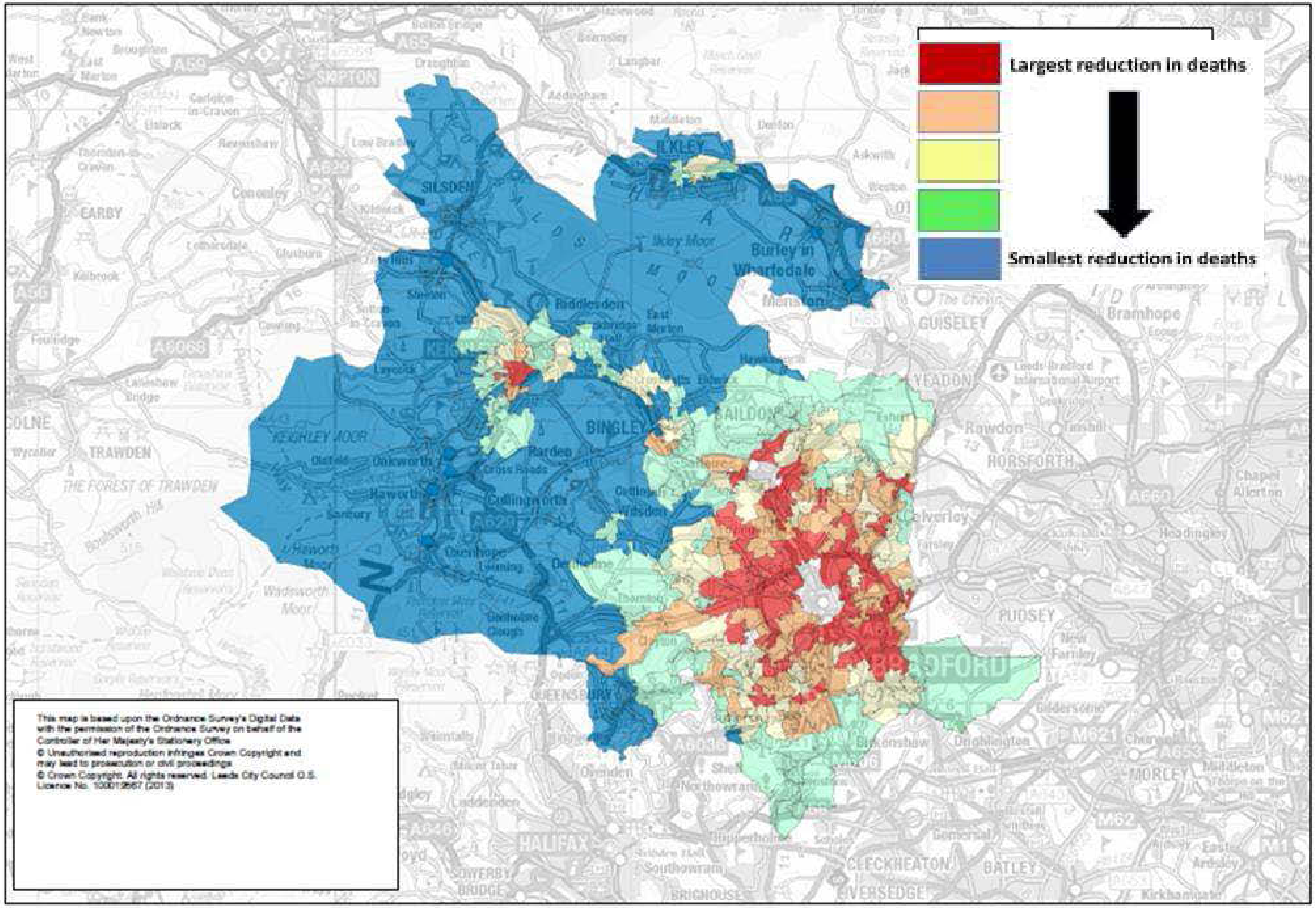


Figure 15. Reduction in coronary events in Bradford as a result of falling PM2.5 given a year 2000 petrol / diesel split by 2021 (Scenario 3)

Areas with the largest predicted health benefit are shown in red.


Largest reduction in deaths
Smallest reduction in deaths
SKIPTON
SILSDEN
ILKLEY
Burley in Wharfedale
Menston
GUISELEY
YEADON
BINGLEY
Bramhope
Rawdon
HORSFORTH
Calverley
PUDSEY
BRADFORD
Haworth
Oxenhope
Cullingworth
QUEENSBURY
HALIFAX
CLECKHEATON
BATLEY
MORLEY
COLNE
TRAWDEN
EARBY
Keighley Moor
THE FOREST OF TRAWDEN
Riddlesden
Ilkley Moor

5. Conclusions

5.1 Main findings

- **This work demonstrates that various low emission zone strategies will improve air quality in most parts of Leeds and Bradford Districts leading to better health for all. Measures to upgrade HGV and bus fleets, increase petrol engines and reduce journeys all showed benefits.**

- **Deprived inner city areas and areas adjacent to major roads are most likely to be affected by poor air quality and suffer adverse health effects. Our estimated improvements in air quality were generally greatest in these same deprived inner city areas. This goes some way to addressing the current inequalities in exposure to air pollution. Improved air quality would benefit those living in central areas inner cities as well as the wider population who commute to or travel through these areas.**

- **There are an estimated 350 deaths per year in Leeds and 222 in Bradford District attributable to fine particulate air pollution. We estimate that LEZ scenarios would lead to between 15 and 19 fewer deaths per year, although importantly we expect a greater number of people to benefit from improved health. Additional health benefits would be seen across all age groups with predicted reductions in preterm birth, low birth weight, childhood asthma, and fewer hospital admissions for heart and respiratory problems. These health benefits would be concentrated in inner city areas that generally experience the worse health and highest pollution levels.**

- **These findings demonstrate the importance of good air quality for vulnerable groups including children, pregnant women, those with long term illness and deprived populations. Improvements in health are most likely to occur when actions to improve air quality span local authorities and encompass wider policies that encourage:**
    - **increased active travel involving walking, cycling and public transport,**
    - **community safety strategies such as traffic calming in residential areas, and**
    - **increased creation and use of urban green space.**

- **In combination these policies could lead to improved air quality as well as wider improvements in physical and mental health, reduced obesity rates and improved safety.**

5.2 Discussion

Approximately 7% of ambient particulate matter (PM2.5) and 40% of oxides of nitrogen (NOx) come from road sources in Leeds and Bradford Districts. The highest concentrations of these pollutants are within city centres, along motorway corridors and in other urban hubs.

People living in deprived areas are the most likely to live in areas with the highest levels of road pollution. Although 0% of the least deprived population live in high pollutant areas, this rises to 10% of the deprived population living in high PM2.5 areas and 19% living in high NOx areas. This gradient represents an inequality in exposure to harmful road pollutants, with adverse health effects more likely in poorer areas.

Our modelled scenarios for 2016 and 2021 estimated that the biggest reductions in PM2.5 and NOx were in deprived areas. This goes some way towards addressing the inequalities in exposure to pollution.

Modelled reductions in NOx were highest for Scenario 3 (achieving a year 2000 petrol/diesel split by 2021) which appeared to have the biggest positive impact (affecting the greatest proportion of the deprived population).

There were an estimated 350 deaths per year in Leeds and 222 in Bradford attributable to particulate air pollution in 2012. It is unlikely that air pollution is the sole cause of a death or health event as genetic and behavioural factors also influence morbidity and mortality. Air pollution should be seen as a contributory factor in these deaths, with an estimated effect equivalent to 572 deaths per year.

Air pollution is a major cause of death in the UK with the annul number of deaths attributable to PM2.5 estimated to be 29,000. To put this in context, in 2012 in the UK there were estimated 100,000 deaths caused by smoking, 8,700 attributable to alcohol, 1,800 due to road fatalities, and 1,200 deaths related to psychoactive drug misuse in 2012. The percentage of low birth weight babies attributable to PM2.5 has been shown to be 22%, above the 15% attributable to smoking (Pederson, 2013) as many more women are exposed to particulate pollution than smoke.

Our scenarios predicted an estimated reduction of between 16 and 20 deaths per year due to lower PM2.5 levels. There were an estimated 8-10 less cardio-pulmonary deaths per year and 12-15 less low birth weight babies due to lowering PM2.5 emissions. Estimated reductions in low birth weight babies due to NO_2 were in the range of 19-44 per year across the four scenarios, with a range of 254 to 580 less children developing asthma.

Reductions in health events due to PM2.5 were more modest in Bradford than in Leeds as a result of its smaller population, a higher concentration of edge of town deprivation in less polluted areas, and differences in fleet parameters within the models.

The estimated reduction in mortality and coronary events as a proportion of the total was modest (<0.5%) with larger estimated reductions for low birth weight babies (1.2-2.9% due to NO_2) and childhood asthma (1-2.3% reduction).

The health benefits may have been underestimated as:

- We have used local fleet characteristics based on local ANPR cameras. These data show that the proportion of vehicles in each weight class in Leeds and Bradford are similar to each other but differ from the average UK values (which have a heavier mix). In most weight classes the age profiles (Euro class) in Leeds and Bradford are also similar but generally older than the UK fleet. As the models use UK fleet characteristic for predicting future fleet renewal, the business as usual situations (i.e. no interventions) assume local fleets become closer to the UK average fleet. This assumption (that Leeds and Bradford fleets match UK fleet characteristics by 2021) appears over optimistic. The knock on effect of this discrepancy is that, firstly, some of the reduced emission benefits in the 'do nothing' scenarios are probably over predicted, and secondly, the additional benefits of the modelled interventions (scenarios) are under predicted as there would be a greater number of local vehicles being affected by the intervention concerned (so greater health benefits).

- Thee population exposure models can underestimate personal exposure by up to 50% (Kioumourtzog, 2013).
- We have not included reductions in other potentially harmful road pollutants such as ozone.
- We have only modelled health effects where quantifiable estimates based on meta-analysis are available. Other direct effects of air pollution (e.g. diabetes (Rajagopalan, 2012)) or traffic noise (e.g. mental health (see Appendix 2)) have also been demonstrated by research studies.
- We have not been able to model the health impact of short term 'spikes' in NOx and PM2.5 and potential reduction of this impact due to a LEZ.

As well being sensitive to model parameters (as described above), the estimated health impacts of different LEZ scenarios vary greatly within the upper and lower confidence limits. For example the estimated reduction in total deaths under Scenario1 was 16 but with 95% confidence of between 2 and 29. The estimates therefore lack precision and should be used to communicate an indicative rather than exact effect of air pollution.

The LEZ scenarios are presented as independent of each other, whereas in combination they represent a multifaceted approach to reducing road emissions. Additive benefits would be seen, for example, by combing improvements to bus and LGV engines with policies that encourage greater use of petrol or hybrid engines and reduced congestion. Other initiatives in Leeds and Bradford - such as the City Connect cycleways between Leeds and Bradford – provide additional health benefits through increased physical activity.

5.3 Recommendations

1. **This methodology should be considered by the WYLES board to expand its scope to a LEZ feasibility study for West Yorkshire. In carrying out this work the additional effects of short term rises in emissions, and additional benefits of active travel policies could be studies in more detail.**

2. **The results should be:**
   - **summarised and presented alongside other work packages within the LEZ feasibility study.**
   - **presented to the West Yorkshire LTP board.**
   - **considered for inclusion within the next refresh of the Joint Strategic Needs Assessment for both Leeds and Bradford Districts.**

3. **The development of a LEZ should be placed within the context of a wider package of public health and environmental policy measures (including a modal shift towards safe active travel and increased physical activity).**

4. **Elected members in both Leeds and Bradford councils should be briefed on the findings of this work, with emphasis on the predicted positive impact of LEZs for large segments of the population and particularly in deprived areas.**

5. **A summary of the results (presented by electoral wards) should be produced for elected members. This could use a dashboard approach to summarise (by ward); deprivation, current road pollution, predicted future road pollution within a LEZ, and likely health benefits.**

6. **It is recommended that all four LEZ scenarios be assessed using a broader HIA tool (Appendix 3), covering the benefits of LEZ for physical and mental health and reduced health care costs.**

7. **Future testing of the SATURN and PITHEM models is required to fully understand how changes in traffic and fleet parameters influence emissions, and how to expand the scope of these models across West Yorkshire.**

References

Cesaroni G, Stafoggia M, Anderson Z, et al. Long term exposure to ambient air pollution and incidence of acute coronary events: prospective cohort study and meta-analysis in 11 European cohorts from the ESCAPE Project. *BMJ* 2014;348: f7412.

COMEAP. Long-Term Exposure to Air Pollution: Effect on Mortality. A report by the Committee on the Medical Effects of Air Pollutants. 2009. [Accessed 7/3/2014 http://www.comeap.org.uk/documents/reports/39-page/linking/51-the-mortality-effects-of-long-term-exposure-to-particulate-air-pollution-in-the-united-kingdom].

COMEAP. The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom: A report by the Committee on the Medical Effects of Air Pollutants. 2010. [Accessed 7/3/2014 http://www.comeap.org.uk/documents/reports/39-page/linking/51-the-mortality-effects-of-long-term-exposure-to-particulate-air-pollution-in-the-united-kingdom].

COMEAP. Statement on Estimating the Mortality Burden of Particulate Air Pollution at the Local Level. Committee on the Medical Effects of Air Pollutants. 2012. [Accessed 9/4/2014 http://www.comeap.org.uk/documents/statements/39-page/linking/46-mortality-burden-of-particulate-air-pollution

Crowther, R. Initial findings from the LEZ source apportionment work for Leeds and Bradford. 2013.

Department for Environment, Food and Rural Affairs. The Air Quality Strategy for England, Scotland, Wales and Northern Ireland (Volume 1). Department for Environment, Food and Rural Affairs in partnership with the Scottish Executive, Welsh Assembly Government and Department of the Environment Northern Ireland. Cm 7169 NIA 61/06-07. July 2007.

Department of Health. Improving outcomes and supporting transparency. Part 1: A public health outcomes framework for England 2013-16.DH, London. 2012.

Fielding T. Health Impact Assessment of Low Emission Zone proposals in Bradford and Leeds 2012. Methodology, baseline assessment and evidence review. [Accessed 24/03/2014 http://www.apho.org.uk/resource/item.aspx?RID=121448].

HIA Baseline Assessment

Health Protection Agency (Centre for Radiation, Chemical and Environmental Hazards). Estimating the effect of pollutants on mortality: using long term exposure to particulate air pollution as an example. Chemical Hazards and Poisons Report 2011: 20:24.

Humphreys C. HIA Workshop 16th May 2013.

HIA workshop writeup Clare Humphr

Kioumourtzoglou MA, Spiegelman D, Szpiro AA, et al. Exposure measurement error in PM2.5 health effects studies: A pooled analysis of eight personal exposure validation studies. *Environ Health* 2013;13(1):2.

Pedersen M, Giorgis-Allem L, Bernard C, et al. Ambient air pollution and low birthweight: a European cohort study (ESCAPE). *Lancet Respir Med* 2013; 1(9): 695-704.

Rajagopalan S, Brook RD. Air Pollution and Type 2 Diabetes: Mechanistic Insights. *Diabetes* 2012; 61(12): 3037–3045.

Sapkota A, Chelikowsky AP, Nachman KE, et al.Exposure to particulate matter and adverse birth outcomes: a comprehensive review and meta-analysis. *Air Quality, Atmosphere & Health 2012;* 5(4): 369-381.

Scott-Samuel, Birley and Arden. The Merseyside Guidelines for Health Impact Assessment. 2nd edition. International HIA Consortium. 2001.

SKC. ppm to mg/m3 Conversion Calculator. [Accessed 7/3/20-14 http://www.skcinc.com/converter/converter.asp].

Takenoue Y, Kaneko T, Miyamae T, et al. Influence of outdoor NO(2) exposure on asthma in childhood: Meta-analysis. *Pediatrics International* 2012; 54:762-769.

Appendix 1. Changes in emissions of PM2.5 and NOX by deprivation quintile for all scenarios

The embedded spreadsheet contains the proportion of the population in each deprivation quintile stratified by emissions category (high, medium and low). This is presented for PM2.5 and NOx separately, and for 2012 baseline emissions and each of the 4 modelled scenarios.

Leeds-Bradford LEZ
HIA - exposure by de

Appendix 2. Evidence of the effects of noise from traffic and health

Systematic reviews and meta-analysis

1. *Nrepepa 2011 - Relationship between noise annoyance from road traffic noise and cardiovascular diseases: a meta-analysis*

Increased annoyance was significantly associated with arterial hypertension (pooled risk estimate = 1.16, 95% confidence interval 1.02-1.29) while the association with ischemic heart disease did not reach statistical significance. **There is a positive and significant association between noise annoyance from road traffic and the risk of arterial hypertension.**

2. *Van kempen – The quantitative relationship between road traffic noise and hypertension: a meta-analysis*

Road traffic noise was positively and significantly associated with hypertension (odds ratio (OR) of 1.034 [95% confidence interval (CI) 1.011-1.056] per 5 dB(A) increase of the 16 h average road traffic noise level (LAeq16hr) [range 45-75 dB(A)]. **There is a slight increase of cardiovascular disease risk in populations exposed to transportation noise. This quantitative relationship has been derived for health impact assessment.**

3. *Omline 2011 - Effects of noise from non-traffic-related ambient sources on sleep: review of the literature of 1990-2010 (lit review)*

Ambient noise has **some effect on human sleep**. However, a quantitative meta-analysis and comparison is not possible due to the small number of studies available.

4. *Stansfeld 2003 - Noise pollution: non-auditory effects on health*

Studies of occupational and environmental noise exposure suggest an association with hypertension., weak relationships with cardiovascular disease. **Aircraft and road traffic noise exposure are associated with psychological symptoms but not with clinically defined psychiatric disorder.**

5. *Stansfeld 2000 – Noise and health in the urban environment*

In carefully controlled studies, noise exposure does **<u>not</u> seem to be related to low birth weight or to congenital birth defects**.

Summary: There is strong evidence that traffic noise increases the risk of hypertension, disturbed sleep patterns and psychological symptoms, with weaker evidence of an increased risk of cardiovascular risk.

Appendix 3. Health Impact Tool

Adapted from Scott-Samuel (2011)

Categories influences on health (examples below)	Elements of proposed intervention	Predicted health impacts What is the nature of impact, size of impact, and how measurable is the impact i.e. is it able to be measured qualitatively (Q), calculated (C) or just estimated (E)?			Risk/likelihood of impact Is it definite (D), probable (P), or speculative (S)?
		Positive impacts	Negative impacts	Uncertain impacts	
Physical health e.g. respiratory, cardiovascular, cancer, mortality rates	e.g. Lower emission concentrations				
Mental health and wellbeing	e.g. Reduction in noise				
Impact on Health services e.g. A and E attendances for asthma and other respiratory conditions	e.g. Lower emission concentrations				
Inequalities e.g. physical health impact by deprivation quintile	e.g. Lower emission concentrations				
Climate Change	e.g. lower emission volume and concentrations				

LEZ HIA project group:

Duncan Cooper (Public Health England Yorkshire and Humber)
Richard Crowther (Leeds City Council)
Richard Dixon (Leeds City Council)
Sally Jones (Bradford Metropolitan District Council)
Dave Cherry (Leeds City Council)
Andrew Whittles (Low Emissions Strategies Ltd)
Mike Gent (Public Health England Yorkshire and Humber)

The project group would also like to acknowledge initial work on this HIA from Tim Fielding (North Lincolnshire Council) and Clare Humphreys (Public Health England) and data support from Jon Stansbie (Bradford Metropolitan District Council).

APPENDIX 4 – COST BENEFIT ANALYSIS

Economic assessment of Bradford and Leeds Low Emission Strategies

Cost benefit analysis

Report for City of Bradford Metropolitan District Council and Leeds City Council

Ricardo-AEA/R/ED57546
Issue Number 1
Date 17/09/2014

Customer:

City of Bradford Metropolitan Council: Leeds City Council

Customer reference:

Click here to enter text.

Confidentiality, copyright & reproduction:

Contact:

Beth Conlan
Ricardo-AEA Ltd
Gemini Building, Harwell, Didcot, OX11 0QR
t: 01235 75 3480
e: beth.conlan@ricardo-aea.com
Ricardo-AEA is certificated to ISO9001 and ISO14001

Author:

John Abbott

Approved By:

Beth Conlan

Date:

17 September 2014

Ricardo-AEA reference:

Ref: ED57546- Issue Number 1

Executive summary

The City of Bradford Metropolitan Council and Leeds City Council undertake air quality management activities to meet the requirements of The Environment Act 1995. The Leeds/Bradford councils cover a densely-populated region which includes major motorways and trunk roads. The Authorities have declared AQMAs for nitrogen dioxide (NO_2) and determined that road transport emissions (of NO_x) are the main factor causing NO_2 to exceed air quality limits. It is imperative that Government meets the EU limit value for NO_2, and should this not be met then central Government may pass infraction fines from the European Commission onto Local Authorities. Both Leeds and Bradford councils are examining the potential for applying control measures for road transport in defined areas - low emission zones (LEZ). The aim of this study is to identify the most cost effective LEZ to inform the process of emission improvement.

The economic analysis is part of a suite of other work streams to develop an LES to reduce road transport emissions. City of Bradford Metropolitan Council and Leeds City Council have identified the following candidate Low Emission Zones for each city:

- Inner Ring Road area
- Outer Ring Road area

Leeds City Council has developed emission baseline projections and the emission changes from the baseline for selected LEZ and measure combination for both cities.

This study examines the economic costs and benefits of selected LEZ and measure combinations to allow assessment of the most cost-effective LES measures combination. It provides estimates of the damage costs and the national abatement costs avoided as the result of the proposed measures. The measures included those to reduce emissions from buses, heavy goods vehicles, light goods vehicles and cars. While the impact of these measures are assessed in both geographical areas identified in both cities, there will be much wider beneficial impact beyond the ring roads as drivers will travel from outside the ring roads to enter the cities. It is not possible to quantify this wider impact at this time.

The economic benefits of the measures were assessed using a four stage abatement cost methodology:

Estimate the likely scale of the impact on emissions by applying damage costs to the change in emissions.

Identify whether there is expected to be any impact on compliance with legally-binding obligations.

Estimate the value of the change in air quality using unit abatement costs, which provide an indicative marginal cost per tonne of emission based on the average marginal abatement technology. This provides an easy to use indicative estimate of the abatement impact.

Where a measure is likely to have a significant impact on compliance (suggested as a value greater than £50m) then more detailed analysis may be justified.

Damage costs provide a means to estimate the value for the impacts of exposure to air pollution on health – both chronic mortality effects (which consider the loss of life years due to air pollution) and morbidity effects (which consider changes in the number of hospital admissions for respiratory or cardiovascular illness) – in addition to damage to buildings (through building soiling) and impacts on materials. The damage costs avoided in the Leeds Outer Ring Road area for individual measures ranged up to £1.26 million over the period 2016-2021 for the measure requiring all buses to achieve the Euro VI standard. The damage costs avoided in the Bradford Outer Ring Road area for individual measures ranged up to £0.33 million over the period 2016-2021 for the measure to return the proportion of diesel cars in the car fleet to 2000 levels.

A review of monitoring data indicated that there were many locations within the Bradford and Leeds Outer Ring Roads where the nitrogen dioxide concentrations exceeded legally binding European limit values for nitrogen dioxide. Concentrations at several sites are projected to remain above the limit value in 2016 and beyond.

The value of the change in air quality was assessed using unit abatement costs. The value of the abatement costs avoided for the measures in Bradford was estimated to be £6.3 million for the period 2016-2021for the measure to return the proportion of diesel cars in the car fleet to 2000 levels. The value of the abatement costs avoided for the measures in Leeds was estimated to be £25.6 million for the period 2016-2021for the measure to requiring all buses and HGVs to achieve the Euro VI standard in 2016.

The cost of the measures was estimated taking into account the numbers of vehicles potentially requiring replacement and their capital cost (less trade-in value) compared to the capital cost for the "business as usual" case without replacement. The estimate took into account additional operating and maintenance costs for Euro VI vehicles. The costs for the measure to return the proportion of diesel cars in the car fleet to 2000 levels were estimated taking into account the additional fuel consumption for petrol cars. The costs for compressed natural gas (CNG) buses took into account the additional capital and operating costs of the gas compression plant: the costs also took into account the lower cost of CNG fuel compared to diesel.

The following table provides a summary of the calculated costs for each measure per tonne of oxides of nitrogen abated in the Outer Ring Road areas for measures implemented in 2016.

City	Measure	Cost per tonne NOx abated , £ 2016 implementation
Bradford	All buses Euro VI (CNG scenario)	2,000
	Pre Euro IV buses to Euro VI (CNG scenario)	10,000
	Fuel split	46,000
	Pre Euro IV buses to Euro VI	49,000
	Pre Euro IV bus and HGV to Euro VI	66,000
	All HGV Euro VI	67,000
	All bus and HGV Euro VI	87,000
	All buses Euro VI	116,000

	Pre Euro IV HGV to Euro VI	117,000
	Promotion of walking and cycling(TravelSmart)	143,000
	Euro II and Euro III bus retrofit	262,000
	All vans Euro 6	411,000
Leeds	All buses Euro VI (CNG scenario)	1,000
	Pre Euro IV buses to Euro VI (CNG scenario)	5,000
	Pre Euro IV buses to Euro VI	20,000
	Pre Euro IV bus and HGV to Euro VI	29,000
	All buses Euro VI	36,000
	Euro II and Euro III bus retrofit	39,000
	Promotion of walking and cycling(TravelSmart)	50,000
	Fuel split	57,000
	All bus and HGV Euro VI	64,000
	All HGV Euro VI	107,000
	Pre Euro IV HGV to Euro VI	160,000
	All vans Euro 6	711,000

The most cost effective option in both Bradford and Leeds would be to implement Low Emission Zones requiring bus operators to meet the Euro VI standard within the Outer Ring Road areas, provided that it is practical to replace existing non-compliant buses with buses running on compressed natural gas.

CNG buses are potentially less expensive to run than diesel buses because fuel costs are lower. However, they are have not been widely used by bus operators in the UK and operators may be reluctant to use CNG buses without more experience of their operation in practice.

If bus operators consider it impractical to operate CNG buses in Leeds, the most cost-effective measure would be to require bus operators to replace existing Pre-Euro IV buses with conventional Euro VI buses in 2016. This measure would also be amongst the most cost-effective in Bradford.

The costs for the fuel split measures to return the proportion of diesel cars to 2000 levels substantially exceed the abatement costs avoided in both Bradford and Leeds largely because of the large numbers of cars affected by the policy. However, the exact shape of a measure focussed on switching the purchase of diesel to petrol cars needs much further thought as this could have a large impact on the costs and benefits of such a policy. Encouraging much older diesels (e.g. pre-Euro 4) to switch to petrol would have a beneficial air quality impact but be less expensive to implement. The time period for implementation also needs consideration. The costs of requiring all vans to meet the Euro 6 standard in the LEZs also substantially exceed the abatement costs avoided in Bradford and Leeds. The measure would require a large number of van owners to buy new vehicles.

The cost of requiring all HGVs to meet the Euro VI standard in the LEZs would also substantially exceed the abatement costs avoided in Bradford and Leeds because a large number of vehicles would need to be replaced. The cost of requiring all pre-Euro IV HGVs to meet the Euro VI standard also exceeds the abatement costs avoided. Enforcement costs can be significant for measures applied to HGVs, particularly for Bradford.

The costs of all the bus measures in Bradford exceed the abatement costs avoided. However, the costs of the bus measures in Leeds are closer to the abatement costs avoided. The difference between cities arises because the abatement costs apply in Leeds over a wider area. The cost of replacing Euro IV buses in Leeds in 2016 with Euro VI buses is less than the abatement costs avoided and so this option is economically attractive. The cost of replacing Euro V buses in Leeds in 2021 with Euro VI buses is approximately the same as the abatement costs avoided: this option therefore appears to be economically neutral. The costs of replacing all buses in Leeds with Euro VI vehicles in 2016 or 2021 exceed the abatement costs avoided.

The abatement costs avoided were calculated on the basis of the default value of £29,150 per tonne of oxides of nitrogen emitted. Defra abatement cost guidance recommends that sensitivity analysis is carried out to reflect the uncertainty in the abatement costs. If the default value of £29,150 is used then it is suggested that a range of £28,000 - £73,000 is appropriate. The measure to replace pre Euro IV buses in Leeds with Euro VI buses remains attractive if the lower range value of the unit abatement costs is used. The measures to replace all non-Euro VI buses in Leeds in 2016 or 2021 become attractive if the higher value of the range is used. The measure to replace pre Euro IV buses with Euro VI vehicles in Bradford also becomes attractive.

The assessment is based on estimates of emissions provided by Leeds City Council for 2016 and 2021. The assessment considers the replacement of pre Euro V buses in Leeds in 2021. It is possible that this measure would be more economically attractive if introduced earlier. It is recommended that Leeds City Council investigate the emissions reductions in the Outer Ring Road area that would arise from earlier introduction of this measure.

The abatement cost avoided for the measure where Pre Euro IV buses in Leeds are replaced with Euro VI buses is estimated to be £4.2 million over the period 2016-2021. The abatement costs avoided for the most economically attractive measure is substantially less than £50 million and so more detailed analysis of abatement costs is not required.

The assessment has considered the damage costs and abatement costs avoided as the result of improved air quality from a reduction of 10% in car traffic. It has been suggested that this change might be achieved by means of interventions to promote walking and cycling. The analysis indicates that the cost effectiveness of these interventions depends on the measures applied. It indicates that the benefit of improved air quality resulting from TravelSmart personalised travel support would exceed the cost of the intervention in Leeds. The other measures considered (Cycling Demonstration Towns, Sustainable Travel Towns) cannot be justified on the basis of improved air quality alone. However, interventions to promote walking and cycling will have other benefits, most importantly improved health resulting from increased physical activity. These benefits are estimated to be substantially greater than the costs of the interventions.

Alongside its impacts on human health and buildings captured by Defra’s damage costs, the measures considered in this study will also have a number of wider effects which have not been quantitatively assessed. Impacts on the productivity of the workforce, the local automotive industry and congestion have been explored qualitatively, considering different economic advantages which might be delivered through the implementation of a LEZ.

Table of contents

Appendices

Introduction

The City of Bradford Metropolitan Council and Leeds City Council undertake air quality management activities to meet the requirements of The Environment Act 1995. The Leeds/Bradford councils cover a densely-populated region which includes major motorways and trunk roads. The Authorities have declared AQMAs for Nitrogen Dioxide (NO_2) and determined that road transport emissions (of NO_x) are the main factor causing NO_2 to exceed air quality limits. The councils are examining the potential for applying control measures for road transport in defined areas - low emission zones (LEZ).

The economic analysis is part of a suite of other work streams to develop an LES to reduce road transport emissions. City of Bradford Metropolitan Council and Leeds City Council have identified the following candidate Low Emission Zones for each city:

- Inner Ring Road area
- Outer Ring Road area

Leeds City Council has developed emission baseline projections and the emission changes from the baseline for the selected LEZ and measure combination for both cities.

This study examines the economic benefits of selected LEZ and measure combinations to allow assessment of the most cost-effective LES measures combination.

Defra's Interdepartmental Group on Costs and Benefits (IGCB) provides advice relating to the quantification and valuation of local environmental impacts[18]. The Group has recommended different methodologies for valuing changes in air quality, depending on the circumstances. The Group recommends the abatement cost approach where pollutant concentrations exceed legally binding obligations. Annual mean nitrogen dioxide concentrations exceed the EU limit value of 40 µg m^{-3} at many monitoring sites in Leeds and so this approach is appropriate.

The EU has the option to impose fines if legally binding obligations, such as the air quality limit value, are not met and so remedial actions are needed to restore compliance. Consequently measures, such as Low Emission Zones, that reduce the need for further remedial action can limit financial liabilities. The abatement cost approach recognises this, and values any improvements in air quality, where concentrations exceed limit values, as the cost saved by avoiding other compliance activity.

The IGCB developed a four stage methodology for the abatement cost approach:

> Estimate the likely scale of the impact on emissions by applying damage costs to the change in emissions. The IGCB have developed a Damage Cost Calculator for this purpose.

[18] Department for Environment, Food and Rural Affairs. Abatement cost guidance for valuing changes in air quality
May 2013

Identify whether there is expected to be any impact on compliance with legally-binding obligations.

Estimate the value of the change in air quality using unit abatement costs, which provide an indicative marginal cost per tonne of emission based on the average marginal abatement technology. This provides an easy to use indicative estimate of the abatement impact.

Where a measure is likely to have a significant impact on compliance (suggested as a value greater than £50m) then more detailed analysis may be justified.

Section 2 of this report applies the damage cost approach for the selected LEZ and measure combinations. Section 3 reviews available air quality monitoring data to establish whether there is expected to be any impact on compliance with EU limit values for nitrogen dioxide and particulate matter, PM_{10}. Section 4 estimates the value of the change in air quality using unit abatement costs and assesses the significance of the impact on compliance. The abatement costs avoided provide an estimate of what it would otherwise cost to achieve the same reduction in emissions as a result of national measures.

Section 5 provides estimates of the costs of the proposed measures. The costs are compared with the abatement costs avoided by the measures. Section 6 provides a summary of the conclusions.

Damage cost calculations

Introduction

This section provides details of the damage cost calculations for the measures proposed by the Councils. The damage costs were calculated following the methodology set out by the Intergovernmental panel on the costs and benefits (IGCB).

Emissions data

Leeds City Council used Defra's Emission Factor Toolkit[19] to calculate the emissions from the Inner Ring Road and Outer Ring Road areas of Bradford and Leeds for a range of emissions scenarios. Fig. 1 shows the Leeds Inner Ring Road (in red) and Outer Ring Road (in blue). The Inner Ring Road area includes the area within the Inner Ring Road but does not include the Inner Ring road links. The Outer Ring Road area includes the area within the Outer Ring Road (including the Inner Ring Road area) but does not include the Outer Ring road links.

The Emission Factor Toolkit calculated the emissions of carbon dioxide, oxides of nitrogen (as nitrogen dioxide) and particulate matter $PM_{2.5}$ for each road link within the specified areas. The emission calculation takes account of the annual average daily vehicle flows, average vehicle speeds, traffic composition (petrol cars, diesel cars, light goods vehicles, heavy goods vehicles, buses and coaches) and the emissions abatement (e.g. Euro class) levels within each vehicle category. Table 1 lists the scenarios considered in the assessment.

Fig. 1: Leeds Inner Ring Road and Outer Ring Road areas

[19] http://laqm.defra.gov.uk/review-and-assessment/tools/emissions.html#eft

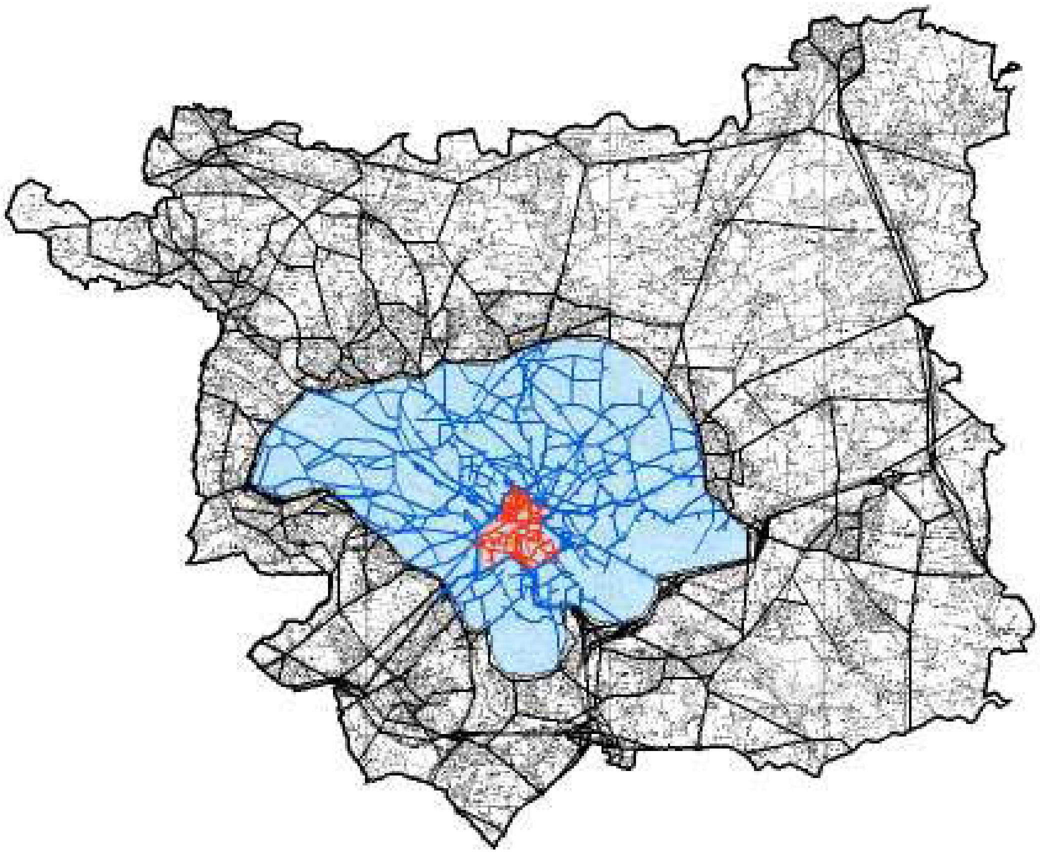


Table 1: Modelled scenarios

Scenario name	Description
2012 base	Existing fleet mix
2016 base	Projected fleet mix do minimum
2016 fuel split	Projected fleet but with the petrol/diesel mix for cars and N1 vans retur
2016 all buses Euro VI	Projected fleet but all buses (including Euro IV and Euro V) become Eurc
2016 all HGV Euro VI	Projected fleet but all HGV (including Euro IV and Euro V) become Euro '
2016 all bus and HGVs Euro VI	Projected fleet but all buses and HGVs (including Euro IV and Euro V) be
2016 All vans Euro 6	Projected fleet but all vans replaced with Euro 6
2016 E2&E3 retrofit	Projected fleet but with Euro II and Euro III buses retrofitted with "non T
2016 all Pre Euro IV buses Euro VI	Projected fleet but all buses older than Euro IV are replaced with an Eur
2016 all Pre Euro IV HGV Euro VI	Projected fleet but all HGV older than Euro IV are replaced with an Euro
2016 Pre Euro IV bus and HGVs to Euro VI	Projected fleet but all buses and HGVs older than Euro 4 are replaced w
2016 10% reduction in car use	Projected fleet with 10 % reduction in car use resulting from measures t
2021 base	Projected fleet mix do minimum
2021 fuel split	Projected fleet but with the petrol/diesel mix for cars and N1 vans retur
2021 All buses to Euro VI	Projected fleet but with all buses (including Euro IV and Euro V) become
2021 All HGVs to Euro VI	Projected fleet but with all HGVs (including Euro IV and Euro V) become

2021 All bus and HGVs to Euro VI	Projected fleet but with all buses and HGVs (including Euro V) become E
2021 All vans to Euro 6	Projected fleet but all vans replaced with Euro 6
2021 All pre Euro V buses to Euro VI	Projected fleet but with all buses older than Euro V are replaced with Eu
2021 All pre Euro V HGV to Euro VI	Projected fleet but all HGVs older than Euro V are replaced with Euro VI
2021 All pre Euro V bus and HGVs to Euro VI	Projected Leeds fleet but All Pre Euro V buses and HGVs become Euro V
2021 10% reduction in car use	Projected fleet with 10 % reduction in car use resulting from measures t

Leeds City Council provided Ricardo-AEA with a summary of the results of the emissions calculations. Appendix 1 lists the results of the emissions calculations.

Damage cost calculations

Air pollution has a number of important impacts on human health, as well as on the natural and built environments. The IGCB provides guidance[20] on the assessing the value for the impacts of exposure to air pollution on health – both chronic mortality effects (which consider the loss of life years due to air pollution) and morbidity effects (which consider changes in the number of hospital admissions for respiratory or cardiovascular illness) – in addition to damage to buildings (through building soiling) and impacts on materials. The IGCB has developed a Damage Cost Calculator[21] to calculate the damage costs from proposed policies. The damage costs do not include the impact on workforce productivity (absenteeism from ill health due to air pollution) and therefore will underestimate the true economic benefit of these LEZ measures. Other impacts, alongside productivity, have been assessed qualitatively in section 5.11.

The IGCB Damage Cost Calculator was used to estimate the damage costs saved compared with the baseline for each of the emissions scenarios. The Damage Cost Calculator requires the user to provide the following inputs:

- The first year of your policy which may or may not be the first year where emissions change. This is also important as a different base year has a different level of damage cost associated with it. For this assessment, the base year was 2012[22], so that all damage costs are expressed at 2012 prices.
- The number of years of the policy appraisal. For this assessment the policy was appraised over the period 2012-2021.
- Data on annual emission changes (in tonnes, by each pollutant)

In most cases, Leeds City Council calculated the emissions for a single year, either 2016 or 2021. The damage cost avoided were thus calculated for a single year of implementation for these scenarios. The Council calculated the emissions for six scenarios (fuel split; all buses Euro VI; all HGV Euro VI; all buses and HGVs Euro VI; all vans Euro 6; 10% reduction in car emissions) for both 2016 and 2021: The damage costs were also calculated for these scenarios assuming that the measure was applied across the period 2016-2021 and assuming a linear change in emissions reductions with time.

Tables 2-5 present the results of the analysis. They show the damage costs avoided for each candidate LEZ and abatement measure. Separate damage cost savings are shown relating to the changes in emissions of oxides of nitrogen, particulate matter, PM_{10} and carbon dioxide. It also shows the total damage cost saved for each scenario, the estimated range (based on the high and low estimates of the health impact of particulate emissions) and high and low sensitivity estimates.

[20] https://www.gov.uk/air-quality-economic-analysis#damage-costs-approach

[21] uk-air.defra.gov.uk/.../1102150857_110211_igcb-damage-cost-calculator.xls

[22] To convert to other base years, multiply the damage costs by the following factors

2012	2013	2014	2015	2016
1	1.036295	1.073442	1.111457	1.150358

Table 2: Damage costs calculated for the Leeds IRR area

Scenario	Damage costs saved, £(2012)							
	NO_x	$PM_{2.5}$	CO_2	Total	Low estimate	High estimate	Sensitivity low value	Sensitivity high value
2016 fuel split	19838	43833	-37459	26211	15392	27018	-21527	112580
2016 all buses Euro VI	31434	50342	-1163	80613	62784	91431	15338	199459
2016 all HGV Euro VI	14166	20005	-202	33969	26491	38548	6661	83367
2016 all bus and HGVs Euro VI	45609	70347	-1364	114591	89281	129988	22001	282845
2016 All vans Euro 6	5982	25218	434	31634	24780	35944	6706	79042
2016 Euro II &Euro III retrofit	6444	25640	-393	31692	24712	35949	6125	80176
2016 all Pre Euro IV buses Euro VI	11846	22388	424	34657	27122	39375	7266	85010
2016 all Pre Euro IV HGV Euro VI	777	2744	113	3634	2855	4134	815	8966
2016 Pre Euro IV bus and HGVs to Euro VI	12623	25113	536	38272	29962	43487	8077	93925
2016 10% reduction in cars	3681	30002	60462	94144	81756	111296	62257	158692
2021 fuel split	13504	4392	-35733	-17837	-18806	-22861	-29220	-1292
2021 All buses to Euro VI	12033	17404	-74	29363	22913	33328	5831	71991
2021 All HGVs to Euro VI	4651	5724	-69	10307	8036	11696	2013	25195
2021 All bus and HGVs to Euro VI	16684	23129	-143	39671	30950	45025	7844	97188
2021 All vans to Euro 6	1586	4216	156	5958	4676	6776	1312	14642
2021 All pre Euro V buses to Euro VI	5331	9829	-74	15086	11771	17121	2977	37303
2021 All pre Euro V HGV to Euro VI	1041	2368	-69	3341	2600	3787	623	8375
2021 All pre Euro V bus and HGVs to Euro VI	6372	12197	-143	18426	14370	20908	3601	45677
2021 10% reduction in cars	2512	24276	54774	81563	71154	96597	55648	134422
2016-2021 fuel split	99691	142421	-219552	22561	-12243	9564	-152743	327329
2016-2021 all buses Euro VI	129313	201387	-3647	327053	254853	371016	62976	807194
2016-2021 all HGVs Euro VI	55917	76380	-803	131494	102541	149219	25760	322403
2016-2021 all buses and HGVs Euro VI	185255	277769	-4451	458573	357414	520265	88742	1129657
2016-2021 all vans Euro 6	22458	87106	1754	111318	87225	126501	23749	277390
2016-2021 10% reduction in cars	18518	162557	345498	526573	458272	623041	353453	878234

Table 3: Damage costs calculated for the Leeds ORR area

Scenario	Damage costs saved, £(2012)							
	NO_x	$PM_{2.5}$	CO_2	Total	Low estimate	High estimate	Sensitivity low value	Sensitivity high value
2016 fuel split	171606	382940	-268487	286059	187017	305121	-134528	1050700
2016 all buses Euro VI	130140	186983	-2508	314615	245275	356980	61247	773330
2016 all HGV Euro VI	97754	132972	-958	229768	179236	260772	45330	562731
2016 all bus and HGVs Euro VI	227954	319970	-3572	544352	424472	617709	106495	1336108
2016 All vans Euro 6	49237	190014	3928	243178	190558	276353	51948	605781
2016 Euro II &Euro III retrofit	25994	100176	-1444	124727	97270	141489	24173	315207
2016 all Pre Euro IV buses Euro VI	48693	107987	-2510	154170	120074	174836	29224	385425
2016 all Pre Euro IV HGV Euro VI	5620	18671	883	25174	19789	28643	5713	61896
2016 Pre Euro IV bus and HGVs to Euro VI	54313	126659	-1627	179344	139863	203479	34937	447321
2016 10% reduction in cars	33091	275434	515879	824405	714091	973604	535488	1407934
2021 fuel split	118872	37993	-234786	-77922	-92956	-105621	-184240	83271
2021 All buses to Euro VI	48722	62045	-250	110517	86233	125445	21939	269850
2021 All HGVs to Euro VI	31522	37178	-408	68293	53248	77499	13365	166653
2021 All bus and HGVs to Euro VI	80244	99222	-658	178808	139480	202942	35304	436499
2021 All vans to Euro 6	13219	31957	1412	46588	36582	52992	10391	113968
2021 All pre Euro V buses to Euro VI	22167	36271	-250	58187	45398	66038	11495	143328
2021 All pre Euro V HGV to Euro VI	7315	15629	-408	22536	17546	25554	4241	56334
2021 All pre Euro V bus and HGVs to Euro VI	29482	51899	-658	80723	62944	91592	15737	199662
2021 10% reduction in cars	22967	228124	468202	719293	625499	850792	480163	1205508
2016-2021 fuel split	868664	1243099	-1508389	603374	265929	574719	-959546	3346612
2016-2021 all buses Euro VI	532021	740053	-8145	1263928	985589	1434265	247352	3101242
2016-2021 all HGVs Euro VI	384099	505034	-4066	885067	690338	1004466	174280	2165795
2016-2021 all buses and HGVs Euro VI	916295	1245129	-12523	2148900	1675810	2438601	421390	5267164
2016-2021 all vans Euro 6	185331	656916	15878	858124	672668	975337	184655	2131290
2016-2021 10% reduction in cars	167643	1508447	2950508	4626598	4015023	5467961	3044805	7831288

Table 4: Damage costs calculated for the Bradford IRR area

Scenario	Damage costs saved, £(2012)							
	NO_x	$PM_{2.5}$	CO_2	Total	Low estimate	High estimate	Sensitivity low value	Sensitivity high value
2016 fuel split	3061	7551	-4203	6409	4436	6968	-1716	21305
2016 all buses Euro VI	5526	8915	-150	14291	11138	16213	2760	35297
2016 all HGV Euro VI	2475	3159	-41	5594	4361	6347	1090	13694
2016 all bus and HGVs Euro VI	8001	12074	-191	19884	15498	22560	3850	48991
2016 All vans Euro 6	1096	4116	192	5405	4249	6149	1229	13320
2016 Euro II &Euro III retrofit	1057	4087	-57	5087	3967	5770	987	12854
2016 all Pre Euro IV buses Euro VI	1987	4631	37	6655	5203	7558	1366	16475
2016 all Pre Euro IV HGV Euro VI	355	1161	19	1535	1202	1744	324	3819
2016 Pre Euro IV bus and HGVs to Euro VI	2342	5792	56	8190	6405	9302	1690	20293
2016 10% reduction in cars	547	4578	8199	13325	11523	15726	8556	22943
2021 fuel split	2064	1201	-3427	-162	-595	-434	-2493	3627
2021 All buses to Euro VI	1840	2547	-20	4367	3406	4956	860	10703
2021 All HGVs to Euro VI	832	968	-14	1785	1392	2026	347	4359
2021 All bus and HGVs to Euro VI	2671	3515	-34	6152	4798	6982	1207	15062
2021 All vans to Euro 6	286	734	69	1089	860	1241	268	2621
2021 All pre Euro V buses to Euro VI	888	1708	-20	2576	2009	2923	503	6387
2021 All pre Euro V HGV to Euro VI	17	0	0	17	13	20	3	39
2021 All pre Euro V bus and HGVs to Euro VI	906	1726	-22	2610	2035	2962	509	6472
2021 10% reduction in cars	371	3715	7346	11433	9929	13516	7564	19290
2016-2021 fuel split	15323	25895	-22854	18364	11235	19177	-12677	73790
2016-2021 all buses Euro VI	21888	34028	-503	55413	43196	62871	10753	136614
2016-2021 all HGVs Euro VI	9829	12257	-164	21922	17089	24875	4269	53632
2016-2021 all buses and HGVs Euro VI	31717	46285	-666	77336	60285	87746	15022	190246
2016-2021 all vans Euro 6	4101	14360	774	19234	15134	21892	4437	47216
2016-2021 10% reduction in cars	2747	24840	46602	74189	64287	87629	48318	126531

Table 5: Damage costs calculated for the Bradford ORR area

Scenario	Damage costs saved, £(2012)							
	NO_x	$PM_{2.5}$	CO_2	Total	Low estimate	High estimate	Sensitivity low value	Sensitivity high value
2016 fuel split	44960	119426	-57246	107140	75940	117446	-19348	340309
2016 all buses Euro VI	22133	33602	-374	55361	43172	62821	10832	136227
2016 all HGV Euro VI	23937	28767	-273	52432	40887	59502	10291	127976
2016 all bus and HGVs Euro VI	46070	62369	-647	107793	84059	122323	21123	264203
2016 All vans Euro 6	16727	59330	3375	79432	62523	90421	18454	194809
2016 Euro II &Euro III retrofit	4255	16301	-228	20329	15855	23061	3945	51358
2016 all Pre Euro IV buses Euro VI	8072	17926	353	26351	20630	29941	5555	64887
2016 all Pre Euro IV HGV Euro VI	3664	11093	292	15049	11797	17105	3244	37228
2016 Pre Euro IV bus and HGVs to Euro VI	11737	29019	645	41400	32426	47046	8799	102115
2016 10% reduction in cars	8206	75871	120696	204773	176371	241289	127703	359903
2021 fuel split	30489	17977	-44187	4279	-2707	1627	-30881	61941
2021 All buses to Euro VI	7205	9467	-75	16596	12945	18835	3269	40609
2021 All HGVs to Euro VI	7724	7976	-112	15588	12149	17688	3032	37899
2021 All bus and HGVs to Euro VI	14929	17443	-188	32184	25094	36523	6301	78509
2021 All vans to Euro 6	4394	9656	1202	15253	12076	17403	3929	36279
2021 All pre Euro V buses to Euro VI	3646	5937	-75	9508	7413	10788	1854	23460
2021 All pre Euro V HGV to Euro VI	195	-138	-18	40	28	44	-6	65
2021 All pre Euro V bus and HGVs to Euro VI	3842	6100	-93	9849	7677	11174	1909	24302
2021 10% reduction in cars	5590	62672	108223	176486	152578	208264	113069	304904
2016-2021 fuel split	225582	406427	-303643	328367	215186	350581	-151415	1190917
2016-2021 all buses Euro VI	87173	127842	-1330	213684	166644	242486	41875	525111
2016-2021 all HGVs Euro VI	94071	109055	-1148	201979	157487	229210	39562	492542
2016-2021 all buses and HGVs Euro VI	181244	236897	-2478	415663	324131	471696	81437	1017653
2016-2021 all vans Euro 6	62666	204129	13611	280406	220930	319323	66326	684250
2016-2021 10% reduction in cars	41252	415007	686272	1142531	985808	1347209	721720	1991916

Health impacts

The damage costs take into account the effects of the emissions on chronic mortality and morbidity. The effects on health of air pollution changes can also be presented as quantified health impacts instead of the monetised impacts discussed in Section 2.2. The IGCB quantifies chronic mortality effects using factors giving the reduction in the number of life years lost over 100 years per tonne of pollutant. Appendix B shows the numbers of life years saved over 100 years as a result of improvement in air quality for each of the proposed scenarios.

Discussion

The “all buses and HGVs to Euro VI” and “10% reduction in cars” scenarios provide the largest reductions in overall damage costs. Applying the “all buses and HGVs to Euro VI” measure over the period 2016-2021 results in damage costs saved of £2.15 million for the Leeds Outer Ring Road area and £0.42 million for the Bradford Outer Ring Road area. Similarly, applying the “10% reduction in cars” measure over the period 2016-2021 results in damage costs saved of £4.63 million for the Leeds Outer Ring Road area and £1.14 million for the Bradford Outer Ring Road area. However, a large part of the damage costs saved by the reduction in car traffic is associated with reductions in the reduction in carbon dioxide emissions as a greenhouse gas rather than reductions in local pollution concentrations. The fuel split options provide larger damage costs saved for oxides of nitrogen and particulate matter but these are offset by the increase in carbon dioxide damage costs associated with the increased fuel use from petrol cars.

Compliance with EU limit values

Introduction

This section reviews air quality monitoring data for the Bradford and Leeds inner and outer Ring Road areas. It identifies the emission reductions required to achieve the EU limit values and compares the required reduction with the reduction expected from each of proposed measures in the Outer Ring Road areas. It considers the extent to which it is appropriate to apply the abatement cost approach.

Air quality monitoring

Leeds

Leeds City Council monitor nitrogen dioxide and particulate matter, PM_{10} concentrations at automatic monitoring sites throughout the city. The Council also monitors nitrogen dioxide concentrations by diffusion tube at sites throughout the city. Fig 2 shows the locations of the monitoring sites.

Fig. 2: Monitoring sites in Leeds.

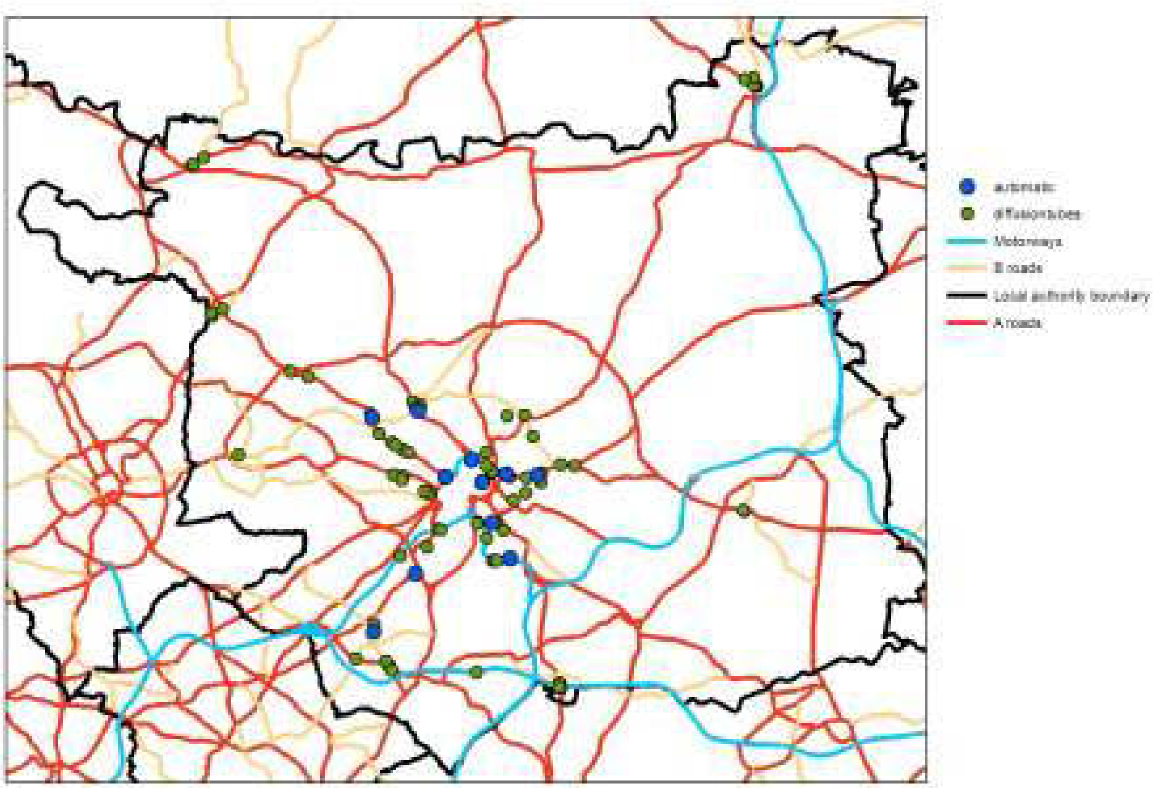


Table 6 lists the main characteristics of the automatic monitoring sites. It lists the Ordnance Survey eastings and northings, the type of device for monitoring PM_{10}, whether the site is in an Air Quality

Management Area (AQMA), whether is relevant public exposure at the site, the distance from the nearest kerb and whether the site represents local worst case exposure. All the sites monitor nitrogen dioxide concentrations. Two of the sites (Leeds Centre and Corn Exchange) are within the Inner Ring Road. Two of the sites (Millshaw and Queen Street, Morley) are outside the Outer Ring Road. The remaining sites are between the Inner and Outer Ring Roads.

Table 6: Automatic monitoring sites in Leeds

Site	Name	Type	Easting, m	Northing, m	PM_{10} monitor	In AQMA?	Relevant exposure?	Distance from kerb	Does site represent worst case local exposure?
A1	Leeds Centre	Urban centre	429969	434259	FDMS	N	N	N/A	N
A2	Corn Exchange	Kerbside	430358	433422	TEOM	N	Y(1 hr NO2)	1m	Y
A3	Headingly	Kerbside	427989	436045	TEOM	N	Y(1 hr NO2)	1m	Y
A5	West Street	Urban centre	429011	433617	N/A	N	N	N/A	N
A6	Haslewood Close	Urban roadside	431274	433711	N/A	Y	Y(1m)	10m	Y
A7	Queen Street Morley	Urban roadside	426332	427870	N/A	N	Y(1m)	5m	Y
A8	Millshaw	Suburban background	427894	430040	TEOM	N	N	N/A	N
A9	Jack Lane, Hunslet	Urban roadside	430731	431911	TEOM	N	y	5m	Y
A12	Norman Row	Urban roadside	426277	435816	N/A	N	Y(1m)	2m	Y
A15	Victoria Avenue	Urban roadside	432419	433674	N/A	N	Y	15m	N
A16	Woodhouse Hill Road	Urban roadside	431407	430597	TEOM	N	Y	30m	N

Leeds City Council Progress Report 2011 indicates that the limit values for PM_{10} were met in each year 2007-2010 at each of the sites monitoring this pollutant. Monitoring data for this pollutant for 2012 was not available for most of the sites: however the limit value continued to be met at the Corn Exchange in 2012.The abatement cost approach is not appropriate for this pollutant because the concentrations have not exceeded the limit values. The damage costs saved from reductions in emissions of particulate matter ($PM_{2.5}$) were assessed in Section 2.

Table 7 provides a summary of the nitrogen dioxide concentration measured in 2010 and 2012 at the continuous monitoring sites. It shows the annual mean concentrations measured in 2010 and 2012 and the number of exceedences of the limit of 200 µg m^{-3} as an hourly mean not to be exceeded more than 18 times in a calendar year.

Table 7: Summary of measured nitrogen dioxide concentrations at automatic sites in Leeds

Site	Name	Area	Relevant exposure?	Annual mean, µg m^{-3}		Data capture, 2012	No. of exceedences	
				2010	2012		2010	2012
A1	Leeds Centre	IRR	N	36	36	49%	1	0 (137)
A2	Corn Exchange	IRR	Y(1 hr NO2)	60	55	95%	2 (171)	0
A3	Headingley	ORR	Y(1 hr NO2)	51	44	46.5%	0	0(156)
A5	West Street	ORR	N	43			2	
A6	Haslewood Close	ORR	Y(1m)	46	46	94.8%	4	0
A7	Queen Street Morley	Urban Area	Y(1m)	45			13	
A8	Millshaw	Urban Area	N	34			0	
A9	Jack Lane, Hunslet	ORR	y	50	45	96.2%	28	1
A12	Norman Row	ORR	Y(1m)	56			0	
A15	Victoria Avenue	ORR	Y	38			7	
A16	Woodhouse Hill Road	ORR	Y	38			0(131)	

The hourly mean nitrogen dioxide concentration did not exceed the EU limit value of 200 µg m^{-3} more than 18 times in 2010 or 2012 at any of the monitoring sites. The abatement cost approach is not appropriate for this objective because the concentrations have not exceeded the limit value.

Table 8 lists details of selected diffusion tube sites. The sites were selected where:

- The measured concentration in 2010 exceeded the limit value in 2010; and
  - There is relevant exposure; or
  - The site is not representative of local worst case exposure.

Table 8: Selected nitrogen dioxide diffusion tube sites in Leeds

Site	Name	Type	Easting, m	Northing, m	In AQMA ?	Relevant exposure?	Distance from kerb	Does site represent worst case local exposure?	Annual mean concentration, 2010, µg m^{-3}	Area
D6	Haslewood Close	Co-located residential façade	431268	433701	Y	Y	7m	Y	45	ORR
D7	Haslewood Close	Co-located residential façade	431268	433701	Y	Y	7m	Y	46	ORR
D8	Haslewood Close	Residential façade	431264	433704	Y	Y	8m	N	48	ORR
D9	Haslewood Close	Residential façade	431269	433720	Y	Y	8m	N	44	ORR
D16	19/20 Ladybeck Close	Residential façade	430750	433813	Y	Y	13m	N	44	IRR
D18	6 Ladybeck Close	Residential façade	430711	433778	Y	Y	11m	N	43	IRR
D19	Ladybeck Reception	Residential façade	430695	433835	Y	Y	14m	N	44	IRR
D20	25 Ladybeck Close	Residential façade	430727	433834	Y	Y	6m	Y	50	IRR
D31	Railway Terrace, East Ardsley	Residential façade	430151	426388	N	Y	14m	Y	45	Urban area
D35	110 Jack Lane, Hunslet	Residential façade	430720	431898	N	Y	7m	Y	46	ORR
D36	7 Blakeney Grove, Middleton	Residential façade	430773	430515	N	Y	22m	N	43	ORR
D37	21 Blakeney Grove, Middleton	Residential façade	430819	430515	N	Y	21m	Y	40	ORR
D38	45 Blakeney Grove, Middleton	Residential façade	430910	430512	N	Y	25m	N	40	ORR

Site	Name	Type	Easting, m	Northing, m	In AQMA ?	Relevant exposure?	Distance from kerb	Does site represent worst case local exposure?	Annual mean concentration, 2010, µg m^{-3}	Area
D39	39 Westgate Lane, Lofthouse	Residential façade	433246	425936	N	Y	35m	Y	41	Urban area
D41	14 Broadland Way, Lofthouse	Residential façade	433274	425806	N	Y	60m	N	40	Urban area
D42	33 Broadland Way, Lofthouse	Residential façade	433195	425840	N	Y	36m	N	41	Urban area
D43	83 New Road Side. Horsforth	Residential façade	423925	437335	N	Y	1m	Y	56	ORR
D44	253 New Road Side, Horsforth	Residential façade	423269	437505	N	Y	2m	Y	49	ORR
D45	2 Norman Row, Kirkstall	Residential façade	426276	435820	N	Y	2m	Y	60	ORR
D46	4 De Lacy Mount, Kirkstall	Residential façade	426214	435955	N	Y	7m	N	43	ORR
D47	2 Back Norman Mount, Kirkstall	Residential façade roadside	426216	435945	N	Y	3m	Y	71	ORR
D48	2 Haddon Place, Kirkstall	Residential façade roadside	427437	434618	N	Y	3m	Y	44	ORR
D60	Kirkstall Road	Colocated roadside	427147	434789	N	N	5m	N	41	ORR
D66	131 Harehills Lane	Residential façade	431928	435910	N	Y	7m	Y	43	ORR
D74	Norman Street Kirkstall Road	Roadside	426291	435800	N	Y	12m	N	46	ORR
D76	302 York Road	Residential façade	432569	433764	N	Y	8m	Y	41	ORR
D78	2 Eyres Terrace	Residential façade	427089	433686	N	Y	6m	Y	45	ORR

Site	Name	Type	Easting, m	Northing, m	In AQMA ?	Relevant exposure?	Distance from kerb	Does site represent worst case local exposure?	Annual mean concentration, 2010, µg m^{-3}	Area
D82	11 Tilbury Row	Residential façade	428736	431676	N	Y	41m	N	41	IRR
D96	21 St James Street, Wetherby	Residential roadside	440408	448407	N	Y	1m	Y	41	Urban area
D98	76 Woodhouse Hill Road	Residential façade	431347	430578	N	Y	22m	Y	43	ORR
C99	71 Longroyd Terrace	Residential façade	430526	431348	N	Y	21m	Y	43	ORR
D105	76 Selby Road, Garforth	Suburban kerbside	440034	432364	N	Y	4m	Y	56	Urban area
D107	4 Micklefield Mews, Rawdon	Residential façade roadside	420355	439566	N	Y	2m	Y	42	Urban area
D109	107 Bradford Road, Otley	Residential façade roadside	419598	445168	N	Y	3m	Y	51	Urban area
D110	23 Westgate, Otley	Residential façade roadside	420037	445462	N	Y	2m	Y	52	Urban area
D114	8 Main Street, Pool	Residential façade roadside	424507	455151	N	Y	2m	Y	71	Urban area
D117	15 Ashfield Road, Morley	Residential façade roadside	425691	426879	N	Y	2m	Y	47	Urban area
D119	109 Bridge Street, Morley	Residential façade roadside	426788	426773	N	Y	6m	Y	55	Urban area
D120	2 Chapel Lane, Morley	Residential façade roadside	426362	428162	N	Y	2m	Y	57	Urban area
D121	32 Otley Road, Headingley	Residential façade roadside	427906	436195	N	Y	2m	Y	61	ORR
D122	North Street, Ls2	Residential	430522	434022	N	Y	2m	Y	43	ORR

Site	Name	Type	Easting, m	Northing, m	In AQMA ?	Relevant exposure?	Distance from kerb	Does site represent worst case local exposure?	Annual mean concentration, 2010, µg m^{-3}	Area
		façade roadside								
D123	Victoria Avenue	Residential façade roadside	432419	433674	N	Y	15m	Y	47	ORR
D124	21 Rein Road, Morley	Residential façade roadside	426990	426466	N	Y	4m	Y	49	Urban area
D125	12 Tilbury Terrace	Residential façade	428824	431658	Y	Y	17m	Y	43	IRR
D126	73 East Park Parade	Residential façade roadside	432527	433409	N	Y	2m	Y	44	ORR

There is little residential exposure within the Inner Ring Road because most of the buildings have retail or commercial uses. There are consequently few diffusion tube sites within the Inner Ring Road. The measured concentrations in Ladybeck Close (D16, D18, D19 and D20) exceeded the limit value of 40 µg m^{-3}. However, these concentrations are most affected by emissions from the A64(M) and the A61, which are outside the Inner Ring Road area. The measured concentrations at Tilbury Terrace (D82, D125) also exceeded the limit value in 2010: however, these concentrations are most affected by emissions from the M621, which is also outside the Inner Ring Road area. The measured concentration at the Corn Exchange automatic continuous monitoring site also exceeded the limit value: however, this site is not considered representative of public exposure over the annual mean period. There are thus no monitoring sites where there is representative exposure above the limit value in the area primarily affected by emissions from within the Inner Ring Road area. The abatement cost approach may therefore not be appropriate for this area. The damage costs saved by the LEZ measures in the IRR area were estimated in Section 2 of this report. It may be necessary to review this if further monitoring becomes available or dispersion modelling studies show that the limit value is exceeded at residential locations within the Inner Ring Road.

The nitrogen dioxide concentration exceeded the annual mean limit value in 2010 at several of the diffusion tube sites in the Outer Ring Road area. The abatement cost approach is therefore appropriate for assessing the potential benefit from measures applied in the Outer Ring Road area.

Particularly high concentrations, greater than 50 µg m^{-3} were observed at sites in the Outer Ring Road area listed in Table 9. Table 9 identifies local features that might contribute to high concentrations at these locations. The abatement cost approach may overestimate the potential benefits of measures if too much emphasis is placed on reducing concentrations at local hot spots.

Table 9: Local features at monitoring sites that measured high concentrations

Site	location	Local features
D43	83 New Road Side. Horsforth	Pedestrian crossing
D45	2 Norman Row, Kirkstall	Proximity to gas boiler outlet.
D47	2 Back Norman Mount, Kirkstall	Bus stop
D121	32 Otley Road, Headingley	Traffic light junction

Bradford

City of Bradford Council monitors nitrogen dioxide and particulate matter, PM_{10} concentrations at automatic monitoring sites throughout the city. The Council also monitors nitrogen dioxide concentrations by diffusion tube at sites throughout the city. Fig 3 shows the locations of the monitoring sites in the city area.

Fig. 3: Monitoring sites in Bradford city

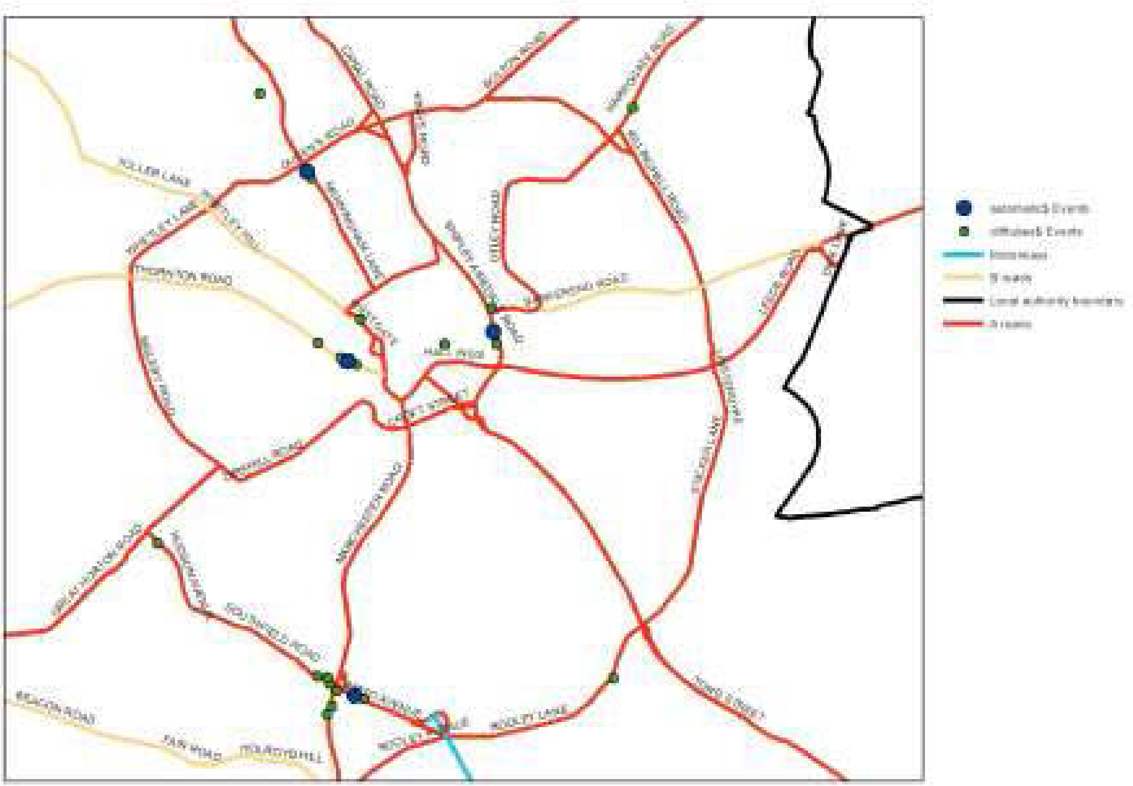


Table 9 list the main characteristics of the automatic monitoring sites. It lists:

- the Ordnance Survey eastings and northings,
- whether the site is in an Air Quality Management Area (AQMA),
- whether there is relevant public exposure at the site,
- the distance from the nearest kerb and
- whether the site represents local worst case exposure.

All the sites monitor nitrogen dioxide concentrations. Three of the sites (Bingley, Keighley and Shipley Airedale Road also measure particulate matter, PM_{10} concentrations. The Shipley Airedale site is within the Inner Ring Road but is influenced primarily by traffic on the Inner Ring Road at Shipley Airedale Road. Three of the sites (Bingley, Keighley and Saltaire roundabout) are outside the Outer Ring Road. The remaining sites are between the Inner and Outer Ring Roads, although the Manchester Road site is primarily influenced by traffic on the Outer Ring Road at Mayo Avenue.

Table 9: Automatic monitoring sites in Bradford

Site	Type	Easting, m	Northing, m	In AQMA?	Relevant exposure?	Distance from kerb, m	Does site represent worst case local exposure?	Measured concentration in 2011, µg m^{-3}	Area
Bingley	Urban centre	410881	438942	N	N	5	N	21	urban area
Keighley	Urban centre	406065	441270	N	n	5	n	29	urban area
Saltaire roundabout	Kerbside	413697	437722	N	y	2	y	33	urban area
Manningham Lane	Kerbside	415584	434455	Y	y	1.5	y	49 (2010)	ORR
Manchester Road	Kerbside	415933	430569	Y	y	2	y	71	ORR
Thornton Road	Kerbside	415887	433047	Y	y	2	y	47	ORR
Shipley Airedale Road	Kerbside	416967	433265	Y	y	2	y	54	IRR

City of Bradford Council Updating and Screening Report 2012 indicates that the limit values for PM_{10} were met in 2011 at each of the sites monitoring this pollutant. The abatement cost approach is therefore not appropriate for this pollutant because the concentrations have not exceeded the limit values. The damage costs saved from reductions in emissions of particulate matter ($PM_{2.5}$) were assessed in Section 2.

Table 10 provides a summary of the nitrogen dioxide concentration measured in 2011 at the Bradford continuous monitoring sites. It shows the measured annual mean concentration in 2011 and the number of exceedences of the hourly limit of 200 µg m^{-3} not to be exceeded more than 18 times in a calendar year.

Table 10: Results of continuous monitoring of nitrogen dioxide concentrations in Bradford

Site	Area	Relevant exposure ?	Annual mean, µg m^{-3}	Data capture, 2011	Number of exceedences
Bingley	urban area	N	21	81	0
Keighley	urban area	n	29	78	0
Saltaire roundabout	urban area	y	33	88	0
Manningham Lane	ORR	y	49	74	0
Manchester Road	ORR	y	71	80	39
Thornton Road	ORR	y	47	80	0
Shipley Airedale Road	IRR	y	54	85.5	0

The hourly mean nitrogen dioxide concentration only exceeded the EU limit value of 200 µg m^{-3} more than 18 times in 2010 or 2012 at the Manchester Road monitoring site. The Manchester Road site is primarily influenced by traffic emissions on the Outer Ring Road itself, which is outside the Outer Ring Road candidate LEZ. The abatement cost approach is therefore not appropriate for assessing the benefits of reducing emissions within the candidate LEZ areas for this objective.

Table 11 lists details of diffusion tube sites within the Outer Ring Road and measured concentrations for 2011.

There were four diffusion tube sites and one continuous monitoring site within the Inner Ring Road measuring concentrations in 2011. However, the Shipley Airedale and Treadwell Mills sites are influenced primarily by traffic on the Shipley Airedale Road, which is outside the Inner Ring Road candidate LEZ. Similarly, the St Mary's Presbytery site is influenced primarily by the traffic on Westgate, which is also outside the Inner Ring Road candidate LEZ. The measured concentrations at sites within the Inner Ring Road are less than the limit value of 40 µg m^{-3}. There are thus no monitoring sites where there is representative exposure above the limit value in the area primarily affected by emissions from within the Inner Ring Road area. The abatement cost approach may therefore not be appropriate for this area. It may be necessary to review this if further monitoring becomes available or dispersion modelling studies show that the limit value is exceeded at residential locations within the Inner Ring Road. The damage costs saved by the LEZ measures in the IRR area were estimated in Section 2 of this report.

The measured concentrations exceeded the annual mean limit value at many of the monitoring sites within the Outer Ring Road candidate area (which includes the Inner Ring Road area). The abatement cost approach is therefore appropriate for this area.

Table 11: Selected nitrogen dioxide diffusion tube measurements in Bradford

Site	Type	X	Y	In Aqma?	Relevant exposure?	Distance to kerb ,m	Does site represent worst case local exposure?	Measured nitrogen dioxide concentration 2011, µg m^{-3}	Area
Manningham Lane	Kerbside	415584	434455	Y	Y	1.5	Y	79	ORR
St Mary's Presbytery	Kerbside	415983	433355	Y	Y	2	N	62	IRR
East Parade Apartments	Kerbside	416993	433172	Y	Y		N	38	IRR
102 Thornton Road	Kerbside	415872	433042	Y	Y	0.5	Y	41	ORR
Mayo Avenue Unit	Kerbside	415937	430573	Y	Y	2	Y	49	ORR
Treadwell Mills	Kerbside	416966	433265	Y	Y	1.5	Y	75	IRR
Central House	Kerbside	416605	433172	N	N	2	N	34	IRR
Cock And Bottle Public House	Kerbside	416950	433436	Y	Y	0.5	Y	61	ORR
TH03 Arkwright Hall, Thornton Road	Urban background	415862	433033	Y	Y	1.5	Y	42	ORR
TH04 Lord Clyde, Thornton Road	Kerbside	415950	433019	Y	Y	1	Y	46	ORR
Th01 112 Thornton Road	Kerbside	415664	433183	Y	Y	0.5	Y	42	ORR
Man1 245 Manningham Lane	Kerbside	415617	434401	Y	Y	2	Y	46	ORR

Required emission reductions

Defra provides a NO_x to NO_2 converter[23] to calculate nitrogen dioxide concentrations from roadside oxides of nitrogen concentrations. The NO_x to NO_2 converter was used to estimate the reduction in emissions required to meet the annual mean limit value for nitrogen dioxide in 2016 and 2021 at diffusion tube sites. The estimates provide upper bound emission reductions which provide upper limits for abatement costs. The required emission reductions are compared with the emissions reductions provided by the proposed LEZ measures.

The calculations assumed that the emissions reductions estimated by Leeds City Council for the candidate LEZ areas apply uniformly across each area. They thus only provide indicative estimates of the potential benefits of the proposed measures. However, they may overestimate the effect of some measures. For example, they may overestimate the effect of measures to reduce bus emissions at the Shipley Airedale/Treadwell Mills site because the Shipley Airedale Road is not on the main bus routes. More detailed dispersion modelling, to be carried out by Leeds City Council, will provide more robust estimates of the effects of emissions reductions on concentrations. However, the estimates are adequate for the purposes of estimating the abatement costs saved by the measures.

The NO_x to NO_2 converter calculates roadside nitrogen dioxide concentrations taking into account:

- Background oxides of nitrogen concentrations
- The contribution from the road to oxides of nitrogen concentrations
- The proportion of oxides of nitrogen released as nitrogen dioxide

The NO_x to NO_2 converter itself provides estimates of regional background ozone, oxides of nitrogen and nitrogen dioxide used in the calculation.

Defra's background maps[24] provided background oxides of nitrogen concentrations for each of the monitoring sites for 2012, 2016 and 2021. The estimates were adjusted to remove the contribution from roads in order to prevent double counting. Leeds City Council provided estimates of emissions for primary nitrogen dioxide and oxides of nitrogen for each area and for each scenario: the primary nitrogen dioxide fraction was calculated as the ratio of these emissions.

The contribution from roads to oxides of nitrogen concentrations was estimated for 2012 as follows. An initial estimate of the road contribution was made for each diffusion tube site. The initial estimate was then adjusted iteratively until the nitrogen dioxide concentration calculated by the NO_x to NO_2 converter matched the measured concentrations. For this analysis, it was assumed, conservatively that concentrations in 2012 are approximately the same as those in 2010 or 2011. Table 7 indicates that concentrations at the automatic monitoring sites in Leeds had reduced slightly at some sites but remained constant at others.

The effects of baseline emission reductions in the candidate LEZs were then estimated for 2016 and 2021. The road contribution for 2012 was scaled for future scenarios by the ratio of the future emission to the 2012 baseline emission. The NO_x to NO_2 converter was then used to estimate future concentrations based on this scaled emission.

[23] http://laqm.defra.gov.uk/tools-monitoring-data/no-calculator.html

[24] http://laqm.defra.gov.uk/review-and-assessment/tools/background-maps.html

The required contribution from roads to meet the limit value in 2016 and 2021 was estimated in a similar way. The initial estimate of the road contribution was adjusted iteratively until the nitrogen dioxide concentration equalled 40 µg m^{-3}. The emission that would achieve the limit value was then estimated as the 2012 emission multiplied by the ratio of the calculated road contributions. The emission reductions required in 2016 and 2021 were then estimated by subtracting the calculated values from the 2016 and 2021 baseline emissions.

Leeds

Table 12 shows the projected concentrations for 2016 and 2021 for diffusion tube sites in the Outer Ring Road area that exceeded the limit value in 2010. It also shows the absolute and percentage reduction from the 2016 or 2021 Outer Ring Road base emissions required to meet the limit value at each site. The projected concentration exceeds the limit value in 2016 at many of the sites. However, by 2021 the projected concentrations are less than the limit value at most of the sites. Three sites are projected to remain above the limit value: the abatement costs saved will be overestimated if the measured concentrations at these sites are not representative of wider exposure.

Table 12: Projected nitrogen dioxide concentrations at Leeds diffusion tube sites and required reduction in emissions to meet the EU limit value

Site	Name	Projected concentration, µg m			Required emission reduction,% of base		Required emission reduction from baseline, tonnes	
		2012 base	2016 base	2021 base	2016	2021	2016	2021
d6	Haslewood Close	45.0	39.2	31.7				
d7	Haslewood Close	46.0	40.1	32.4	0.7		6	
d8	Haslewood Close	48.0	42.0	33.9	10.0		75	
d9	Haslewood Close	44.0	38.3	31.0				
d35	110 Jack Lane, Hunslet	46.0	40.0	31.8				
d36	7 Blakeney Grove, Middleton	43.0	37.0	29.5				
d37	21 Blakeney Grove, Middleton	40.0	34.3	27.4				
d38	45 Blakeney Grove, Middleton	40.0	34.3	27.4				
d43	83 New Road Side. Horsforth	56.0	49.7	39.2	30.7		231	
d44	253 New Road Side, Horsforth	49.0	42.9	33.8	11.3		85	
d45	2 Norman Row, Kirkstall	60.0	53.8	42.5	39.3	9.3	296	44
d46	4 De Lacy Mount, Kirkstall	43.0	37.3	29.4				
d47	2 Back Norman Mount, Kirkstall	71.0	64.8	51.3	55.2	33.0	416	157
d48	2 Haddon Place, Kirkstall	44.0	38.3	30.5				
d60	Kirkstall Road	41.0	35.6	28.3				
d66	131 Harehills Lane	43.0	37.3	29.3				
d74	Norman Street Kirkstall Road	46.0	40.2	31.6	0.8		6	
d76	302 York Road	41.0	35.6	28.5				
d78	2 Eyres Terrace	45.0	39.3	31.4				
d98	76 Woodhouse Hill Road	43.0	37.0	29.6				
c99	71 Longroyd Terrace	43.0	37.2	29.7				
d121	32 Otley Road, Headingley	61.0	54.8	43.1	40.3	11.3	304	54
d122	North Street, Ls2	43.0	37.4	29.8				
d123	Victoria Avenue	47.0	41.1	32.8	5.1		39	
d126	73 East Park Parade	44.0	38.3	30.7				

Table 13 shows the reduction in emissions in the Outer Ring Road area with respect to the 2016 or 2021 baselines for each of the scenarios. These values may be compared with the required reductions. Generally, the emission reductions supplied by the measures are not sufficient to meet the limit value at all sites. It is therefore appropriate to estimate the abatement cost saved on the entire emissions reductions. However, if the abatement costs saved (i.e. the benefit of the measures) may be overestimated if the measured concentrations at, for example 2 Back Norman Mount, are not representative of wider exposure.

Table 13: Emission reductions provided by Leeds ORR scenarios compared with required reductions

Measure	Reduction, tonnes	
	2016	2021
2016 fuel split	177.0	
2016 all buses Euro VI	134.2	
2016 all HGV Euro VI	100.8	
2016 all bus and HGVs Euro VI	235.1	
2016 All vans Euro 6	50.8	
2016 Euro II &Euro III retrofit	26.8	
2016 all Pre Euro IV buses Euro VI	50.2	
2016 all Pre Euro IV HGV Euro VI	5.8	
2016 Pre Euro IV bus and HGVs to Euro VI	56.0	
2016 10% reduction in car traffic	34.1	
2021 fuel split		131.9
2021 All buses to Euro VI		54.1
2021 All HGVs to Euro VI		35.0
2021 All bus and HGVs to Euro VI		89.0
2021 All vans to Euro 6		14.7
2021 All pre Euro V buses to Euro VI		24.6
2021 All pre Euro V HGV to Euro VI		8.1
2021 All pre Euro V bus and HGVs to Euro VI		32.7
2021 10% reduction in car traffic		25.5
Required reductions		
2 Back Norman Mount, Kirkstall	416	157
32 Otley Road, Headingley	304	54
2 Norman Row, Kirkstall	296	44
83 New Road Side. Horsforth	231	0

Bradford

Table 14 shows the projected concentrations for 2016 and 2021 for diffusion tube sites in the Outer Ring Road area that exceeded the limit value in 2011. It also shows the absolute and percentage reduction from the 2016 or 2021 Outer Ring Road base emissions required to meet the limit value at each site. The projected concentration exceeds the limit value in 2016 at many of the sites. However, by 2021 the projected concentrations are less than the limit value at most of the sites. Three sites are projected to remain above the limit value: the abatement costs saved will be overestimated if the measured concentrations at these sites are not representative of wider exposure.

Table 14: Projected nitrogen dioxide concentrations at Bradford diffusion tube sites and required reduction in emissions to meet the EU limit value

Name	Projected concentration, µg m			Required emission reduction,% of base		Required emission reduction from baseline, tonnes	
	2012 base	2016 base	2021 base	2016	2021	2016	2021
Manningham Lane	79	72.7	55.9	63	41	107	44
St Mary's Presbytery	62	55.0	43.2	46	14	78	14
East Parade Apartments	38	32.6	26.2				
102 Thornton Road	41	34.9	28.6				
Mayo Avenue Unit	49	43.1	33.1	12		20	
Treadwell Mills	75	68.5	53.0	61	38	104	40
Central House	34	29.0	23.7				
Cock And Bottle Public House	61	54.5	42.2	42	9	72	9
TH03 Arkwright Hall, Thornton Road	42	35.8	29.2				
TH04 Lord Clyde, Thornton Road	46	39.5	31.8				
Th01 112 Thornton Road	42	35.8	29.2				
Man1 245 Manningham Lane	46	40.0	30.8	0		0	

Table 15 shows the reduction in emissions in the Outer Ring Road area with respect to the 2016 or 2021 baselines for each of the scenarios. These values may be compared with the required reductions. Generally, the emission reductions supplied by the measures are not sufficient to meet the limit value at all sites. It is therefore appropriate to estimate the abatement cost saved on the entire emissions reductions. However, the abatement costs saved (i.e. the benefit of the measures) may be overestimated if the measured concentrations at, for example Manningham Lane, are not representative of wider exposure.

Table 15: Emission reductions provided by Bradford ORR scenarios compared with required reductions

Scenario	Emission reduction, tonnes	
	2016	2021
2016 fuel split	46.4	
2016 all buses Euro VI	22.8	
2016 all HGV Euro VI	24.7	
2016 all bus and HGVs Euro VI	47.5	
2016 All vans Euro 6	17.3	
2016 Euro II &Euro III retrofit	4.4	
2016 all Pre Euro IV buses Euro VI	8.3	
2016 all Pre Euro IV HGV Euro VI	3.8	
2016 Pre Euro IV bus and HGVs to Euro VI	12.1	
2016 10% reduction in car traffic	8.5	
2021 fuel split		33.8
2021 All buses to Euro VI		8.0
2021 All HGVs to Euro VI		8.6
2021 All bus and HGVs to Euro VI		16.6
2021 All vans to Euro 6		4.9
2021 All pre Euro V buses to Euro VI		4.0
2021 All pre Euro V HGV to Euro VI		0.2
2021 All pre Euro V bus and HGVs to Euro VI		4.3
2021 10% reduction in car traffic		6.2
Required reductions		
Manningham Lane	107	44
Treadwell Mills	104	40
St Mary's Presbytery	78	14
Cock And Bottle Public House	72	9

Unit abatement costs

Introduction

This section provides a summary of the abatement costs avoided by the proposed measures in the Outer Ring Road areas of Bradford and Leeds. The abatement costs have not been calculated for the Inner Ring Road areas because this approach is not appropriate unless concentrations exceed limit values at relevant receptor locations.

Choice of unit abatement costs

Defra developed estimates of the unit costs for emission abatement using a marginal abatement cost curve (MACC) to estimate the potential supply of abatement at a national scale. The MACC reflects the abatement potential and cost for a range of different abatement technologies. Wider impacts on society are incorporated, including: impacts on other pollutants; energy and fuel impacts, and health impacts (damage costs). The abatement represented by the national average compliance gap is compared against the MACC to estimate an indicative unit cost of abatement. It is only indicative because both the gap and the abatement potential from different technologies will vary between areas.

The unit cost is provided in terms of the marginal cost of emissions, usually measured in £/tonne. Table 16 below shows the menu of abatement costs which have been derived from the NO_x MACC. These are derived from the full package of measures that would mitigate the typical compliance gap, assessed for the year 2015. It is an extract from the complete MACC. The measures shown include those which may represent the marginal technology once all cheaper options have been exhausted. It also includes some of the cheaper options considered for the Leeds and Bradford LEZs.

Defra's guidance recommends that the appraiser should decide which value is most appropriate for a particular case. If there is no clear rationale to use a particular measure the recommended default value is £29,150.

Sensitivity analysis is recommended to reflect the uncertainty in the abatement costs, using both a higher and lower abatement cost technology selected from Table 16. The selection of these technologies is for the judgement of the analyst. If the default value of £29,150 is used then it is suggested that a range of £28,000 - £73,000 is appropriate, derived from the rounded values of the abatement technologies on either side of the default value in Table 16.

The proposed measures for the Bradford and Leeds LEZ include some of the cheaper measures included in the national MACC, in particular the retrofitting of Euro II and Euro III buses with Selective Catalytic Reduction. It is appropriate to use these specific values for the abatement cost where they are lower than the default value of £29,150 because the national MACC assumes these measures will be applied. The default value is appropriate for measures that are not included in the national MACC.

Table 16: Marginal abatement costs of national measures to reduce oxides of nitrogen emissions

Sector	Sub sector	Baseline Technology	Abatement Measure	Marginal Abatement Cost (£/Tonne of NOx) 2015
RT	HGV	Euro II	SCR	5099
RT	HGV	Euro III	SCR	5380
RT	Buses	Euro II	SCR	6251
RT	Buses	Euro I	Hybrid	6500
RT	Buses	Euro I	SCR	6625
RT	*Buses*	*Euro III*	*SCR*	*7257*
RT	Buses	Euro II	Hybrid	7462
RT	HGV	Euro IV	SCR	8053
RT	Buses	Euro III	Hybrid	9423
RT	Buses	Euro IV	SCR	11889
RT	Buses	Euro I	Electric	14669
RT	Buses	Euro II	Electric	14872
RT	Buses	Euro III	Electric	17352
RT	Articulated HGV	New Euro V	Euro VI	17743
RT	Buses	Euro IV	Hybrid	18391
Commercial	Buildings		Boiler replacement	19332
RT	Buses	New Euro V	Euro VI	24852
RT	Rigid HGV	New Euro V	Euro VI	28374
RT	**Buses**	**Euro IV**	**Electric**	**29150**
RT	Buses	Euro V	Hydrogen	72932
RT	Diesel LGV - class 1	New Euro 5 class I	Euro 6	79323
RT	Diesel LGV	Euro 1	Electric	100665
RT	Diesel LGV	Euro 2	Electric	111619
RT	Petrol cars	Euro 1	Electric	112030
RT	Diesel cars	Euro 1	Electric	135949
RT	Diesel LGV - class 2	New Euro 5 class II	Euro 6	144124
RT	Diesel LGV - class 3	New Euro 5 class III	Euro 6	144124
RT	Diesel cars	Euro 2	Electric	156046
RT	Diesel LGV	Euro 5	Electric	240484
RT	Diesel LGV	Euro 3	Electric	262466
RT	Petrol cars	Euro 2	Electric	280450
RT	Diesel cars	Euro 3	Electric	304593

RT=Road Transport

Abatement costs avoided

Tables 17 and 18 show the abatement costs avoided for each of the emission reduction measures applied to the Bradford and Leeds Outer Ring Road areas. As discussed in Section 3, it is not appropriate to apply the abatement cost methodology to the Inner Ring Road areas. Tables 17 and 18 show the emission reduction for each measure compared with the 2016 or 2021 base case, as appropriate. It shows the unit abatement cost applied in each case and the net present value (base year 2015) of the abatement cost avoided by the measure. A discount rate of 3.5% was applied to future year abatement costs avoided: this discount rate has been used throughout this report.

The abatement cost methodology is applicable while nitrogen dioxide concentrations at relevant receptors throughout the area remain above the limit value. The analysis in Section 3 indicated that the concentrations at the most polluted sites would remain above the limit value for nitrogen dioxide following the application of each of the measures. The abatement cost avoided has therefore been calculated based on the total emission reduction for each measure.

Table 17 and 18 show the value of the national abatement costs avoided by the measures for single years, 2016 or 2021. It also shows the value of the costs avoided over the period 2016-2021 for five measures.

The “fuel split” and “all bus and HGV to Euro VI” options provide the largest abatement cost avoided in both Bradford and Leeds. The Euro II and Euro III retrofit options provide the smallest cost avoided.

Table 17: Abatement costs saved in the Leeds Outer Ring Road area

Scenario	Emission reduction, tonnes 2016	Emission reduction, tonnes 2021	Unit abatement cost, £(2015)	Abatement cost, £(2015)
2016 fuel split	**177**		29,150	4,985,072
2016 all buses Euro VI	134.2		29,150	3,779,643
2016 all HGV Euro VI	100.8		29,150	2,838,957
2016 all bus and HGVs Euro VI	235.1		29,150	6,621,415
2016 All vans Euro 6	50.8		29,150	1,430,744
2016 Euro II &Euro III retrofit	26.8		7,257	187,911
2016 all Pre Euro IV buses Euro VI	50.2		29,150	1,413,845
2016 all Pre Euro IV HGV Euro VI	5.8		29,150	163,353
2016 Pre Euro IV bus and HGVs to Euro VI	56		29,150	1,577,198
2016 10% reduction in cars	34.1		29,150	960,401
2021 fuel split		131.9	29,150	3,127,816
2021 All buses to Euro VI		54.1	29,150	1,282,903
2021 All HGVs to Euro VI		35	29,150	829,974
2021 All bus and HGVs to Euro VI		89	29,150	2,110,505
2021 All vans to Euro 6		14.7	29,150	348,589
2021 All pre Euro V buses to Euro VI		24.6	29,150	583,353
2021 All pre Euro V HGV to Euro VI		8.1	29,150	192,080
2021 All pre Euro V bus and HGVs to Euro VI		32.7	29,150	775,433
2021 10% reduction in cars		25.5	29,150	604,695
2016-2021 fuel split	926.7		29,150	24,130,780
2016-2021 all buses Euro VI	564.9		29,150	14,873,559
2016-2021 all HGVs Euro VI	407.4		29,150	10,751,676
2016-2021 all buses and HGVs Euro VI	972.3		29,150	25,625,858
2016-2021 all vans Euro 6	196.5		29,150	5,199,413
2016-2021 10% reduction in cars	178.9		29,150	4,657,007

Table 18: Abatement costs saved in the Bradford Outer Ring Road area

Scenario	Emission reduction, tonnes 2016	Emission reduction, tonnes 2021	Unit abatement cost, £(2015)	Abatement cost, £(2015)
2016 fuel split	**46.4**		29,150	1,306,821
2016 all buses Euro VI	22.8		29,150	642,145
2016 all HGV Euro VI	24.7		29,150	695,657
2016 all bus and HGVs Euro VI	47.5		29,150	1,337,802
2016 All vans Euro 6	17.3		29,150	487,242
2016 Euro II &Euro III retrofit	4.4		7,257	30,851
2016 all Pre Euro IV buses Euro VI	8.3		29,150	233,763
2016 all Pre Euro IV HGV Euro VI	3.8		29,150	107,024
2016 Pre Euro IV bus and HGVs to Euro VI	12.1		29,150	340,787
2016 10% reduction in cars	8.5		29,150	238,399
2021 fuel split		33.8	29,150	801,518
2021 All buses to Euro VI		8	29,150	189,708
2021 All HGVs to Euro VI		8.6	29,150	203,936
2021 All bus and HGVs to Euro VI		16.6	29,150	393,645
2021 All vans to Euro 6		4.9	29,150	116,196
2021 All pre Euro V buses to Euro VI		4	29,150	94,854
2021 All pre Euro V HGV to Euro VI		0.2	29,150	4,743
2021 All pre Euro V bus and HGVs to Euro VI		4.3	29,150	101,968
2021 10% reduction in cars		6.2	29,150	147,099
2016-2021 fuel split	240.6		29,150	6,267,872
2016-2021 all buses Euro VI	92.4		29,150	2,438,139
2016-2021 all HGVs Euro VI	99.9		29,150	2,636,347
2016-2021 all buses and HGVs Euro VI	192.3		29,150	5,074,487
2016-2021 all vans Euro 6	66.6		29,150	1,762,756
2016-2021 10% reduction in cars	44.0		29,150	1,146,194

Significance of the impact on compliance

The abatement cost guidance for valuing changes in air quality recommends that more detailed analysis is required if the net present value of the air quality impacts valued using unit costs is greater than £50m. The net present value of the abatement costs avoided in the Bradford Outer Ring Road area is substantially less than £50m. The net present value of the abatement costs avoided in the Leeds Outer Ring Road area is, at most, approximately half of £50m. More detailed analysis is therefore not formally required. However, a sensitivity test based on a unit abatement cost of £73,000 per tonne NO_x gives an abatement cost avoided of £64.2m for the “2016-2021 all buses and HGVs Euro VI” scenario. This value is greater than £50m and so more detailed analysis may be appropriate.

Costs of the measures

Introduction

The implementation of Low Emission Zones in Bradford and Leeds will result in additional costs to the Councils for the enforcement of the LEZs and, more generally, the additional capital, operating and maintenance costs for the owners of vehicles associated with replacement or retrofitting vehicles. This section estimates the additional costs associated with the LEZs. The additional costs are compared with the abatement costs and damage costs avoided as the result of implementing the measures.

Bus replacement measures

Approach

Four of the measures potentially require the replacement of buses to meet the Euro VI standard by 2016:

- All buses Euro VI
- All bus and HGVs Euro VI
- Pre Euro IV buses Euro VI
- Pre Euro IV bus and HGVs to Euro VI

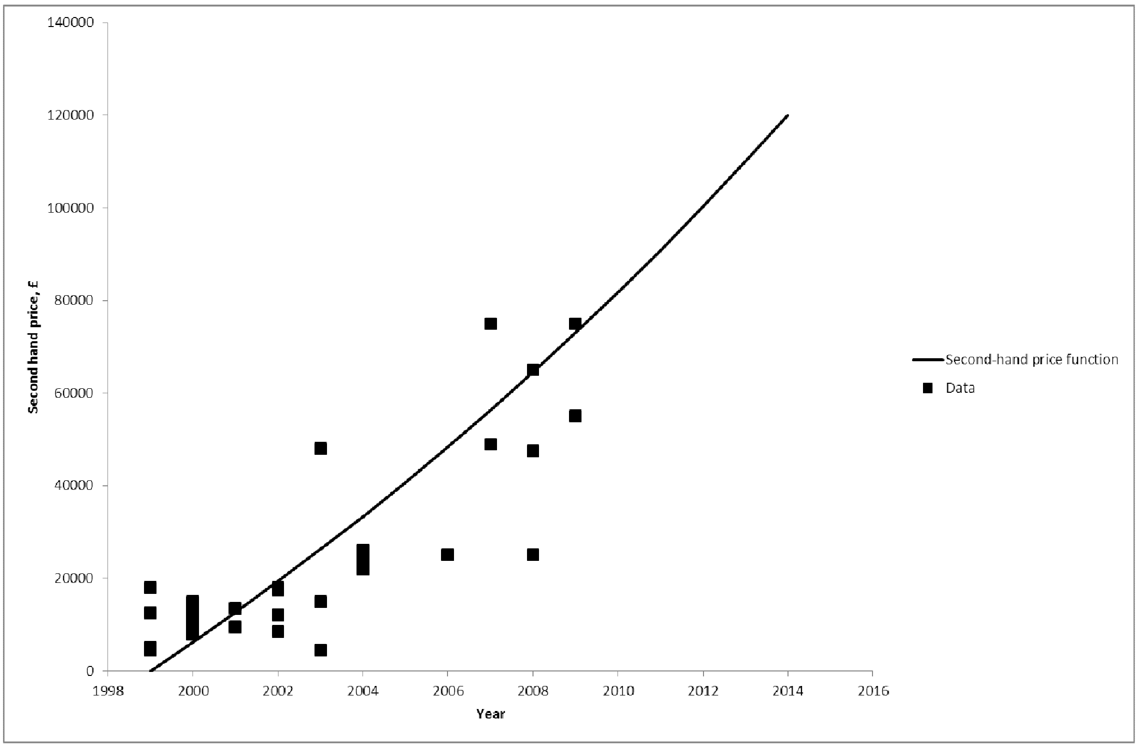
The changes will result in

- additional capital expenditure for the bus operator
- additional operational costs (e.g. urea consumption in selective catalytic reduction)
- additional maintenance costs.

The capital cost of a new bus depends on its specification. This assessment assumes a capital cost for a new bus in 2016 of £180,000. Many of the bus companies operate large fleets of buses across the UK and, in theory, it might be possible to accommodate a requirement to replace buses in Bradford or Leeds by redeploying the older buses throughout the country, at minimal cost. In practice, this will not always be possible and it will then be necessary to sell surplus buses second-hand.

The price of second-hand buses depends on the age, specification and condition of the buses. Fig.4 shows the advertised prices of second-hand buses on coachandbusmarket.com on 14th May 2014. Fig. 4 also shows the second-hand price function used in this assessment.

Fig. 4: Second-hand bus prices, 2014



New buses entering service in 2016 would be expected to continue operating for 15 years until 2030 based on the age profile of the buses currently operating on the main bus routes in Bradford and Leeds (see Table 22 below). Under the business as usual case, older buses would gradually be replaced throughout the period 2016-2030 with new buses that meet the Euro VI standard or better. The capital cost for the business as usual replacement of buses was calculated as the sum of the discounted equivalent annualised costs for the years of operation of the replacement buses[25] in the period 2016-2030, assuming a discount rate of 3.5%. In effect, this assumes that the cost of new buses can be spread throughout their lifetime: the method allows the costs to be attributed consistently to the life of the buses replaced in 2016.

The net capital cost of replacing buses in 2016 was calculated as the capital cost of a new bus (£180,000) less the second hand price of the replaced bus and less the business as usual capital cost. The 2016 capital costs have been discounted to a 2015 base year to allow comparison with the abatement costs and damage costs.

Additional operational costs for replacing Euro I-Euro IV buses with Euro VI buses were assumed to be £427 per year[26], based on estimates of the additional use of urea in selective catalytic reduction. It

[25] Calculated as $NPV = \frac{\mathrm{Pr}^{(q-p)} \square \left(\left(r^{(s-q)} - r^{n} \right) \right)}{(1 - r^{n})}$ where P is the capital cost of the bus, r=1/(1+d), d is the discount rate, s is the replacement year of the bus under business as usual, q is the implementation year of the measure, p is the base year and n is the life of the bus.

[26] Department for Transport Clean Bus Technology Application Project BREATHE (Bus REtrofit: ATtenuating Harmful Emissions)

was assumed that this cost would also be incurred by existing Euro V buses. The additional operating costs were assumed to apply also to buses replaced under the business as usual scenario.

Additional maintenance costs for replacing Euro I-Euro IV buses with Euro VI buses were assumed to be £1000 per year[27]. It was assumed that this cost would also be incurred by existing Euro V buses. The additional operating costs were assumed to also apply to buses replaced under the business as usual scenario.

Four of the measures potentially require the replacement of buses to meet the Euro VI standard by 2021:

- All buses Euro VI
- All bus and HGVs Euro VI
- Pre Euro V buses Euro VI
- Pre Euro V bus and HGVs to Euro VI

The costs of these measures were calculated in the same way as for the measures implemented in 2016.

Bus services

Buses services in Bradford and Leeds are operated by various bus companies. First Bradford and First Leeds operate most services in their respective cities. Almost all of the regular bus routes operated by First Bradford enter the areas within the Bradford Inner and Outer Ring Roads. Similarly, almost all of the regular bus routes operated by First Leeds enter the areas within the Leeds Inner and Outer Ring Road areas. It is therefore expected that First Bradford and First Leeds would need to update almost all of their fleets to meet the requirements of Low Emission Zones in the respective cities.

The other bus operators operate relatively few bus services into the Bradford and Leeds Ring Road areas with most of their fleets deployed on other routes or used to provide other services. Table 19 lists the bus routes that travel into the centre of Bradford: it shows the operator, the frequency of buses at morning peak times on weekdays and typical round trip times. It also shows the theoretical minimum number of buses on each route, calculated from the frequency of buses and the round trip time. Table 20 similarly lists the bus routes that travel into the centre of Leeds.

Table 21 lists, in summary, the theoretical minimum total number of buses required for bus companies to operate the services into Bradford and Leeds city centres. In practice, the bus companies will need more than this minimum number to allow for maintenance, crew changeover, etc. Comparing the theoretical minimum First Bradford and First Leeds fleets with the total fleet sizes in Table 22 (below) indicates that the required fleet size will be approximately 50% larger than the theoretical minimum value. The required fleet sizes for other bus companies have therefore been estimated by increasing the minimum theoretical fleet sizes by 50%.

[27] Department for Transport Clean Bus Technology Application Project BREATHE (Bus REtrofit: ATtenuating Harmful Emissions)

Table19: Bus routes into Bradford city centre

Route	Operator	Round trip time, minutes	Time between services, minutes	Theoretical minimum number on route
72	First Leeds	100	7.5	14
253	Arriva Yorkshire	215	60	4
268	Arriva Yorkshire	135	12	12
363/x63	First Huddersfield	137	20	7
425/427	Arriva Yorkshire	143	30	5
571	First Huddersfield	145	60	3
576	First Huddersfield	81	15	6
607	First Bradford	96	10	10
610	First Bradford	54	60	1
611	First Leeds	70	60	2
612	First Bradford	79	15	6
613	First Bradford	99	20	5
614	First Bradford	100	20	5
615	First Bradford	80	30	3
616	First Bradford	96	30	4
617/618	First Bradford	101	10	11
620/621	First Bradford	90	10	9
622/623/625/626/627	First Bradford	94	20	5
630	First Bradford	36	20	2
633	First Bradford	116	30	4
634	First Bradford	54	30	2
636	First Bradford	96	20	5
637	First Bradford	86	20	5
640	First Bradford	79	20	4
641	First Bradford	89	20	5
645	First Bradford	53	10	6
656/658/659	TLC travel	102	60	2
660	TLC travel	152	60	3
662	Keighley and District	109	10	11
670	First Bradford	159	60	3
671	First Bradford	134	60	3
675	First Bradford	83	60	2
677	First Bradford	83	60	2
680	First Bradford	54	30	2
681/682	First Bradford	83	30	3
696/697/698	Keighley and District	115	30	4
711	Geldards Coaches	116	60	2
737	Yorkshire Tiger	116	60	2
747	Yorkshire Tiger	101	60	2
846	First Bradford	144	60	3
847	First Bradford	147	60	3
947	TLC travel	55	60	1
x6	First Bradford	167	30	6

x33	SGI Community Transport	110	60	2

Table 20: Bus routes into Leeds city centre

Route	Operator	Round trip time, minutes	Time between services, minutes	Theoretical minimum number on route
Leeds City Bus	First Leeds	32	9	4
1	First Leeds	119	8	15
2	First Leeds	118	10	12
3	First Leeds	105	20	6
3A	First Leeds	105	20	6
4	First Leeds	138	20	7
4a	First Leeds	138	20	7
5(i)	First Leeds	59	20	3
5(ii)	First Leeds	119	20	6
6	First Leeds	97	10	10
7	First Leeds	75	10	8
7A	First Leeds	85	20	5
7s	First Leeds	80	20	4
11	First Leeds	112	60	2
12	First Leeds	96	10	10
13	First Leeds	123	20	7
13a	First Leeds	123	20	7
16/16a	First Leeds	184	10	19
19	First Leeds	168	30	6
19a	First Leeds	166	30	6
28	First Leeds	88	20	5
28B	Geldards Coaches	34	20	2
33/33A (i)	First Leeds	100	60	2
33/33A (ii)	First Leeds	110	30	4
33/33A (iii)	First Leeds	148	30	5
36	Harrogate and District	185	15	13
40	First Leeds	89	8	12
42	First Leeds	112	10	12
48	First Leeds	118	60	2
49	First Leeds	138	10	14
50/50a	First Leeds	142	10	15
51	First Leeds	127	15	9
52	First Leeds	127	15	9
55	First Leeds	84	30	3
56	First Leeds	143	8	18
62	First Leeds	180	60	3
62a	First Leeds	120	60	2
63	Yorkshire Tiger	60	60	1
64	First Leeds	198	30	7
72	First Leeds	101	7.5	14
74/74a	First Leeds	116	30	4
85/85a/87 (i)	First Leeds	174	60	3
85/85a/87 (ii)	First Leeds	234	60	4
92	Yorkshire Tiger	71	30	3
93	Yorkshire Tiger	72	30	3
97	First Leeds	133	20	7

Route	Operator	Round trip time, minutes	Time between services, minutes	Theoretical minimum number on route
110(i)	Arriva Yorkshire	134	20	7
110(ii)	Arriva Yorkshire	135	20	7
117	Arriva Yorkshire	170	60	3
163	Arriva Yorkshire	150	30	5
166	Arriva Yorkshire	150	30	5
167	Arriva Yorkshire	100	60	2
168	Arriva Yorkshire	100	60	2
189	Arriva Yorkshire	145	30	5
202/203	Arriva Yorkshire	214	15	15
220	Arriva Yorkshire	120	60	2
221/223	Arriva Yorkshire	170	60	3
222	Arriva Yorkshire	153	60	3
209/219/229 (i)	Arriva Yorkshire	102	60	2
209/219/229 (i)	Arriva Yorkshire	205	60	4
254	Arriva Yorkshire	175	60	3
255	Arriva Yorkshire	165	60	3
402	Arriva Yorkshire	235	60	4
403	Arriva Yorkshire	180	60	3
410	Arriva Yorkshire	110	30	4
444	Arriva Yorkshire	189	20	10
446	Arriva Yorkshire	123	60	3
481	Arriva Yorkshire	165	60	3
508	Arriva Yorkshire	170	30	6
670	First Bradford	159	60	3
671	First Bradford	139	60	3
757	Yorkshire Tiger	100	25	4
760	Keighley and District	178	30	6
770	Harrogate and District	200	30	7
781	Yorkshire Tiger	239	239	1
840/843/845/ x45 (i)	Yorkshire Coastliner	223	60	4
840/843/845/ x45 (ii)	Yorkshire Coastliner	254	120	3
840/843/845/ x45 (iii)	Yorkshire Coastliner	187	90	3
840/843/845/ x45 (iv)	Yorkshire Coastliner	166	30	6
x6	First Bradford	167	20	9
x14/x15	First Leeds	70	35	2
x62	Stagecoach in Hull	240	60	4
x98	First Leeds	117	60	2
x99	First Leeds	117	60	2
x84(i)	First Leeds	210	60	4
x84(ii)	First Leeds	90	60	2
x84(iii)	First Leeds	150	60	3

Table 21: Theoretical total numbers of buses to operate peak services

Bus company	Leeds	Bradford
First Leeds	319	16
First Bradford	15	119
Arriva Yorkshire	104	21
First Huddersfield		16
TLC travel		6
Keighley and District	6	15
Geldards Coaches	2	2
Yorkshire Tiger (Centrebus)	12	4
SGI Community Transport		2
Stagecoach in Hull	4	
Harrogate and District	20	
Yorkshire Coastliner	16	
Total	498	201

Bus fleets

Leeds City Council provided data on the age profile of the buses operated by the main bus companies with routes into the centre of Bradford or Leeds. Table 22 shows the age profiles. The age profile for Yorkshire Coastliner was obtained from Yorkbus[28].

Examination of Table 22 indicates that there are few buses over 15 years old in the bus fleets operating regular bus services in Leeds. Only Geldards Coaches have substantial numbers of older buses but this company does not operate very many regular services in Bradford or Leeds. For this assessment, it was assumed that buses older than 15 years old would be replaced each year under the business as usual case. Table 23 shows the assumed bus fleets serving Bradford and Leeds centres at the end of 2015.

The age profile of the bus fleets considered for replacement is different from the bus-kilometre age profile used in the assessment of emissions because newer buses are generally used on the busiest routes and because not all the bus companies operate services with the same frequency.

[28] http://www.yorkbus.co.uk/

Table 22: Age profiles of bus fleets of companies with routes into Bradford or Leeds, 2011

Date new	Age	EURO Standard	First Leeds	Arriva Yorkshire	First Bradford	Centrebus	Keighley and District	First Hudders field	Geldards	TLC travel	Yorkshire Coastliner	Harrogate and District
<1995	>16	1	0	0	0	1	0	0	24	0	0	0
1995	16	1	0	1	0	2	0	0	5	0	0	0
1996	15	1	3	0	0	0	0	2	6	0	0	0
1997	14	2	6	28	11	1	0	2	2	0	0	0
1998	13	2	19	52	8	11	5	23	3	0	0	0
1999	12	2	36	4	6	11	8	4	1	0	0	0
2000	11	2	34	59	58	3	8	15	0	2	0	0
2001	10	3	19	20	4	14	22	0	2	0	0	0
2002	9	3	0	26	14	3	2	0	1	0	0	0
2003	8	3	15	0	1	14	0	0	0	0	0	0
2004	7	3	45	1	2	4	15	17	2	3	4	22
2005	6	3	3	0	0	7	27	28	0	1	0	0
2006	5	4	48	26	24	6	8	3	0	1	6	0
2007	4	4	45	7	11	11	0	9	0	7	0	0
2008	3	4	28	44	53	8	8	8	2	0	10	0
2009	2	5	94	41	40	2	0	4	0	8	6	0
2010	1	5	0	0	0	14	0	0	0	1	0	0
2011	0	5	22	0	0	13	0	0	0	0	0	0
Total Fleet Size			417	309	232	125	116	115	48	23	26	22
Ave. Fleet Age			6.0	8.4	6.7	6.7	9.6	8.2	16.4	4.3	3.8	7.0

Table23: Assumed bus fleets serving Bradford and Leeds centres at the end of 2015.

Year when new	Euro Class	Number required for Bradford bus routes	Number required for Leeds bus routes
2001	III	12	33
2002	III	17	16
2003	III	2	17
2004	III	12	81
2005	III	12	6
2006	IV	32	71
2007	IV	19	52
2008	IV	63	68
2009	V	53	126
2010	V	1	2
2011	V	2	24
2012	V	21	23
2013	V	21	35
2014	VI	11	24
2015	VI	71	74
Total		**350**	**652**
Total Pre Euro VI		**268**	**554**
Total Pre Euro IV		**56**	**154**

Cost of bus replacement measures

Tables 24 and 25 show the calculated costs of the bus replacement measures in Bradford and Leeds.

Table 24: Costs of 2016 bus replacement measures

Cost	Net present value, £ million base year 2015			
	Bradford		Leeds	
	All buses Euro VI	Pre Euro IV buses Euro VI	All buses Euro VI	Pre Euro IV buses Euro VI
Number of buses replaced in 2016	268	56	554	154
Capital cost, new buses	46.6	9.8	96.4	26.7
Return on second-hand sales	-12.0	-0.7	-23.0	-2.0
Capital cost, business as usual,	-23.8	-8.3	-52.0	-22.2
Additional operating cost,	0.3	0.04	0.6	0.1
Additional maintenance,	0.7	0.1	1.3	0.3
Total	**11.9**	**1.0**	**23.2**	**2.9**

Table 25: Costs of 2021 bus replacement measures

Cost	Net present value, £ million base year 2015			
	Bradford		Leeds	
	All buses Euro VI	Pre Euro V buses Euro VI	All buses Euro VI	Pre Euro V buses Euro VI
Number of buses replaced in 2021	212	114	401	191
Capital cost, new buses	31.0	16.7	58.6	27.9
Return on second-hand sales	-3.2	-0.7	-5.8	-1.0
Capital cost, business as usual,	-24.1	-14.9	-46.1	-25.6
Additional operating cost,	0.05	0.05	0.06	0.06
Additional maintenance,	0.1	0.1	0.15	0.15
Total	**3.8**	**1.2**	**7.0**	**1.5**

Bus replacement with CNG buses

Some bus companies in the UK have considered replacing parts of their fleet with buses running on compressed natural gas (CNG). For example, Reading Buses have recently started operating a fleet of 20 CNG buses and have a further 34 on order. This section of the report considers the additional cost of implementing LEZs in 2016 and 2021 if the bus companies in Bradford and Leeds were to adopt the policy of replacing buses (otherwise at the end of their operating lives) with CNG buses that meet the Euro VI standard. The assessment methodology is the same as that used for conventional bus replacement with the following additional assumptions.

This assessment assumes a capital cost for a new CNG bus in 2016 of £180,000. It will also be necessary to provide sufficient gas compression capacity to supply the buses with fuel. A recent study for Bradford City Council[29] considered the capital and operating costs for CNG plant to supply the Council's fleet of vehicles. The estimated capital cost for a gas compression facility to supply 14,000 kg CNG per day was £2,710,000 including £265,000 civil engineering costs. We assume here that each bus will travel 160 miles per day and consume 0.4 kg CNG per km[30] (0.64 kg per mile): each bus will consume 103 kg per day of operation. The capital cost of compression plant is thus estimated to be £19,937 per bus.

This assessment assumes a base price for CNG of 39p per kg, based on the range of costs considered in the recent study for Bradford Council. Fuel duty of 24.7p per kg and compressor operating costs of 8 p per kg (electricity and maintenance) has been added to the base price: the Bus Service Operators Grant of 18.88 p per kg has been subtracted to give a net price of 52.82p per kg. The fuel cost per bus, operating 330 days per year is thus estimated to be £17,953. Bus operators using biogas may also be eligible for a grant of 6p per km under the Low Carbon Emission bus incentive scheme: it is assumed here that the additional cost of supplying biogas offsets the grant.

The CNG bus will replace an existing bus running on diesel fuel. This assessment assumes that diesel fuel costs 115 p per litre (ex VAT) less the Bus Service Operators Grant of 34.57 p per litre and that

[29] D. Scholfield and A. Whittles. Gas refuelling station feasibility study. LES Limited June 2013
[30] HBEFA Handbook of Emission Factors for Road Transport v 3.2.

each bus consumes 0.4 litres per km. The fuel cost per bus per year is thus estimated to be £27,338. The use of CNG thus results in a saving in fuel costs of £9,384 per year compared to diesel.

There is currently no evidence that vehicle maintenance costs will be significantly different for gas vs diesel vehicles, and so no allowance for increased maintenance costs has been made in this assessment[31].

Tables 26 and 27 show the calculated costs of the bus replacement measures in Bradford and Leeds.

Table 26: Costs of 2016 bus replacement measures, CNG scenario

Cost	Net present value, £ million base year 2015			
	Bradford		Leeds	
	All buses Euro VI	Pre Euro IV buses Euro VI	All buses Euro VI	Pre Euro IV buses Euro VI
Number of buses replaced in 2016	268	56	554	154
Capital cost buses, LEZ	46.6	9.8	96.4	26.7
Return on second-hand sales	-12.0	-0.7	-23.0	-2.0
Capital cost buses, business as usual,	-23.8	-8.3	-52.0	-22.2
Capital cost plant, LEZ	5.2	1.1	10.7	3.0
Capital cost plant, business as usual	-2.6	-0.9	-5.8	-2.5
Change in operating and maintenance costs	-13.1	-0.8	-25.7	-2.4
Total	**0.2**	**0.2**	**0.5**	**0.7**

Table 27: Costs of 2021 bus replacement measures, CNG scenario

Cost	Net present value, £ million base year 2015			
	Bradford		Leeds	
	All buses Euro VI	Pre Euro V buses Euro VI	All buses Euro VI	Pre Euro V buses Euro VI
Number of buses replaced in 2021	212	114	401	191
Capital cost buses, LEZ	31.0	16.7	58.6	27.9
Return on second-hand sales	-3.2	-0.7	-5.8	-1.0
Capital cost buses, business as usual,	-24.1	-14.9	-46.1	-25.6
Capital cost plant, LEZ	3.4	1.8	6.5	3.1
Capital cost plant, business as usual	-2.7	-1.7	-5.1	-2.8
Change in operating and maintenance costs	-4.1	-0.9	-7.6	-1.2
Total	**0.3**	**0.3**	**0.6**	**0.4**

[31]C.Johnson . Business case for compressed natural gas in municipal fleets. National Renewable Energy Laboratory NREL/TP-7A2-47919, June 2010 http://www.afdc.energy.gov/pdfs/47919.pdf
Also webinar
http://www.nrel.gov/docs/fy10osti/48981.pdf

Bus retrofitting measures

The bus retrofit scenario involves retrofitting Euro II and Euro III buses with combined Selective Catalytic Reduction systems and Diesel Particle Filters (SCRT).

For this assessment, it was assumed that the cost of retrofitting SCRT technology was £14,235 per bus[32]. Retrofitting this equipment can result in increases in fuel consumption, but it is usually most cost-effective to offset this by fitting a micro-hybrid electric fan to improve efficiency, at an additional cost of £4,000[33]. It was assumed that the electric fans will be fitted for this assessment.

Retrofitting of the buses will result in additional operating and maintenance costs. It was assumed that these are the same as those associated with the replacement of older buses with Euro VI buses (see above). It was also assumed that retrofitting SCRT technology to Euro II and Euro III buses does not extend the life of the buses so that these additional costs do not apply beyond the normal life of the buses.

Table 28 shows the additional costs of the bus retrofit measures.

Table 28: Cost of bus retrofit measures

Cost	Net present value, £ million base year 2015	
	Bradford	Leeds
Number of buses retrofitted in 2016	44	120
Capital cost, SCRT retrofit	0.6	1.7
Capital cost, microhybrid electric fan retrofit	0.2	0.5
Additional operating cost,	0.04	0.1
Additional maintenance,	0.1	0.3
Total	0.9	2.5

HGV replacement measures

Approach

Four of the measures potentially require the replacement of heavy goods vehicles to meet the Euro VI standard by 2016:

- All HGV Euro VI
- All bus and HGVs Euro VI
- Pre Euro IV HGV Euro VI
- Pre Euro IV bus and HGVs to Euro VI

The changes will result in

- additional capital expenditure for the goods vehicle operator
- additional operational costs (e.g. urea consumption in selective catalytic reduction)
- additional maintenance costs.

[32] Department for Transport Clean Bus Technology Application Project BREATHE (Bus REtrofit: ATtenuating Harmful Emissions

[33] Department for Transport Clean Bus Technology Application Project BREATHE (Bus REtrofit: ATtenuating Harmful Emissions

The capital cost of a new HGV depends on its specification. This assessment assumes a capital cost for a new articulated truck unit in 2016 of £80,000 and a capital cost for a rigid truck of £65,000.

HGVs based within the ring road areas would have to be replaced or upgraded to meet the higher standards specified for the LEZs. However, it was assumed for this assessment that haulage companies with fleets based outside the proposed LEZs would be able to manage their operations using compliant vehicles at minimal additional cost.

The price of second-hand HGVs depends on the age, specification and condition of the buses. Fig.5 shows the advertised prices of second-hand articulated tractor units (6x2) on trucklocator.co.uk on 2nd June 2014. Fig. 6 also shows the second-hand price function used in this assessment. Fig. 7 similarly shows the advertised process of second-hand rigids (curtainsiders).

Fig. 5: Second-hand articulated tractor unit prices, 2014

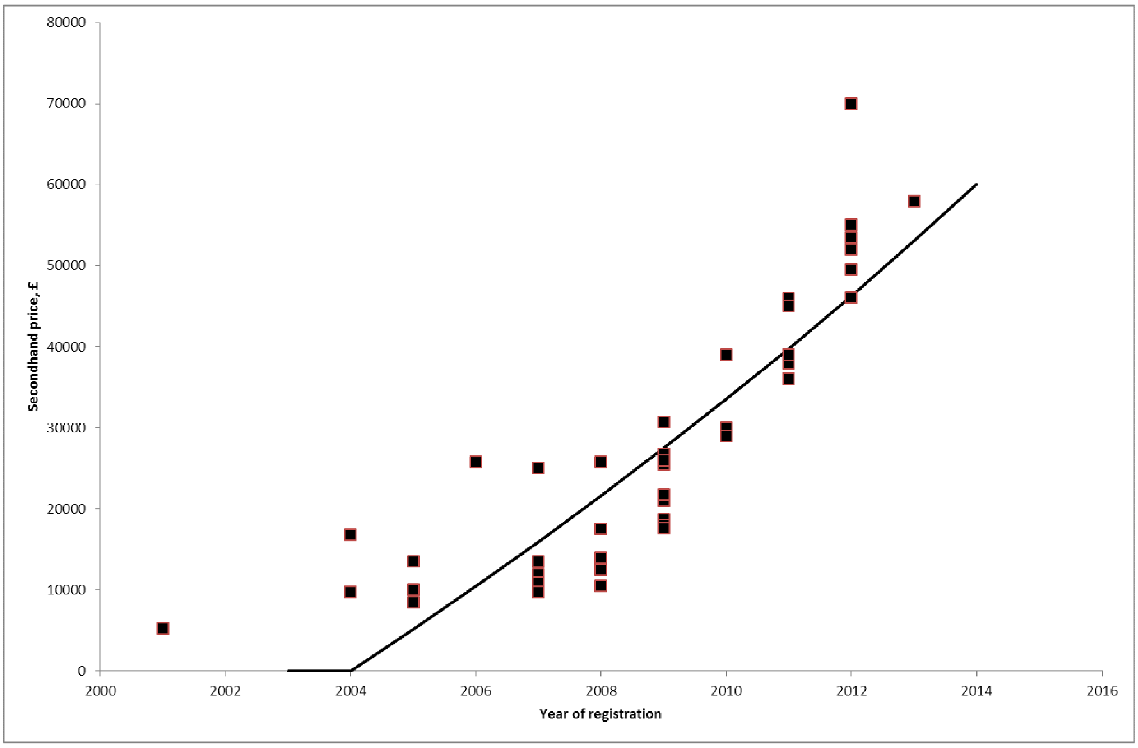
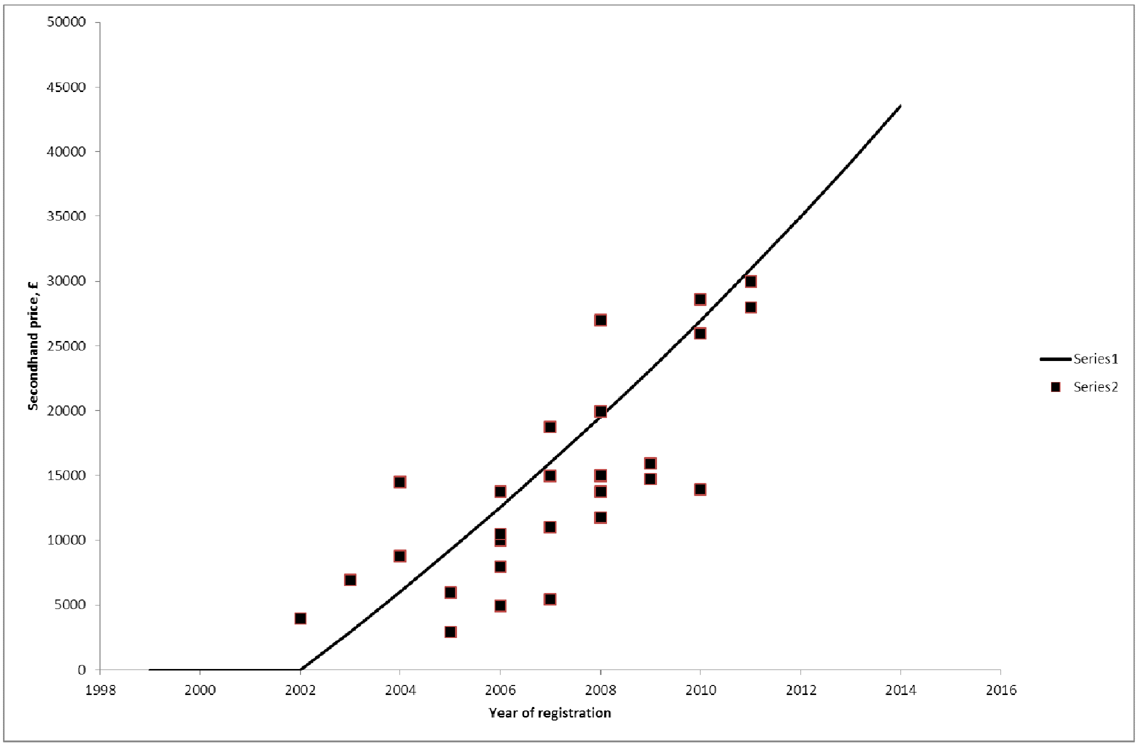


Fig. 6: Second-hand rigid HGV prices, 2014



New rigid HGVs entering service in 2016 would be expected to continue operating for approximately 12 years until the end of 2027. Under the business as usual case, older HGVs would gradually be replaced throughout the period 2016-2027 with new HGVs that meet the Euro VI standard or better. The capital cost for the business as usual replacement of HGVs was calculated as the sum of the discounted equivalent annualised costs for the years of operation of the replacement vehicles in the period 2016-2027, assuming a discount rate of 3.5%. In effect, this assumes that the cost of new HGVs can be spread throughout their lifetime: the method allows the costs to be attributed consistently to the life of the HGVs replaced in 2016.

New articulated HGVs entering service in 2016 would be expected to continue operation until the end of 2025. The capital cost of the business as usual case was estimated as above but taking account of the typical shorter operational life.

The net capital cost of replacing HGVs in 2016 was calculated as the capital cost of a new HGV less the second hand price of the replaced vehicles and less the business as usual capital cost. The 2016 capital costs have been discounted to a 2015 base year to allow comparison with the abatement costs and damage costs.

Additional operational costs for replacing Euro I-Euro IV HGV with Euro VI vehicles were assumed to be £427 per year[34], based on estimates of the additional use of urea in selective catalytic reduction. It was assumed that this cost would also be incurred by existing Euro V vehicles. The additional operating costs were assumed to apply also to HGVs replaced under the business as usual scenario.

Additional maintenance costs for replacing Euro I-Euro IV vehicles with Euro VI were assumed to be £1000 per year[35]. It was assumed that this cost would also be incurred by existing Euro V HGVs. The additional operating costs were assumed to also apply to HGVs replaced under the business as usual scenario.

Four of the measures potentially require the replacement of HGVs to meet the Euro VI standard by 2021:

- All HGV Euro VI
- All bus and HGVs Euro VI
- Pre Euro V HGV Euro VI
- Pre Euro V bus and HGVs to Euro VI

The costs of these measures were calculated in the same way as for the measures implemented in 2016.

HGV fleets

DfT Vehicle Statistics table veh0105 reports that there were 2449 HGV registered in Bradford and 5408 HGV registered in Leeds in 2013. Vehicle Statistics table veh0122 gives the numbers of cars, motorcycles and other vehicles (including HGV) registered in each postcode district in the last quarter of 2013. Postcode districts BD1-BD8 are within or intersect the Bradford Outer Ring Road; of these BD1 is substantially within the Inner Ring Road. Postcode districts LS1-LS18 and LS28 are within or intersect the Leeds Outer Ring Road; of these, substantial parts of LS1, LS2, LS10 and LS11 are

[34] Department for Transport Clean Bus Technology Application Project BREATHE (Bus REtrofit: ATtenuating Harmful Emissions)
[35] Department for Transport Clean Bus Technology Application Project BREATHE (Bus REtrofit: ATtenuating Harmful Emissions)

within the Inner Ring Road. The number of HGVs registered in each postcode district was estimated, pro-rata, from the veh0105 statistics on the basis of the “other” vehicle counts in the veh0122 statistics. On this basis, there were an estimated 596 HGVs registered in postcode districts BD1-BD8 and 30 HGVs registered in postcode district BD1. Similarly, there were an estimated 3564 HGVs registered in postcode districts LS1-LS18 and LS28 and 568 HGVs registered in LS1, LS2, LS10 and LS11.

Automatic Number Plate Recognition (ANPR) cameras installed between the Bradford Inner and Outer Ring Roads identified vehicles on key roads during the period 17-19th April 2012. The data was referenced against DfT licensing data to provide details of each vehicle including registration postcode, date of manufacture, date of first registration, engine size and gross weight. Vehicles registered in postcode districts BD1-BD8 were selected from this data set. The data set includes some vehicles more than once: duplicates were removed where the registration postcode, date of manufacture, date of first registration, engine size and gross weight were the same. This produced a sample of 332 rigid and 45 articulated HGVs. There were thus 88% rigid HGVs in the HGV fleet. Fig. 7 and Fig. 8 show the age profile of articulated and rigid HGVs registered in postcode districts BD1-BD8. This analysis assumes that the 2016 HGV fleet for the business as usual case would have the same age profile.

Automatic Number Plate Recognition (ANPR) cameras installed between the Leeds Inner and Outer Ring Roads identified vehicles on key roads during part of 2011. The data was referenced against DfT licensing data to provide details of each vehicle including registration postcode, licence plate number, date of first registration and gross weight. Vehicles registered in postcode districts LS1-LS18 and LS28 were selected from this data set. Individual vehicles were identified from their licence plate number. This produced a sample of 446 rigid and 29 articulated HGVs. There were thus 94% rigid HGVs in the HGV fleet. Fig. 9 and Fig. 10 show the age profile of articulated and rigid HGVs registered in postcode districts LS1-LS18 and LS28. This analysis assumes that the 2016 HGV fleet for the business as usual case would have the same age profile.

Fig. 7: Age profile of articulated HGVs registered in BD1-BD8

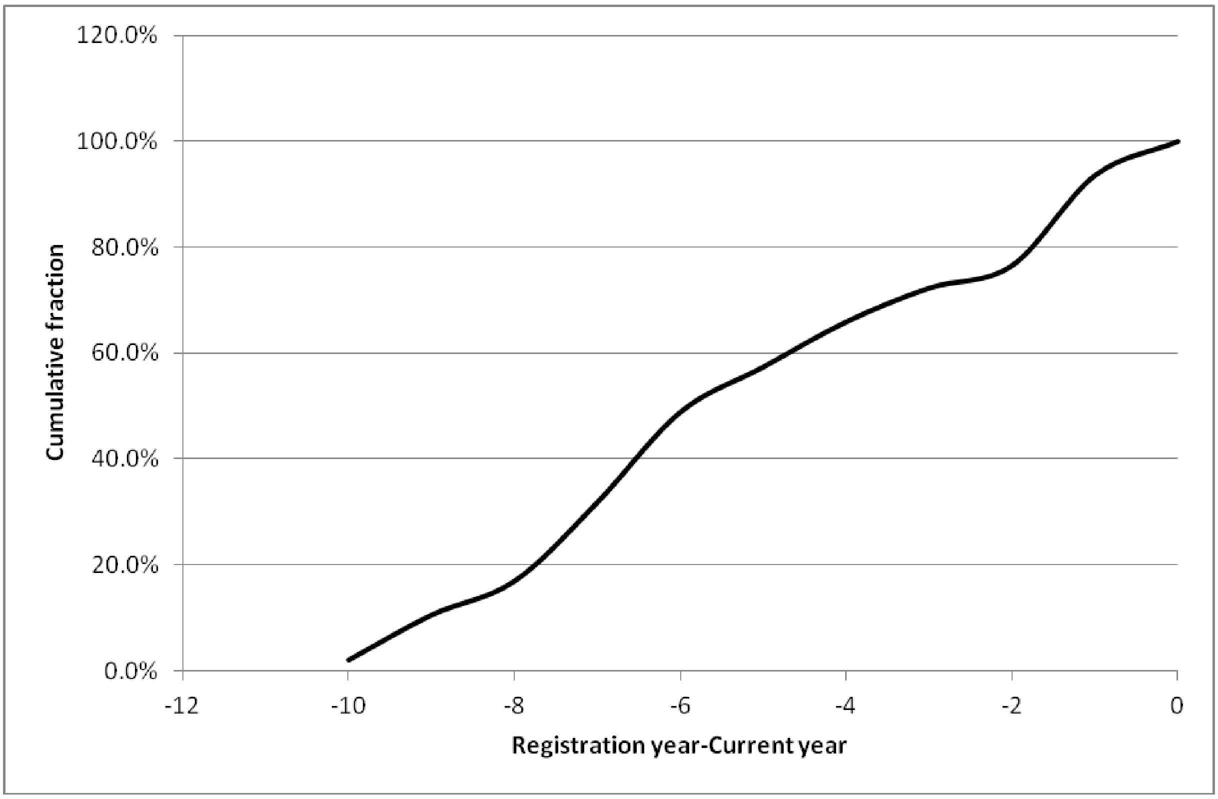


Fig. 8: Age profile of rigid HGVs registered in BD1-BD8

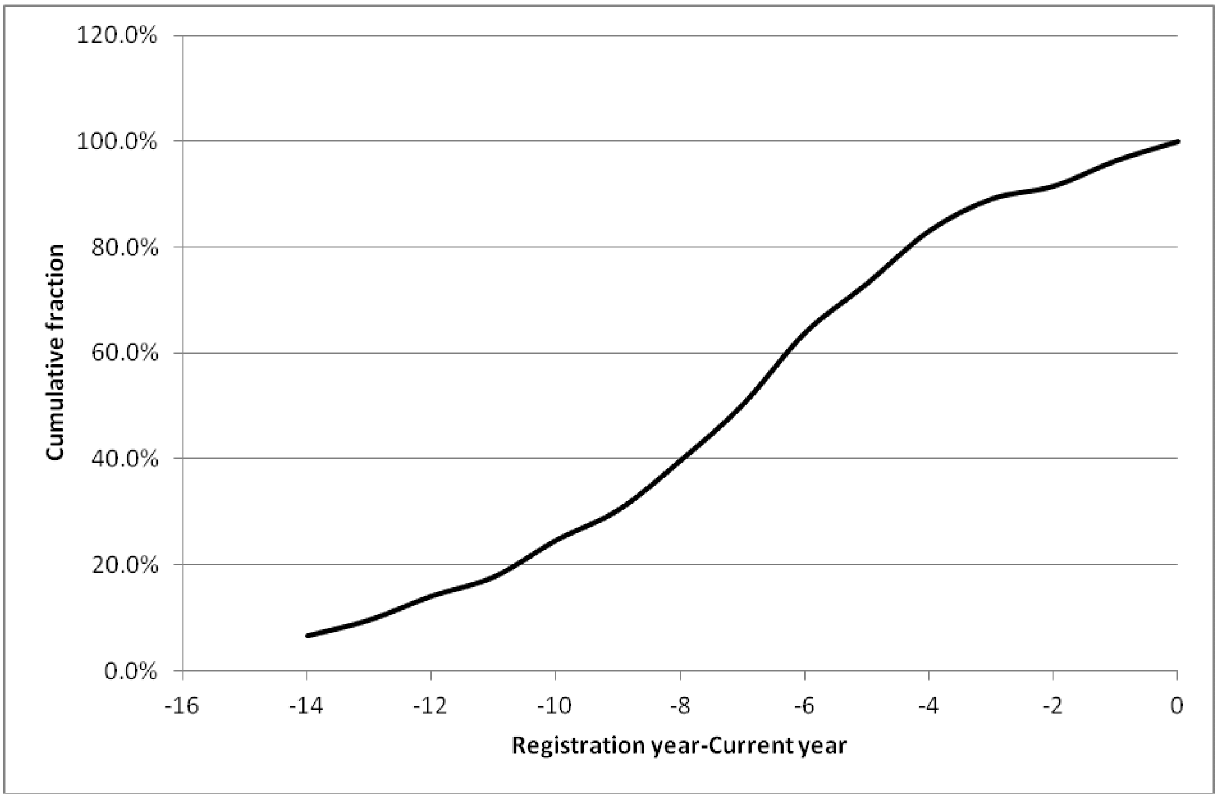


Fig. 9: Age profile of articulated HGVs registered in LS1-LS18 and LS28

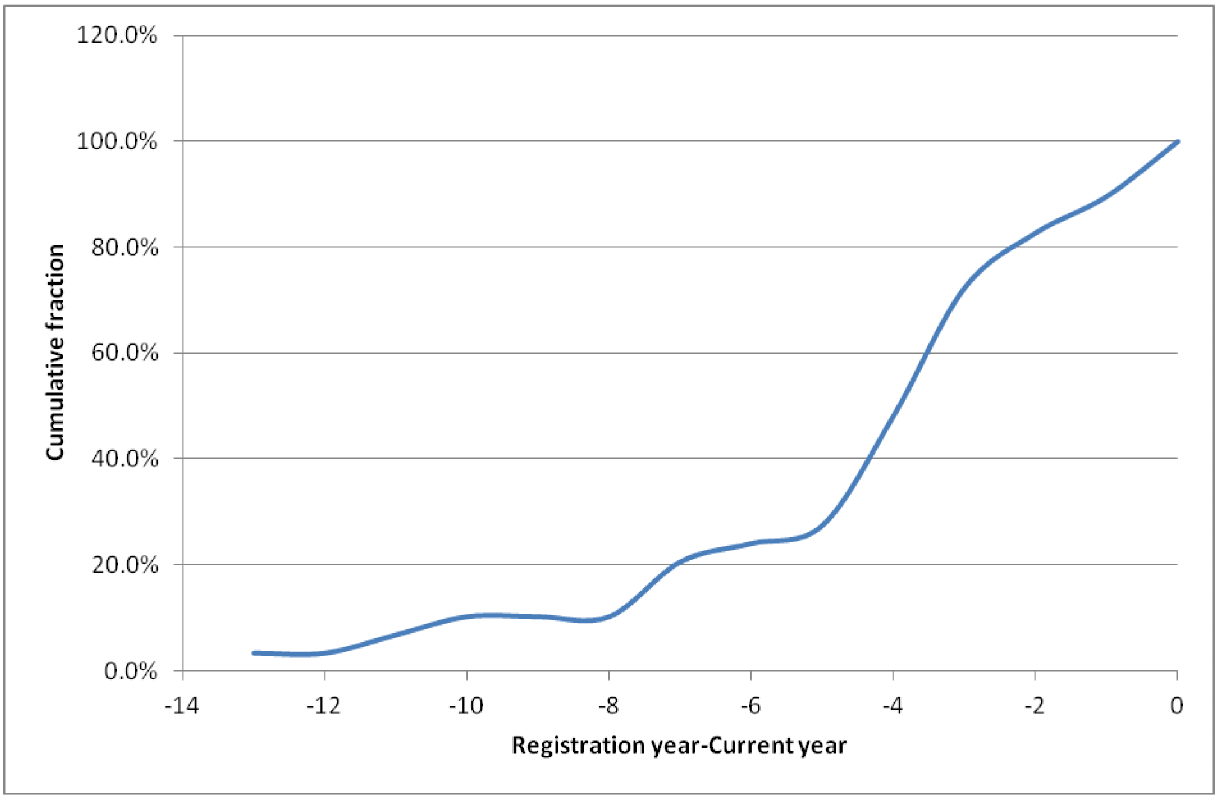
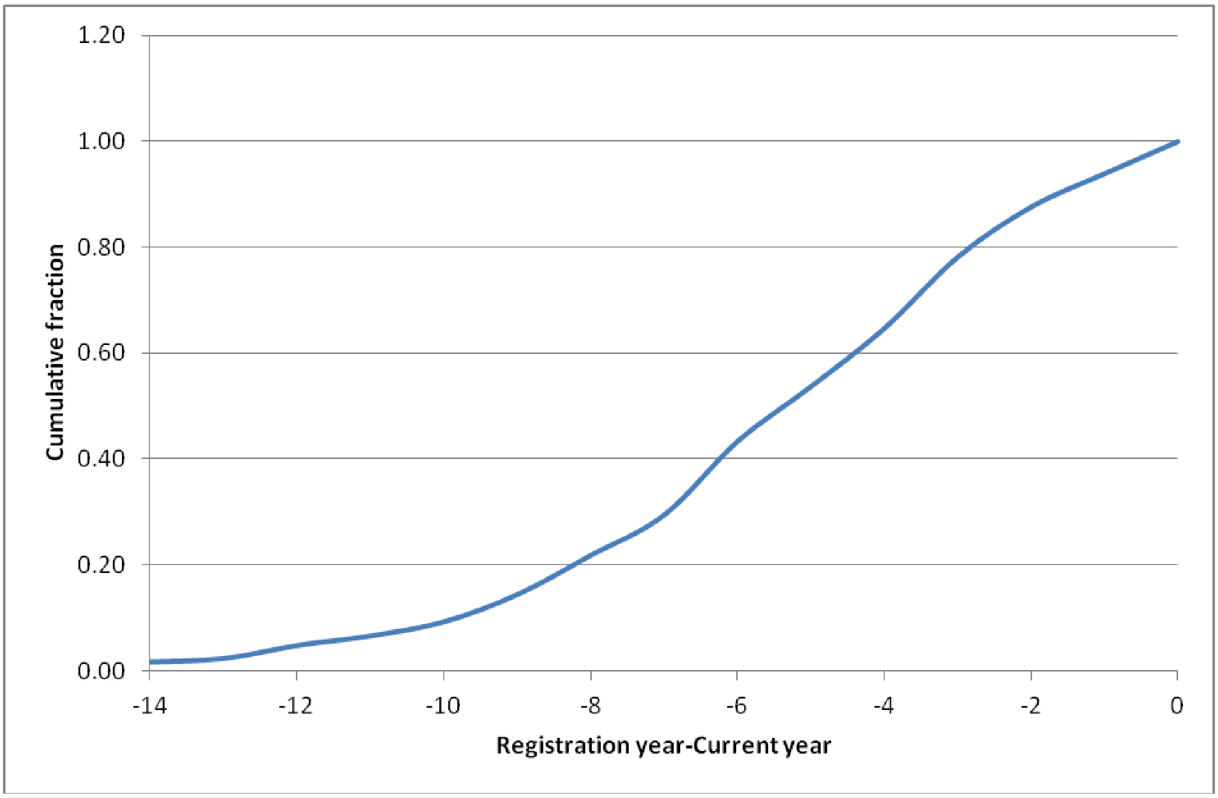


Fig. 10: Age profile of rigid HGVs registered in LS1-LS18 and LS28



Cost of HGV replacement measures

Tables 29 and 30 show the calculated costs of the HGV replacement measures in Bradford and Leeds for implementation in 2016 and 2021.

Table 29: Costs of 2016 HGV replacement measures

Cost	Net present value, £ million base year 2015			
	Bradford		Leeds	
	All HGV Euro VI	Pre Euro IV HGV Euro VI	All HGVs Euro VI	Pre Euro IV HGV Euro VI
Number of HGVs replaced in 2016	494	55	2994	180
Capital cost, new HGVs	31.8	3.47	190.4	11.32
Return on second-hand sales	-7.7	-0.10	-54.7	-0.28
Capital cost, business as usual,	-18.0	-3.24	-93.2	-10.7
Additional operating cost	0.2	0.01	0.9	0.04
Additional maintenance	0.5	0.04	2.1	0.09
Total	**6.8**	**0.17**	**45.5**	0.47

Table 30: Costs of 2021 HGV replacement measures

Cost	Net present value, £ million base year 2015			
	Bradford		Leeds	
	All HGV Euro VI	Pre Euro V HGV Euro VI	All HGVs Euro VI	Pre Euro V HGV Euro VI
Number of HGVs replaced in 2021	212	0	893	0
Capital cost, new HGVs	11.5	0	47.5	0
Return on second-hand sales	-1.4	0	-5.9	0
Capital cost, business as usual,	-8.8	0	-35.7	0
Additional operating cost	0	0	0	0
Additional maintenance	0	0	0	0
Total	**1.3**	0	**5.9**	0

LGV replacement measures

Approach

The scenarios include two measures that involve the replacement of light goods vehicles that do not meet the Euro 6 standard with Euro 6 vehicles. The scenarios consider implementing this measure in either 2016 or 2021.

The changes will result in

- additional capital expenditure for the goods vehicle operator
- additional operational costs (e.g. urea consumption in selective catalytic reduction)
- additional maintenance costs.

The capital cost of a new light goods vehicles depends on its specification. This assessment assumes a capital cost for a new van in 2016 of £35,000.

Vans based within the ring road areas would have to be replaced or upgraded to meet the higher standards specified for the LEZs. However, it was assumed for this assessment that van operators with fleets based outside the proposed LEZs would be able to manage their operations using compliant vehicles at minimal additional cost.

The price of second-hand LGVs depends on the age, specification and condition of the buses. For this assessment, it has been assumed that the second-hand price may be estimated from:

$$S = 0.67P\frac{(r^m - r^n)}{(1 - r^n)}$$

where P is the new price, r=1/(1+d), d is the discount rate of 3.5%,m is the age of the vehicle and n is the life of the vehicle, assumed to be 12 years.

New vans entering service in 2016 would be expected to continue operating for approximately 12 years until the end of 2027. Under the business as usual case, older vans would gradually be replaced throughout the period 2016-2027 with new vans that meet the Euro 6 standard or better. The capital cost for the business as usual replacement of vans was calculated as the sum of the discounted equivalent annualised costs for the years of operation of the replacement vehicles in the period 2016-2027, assuming a discount rate of 3.5%. In effect, this assumes that the cost of new vans can be spread throughout their lifetime: the method allows the costs to be attributed consistently to the life of the vans replaced in 2016.

The net capital cost of replacing vans in 2016 was calculated as the capital cost of a new van less the second hand price of the replaced vehicles and less the business as usual capital cost. The 2016 capital costs have been discounted to a 2015 base year to allow comparison with the abatement costs and damage costs.

It was assumed that replacing older vans with Euro 6 models would not increase operating and maintenance costs.

Van fleets

DfT Vehicle Statistics table veh0105 reports that there were 18,207 LGV registered in Bradford and 33,661 LGV registered in Leeds in 2013. Vehicle Statistics table veh0122 gives the numbers of cars, motorcycles and other vehicles (including LGV) registered in each postcode district in the last quarter of 2013. Postcode districts BD1-BD8 are within or intersect the Bradford Outer Ring Road; of these BD1 is substantially within the Inner Ring Road. Postcode districts LS1-LS18 and LS28 are within or intersect the Leeds Outer Ring Road; of these, substantial parts of LS1, LS2, LS10 and LS11 are within the Inner Ring Road. The number of LGVs registered in each postcode district was estimated, pro-rata, from the veh0105 statistics on the basis of the other vehicle counts in the veh0122 statistics. On this basis, there were an estimated 4,433 LGVs registered in postcode districts BD1-BD8 and 226 LGVs registered in postcode district BD1. Similarly, there were an estimated 22,183 LGVs registered in postcode districts LS1-LS18 and LS28 and 4,761 LGVs registered in LS1, LS2, LS10 and LS11.

It was assumed for the assessment of replacement costs that the oldest twelfth of the LGVs were replaced each year.

Cost of LGV replacement measures

Table 31 shows the calculated costs of the LGV measures implemented in 2016 and 2021.

Table 31: Costs of LGV replacement measures

Cost	Net present value, £ million base year 2015			
	Bradford		Leeds	
	2016	2021	2016	2021
Number of LGVs replaced	4,433	2,586	22,183	12,940
Capital cost, new LGVs	150	74	750	368
Return on second-hand sales	-43	-11	-213	-54
Capital cost, business as usual,	-76	-53	-381	-264
Total	**31**	10	**156**	51

Fuel split

The fuel split scenarios consider the possibility of returning the petrol/diesel mix for cars and N1 vans in 2016 or 2021 to year 2000 ratios. Diesel cars made up 12.9% of the Great Britain car fleet in 2000 and this increased to 34.5% in 2013[36]. Linear extrapolation indicates that diesel cars will make up 38.8% of the car fleet in 2016 and 45.9% of the fleet in 2021. Thus the 2016 scenario requires that 25.9% of cars would be replaced in 2016. The 2021 scenario requires the replacement of 33.0% of cars.

Owners of diesel cars might be encouraged to replace their cars with similar petrol cars if they were offered a suitable incentive. The incentive should be sufficient to cover the costs of changing the cars and the additional fuel costs associated with petrol cars.

For this assessment, it has been assumed that diesel car owners will exchange their cars for petrol cars of similar age and specification. It has been assumed also that the exchange can be made at little cost because equivalent diesel cars are typically around 10% more expensive than the equivalent petrol cars.

Cars in England typically travel 13,400 km each year over a 15 year life[37]. Fuel consumption varies between vehicles: a typical diesel car uses 4.2 litres per 100 kilometres while a typical petrol car uses 5.9 litres per 100 kilometre[38]. Fuel prices also vary: for this assessment, we have assumed a diesel price of £1.40 per litre and a petrol price of £1.30 per litre. The additional cost of running a petrol car is estimated to be £240 per year. The average net present value of this additional cost over the remaining life of cars was estimated to £1,492 (base 2015) if the measure was implemented in 2016 and £1,256 if implemented in 2021

There were 49,907 cars registered in postcode districts BD1-BD8 at the end of 2013 and 216,976 cars registered in postcode districts LS1-LS18, LS28. The net present value of the incentive to replace 25.9% of these cars in 2016 is estimated to be £19.3 million for Bradford and £83.8 million for Leeds. Similarly, the net present value of the incentive to replace 33% of the cars in 2021 is estimated to be £20.7 million for Bradford and £89.9 million for Leeds.

---

[36] DfT vehicle statistics veh 0203

[37] Based on DfT statistics veh0105, TRA8902, veh0208

[38] Ford Focus 1.6 Zetec 105PS and Ford Focus 1.6RDCi 115 PS

The implementation of this scenario requires much more detail consideration, which will impact the cost benefit analysis. The Ultra Low Emission Zone proposals in London published in October 2014 differentiates between petrol and diesel vehicles, and is the first policy to do so. Euro 4 petrol cars (up to and including 14 years old in 2020, the date of implementation) would be allowed into the LEZ while Euro 6 diesel cars (up to and including 5 years old) would be allowed into the LEZ. Older vehicles would still be allowed into the LEZ but would be liable to a fine of £12.50. It is estimated that this policy, including emission reduction targets on buses and HGVs, would result in a reduction of NOx emissions by 51%.

The detail of how a diesel/petrol fuel split measure could be implemented in Leeds and Bradford is needed to provide robust economic assessment of a measure which has practical and acceptable implementation potential.

Walking and cycling

This report has considered the damage costs and abatement costs avoided resulting from a 10% reduction in car traffic. One of the ways of achieving this reduction is to promote walking and cycling. Recent guidance prepared by the National Institute of Health and Care Excellence (NICE) aims to set out how people can be encouraged to increase the amount they walk or cycle for travel or recreation purposes[39].A health, economic and modelling report provides estimates of the costs and benefits of these measures[40]. The health, economic and modelling report considered evidence from various interventions including:

- The Cycling Demonstration Towns (CDT) programme was a £14 million investment in eight towns, designed to promote cycling. It consisted of infrastructure measures such as building cycle paths, combined with a programme of education and marketing, and was aimed at the general population.
- Sustainable Travel Towns (STT). Darlington, Peterborough and Worcester received funding over 4 years to promote sustainable travel, including walking and cycling infrastructure, Smarter Choices personalised travel planning, promotion of active modes and 'soft measures' for public transport.
- TravelSmart: personalised travel support.

The costs per person were estimated to be £30 for the Cycling Demonstration Towns programme, £46.93 for the Sustainable Travel Towns programme and £25 for the TravelSmart personalised travel support. It was estimated that 10.8% of the population would take up the offer of the TravelSmart personal support. Applying these costs pro-rata to Leeds (population 751,500) would give costs of £22.5 million, £35.3 million and £2.0 million respectively. Similarly for Bradford (population 522,452) the costs would be £15.7 million, £24.5 million and £1.4 million respectively. The costs for the CDT and STT programmes exceed the damage costs and abatement costs avoided by a 10 % reduction in car traffic in Leeds or Bradford. The costs for the TravelSmart programme are less than the total

[39] Walking and cycling: local measures to promote walking and cycling as forms of travel or recreation. NICE, 2012. http://www.nice.org.uk/guidance/ph41/resources/guidance-walking-and-cycling-local-measures-to-promote-walking-and-cycling-as-forms-of-travel-or-recreation-pdf

[40] Walking and cycling: local measures to promote walking and cycling as forms of travel or recreation: Health economic and modelling report. University of Sheffield, 2012. https://www.nice.org.uk/guidance/ph41/resources/economic-modelling-report2

damage and abatement costs avoided (22% of costs avoided for Leeds, 63% for Bradford) calculated for a 10% reduction in car traffic. The TravelSmart programme would thus be cost neutral with respect to air quality benefits if it achieved a 2.2% reduction in car traffic in Leeds and a 6.3% reduction in Bradford).

The health, economic and modelling report developed a statistical model of the reduction in the distance travelled by cars resulting from walking and cycling interventions. The model results indicate the following reductions in the annual distance travelled by cars: 0.1%, 4.3% and 2.5% for the CDT, STT and TravelSmart interventions respectively. Clearly, a greater (but unquantified) investment would be required to achieve a 10% reduction in car traffic. On this basis, it is unlikely that the CDT and STT measures could be justified on the grounds of improved air quality alone. On the other hand, the air quality benefits of the Travel Smart intervention would exceed the costs in Leeds provided that the expected reductions in car traffic were achieved.

However, interventions to promote walking and cycling will have significant other benefits including improved health resulting from greater levels of activity and reduction in congestion. The health, economic and modelling report estimated the cost of intervention per Quality-Adjusted Life Year (QALY) saved resulting from greater levels of physical activity for each intervention. These were £5000, £900 and £300-2500 per QALY for CDT, STT and TravelSmart interventions respectively. The report assumes a “value” of £20,000 per QALY: on this basis the benefits of the walking and cycling measures are substantially greater than the cost of the intervention.

LEZ enforcement costs

The enforcement of Low Emission Zones in Bradford and Leeds would lead to additional costs for the Councils. Costs would be involved in setting up and operating the schemes.

The main costs for the fuel split measures for cars and N1 light goods vehicles would be the costs of the incentives themselves. Other costs related to the management of the incentive scheme would add to the cost. These are estimated to be small compared with the costs of the incentives.

The bus emission reduction measures would apply primarily to bus companies providing scheduled services. The measures could be introduced as part of a Quality Bus Contract Scheme. West Yorkshire Metro are currently developing and evaluating the potential for a Quality Bus Contract Scheme. However, most of the large bus companies are not in favour of Metro’s proposals for a Quality Bus Contract scheme and have devised an alternative Partnership Scheme. Metro has engaged in extensive discussions with them collectively, as the Association of Bus Operators in West Yorkshire (ABOWY), regarding this partnership alternative. Either scheme could form the basis for cost-effective management of bus access to the Low Emission Zones.

Measures to reduce emissions in the LEZs from heavy goods and light goods vehicles would require enforcement because some operators of these vehicles would otherwise ignore the restrictions on access.

There are three main options for the enforcement of the LEZs:

- Manual enforcement
- Fixed Automatic Number Plate Recognition (ANPR) cameras
- Mobile ANPR cameras

Manual enforcement involves enforcement personnel (e.g. traffic wardens) visually checking vehicles travelling within or parked within the scheme area for identification marks. In practice, for a scheme based on the vehicle Euro standards, identification can most easily be carried out on the basis of the vehicle registration mark on the number plate. The checks would tend to focus on older-looking vehicles and would use a mixture of manual recording and photography. Some post-checking against a database of compliant vehicles (e.g. from the DVLA) would then be necessary. Operators of retrofitted vehicles that meet the emissions criteria could be required to obtain exemptions and be issued with permits/stickers to show compliance. Manual checking of parked vehicles can be relatively effective but only a small proportion of the vehicles travelling through the LEZs can be checked by manual enforcement methods. Manual enforcement in Bradford and Leeds is not likely to be effective because of the size of the proposed LEZs and the large volumes of traffic.

ANPR systems use optical character recognition software to read camera images of vehicle license plates to identify vehicles and their owners. The cameras can be installed on roadside poles (Fixed ANPR) or in vehicles parked at the side of the road (Mobile ANPR). The recorded images of the vehicle number plates are compared with the DVLA database to identify non-compliant vehicles. ANPR systems are able to capture 90%+ of passing number plates. Fixed ANPR systems are relatively inflexible and cannot take account of drivers finding alternative routes through minor roads to avoid detection. Mobile ANPR systems are effective in deterring such behaviour.

Examination of the Bradford road network suggests the following locations for fixed ANPR cameras:

- A6037 Canal Road
- Kings Road
- Idle Road
- A658 Harrogate Road/Otley Road
- B6381 Barkerend Road
- A647 Leeds Road
- Bowling Back Lane
- A650 Wakefield Road
- A641 Manchester Road
- Little Horton Lane
- A647 Morley Street
- Listerhills Road
- Thornton Road
- White Abbey Road
- Manningham Lane

Similar examination of the Leeds road network suggests the following locations for fixed ANPR cameras:

- A61 Scott Hall Road
- A58 Easterley Road
- York Road
- A64 Inglewood Drive
- Cross Gates Road
- A63 Pontefract Lane
- B6481 Pontefract Road
- A639 Wakefield Road
- Balm Road

- A653 Dewsbury Road
- Old Lane
- Town Street
- A643
- A62 Gelderd Road
- Whitehall Road
- B6154 Tong Road
- A647 Stanningley By-Pass
- B6157 Bradford Road
- A657
- A65 New Road Side
- Spen Lane
- A660 Otley Road

The cost of installing and operating ANPR systems depends to a considerable extent on the existing infrastructure. Start-up costs include the costs of the cameras, site preparation, signage, mounting structures and associated civil engineering, security provision, back office accommodation and equipment, and back office training. Operating costs include maintenance of the cameras and back office staff, accommodation and supervision costs. The existing infrastructure may already cover some of these aspects.

Bradford City Council have estimated an installation cost of £10,000 per camera and operating costs associated with two full time staff equivalents, approximately £80,000 per year. The net present value (base 2015) of installing and operating 15 cameras in Bradford over the period 2016-2021 is estimated on this basis to be £571,000.

The net present value for Leeds, based on 22 cameras and four full time staff equivalents and calculated on the same basis would be £1,065,000.

Cost estimates from other cities are often different. The Mayor of London Office for Policing and Crime, for example, estimated that the cost of setting up and running a system equivalent to the 1280 camera Transport for London network used for congestion charging was £32 million with annual revenue costs of £4.6 million[41]. The net present value (base 2015) of installing and operating 15 cameras in Bradford over the period 2016-2021 is estimated pro rata to be £650,000. The net present value (base 2015) of installing and operating 22 cameras in Leeds over the period 2016-2021 is estimated pro rata to be £953,000.

Bradford City Council estimate that the cost of the ANPR system would be broadly neutral in that the revenue to the Council from Fixed Penalty Notices would match the cost of operating the system. However, the cost would still be borne by the populace at large.

41 http://www.london.gov.uk/sites/default/files/DMPCD%202013%20110%20Automatic%20Number%20Plate%20Recognition%20Part%201.pdf

Cost effectiveness of measures

Tables 32 and 33 provide a summary of the costs of implementing the measures for Bradford and Leeds. The tables show the cost of the measures for implementation in 2016 and 2021 (net present value, base 2015). The costs for the HGV measures include the cost of enforcement of the LEZ.

The total NOx emission reduction for each of the scenarios for the periods 2016-2021 and 2021 onwards was estimated from the emission estimates provided by Leeds City Council for 2016 and 2021. The emission reductions for intermediate years between 2016 and 2021 were estimated by interpolation. The emission reductions for years beyond 2021 were assumed to taper to zero between 2021 and 2029, because pre- Euro 6 and pre-Euro VI vehicles will no longer be in service by then in most cases. The emissions in future years were discounted using a discount rate of 3.5%, to allow comparison with the discounted costs. Tables 32 and 33 also show the discounted emission reduction for each scenario and the cost per tonne of oxides of nitrogen emissions abated for implementation of the measures in 2016 and 2021 (as appropriate). The tables also list the measures in order of increasing cost per tonne of NOx abated.

In general, the cost per tonne abated is lower for implementation in 2016 than in 2021 for comparable measures. It is thus most cost effective to implement measures as soon as possible: cost effectiveness is reduced if implementation is delayed.

The most cost effective option in both Bradford and Leeds would be to implement Low Emission Zones requiring bus operators to meet the Euro VI standard within the Outer Ring Road areas, provided that it is practical to replace existing non-compliant buses with buses running on compressed natural gas.

CNG buses are potentially less expensive to run than diesel buses because fuel costs are lower. However, they are have not been widely used by bus operators in the UK and operators may be reluctant to use CNG buses without more experience of their operation in practice.

If bus operators consider it impractical to operate CNG buses in Leeds, the most cost-effective measure would be to require bus operators to replace existing Pre-Euro IV buses with conventional Euro VI buses in 2016. This measure would also be amongst the most cost-effective in Bradford.

Tables 34 and 35 provide a summary of the costs of implementing the measures and the abatement costs avoided for Bradford and Leeds. The tables show the cost of the measures for implementation in 2016 and 2021 (net present value, base 2015). The costs for the HGV measures include the cost of enforcement of the LEZ. The Tables show the abatement costs avoided for the individual years 2016 and 2021 and for the periods 2016-2021 and 2021 onwards.

The costs for the fuel split measures substantially exceed the abatement costs avoided in both Bradford and Leeds largely because of the large numbers of cars affected by the policy. Furthermore, it is unlikely that the full benefit of the measure in terms of abatement costs avoided could be achieved by offering incentives to local residents. Part of the emissions in the proposed LEZs would come from non-residents. Some residents would revert to diesel car usage after receiving the incentive payment. If the councils were to introduce this measure with an implementation lag of a number of years (e.g.2 years) then over this time there would be a percentage of vehicles which would be naturally replaced and therefore cost neutral. The resultant overall cost of this measure may therefore be lower.

The costs of requiring all vans to meet the Euro 6 standard in the LEZs also substantially exceed the abatement costs avoided in Bradford and Leeds. The measure would require a large number of van owners to buy new vehicles.

The cost of requiring all HGVs to meet the Euro VI standard in the LEZs would also substantially exceed the abatement costs avoided in Bradford and Leeds because a large number of vehicles would need to be replaced. The cost of requiring all pre-Euro IV HGVs to meet the Euro VI standard also exceeds the abatement costs avoided. Enforcement costs can be significant for measures applied to HGVs, particularly for Bradford.

The costs of the non-CNG bus measures in Bradford exceed the abatement costs avoided. However, the costs of the non-CNG bus measures in Leeds are closer to the abatement costs avoided. The difference between cities arises because the abatement costs apply in Leeds over a wider area. The cost of replacing Euro IV buses in Leeds in 2016 with Euro VI buses is less than the abatement costs avoided and so this option is economically attractive. The cost of replacing Euro V buses in Leeds in 2021 with Euro VI buses is approximately the same as the abatement costs avoided: this option therefore appears to be economically neutral. The costs of replacing all non-Euro VI buses in Leeds in 2016 or 2021 exceed the abatement costs avoided.

The abatement costs avoided were calculated on the basis of the default value of £29,150 per tonne of oxides of nitrogen emitted. Defra abatement cost guidance recommends that sensitivity analysis is carried out to reflect the uncertainty in the abatement costs. If the default value of £29,150 is used then it is suggested that a range of £28,000 - £73,000 is appropriate. The measure to replace pre Euro IV buses in Leeds with Euro VI buses remains attractive if the lower range value of the unit abatement costs is used. The measures to replace all non-Euro VI buses in Leeds in 2016 or 2021 become attractive if the higher value of the range is used. The measure to replace pre Euro IV buses in Bradford also becomes attractive.

The assessment is based on estimates of emissions provided by Leeds City Council for 2016 and 2021. The assessment considers the replacement of pre Euro V buses in Leeds in 2021. It is possible that this measure would be more economically attractive if introduced earlier. It is recommended that Leeds City Council investigate the emissions reductions in the Outer Ring Road area that would arise from earlier introduction of this measure.

Table 32: Costs of measures per tonne of oxides of nitrogen abated, Bradford

Measure	Discounted cost , £million 2015		Discounted emission reduction, tonnes 2015			Cost per tonne abated, £	
	2016 implementation	2021 implementation	2016-2021	2021 onwards	2016-onwards	2016 implementation	2021 implementation
Fuel split	19.3	20.7	215	199	415	46,000	104,000
All buses Euro VI	11.9	3.8	84	21	103	116,000	185,000
All buses Euro VI (CNG scenario)	**0.2**	**0.3**	84	21	103	2,000	15,000
All HGV Euro VI	7.4[+]	1.9[+]	90	21	110	67,000	92,000
All bus and HGV Euro VI	18.9[+]	5.6[+]	174	41	216	87,000	136,000
Pre Euro IV buses to Euro VI	1.0		21		21	49,000	
Pre Euro IV buses to Euro VI (CNG scenario)	**0.2**		21		21	10,000	
Pre Euro IV HGV to Euro VI	0.8[+]	-	7		7	117,000	
Pre Euro IV bus and HGV to Euro VI	1.8[+]	-	27		27	66,000	
All vans Euro 6	31	10	61	14	75	411,000	729,000
Euro II and Euro III bus retrofit	0.9	-	3		3	262,000	
Pre Euro V buses to Euro VI		1.2		9	9		140,000
Pre Euro V buses to Euro VI (CNG scenario)		0.3		9	9		35,000
Pre Euro V HGV to Euro VI		0.5[+]		0	0		Indeterminate
Pre Euro V bus and HGV to Euro VI		1.7		9	9		198,000
Promotion of walking and cycling(TravelSmart)	1.4		10		10	143,000	

Measure	Cost per tonne abated , £ 2016 implementation
All buses Euro VI (CNG scenario)	2,000
Pre Euro IV buses to Euro VI (CNG scenario)	10,000
Fuel split	46,000
Pre Euro IV buses to Euro VI	49,000
Pre Euro IV bus and HGV to Euro VI	66,000
All HGV Euro VI	67,000
All bus and HGV Euro VI	87,000
All buses Euro VI	116,000
Pre Euro IV HGV to Euro VI	117,000
Promotion of walking and cycling(TravelSmart)	143,000
Euro II and Euro III bus retrofit	262,000
All vans Euro 6	411,000

Table 33: Costs of measures per tonne of oxides of nitrogen abated, Leeds

Measure	Discounted cost , £million 2015		Discounted emission reduction, tonnes 2015			Cost per tonne abated, £(2015)	
	2016 implementation	2021 implementation	2016-2021	2021 onwards	2016-onwards	2016 implementation	2021 implementation
Fuel split	83.8	89.9	827.8	652	1479.8	57,000	138,000
All buses Euro VI	23.2	7	510.2	137	647.2	36,000	51,000
All buses Euro VI (CNG scenario)	0.5	0.6	510.2	137	647.2	1,000	4,000
All HGV Euro VI	46.6	6.9	368.8	68	436.8	107,000	101,000
All bus and HGV Euro VI	69.8	13.9	879.1	206	1085.1	64,000	67,000
Pre Euro IV buses to Euro VI	2.9		144			20,000	
Pre Euro IV buses to Euro VI (CNG scenario)	0.7		144			5,000	
Pre Euro IV HGV to Euro VI	1.6[+]		10			160,000	
Pre Euro IV bus and HGV to Euro VI	4.5[+]		154			29,000	
All vans Euro 6	156	51	178.4	41	219.4	711,000	1,244,000
Euro II and Euro III bus retrofit	2.5		64.7			39,000	
Pre Euro V buses to Euro VI		1.5		52			29,000
Pre Euro V buses to Euro VI (CNG scenario)		0.4		52			8,000
Pre Euro V HGV to Euro VI		1		7			143,000
Pre Euro V bus and HGV to Euro VI		2.5		58			43,000
Promotion of walking and cycling(TravelSmart)	2.0		39.9			50,000	

Measure	Cost per tonne abated , £ 2016 implementation
All buses Euro VI (CNG scenario)	1,000
Pre Euro IV buses to Euro VI (CNG scenario)	5,000
Pre Euro IV buses to Euro VI	20,000
Pre Euro IV bus and HGV to Euro VI	29,000
All buses Euro VI	36,000
Euro II and Euro III bus retrofit	39,000
Promotion of walking and cycling(TravelSmart)	50,000
Fuel split	57,000
All bus and HGV Euro VI	64,000
All HGV Euro VI	107,000
Pre Euro IV HGV to Euro VI	160,000
All vans Euro 6	711,000

Table 34: Comparison of costs and abatement costs avoided for Bradford measures

Measure	Cost, £ million		Abatement costs avoided, £ million			
	2016	2021	2016	2021	2016-2021	2021-?
Fuel split	19.3	20.7	1.3	0.8	6.3	5.8*
All buses Euro VI	11.9	3.8	0.6	0.2	2.4	0.6*
All buses Euro VI (CNG scenario)	**0.2**	**0.3**	**0.6**	**0.2**	**2.4**	**0.6***
All HGV Euro VI	7.4+	1.9+	0.7	0.2	2.6	0.6*
All bus and HGV Euro VI	18.9+	5.6+	1.3	0.4	5.1	1.2*
Pre Euro IV buses to Euro VI	1.0		0.2	-	0.6**	-
Pre Euro IV buses to Euro VI (CNG scenario)	**0.2**		**0.2**	**-**	**0.6****	**-**
Pre Euro IV HGV to Euro VI	0.8+	-	0.1	-	0.2**	-
Pre Euro IV bus and HGV to Euro VI	1.8+	-	0.34	-	0.8**	-
All vans Euro 6	31	10	0.5	0.1	1.8	0.4*
Euro II and Euro III bus retrofit	0.9	-	0.03	-	0.1**	-
Pre Euro V buses to Euro VI		1.2		0.1		0.25*
Pre Euro V buses to Euro VI (CNG scenario)		0.3		0.1		0.25*
Pre Euro V HGV to Euro VI		0.5+		0		0*
Pre Euro V bus and HGV to Euro VI		1.7		0.1		0.25*

+ Includes enforcement costs

* The Council provided emission estimates for 2016 and 2021. The abatement costs avoided for the years after 2021 have been estimated from the abatement costs avoided for 2021 and the expected lifetime of key vehicle categories beyond 2021. For example, pre Euro VI buses are likely to be taken out of service in 2029 or before. The abatement costs avoided for the period beyond 2021 were estimated assuming that the annual abatement costs avoided taper to zero over the period 2021-2029.

** The Council provided emission estimates for 2016 only. It is expected that pre Euro IV buses will be taken out of service in 2021 or before. The abatement costs avoided for the period beyond 2016 were estimated assuming that the annual abatement costs avoided taper to zero over the period 2016-2021.

Table 35: Comparison of costs and abatement costs avoided for Leeds measures

Measure	Cost, £ million		Abatement costs avoided, £ million			
	2016	2021	2016	2021	2016-2021	2021-?
Fuel split	83.8	89.9	5.0	3.1	24.1	19*
All buses Euro VI	23.2	7.0	3.8	1.3	14.9	4*
All buses Euro VI (CNG scenario)	**0.5**	**0.6**	**3.8**	**1.3**	**14.9**	**4***
All HGV Euro VI	46.6[+]	6.9[+]	2.8	0.8	10.8	2*
All bus and HGV Euro VI	69.8[+]	13.9[+]	6.6	2.1	25.6	6*
Pre Euro IV buses to Euro VI	**2.9**		**1.4**		**4.2****	
Pre Euro IV buses to Euro VI (CNG scenario)	**0.7**		**1.4**		**4.2****	
Pre Euro IV HGV to Euro VI	1.6[+]		0.2		0.3**	
Pre Euro IV bus and HGV to Euro VI	**4.5**[+]		**1.6**		**4.5****	
All vans Euro 6	156	51	1.4	0.3	5.2	1.2*
Euro II and Euro III bus retrofit	2.5		0.2		0.6**	
Pre Euro V buses to Euro VI		**1.5**		**0.6**		**1.5***
Pre Euro V buses to Euro VI (CNG scenario)		**0.4**		**0.6**		**1.5***
Pre Euro V HGV to Euro VI		1.0[+]		0.2		0.2*
Pre Euro V bus and HGV to Euro VI		2.5[+]		0.8		1.7*

+ Includes enforcement costs

* The Council provided emission estimates for 2016 and 2021. The abatement costs avoided for the years after 2021 have been estimated from the abatement costs avoided for 2021 and the expected lifetime of key vehicle categories beyond 2021. For example, pre Euro VI buses are likely to be taken out of service in 2029 or before. The abatement costs avoided for the period beyond 2021 were estimated assuming that the annual abatement costs avoided taper to zero over the period 2021-2029.

** The Council provided emission estimates for 2016 only. It is expected that pre Euro IV buses will be taken out of service in 2021 or before. The abatement costs avoided for the period beyond 2016 were estimated assuming that the annual abatement costs avoided taper to zero over the period 2016-2021.

Wider economic advantage impact of measures

Improving air quality in an urban environment can have a range of positive impacts, including enhancing human health, productivity, amenity and the health of the local environment. Many of the most significant impacts are included in Defra's air quality damage costs and hence will be captured in the cost-benefit analysis (CBA) of options presented in this report. However, a range of wider benefits are not currently captured given difficulties associated with quantifying these impacts. In particular, several important effects which provide a local economic advantage through reducing air pollution are not captured. When undertaking impact assessment it is important to consider the potential significance of these impacts alongside the quantitative analysis to provide a more comprehensive view of the possible outcomes of the measures considered.

Four key effects providing an economic advantage associated with the measures considered in this study have been qualitatively assessed in this section. These are the impacts on:

- Productivity of the work-force
- Local automotive industries
- Congestion
- Other local economic impacts

These impacts are assessed qualitatively due to the scope of the study and restricted availability of quantitative information. Given these impacts are not captured by the quantitative analysis, they should be considered additional to the CBA.

Productivity of the work-force

The impact of air pollution on human health is widely recognised. There is substantial evidence linking exposure to particular pollutants to a range of respiratory and cardio-vascular conditions.

Alongside impacting directly on an individual's enjoyment of life and on the burden placed on health services, detrimental health impacts will also have an impact on the ability of a person to work (or engage in 'productive' activities[42]). Where a person is restricted from working due to a health condition or ailment, this will have a consequent negative impact on the output of the business they are employed by and the aggregate city region, incurring a real cost to the local economy.

The ability of people to work can be affected through two pathways associated with air pollution: absenteeism and presenteeism. Absenteeism is where an affected individual is unable to attend work due to their health condition, whereas presenteeism is where a person is able to attend work whilst ill, but is less productive in undertaking their usual duties.

The Defra damage costs capture some of the key impacts of air pollution on human health, specifically the impact on deaths and hospital admissions. Where an affected person is employed (or engaged in an informal productive activity) the damage costs will capture the impact on the productive output of that person. However, a range of more minor health conditions are not currently captured by the damage costs. This includes a number of pathways which have been included in air quality impact studies in the US[43] and at the EU level[44] for a number of years, for example:

- Chronic bronchitis, acute bronchitis, restricted activity days, lower respiratory symptom days and asthma associated with exposure to particulate emissions, and
- Minor restricted activity days and school days lost associated exposure to ozone.

The impact of these conditions on a person's ability to work will of course depend on a number of factors specific to the individual, not least: the severity of the ailment, the underlying health of the person and whether that person is employed or not. However, the impact of air pollution through these pathways could have a significant impact: for example, 'work days lost' are explicitly included

[42] Productive activities here refers to activities which have a beneficial output and hence value for society, for example, care work, volunteering and other non-paid activities which fall outside the scope of the formal labour market.
[43] See for example: http://www.epa.gov/air/sect812/feb11/fullreport_rev_a.pdf
[44] See for example: http://www.climatecost.cc/images/Policy_Brief_master_REV_WEB_medium_.pdf

in the wider definition of 'restricted activity days' associated with particulate emissions, hence creating a direct link to absenteeism in the workforce. Further, minor restricted activity days[45] which affect employed persons during their working week could be associated with a loss of productivity at work (presenteeism) and school days lost could lead to absenteeism where parents need to take time off work to care for sick dependents. Chronic conditions could also lead to productivity loss where these conditions force affected individuals to retire early from the workforce.

It has not been possible to quantify these impacts as part of this study. However, the size of these impacts will scale with the level of emissions reductions achieved, associating the greatest benefit with those measures which deliver the greatest air quality improvement. When quantified by the US and EU studies, although the CBA is dominated by the impacts on mortality, working days lost and restricted activity days form a significant part of the valued impacts.

Further, the likely significance will also depend on the baseline rate of absenteeism and presenteeism in Leeds and Bradford: recent data from the ONS[46] suggests that on average, 4.8 days per worker were lost due to sickness in 2012/13 for the Yorkshire and Humber region, ranking the region one of the highest in the UK and above the national average of 4.5 per worker. However, it is unclear from this data whether these absences were due to air pollution related ailments or otherwise.

The pollution reductions associated with the measures considered in this study are likely therefore to provide an additional benefit to local businesses and in aggregate to the local economy. The reduction of particulates in particular will lead to improvements in human health, with subsequent reductions in the incidence of absence from work (or presenteeism) associated with air pollution related conditions. The impacts across measures will scale with the emissions reductions achieved and these effects could be amplified where additional benefits are delivered through the direct impact of walking and cycling on human health where these behaviours are encouraged in response to the measures.

Impacts on local automotive industry

This study has considered a number of options for how a LEZ in Leeds and Bradford could be implemented, exploring different restrictions across different vehicle types to improve air quality. It is assumed that the costs associated with meeting the requirements of an LEZ will be borne by the private owners of the vehicles.

To meet the requirements of the LEZ, vehicle owners will either have to retro-fit existing vehicles to ensure compliance or purchase new vehicles meeting the necessary environmental standards. Although there will be a cost associated with retro-fit or replacement (as captured by the CBA above), these activities could also provide an economic benefit to local automotive industries where they create additional activity in the local supply chains for the manufacture, distribution, application or sale of cleaner vehicle technologies.

[45] Minor restricted activity days are defined as restricted activity days where a person is not confined to bed or misses a day of work

[46] ONS (2013): 'Sickness absence in the labour market 2014'; http://www.ons.gov.uk/ons/rel/lmac/sickness-absence-in-the-labour-market/2014/rpt---sickness-absence-in-the-labour-market.html

The size of any likely economic advantage provided will be determined by a number of factors, including the locations of: vehicle owners, part and vehicle manufacturers, and retro-fit activities. The latter will in turn be determined by the ability of local mechanics to undertake the necessary retro-fit work and/or whether this work requires specialist skills.

This study assumes that the measures will apply only to vehicles registered within the Leeds and Bradford study areas. In doing so, it has identified a large number of vehicles which require upgrade or replacement. Although it is difficult to predict with certainty and will depend on the individual choice of the vehicle owners, it is conceivable that vehicle owners are more likely to upgrade or purchase new vehicles locally at greatest convenience where possible. This is in comparison to, for example, a national haulage company, based outside of the study area but affected by the measures, which may choose to upgrade or replace vehicles elsewhere.

Where owners purchase new vehicles, it is likely that the majority of the associated manufacturing benefits will fall outside the study area given the relatively low level of vehicle manufacturing in the region. However, some benefits may be captured through the production of low-emission buses. Optare has a manufacturing plant based just outside of Leeds in Sherburn-in-Elmet and is actively producing buses fit to meet the stringent standards of LEZ's[47]. The size of any impact will depend on what brand and how many new buses are purchased by local bus operators but where purchases are of Optare vehicles and area additional to existing orders this will deliver an economic advantage to the local area, supporting business (and potentially jobs) in the region. Further, some small benefits may accrue in the sale and distribution of new vehicles and parts.

The economic benefit associated with retro-fit activity is more uncertain but potentially more lucrative for the study area. The retro-fit of buses is considered explicitly as an option in this study but it is conceivable that some HGVs and vans can also be retro-fitted to meet stricter emissions standards where feasible and economical given vehicles have been retro-fitted previously to meet Euro IV and V standards[48]. Hence a greater number of vehicle retro-fits could take place in the study area than new vehicles produced.

Whether retro-fit delivers a local economic benefit will depend on where parts are manufactured and fitted. Where retro-fit can be undertaken by local mechanics, this will deliver economic advantage for the study area through to additional business generated. Further, the introduction of an LEZ with specific conditions may attract businesses with the necessary skills to the area, potentially delivering additional economic activity and jobs even where these did not exist originally.

Compliance activities could therefore stimulate local supply chains in the production, distribution, fitting and sale of retro-fit parts or new vehicles. It is difficult to determine the exact size of any potential economic benefit to the local economy given a number of uncertain supporting factors, for example, where private owners will source upgrades or new vehicles, whether local businesses possess the necessary skills to retro-fit vehicles and whether the introduction of an LEZ will attract new activity to the study area.

[47] http://www.transportengineer.org.uk/transport-engineer-news/optare-unveils-euro-6-double-decker-for-london-market/61656/

[48] See for example: http://www.dieselretrofit.eu/projects.html and http://healthyair.org.uk/documents/2013/10/black-carbon-retrofit-guidance.pdf

Across the measures, the size of any likely benefit will scale with the quantity of vehicles requiring upgrade or replacement and the cost (specifically the value of the labour engaged in the improvement activity). The aggregate impact is likely to be positive and will provide an additional benefit to those considered in the quantitative analysis above. The impact of car measures (both fuel switching and reduction in trips) will provide limited, if any, benefit to local automotive industries.

Congestion and other local economic impacts

The modelling of impacts and emissions undertaken as part of this study assumes no change to the type, mode or number of trips made in the study areas over the assessment period (with the exception of the measure directly considering reduction in car trips). Instead, to comply with the restrictions of the LEZ, private vehicle owners are simply assumed to invest in new or upgrades to existing vehicles. In making these assumptions, the modelling also implicitly assumes that there would be no impact on traffic flows and journeys made as a result of the introduction of the LEZ.

In practice, the strength of this assumption will depend on the significance of the costs placed on vehicle owners and their reason for travel. For example, where costs are low, private owners are more likely to internalise[49] these costs, with no consequent impact on behaviour. However, many of the measures considered in this study may not imply a cost which is insignificant to the owner. Where the cost of measures is more significant, this could start to impact on the behaviour of the vehicle owners, with a potential impact on either the mode of travel or amount of trips.

Impacts of modal shift - congestion

Where measures impact on the mode of travel, this could impact on congestion in and around the study area. Congestion carries with it a cost associated with both the time lost and additional fuel costs incurred whilst vehicles are held up in traffic. This could be time lost from both recreational and business activity, such as commuting and delivery of goods. Hence where measures could improve congestion, these would provide a positive economic advantage through a decrease in work-time lost (for example to commuting) and increased productivity for vehicle based services (for example, increasing the number of deliveries per day, improving reliability of services or reducing fuel cost associated with deliveries).

The extent of modal shift will depend on the availability, suitability and cost of alternatives.

For private businesses, for example owners of vans and HGVs, some modal shift may occur where the LEZ places restrictions on a specific vehicle type but not on others capable of providing the same service, for example, switching local delivery from HGVs to vans. Where a more comprehensive LEZ is put in place, businesses are likely to simply pass on any additional costs to end consumers in the absence of viable alternative modes, with no consequent impact on congestion.

For car-users under the fuel-switching option, the assumption of no change in mode or trips may be weaker given the range of available alternatives for trips into the centres of Bradford and Leeds, including bus, train, car-sharing and non-motorised travel. Of course, the size of any impact will depend on the relative cost, feasibility and preference around alternative modes, taking into account factors such as comfort and reliability. A key driving factor in determining changing household

[49] I.e. through a slight reduction in profit for businesses associated with a particular trip or household budget as a result of the trip.

behaviour could be how they are incentivised under the LEZ: where they face the cost privately, this could facilitate greater modal shift relative to the case where switching is subsidised.

For those traveling by bus, it is likely that the costs of vehicle upgrade will be passed directly through to bus-users, increasing the cost of travel. This could also incentivise some mode switching (in particular to cheaper alternatives) but this could be somewhat offset by switching to bus travel from cars where measures are implemented together.

The measure directly considering a 10% reduction in car trips assumes that these will be replaced by alternative modes of transport, in particular walking and cycling. Hence in comparison to the other measures, this option implies a more certain improvement in congestion with associated time-saving benefits.

The size of any impact will also depend on the current extent of congestion in and around the study areas and the exact boundaries of any LEZ put in place. For example, an ex-ante feasibility study of London's LEZ[50], the analysis considered that placing restrictions on particular roads could increase congestion and traffic on alternative routes around the capital, undermining the congestion and air pollution related benefits gained inside the zone.

Impacts of trip numbers – congestion and local business

Alongside the impact of modal shift, the costs that measures place on private vehicle owners could also impact on the number of trips made to and within the study areas. This will also impact on congestion and could have a further effect on local businesses, as explored in this section. In this case, it is interesting to distinguish between trips made for business (i.e. by businesses or commuting) and recreation as the susceptibility of both to changes in cost[51] (and air quality) will differ.

For businesses, as discussed above, where costs incurred are low these are likely to be internalised and/or passed directly onto the consumer, creating only a marginal change if any in the number of trips. However, where costs are more significant, this could reduce the profitability of the trip or consumer demand due to higher prices, which in turn could reduce the number of trips made. Although this could have a positive impact on congestion, this would also have a negative knock-on effect for businesses and the local economy through reduced economic activity.

For commuters, given the relatively fixed nature of the locations of residence and work, the measures are unlikely to impact on the number of trips and are more likely to impact on the mode of travel, as considered above.

Where the measures increase costs for recreational (or optional) trips by households into the LEZ intended areas, either by car or bus, this may incentivise travellers to find alternative destinations depending on the significance of the costs, the reason for the trip and availability of alternatives.

On the other hand, the number of recreational trips made to the study zones could also increase due to the improved air quality. Where perceptions of the environmental quality of the city centres are improved, this increases the attractiveness of visiting the centres, both for local residents and

[50] TfL (2003): 'The London Low Emission Zone Feasibility Study'; https://www.tfl.gov.uk/cdn/static/cms/documents/phase-2-feasibility-summary.pdf

[51] In economics this is known as the elasticity.

tourists located outside the study area. More visitors to the city centres could provide a boost to local businesses but with consequent negative impacts on congestion and emissions savings. Again, a number of factors will determine the size of the impact, in particular the current perceptions of air quality in the city centres and how significant this factor is in individual decisions to visit the study area relative to alternatives.

The measure considering a 10% reduction in car trips implicitly assumes no change in the number of trips.

Net impact on congestion and other local economic impacts

In this section we have discussed the potential impacts of the measures on the behaviour of vehicle owners, some of which move in opposing directions. The introduction of an LEZ could have an impact on either (or both) modes of transport used or numbers of trips made to the study zones, with consequent impacts for congestion, local businesses and a potential additional impact on emissions.

These impacts have not been explored as part of the modelling and hence it is difficult to predict the balance of impacts without more detailed quantitative analysis of individual vehicle owners' decisions. In addition, the impacts will be strongly influenced by the detail of the measures implemented, for example, the boundaries of the LEZ, coverage of vehicles and incentives placed on vehicle owners.

Where households directly face the costs of vehicle improvements, it is conceivable that some modal shifting for commuting or recreational journeys could occur, in particular where economically-viable alternatives exist. Where the measures encourage modal shifting with no impact on the number of trips, this could reduce congestion (with further potential increases in emissions) without a detrimental impact on the wider local economy. However, where costs are more significant, it is uncertain where the balance of impacts will lie for recreational trips between fuel switching and modal shift (with no impact on trip numbers) or shifting the destination of trips which could impact on local businesses.

For businesses, where the costs are relatively low, it is likely that costs will be passed through to consumers with little or no impact on the mode or number of trips. However, where costs become more significant, this could impact on both mode and quantity of trips which could provide a benefit through reduced congestion but a cost for local businesses through reduced economic activity.

Summary of assessment

Alongside its impacts on human health and buildings captured by Defra's damage costs, the measures considered in this study will also have a number of wider effects which have not been quantitatively assessed. Four impacts have been explored qualitatively in this discussion, considering different economic advantages which might be delivered through the implementation of a LEZ. These effects and a summary of their likely direction and significance are presented in Table 36.

Table 36 – Summary of qualitative assessment of economic advantage

Impact	Direction and significance	Impact of individual measures
Productivity of the workforce	**Positive impact** Air quality improvements reduce detrimental impacts on human health. This reduces absenteeism and presenteeism in the work-force (and in other productive activities)	Impacts increase with extent of emissions reductions of measures Additional benefits would be implied by switching to modes which increase physical activity, eg under 10% reduction in car travel measure
Local automotive industries	**Slight positive impact** Introduction of LEZ stimulates demand for upgrade or replacement of vehicles. This supports local automotive supply chain across the production, distribution, retro-fit and sale of clean technology. Benefits in manufacture may be small and limited to one plant but vehicle retro-fit, where able to undertaken by local mechanics, could deliver greater benefits	Most significant benefits likely to be associated with vehicle retro-fit carried out under bus retro-fit and vehicle upgrade to higher Euro standard options, with the latter potentially met through either retro-fit or replacement. Only marginal (if any) impacts from car measures (fuel-switching and trip reduction).
Congestion	**Impact uncertain** Modal shift in household journeys could reduce congestion (both commuting and recreational); but improved air quality in city centre may attract additional visitors Unlikely to be significant impact on mode or number of trips made by private businesses unless costs are significant	Fuel switching for cars, 10% reduction in car trips and (to a lesser extent) bus retro-fit are likely to have most significant impact due to availability of alternative options. Impacts on HGVs and vans begin to impact where costs become significant All measures impact on improved city centre environment, with impacts scaling with extent of emissions reductions
Other local economic impacts	**Impact uncertain** Improved air quality may attract more visitors to city centre; however, impact will be offset to some extent by increased costs of travel Unlikely to be significant impact on mode or number of trips made by private businesses unless costs are significant	Fuel switching for cars likely to have most significant impact. Impacts on HGVs and vans begin to impact where costs become significant All measures impact on improved city centre environment, with impacts scaling with extent of emissions reductions

Conclusions

The costs and benefits of a range of measures suggested by Bradford and Leeds Councils to reduce nitrogen dioxide concentrations have been evaluated. The measures included measures to reduce emissions from buses, heavy goods vehicles, light goods vehicles and cars.

The economic benefits of the measures were assessed using a four stage abatement cost methodology:

Estimate the likely scale of the impact on emissions by applying damage costs to the change in emissions.

Identify whether there is expected to be any impact on compliance with legally-binding obligations.

Estimate the value of the change in air quality using unit abatement costs, which provide an indicative marginal cost per tonne of emission based on the average marginal abatement technology. This provides an easy to use indicative estimate of the abatement impact.

Where a measure is likely to have a significant impact on compliance (suggested as a value greater than £50m) then more detailed analysis may be justified.

Damage costs provide a means to estimate the value for the impacts of exposure to air pollution on health – both chronic mortality effects (which consider the loss of life years due to air pollution) and morbidity effects (which consider changes in the number of hospital admissions for respiratory or cardiovascular illness) – in addition to damage to buildings (through building soiling) and impacts on materials. The damage costs avoided in the Leeds Outer Ring Road area for individual measures ranged up to £1.26 million over the period 2016-2021 for the measure requiring all buses to achieve the Euro VI standard. The damage costs avoided in the Bradford Outer Ring Road area for individual measures ranged up to £0.33 million over the period 2016-2021 for the measure to return the proportion of diesels cars in the car fleet to 2000 levels.

A review of monitoring data indicated that there were many locations within the Bradford and Leeds Outer Ring Roads where the nitrogen dioxide concentrations exceeded legally binding European limit values for nitrogen dioxide. Concentrations at several sites are projected to remain above the limit value in 2016 and beyond.

The value of the change in air quality was assessed using unit abatement costs. The value of the abatement costs avoided for the measures in Bradford was estimated to be £6.3 million for the period 2016-2021for the measure to return the proportion of diesels cars in the car fleet to 2000 levels. The value of the abatement costs avoided for the measures in Leeds was estimated to be £25.6 million for the period 2016-2021for the measure to requiring all buses and HGVs to achieve the Euro VI standard in 2016.

The cost of the measures was estimated taking into account the numbers of vehicles potentially requiring replacement and their capital cost (less trade-in value) compared to the capital cost for the "business as usual" case without replacement. The estimate took into account additional operating and maintenance costs for Euro VI vehicles. The costs for the measure to return the proportion of diesel cars in the car fleet to 2000 levels were estimated taking into account the additional fuel consumption for petrol cars. The costs for CNG buses took into account the additional capital and operating costs of the gas compression plant: the costs also took into account the lower cost of CNG fuel compared to diesel.

The most cost effective option in both Bradford and Leeds would be to implement Low Emission Zones requiring bus operators to meet the Euro VI standard within the Outer Ring Road areas, provided that it is practical to replace existing non-compliant buses with buses running on compressed natural gas.

CNG buses are potentially less expensive to run than diesel buses because fuel costs are lower. However, they are have not been widely used by bus operators in the UK and operators may be reluctant to use CNG buses without more experience of their operation in practice.

The costs for the fuel split measures to return the proportion of diesel cars to 2000 levels substantially exceed the abatement costs avoided in both Bradford and Leeds largely because of the large numbers of cars affected by the policy. Furthermore, it is unlikely that the full benefit of the measure in terms of abatement costs avoided could be achieved by offering incentives to local residents. Part of the emissions in the proposed LEZs would come from non-residents. Some residents would revert to diesel car usage after receiving the incentive payment.

The costs of requiring all vans to meet the Euro 6 standard in the LEZs also substantially exceed the abatement costs avoided in Bradford and Leeds. The measure would require a large number of van owners to buy new vehicles.

The cost of requiring all HGVs to meet the Euro VI standard in the LEZs would also substantially exceed the abatement costs avoided in Bradford and Leeds because a large number of vehicles would need to be replaced. The cost of requiring all pre-Euro IV HGVs to meet the Euro VI standard also exceeds the abatement costs avoided. Enforcement costs can be significant for measures applied to HGVs, particularly for Bradford.

The costs of all the bus measures in Bradford exceed the abatement costs avoided. However, the costs of the bus measures in Leeds are closer to the abatement costs avoided. The difference between cities arises because the abatement costs apply in Leeds over a wider area. The cost of replacing Euro IV buses in Leeds in 2016 with Euro VI buses is less than the abatement costs avoided and so this option is economically attractive. The cost of replacing Euro V buses in Leeds in 2021 with Euro VI buses is approximately the same as the abatement costs avoided: this option therefore appears to be economically neutral. The costs of replacing all buses in Leeds with Euro VI vehicles in 2016 or 2021 exceed the abatement costs avoided.

The abatement costs avoided were calculated on the basis of the default value of £29,150 per tonne of oxides of nitrogen emitted. Defra abatement cost guidance recommends that sensitivity analysis is carried out to reflect the uncertainty in the abatement costs. If the default value of £29,150 is used then it is suggested that a range of £28,000 - £73,000 is appropriate. The measure to replace pre Euro IV buses in Leeds with Euro VI buses remains attractive if the lower range value of the unit abatement costs is used. The measures to replace all non-Euro VI buses in Leeds in 2016 or 2021 become attractive if the higher value of the range is used. The measure to replace pre Euro IV buses with Euro VI vehicles in Bradford also becomes attractive.

The assessment is based on estimates of emissions provided by Leeds City Council for 2016 and 2021. The assessment considers the replacement of pre Euro V buses in Leeds in 2021. It is possible that this measure would be more economically attractive if introduced earlier. It is recommended that Leeds City Council investigate the emissions reductions in the Outer Ring Road area that would arise from earlier introduction of this measure.

The abatement cost avoided for the measure where Pre Euro IV buses in Leeds are replaced with Euro VI buses is estimated to be £4.2 million over the period 2016-2021. The abatement costs avoided for the most economically attractive measure is substantially less than £50 million and so more detailed analysis of abatement costs is required.

The assessment has considered the damage costs and abatement costs avoided as the result of improved air quality from a reduction of 10% in car traffic. It has been suggested that this change might be achieved by means of interventions to promote walking and cycling. The analysis indicates that the cost effectiveness of these interventions depends on the measures applied. It indicates that the benefit of improved air quality resulting from TravelSmart personalised travel support would exceed the cost of the intervention in Leeds. The other measures considered (Cycling Demonstration Towns, Sustainable Travel Towns) cannot be justified on the basis of improved air quality alone. However, interventions to promote walking and cycling will have other benefits, most importantly improved health resulting from increased physical activity. These benefits are estimated to be substantially greater than the costs of the interventions.

Appendix 1 – Emission reductions

Table A1: Carbon dioxide emissions from the Leeds Inner Ring Road area, tonnes per annum

EFT5_CO2u	Car	LGV	HGV&Coach	BUS
2012 base	22,548	3,549	3,589	8,204
2016 base	22,730	4,068	4,017	8,033
2016 fuel split	24,096	4,110	4,017	8,033
2016 all buses Euro VI	22,730	4,068	4,017	8,077
2016 all HGV Euro VI	22,730	4,068	4,024	8,033
2016 all bus and HGVs Euro VI	22,730	4,068	4,024	8,077
2016 All vans Euro 6	22,730	4,051	4,017	8,033
2016 E2&E3 retrofit	22,730	4,068	4,017	8,047
2016 all Pre Euro IV buses Euro VI	22,730	4,068	4,017	8,017
2016 all Pre Euro IV HGV Euro VI	22,730	4,068	4,012	8,033
2016 Pre Euro IV bus and HGVs to Euro VI	22,730	4,068	4,012	8,017
2016 10% reduction in car use	20,457	4,068	4,017	8,033
2021 base	22,151	4,564	4,240	8,882
2021 fuel split	23,556	4,604	4,240	8,882
2021 All buses to Euro VI	22,151	4,564	4,240	8,885
2021 All HGVs to Euro VI	22,151	4,564	4,243	8,882
2021 All bus and HGVs to Euro VI	22,151	4,564	4,243	8,885
2021 All vans to Euro 6	22,151	4,557	4,240	8,882
2021 All pre Euro V buses to Euro VI	22,151	4,564	4,240	8,885
2021 All pre Euro V HGV to Euro VI	22,151	4,564	4,243	8,882
2021 All pre Euro V bus and HGVs to Euro VI	22,151	4,564	4,243	8,885
2021 10% reduction in car use	19,936	4,564	4,240	8,882

Table A2: Oxides of nitrogen emissions from the Leeds Inner Ring Road area, tonnes per annum

EFT5_NOx	Car	LGV	HGV&Coach	BUS
2012 base	46.2	13.02	25.5	58.3
2016 base	38.0	10.87	19.3	38.8
2016 fuel split	17.7	10.64	19.3	38.8
2016 all buses Euro VI	38.0	10.87	19.3	6.4
2016 all HGV Euro VI	38.0	10.87	4.7	38.8
2016 all bus and HGVs Euro VI	38.0	10.87	4.7	6.4
2016 All vans Euro 6	38.0	4.69	19.3	38.8
2016 E2&E3 retrofit	38.0	10.87	19.3	32.1
2016 all Pre Euro IV buses Euro VI	38.0	10.87	19.3	26.6
2016 all Pre Euro IV HGV Euro VI	38.0	10.87	18.5	38.8
2016 Pre Euro IV bus and HGVs to Euro VI	38.0	10.87	18.5	26.6
2016 10% reduction in car use	34.2	10.9	19.3	38.8
2021 base	27.9	6.88	10.0	20.3
2021 fuel split	13.1	6.68	10.0	20.3
2021 All buses to Euro VI	27.9	6.88	10.0	7.0
2021 All HGVs to Euro VI	27.9	6.88	4.8	20.3
2021 All bus and HGVs to Euro VI	27.9	6.88	4.8	7.0
2021 All vans to Euro 6	27.9	5.12	10.0	20.3

2021 All pre Euro V buses to Euro VI	27.9	6.88	8.8	14.4
2021 All pre Euro V HGV to Euro VI	27.9	6.88	10.0	14.4
2021 All pre Euro V bus and HGVs to Euro VI	27.9	6.88	8.8	20.3
2021 10% reduction in car use	25.1	6.9	10.0	20.3

Table A3: $PM_{2.5}$ emissions from the Leeds Inner Ring Road area, tonnes per annum

EFT5_PM2.5	Car	LGV	HGV&Coach	BUS
2012 base	2.78	0.87	0.90	1.35
2016 base	2.51	0.56	0.41	0.84
2016 fuel split	2.15	0.55	0.41	0.84
2016 all buses Euro VI	2.51	0.56	0.41	0.42
2016 all HGV Euro VI	2.51	0.56	0.24	0.84
2016 all bus and HGVs Euro VI	2.51	0.56	0.24	0.42
2016 All vans Euro 6	2.51	0.35	0.41	0.84
2016 E2&E3 retrofit	2.51	0.56	0.41	0.63
2016 all Pre Euro IV buses Euro VI	2.51	0.56	0.41	0.65
2016 all Pre Euro IV HGV Euro VI	2.51	0.56	0.39	0.84
2016 Pre Euro IV bus and HGVs to Euro VI	2.51	0.56	0.39	0.65
2016 10% reduction in car use	2.26	0.56	0.41	0.84
2021 base	2.18	0.42	0.30	0.61
2021 fuel split	2.14	0.41	0.30	0.61
2021 All buses to Euro VI	2.18	0.42	0.30	0.45
2021 All HGVs to Euro VI	2.18	0.42	0.25	0.61
2021 All bus and HGVs to Euro VI	2.18	0.42	0.25	0.45
2021 All vans to Euro 6	2.18	0.38	0.30	0.61
2021 All pre Euro V buses to Euro VI	2.18	0.42	0.30	0.52
2021 All pre Euro V HGV to Euro VI	2.18	0.42	0.28	0.61
2021 All pre Euro V bus and HGVs to Euro VI	2.18	0.42	0.28	0.52
2021 10% reduction in car use	1.96	0.42	0.30	0.61

Table A4: Primary nitrogen dioxide emissions from the Leeds Inner Ring Road area, tonnes per annum

EFT5_pNO2	Car	LGV	HGV&Coach	BUS
2012 base	11.66	4.24	3.34	6.42
2016 base	12.34	4.07	2.11	4.28
2016 fuel split	2.98	3.92	2.11	4.28
2016 all buses Euro VI	12.34	4.07	2.11	0.64
2016 all HGV Euro VI	12.34	4.07	0.47	4.28
2016 all bus and HGVs Euro VI	12.34	4.07	0.47	0.64
2016 All vans Euro 6	12.34	1.87	2.11	4.28
2016 E2&E3 retrofit	12.34	4.07	2.11	3.41
2016 all Pre Euro IV buses Euro VI	12.34	4.07	2.11	2.66
2016 all Pre Euro IV HGV Euro VI	12.34	4.07	1.99	4.28
2016 Pre Euro IV bus and HGVs to Euro VI	12.34	4.07	1.99	2.66
2016 10% reduction in car use	11.10	4.07	2.11	4.28
2021 base	9.53	2.71	1.04	2.16
2021 fuel split	2.11	2.59	1.04	2.16
2021 All buses to Euro VI	9.53	2.71	1.04	0.70
2021 All HGVs to Euro VI	9.53	2.71	0.48	2.16
2021 All bus and HGVs to Euro VI	9.53	2.71	0.48	0.70

2021 All vans to Euro 6	9.53	2.04	1.04	2.16
2021 All pre Euro V buses to Euro VI	9.53	2.71	1.04	1.44
2021 All pre Euro V HGV to Euro VI	9.53	2.71	0.88	2.16
2021 All pre Euro V bus and HGVs to Euro VI	9.53	2.71	0.88	1.44
2021 10% reduction in car use	8.58	2.71	1.04	2.16

Table A5: Carbon dioxide emissions from the Leeds Outer Ring Road area, tonnes per annum

EFT5_CO2	Car	LGV	HGV&Coach	BUS
2012 base	190,719	32,441	30,356	34,322
2016 base	193,937	37,775	34,090	30,561
2016 fuel split	203,658	38,147	34,090	30,561
2016 all buses Euro VI	193,932	37,775	34,090	30,659
2016 all HGV Euro VI	193,932	37,775	34,130	30,561
2016 all bus and HGVs Euro VI	193,932	37,775	34,130	30,659
2016 All vans Euro 6	193,936	37,628	34,090	30,561
2016 E2&E3 retrofit	193,936	37,775	34,090	30,616
2016 all Pre Euro IV buses Euro VI	193,932	37,775	34,090	30,659
2016 all Pre Euro IV HGV Euro VI	193,937	37,775	34,057	30,561
2016 Pre Euro IV bus and HGVs to Euro VI	193,932	37,775	34,057	30,659
2016 10% reduction in car use	174,543	37,775	34,090	30,561
2021 base	189,342	42,543	35,501	33,006
2021 fuel split	198,493	42,886	35,501	33,006
2021 All buses to Euro VI	189,342	42,543	35,501	33,017
2021 All HGVs to Euro VI	189,342	42,543	35,518	33,006
2021 All bus and HGVs to Euro VI	189,342	42,543	35,518	33,017
2021 All vans to Euro 6	189,342	42,486	35,501	33,006
2021 All pre Euro V buses to Euro VI	189,342	42,543	35,501	33,017
2021 All pre Euro V HGV to Euro VI	189,342	42,543	35,518	33,006
2021 All pre Euro V bus and HGVs to Euro VI	189,342	42,543	35,518	33,017
2021 10% reduction in car use	170,407	42,543	35,501	33,006

Table A6: Oxides of nitrogen emissions from the Leeds Outer Ring Road area, tonnes per annum

EFT5_NOx	Car	LGV	HGV&Coach	BUS
2012 base	385.2	122.2	231.8	249.0
2016 base	341.3	104.7	152.5	155.7
2016 fuel split	166.1	102.9	152.5	155.7
2016 all buses Euro VI	341.4	104.7	152.5	21.4
2016 all HGV Euro VI	341.3	104.7	51.7	155.7
2016 all bus and HGVs Euro VI	341.3	104.7	51.7	21.4
2016 All vans Euro 6	341.3	53.9	152.5	155.7
2016 E2&E3 retrofit	341.4	104.7	152.5	128.7
2016 all Pre Euro IV buses Euro VI	341.3	104.7	152.5	105.5
2016 all Pre Euro IV HGV Euro VI	341.3	104.7	146.7	155.7
2016 Pre Euro IV bus and HGVs to Euro VI	341.3	104.7	146.7	105.5
2016 10% reduction in car use	307.2	104.7	152.5	155.7
2021 base	254.8	67.5	74.3	77.0
2021 fuel split	124.4	66.1	74.3	77.0
2021 All buses to Euro VI	254.8	67.5	74.3	23.0
2021 All HGVs to Euro VI	254.8	67.5	39.3	77.0

2021 All bus and HGVs to Euro VI	254.8	67.5	39.3	23.0
2021 All vans to Euro 6	254.8	52.8	74.3	77.0
2021 All pre Euro V buses to Euro VI	254.8	67.5	74.3	52.5
2021 All pre Euro V HGV to Euro VI	254.8	67.5	66.2	77.0
2021 All pre Euro V bus and HGVs to Euro VI	254.8	67.5	66.2	52.5
2021 10% reduction in car use	229.4	67.5	74.3	77.0

Table A7: $PM_{2.5}$ emissions from the Leeds Outer Ring Road area, tonnes per annum

EFT5_PM2.5	Car	LGV	HGV&Coach	BUS
2012 base	25.28	7.75	7.06	5.75
2016 base	23.02	5.17	3.55	3.58
2016 fuel split	19.90	5.09	3.55	3.58
2016 all buses Euro VI	23.02	5.17	3.55	2.01
2016 all HGV Euro VI	23.02	5.17	2.44	3.58
2016 all bus and HGVs Euro VI	23.02	5.17	2.44	2.01
2016 All vans Euro 6	23.02	3.58	3.55	3.58
2016 E2&E3 retrofit	23.02	5.17	3.55	2.74
2016 all Pre Euro IV buses Euro VI	23.02	5.17	3.55	2.68
2016 all Pre Euro IV HGV Euro VI	23.02	5.17	3.39	3.58
2016 Pre Euro IV bus and HGVs to Euro VI	23.02	5.17	3.39	2.68
2016 10% reduction in car use	20.72	5.17	3.55	3.58
2021 base	20.51	4.06	2.63	2.69
2021 fuel split	20.17	4.05	2.63	2.69
2021 All buses to Euro VI	20.51	4.06	2.63	2.13
2021 All HGVs to Euro VI	20.51	4.06	2.30	2.69
2021 All bus and HGVs to Euro VI	20.51	4.06	2.30	2.13
2021 All vans to Euro 6	20.51	3.77	2.63	2.69
2021 All pre Euro V buses to Euro VI	20.51	4.06	2.63	2.36
2021 All pre Euro V HGV to Euro VI	20.51	4.06	2.49	2.69
2021 All pre Euro V bus and HGVs to Euro VI	20.51	4.06	2.49	2.36
2021 10% reduction in car use	18.46	4.06	2.63	2.69

Table A8: Primary nitrogen dioxide emissions from the Leeds Outer Ring Road area, tonnes per annum

EFT5_pNO2	Car	LGV	HGV&Coach	BUS
2012 base	103.65	40.06	27.29	27.40
2016 base	111.16	39.24	16.86	17.18
2016 fuel split	29.73	37.83	16.86	17.18
2016 all buses Euro VI	111.16	39.24	16.86	2.14
2016 all HGV Euro VI	111.16	39.24	5.53	17.18
2016 all bus and HGVs Euro VI	111.16	39.24	5.53	2.14
2016 All vans Euro 6	111.16	21.14	16.86	17.18
2016 E2&E3 retrofit	111.16	39.24	16.86	13.68
2016 all Pre Euro IV buses Euro VI	111.16	39.24	16.86	10.55
2016 all Pre Euro IV HGV Euro VI	111.16	39.24	16.02	17.18
2016 Pre Euro IV bus and HGVs to Euro VI	111.16	39.24	16.02	12.46
2016 10% reduction in car use	100.04	39.24	16.86	17.18
2021 base	87.59	26.54	7.76	8.19
2021 fuel split	21.58	25.45	7.76	8.19
2021 All buses to Euro VI	87.59	26.54	7.76	2.30
2021 All HGVs to Euro VI	87.59	26.54	4.01	8.19

2021 All bus and HGVs to Euro VI	87.59	26.54	4.01	2.30
2021 All vans to Euro 6	87.59	20.92	7.76	8.19
2021 All pre Euro V buses to Euro VI	87.59	26.54	7.76	5.25
2021 All pre Euro V HGV to Euro VI	87.59	26.54	6.69	8.19
2021 All pre Euro V bus and HGVs to Euro VI	87.59	26.54	6.69	5.25
2021 10% reduction in car use	78.83	26.54	7.76	8.19

Table A9: Carbon dioxide emissions from Bradford Inner Ring Road area, tonnes per annum

EFT5_CO2	Car	LGV	HGV&Coach	BUS
2012 base	3056.9	639.9	637.5	1279.7
2016 base	3082.3	693.6	724.1	1278.1
2016 fuel split	3224.4	709.6	724.1	1278.1
2016 all buses Euro VI	3082.3	693.6	724.1	1283.8
2016 all HGV Euro VI	3082.3	693.6	725.6	1278.1
2016 all bus and HGVs Euro VI	3082.3	693.6	725.6	1283.8
2016 All vans Euro 6	3082.3	686.4	724.1	1278.1
2016 E2&E3 retrofit	3082.3	693.6	724.1	1280.3
2016 all Pre Euro IV buses Euro VI	3082.3	693.6	724.1	1276.7
2016 all Pre Euro IV HGV Euro VI	3082.3	693.6	723.4	1278.1
2016 Pre Euro IV bus and HGVs to Euro VI	3082.3	693.6	723.4	1276.7
2016 10% reduction in car use	2,774.1	693.6	724.1	1,278.1
2021 base	2970.7	724.4	797.8	1280.8
2021 fuel split	3095.8	737.8	797.8	1280.8
2021 All buses to Euro VI	2970.7	724.4	797.8	1281.6
2021 All HGVs to Euro VI	2970.7	724.4	798.4	1280.8
2021 All bus and HGVs to Euro VI	2970.7	724.4	798.4	1281.6
2021 All vans to Euro 6	2970.7	721.6	797.8	1280.8
2021 All pre Euro V buses to Euro VI	2970.7	724.4	797.8	1281.6
2021 All pre Euro V HGV to Euro VI	2970.7	724.4	797.8	1280.8
2021 All pre Euro V bus and HGVs to Euro VI	2970.7	724.4	797.9	1281.6
2021 10% reduction in car use	2,673.6	724.4	797.8	1,280.8

Table A10: Oxides of nitrogen emissions from the Bradford Inner Ring Road area, tonnes per annum

EFT5_NOx	Car	LGV	HGV&Coach	BUS
2012 base	6.35	2.47	4.64	10.06
2016 base	5.65	1.96	3.31	6.43
2016 fuel split	2.59	1.86	3.31	6.43
2016 all buses Euro VI	5.65	1.96	3.31	0.73
2016 all HGV Euro VI	5.65	1.96	0.76	6.43
2016 all bus and HGVs Euro VI	5.65	1.96	0.76	0.73
2016 All vans Euro 6	5.65	0.83	3.31	6.43
2016 E2&E3 retrofit	5.65	1.96	3.31	5.34
2016 all Pre Euro IV buses Euro VI	5.65	1.96	3.31	4.38
2016 all Pre Euro IV HGV Euro VI	5.65	1.96	2.94	6.43
2016 Pre Euro IV bus and HGVs to Euro VI	5.65	1.96	2.94	4.38
2016 10% reduction in car use	5.08	1.96	3.31	6.43
2021 base	4.12	1.19	1.76	2.77

2021 fuel split	1.91	1.11	1.76	2.77
2021 All buses to Euro VI	4.12	1.19	1.76	0.73
2021 All HGVs to Euro VI	4.12	1.19	0.84	2.77
2021 All bus and HGVs to Euro VI	4.12	1.19	0.84	0.73
2021 All vans to Euro 6	4.12	0.88	1.76	2.77
2021 All pre Euro V buses to Euro VI	4.12	1.19	1.76	1.78
2021 All pre Euro V HGV to Euro VI	4.12	1.19	1.74	2.77
2021 All pre Euro V bus and HGVs to Euro VI	4.12	1.19	1.74	1.78
2021 10% reduction in car use	3.71	1.19	1.76	2.77

Table A11: $PM_{2.5}$ emissions from the Bradford Inner Ring Road area, tonnes per annum

EFT5_PM2.5	Car	LGV	HGV&Coach	BUS
2012 base	0.409	0.156	0.099	0.232
2016 base	0.383	0.101	0.073	0.155
2016 fuel split	0.323	0.098	0.073	0.155
2016 all buses Euro VI	0.383	0.101	0.073	0.080
2016 all HGV Euro VI	0.383	0.101	0.047	0.155
2016 all bus and HGVs Euro VI	0.383	0.101	0.047	0.080
2016 All vans Euro 6	0.383	0.067	0.073	0.155
2016 E2&E3 retrofit	0.383	0.102	0.074	0.119
2016 all Pre Euro IV buses Euro VI	0.383	0.101	0.073	0.116
2016 all Pre Euro IV HGV Euro VI	0.383	0.101	0.063	0.155
2016 Pre Euro IV bus and HGVs to Euro VI	0.383	0.101	0.063	0.116
2016 10% reduction in car use	0.344	0.101	0.073	0.155
2021 base	0.334	0.076	0.060	0.103
2021 fuel split	0.324	0.075	0.060	0.103
2021 All buses to Euro VI	0.334	0.076	0.060	0.080
2021 All HGVs to Euro VI	0.334	0.076	0.051	0.103
2021 All bus and HGVs to Euro VI	0.334	0.076	0.051	0.080
2021 All vans to Euro 6	0.334	0.070	0.060	0.103
2021 All pre Euro V buses to Euro VI	0.334	0.076	0.060	0.088
2021 All pre Euro V HGV to Euro VI	0.334	0.076	0.060	0.103
2021 All pre Euro V bus and HGVs to Euro VI	0.334	0.076	0.060	0.088
2021 10% reduction in car use	0.301	0.076	0.060	0.103

Table A12: Primary nitrogen dioxide emissions from the Bradford Inner Ring Road area, tonnes per annum

EFT5_pNO2	Car	LGV	HGV&Coach	BUS
2012 base	1.688	0.784	0.524	1.131
2016 base	1.833	0.728	0.353	0.698
2016 fuel split	0.432	0.661	0.353	0.698
2016 all buses Euro VI	1.833	0.728	0.353	0.073
2016 all HGV Euro VI	1.833	0.728	0.076	0.698
2016 all bus and HGVs Euro VI	1.833	0.728	0.076	0.073
2016 All vans Euro 6	1.833	0.331	0.353	0.698
2016 E2&E3 retrofit	1.833	0.728	0.353	0.561
2016 all Pre Euro IV buses Euro VI	1.833	0.728	0.353	0.438
2016 all Pre Euro IV HGV Euro VI	1.833	0.728	0.301	0.698
2016 Pre Euro IV bus and HGVs to Euro VI	1.833	0.728	0.301	0.438
2016 10% reduction in car use	1.650	0.728	0.353	0.698
2021 base	1.418	0.469	0.180	0.291

2021 fuel split	0.308	0.421	0.180	0.291
2021 All buses to Euro VI	1.418	0.469	0.180	0.073
2021 All HGVs to Euro VI	1.418	0.469	0.084	0.291
2021 All bus and HGVs to Euro VI	1.418	0.469	0.084	0.073
2021 All vans to Euro 6	1.418	0.349	0.180	0.291
2021 All pre Euro V buses to Euro VI	1.417	0.469	0.180	0.178
2021 All pre Euro V HGV to Euro VI	1.418	0.469	0.180	0.291
2021 All pre Euro V bus and HGVs to Euro VI	1.417	0.469	0.177	0.178
2021 10% reduction in car use	1.276	0.469	0.180	0.291

Table A13: Carbon dioxide emissions from Bradford Outer Ring Road area, tonnes per annum

EFT5_CO2	Car	LGV	HGV&Coach	BUS
2012 base	45290.8	9496.8	6665.3	5104.9
2016 base	45373.6	10334.4	7328.9	5093.0
2016 fuel split	47295.4	10564.6	7328.9	5093.0
2016 all buses Euro VI	45373.6	10334.3	7328.9	5107.1
2016 all HGV Euro VI	45373.6	10334.4	7339.2	5093.0
2016 all bus and HGVs Euro VI	45373.5	10334.3	7339.2	5107.1
2016 All vans Euro 6	45373.6	10207.5	7328.9	5093.0
2016 E2&E3 retrofit	45373.6	10334.4	7328.9	5101.5
2016 all Pre Euro IV buses Euro VI	45373.6	10334.3	7328.9	5079.7
2016 all Pre Euro IV HGV Euro VI	45373.6	10334.4	7318.0	5093.0
2016 Pre Euro IV bus and HGVs to Euro VI	45373.6	10334.3	7318.0	5079.7
2016 10% reduction in car use	40,836.2	10,334.4	7,328.9	5,093.0
2021 base	43765.6	10936.6	7880.2	5085.9
2021 fuel split	45364.2	11124.9	7880.2	5085.9
2021 All buses to Euro VI	43765.6	10936.6	7880.2	5088.9
2021 All HGVs to Euro VI	43765.6	10936.6	7884.7	5085.9
2021 All bus and HGVs to Euro VI	43765.6	10936.6	7884.7	5088.9
2021 All vans to Euro 6	43765.6	10887.9	7880.2	5085.9
2021 All pre Euro V buses to Euro VI	43765.6	10936.6	7880.2	5088.9
2021 All pre Euro V HGV to Euro VI	43765.6	10936.6	7880.9	5085.9
2021 All pre Euro V bus and HGVs to Euro VI	43765.6	10936.6	7880.9	5088.9
2021 10% reduction in car use	39,389.1	10,936.6	7,880.2	5,085.9

Table A14: Oxides of nitrogen emissions from the Bradford Outer Ring Road area, tonnes per annum

EFT5_NOx	Car	LGV	HGV&Coach	BUS
2012 base	96.77	37.63	46.21	40.30
2016 base	84.65	29.89	30.83	25.37
2016 fuel split	39.56	28.60	30.83	25.37
2016 all buses Euro VI	84.65	29.89	30.83	2.54
2016 all HGV Euro VI	84.65	29.89	6.13	25.37
2016 all bus and HGVs Euro VI	84.65	29.89	6.13	2.54
2016 All vans Euro 6	84.65	12.64	30.83	25.37
2016 E2&E3 retrofit	84.64	29.89	30.83	20.98
2016 all Pre Euro IV buses Euro VI	84.65	29.89	30.83	17.04
2016 all Pre Euro IV HGV Euro VI	84.65	29.89	27.05	25.37
2016 Pre Euro IV bus and HGVs to Euro VI	84.65	29.89	27.05	17.04
2016 10% reduction in car use	76.18	29.89	30.83	25.37

2021 base	62.03	18.41	15.20	10.53
2021 fuel split	29.39	17.23	15.20	10.53
2021 All buses to Euro VI	62.03	18.41	15.20	2.54
2021 All HGVs to Euro VI	62.03	18.41	6.63	10.53
2021 All bus and HGVs to Euro VI	62.03	18.41	6.63	2.54
2021 All vans to Euro 6	62.03	13.53	15.20	10.53
2021 All pre Euro V buses to Euro VI	62.03	18.41	15.20	6.49
2021 All pre Euro V HGV to Euro VI	62.03	18.41	14.98	10.53
2021 All pre Euro V bus and HGVs to Euro VI	62.03	18.41	14.98	6.49
2021 10% reduction in car use	55.83	18.41	15.20	10.53

Table A15: $PM_{2.5}$ emissions from the Bradford Outer Ring Road area, tonnes per annum

EFT5_PM2.5	Car	LGV	HGV&Coach	BUS
2012 base	6.709	2.366	1.061	0.935
2016 base	6.340	1.616	0.798	0.637
2016 fuel split	5.394	1.565	0.798	0.637
2016 all buses Euro VI	6.340	1.616	0.798	0.357
2016 all HGV Euro VI	6.340	1.616	0.558	0.637
2016 all bus and HGVs Euro VI	6.340	1.616	0.558	0.357
2016 All vans Euro 6	6.340	1.121	0.798	0.637
2016 E2&E3 retrofit	6.340	1.617	0.799	0.500
2016 all Pre Euro IV buses Euro VI	6.340	1.616	0.798	0.488
2016 all Pre Euro IV HGV Euro VI	6.340	1.616	0.705	0.637
2016 Pre Euro IV bus and HGVs to Euro VI	6.340	1.616	0.705	0.488
2016 10% reduction in car use	5.706	1.616	0.798	0.637
2021 base	5.634	1.280	0.668	0.439
2021 fuel split	5.482	1.271	0.668	0.439
2021 All buses to Euro VI	5.634	1.280	0.668	0.354
2021 All HGVs to Euro VI	5.634	1.280	0.597	0.439
2021 All bus and HGVs to Euro VI	5.634	1.280	0.597	0.354
2021 All vans to Euro 6	5.634	1.194	0.668	0.439
2021 All pre Euro V buses to Euro VI	5.634	1.280	0.671	0.384
2021 All pre Euro V HGV to Euro VI	5.634	1.280	0.670	0.439
2021 All pre Euro V bus and HGVs to Euro VI	5.634	1.280	0.670	0.384
2021 10% reduction in car use	5.071	1.280	0.668	0.439

Table A16: Primary nitrogen dioxide emissions from the Bradford Outer Ring Road area, tonnes per annum

EFT5_pNO2	Car	LGV	HGV&Coach	BUS
2012 base	25.272	11.897	5.265	4.526
2016 base	27.255	11.098	3.310	2.756
2016 fuel split	6.463	10.113	3.310	2.756
2016 all buses Euro VI	27.256	11.098	3.310	0.253
2016 all HGV Euro VI	27.255	11.098	0.612	2.756
2016 all bus and HGVs Euro VI	27.256	11.098	0.612	0.253
2016 All vans Euro 6	27.255	5.044	3.310	2.756
2016 E2&E3 retrofit	27.256	11.097	3.311	2.208
2016 all Pre Euro IV buses Euro VI	27.256	11.098	3.310	1.704
2016 all Pre Euro IV HGV Euro VI	27.255	11.098	2.785	2.756
2016 Pre Euro IV bus and HGVs to Euro VI	27.256	11.098	2.785	1.704

2016 10% reduction in car use	24.530	11.098	3.310	2.756
2021 base	21.225	7.251	1.558	1.109
2021 fuel split	4.641	6.519	1.558	1.109
2021 All buses to Euro VI	21.225	7.251	1.558	0.254
2021 All HGVs to Euro VI	21.225	7.251	0.661	1.109
2021 All bus and HGVs to Euro VI	21.225	7.251	0.661	0.254
2021 All vans to Euro 6	21.225	5.391	1.558	1.109
2021 All pre Euro V buses to Euro VI	21.225	7.249	1.558	0.649
2021 All pre Euro V HGV to Euro VI	21.225	7.251	1.527	1.109
2021 All pre Euro V bus and HGVs to Euro VI	21.225	7.249	1.527	0.649
2021 10% reduction in car use	19.102	7.251	1.558	1.109

Appendix 2 – Health impacts

This section provides estimates of the reduction in life years lost compared with the 2016 or 2021 base conditions as appropriate. The reductions were calculated using the methods set out in the ICGB damage cost guidance..

Table B1: Reduction in the number of years lost over 100 years for measures in the Leeds Inner Ring Road

Scenario	Emission reduction, tonnes		Number of life years lost over 100 years			
			NO_x		PM	
	NO_x	PM	No lag	40 year lag	No lag	40 year lag
Per tonne	**1**	**1**	**0.082**	**0.089**	**5.438**	**5.003**
2016 fuel split	20.5	0.37	1.7	1.8	2.0	1.8
2016 all buses Euro VI	32.4	0.42	2.7	2.9	2.3	2.1
2016 all HGV Euro VI	14.6	0.17	1.2	1.3	0.9	0.8
2016 all bus and HGVs Euro VI	47.0	0.59	3.9	4.2	3.2	2.9
2016 All vans Euro 6	6.2	0.21	0.5	0.5	1.1	1.1
2016 Euro II &Euro III retrofit	6.6	0.21	0.5	0.6	1.2	1.1
2016 all Pre Euro IV buses Euro VI	12.2	0.19	1.0	1.1	1.0	0.9
2016 all Pre Euro IV HGV Euro VI	0.8	0.02	0.1	0.1	0.1	0.1
2016 Pre Euro IV bus and HGVs to Euro VI	13.0	0.21	1.1	1.2	1.1	1.0
2016 10% reduction in cars	3.8	0.25	0.3	0.3	1.4	1.3
2021 fuel split	15.0	0.04	1.2	1.3	0.2	0.2
2021 All buses to Euro VI	13.4	0.16	1.1	1.2	0.9	0.8
2021 All HGVs to Euro VI	5.2	0.05	0.4	0.5	0.3	0.3
2021 All bus and HGVs to Euro VI	18.5	0.21	1.5	1.6	1.1	1.0
2021 All vans to Euro 6	1.8	0.04	0.1	0.2	0.2	0.2
2021 All pre Euro V buses to Euro VI	5.9	0.09	0.5	0.5	0.5	0.4
2021 All pre Euro V HGV to Euro VI	1.2	0.02	0.1	0.1	0.1	0.1
2021 All pre Euro V bus and HGVs to Euro VI	7.1	0.11	0.6	0.6	0.6	0.5
2021 10% reduction in cars	2.8	0.22	0.2	0.2	1.2	1.1
2016-2021 fuel split	106.3	1.22	8.7	9.5	6.6	6.1
2016-2021 all buses Euro VI	137.3	1.73	11.3	12.2	9.4	8.7
2016-2021 all HGVs Euro VI	59.3	0.66	4.9	5.3	3.6	3.3
2016-2021 all buses and HGVs Euro VI	196.7	2.39	16.1	17.5	13.0	11.9
2016-2021 all vans Euro 6	23.8	0.75	2.0	2.1	4.1	3.7
2016-2021 10% reduction in cars	19.8	1.41	1.6	1.8	7.7	7.0

Table B2: Reduction in the number of years lost over 100 years for measures in the Leeds Outer Ring Road

Scenario	Emission reduction, tonnes		Number of life years lost over 100 years			
			NO_x		PM	
	NO_x	PM	No lag	40 year lag	No lag	40 year lag
Per tonne	**1**	**1**	**0.082**	**0.089**	**5.438**	**5.003**
2016 fuel split	177.0	3.20	14.5	15.8	17.4	16.0
2016 all buses Euro VI	134.2	1.56	11.0	11.9	8.5	7.8
2016 all HGV Euro VI	100.8	1.11	8.3	9.0	6.0	5.6
2016 all bus and HGVs Euro VI	235.1	2.67	19.3	20.9	14.5	13.4
2016 All vans Euro 6	50.8	1.59	4.2	4.5	8.6	7.9
2016 Euro II &Euro III retrofit	26.8	0.84	2.2	2.4	4.6	4.2
2016 all Pre Euro IV buses Euro VI	50.2	0.90	4.1	4.5	4.9	4.5
2016 all Pre Euro IV HGV Euro VI	5.8	0.16	0.5	0.5	0.8	0.8
2016 Pre Euro IV bus and HGVs to Euro VI	56.0	1.06	4.6	5.0	5.8	5.3
2016 10% reduction in cars	34.1	2.3	2.8	3.0	12.5	11.5
2021 fuel split	131.9	0.34	10.8	11.7	1.9	1.7
2021 All buses to Euro VI	54.1	0.56	4.4	4.8	3.0	2.8
2021 All HGVs to Euro VI	35.0	0.33	2.9	3.1	1.8	1.7
2021 All bus and HGVs to Euro VI	89.0	0.89	7.3	7.9	4.9	4.5
2021 All vans to Euro 6	14.7	0.29	1.2	1.3	1.6	1.4
2021 All pre Euro V buses to Euro VI	24.6	0.33	2.0	2.2	1.8	1.6
2021 All pre Euro V HGV to Euro VI	8.1	0.14	0.7	0.7	0.8	0.7
2021 All pre Euro V bus and HGVs to Euro VI	32.7	0.47	2.7	2.9	2.5	2.3
2021 10% reduction in cars	25.5	2.1	2.1	2.3	11.2	10.3
2016-2021 fuel split	926.7	10.62	76.0	82.5	57.8	53.2
2016-2021 all buses Euro VI	564.9	6.36	46.3	50.3	34.6	31.8
2016-2021 all HGVs Euro VI	407.4	4.34	33.4	36.3	23.6	21.7
2016-2021 all buses and HGVs Euro VI	972.5	10.70	79.7	86.6	58.2	53.5
2016-2021 all vans Euro 6	196.4	5.63	16.1	17.5	30.6	28.1
2016-2021 10% reduction in cars	178.9	13.1	14.7	15.9	71.0	65.3

Table B3: Reduction in the number of years lost over 100 years for measures in the Bradford Inner Ring Road

Scenario	Emission reduction, tonnes		Number of life years lost over 100 years			
			NO_x		PM	
	NO_x	PM	No lag	40 year lag	No lag	40 year lag
Per tonne	**1**	**1**	**0.082**	**0.089**	**5.438**	**5.003**
2016 fuel split	3.2	0.06	0.3	0.3	0.3	0.3
2016 all buses Euro VI	5.7	0.07	0.5	0.5	0.4	0.4
2016 all HGV Euro VI	2.6	0.03	0.2	0.2	0.1	0.1
2016 all bus and HGVs Euro VI	8.3	0.10	0.7	0.7	0.5	0.5
2016 All vans Euro 6	1.1	0.03	0.1	0.1	0.2	0.2
2016 Euro II &Euro III retrofit	1.1	0.03	0.1	0.1	0.2	0.2
2016 all Pre Euro IV buses Euro VI	2.0	0.04	0.2	0.2	0.2	0.2
2016 all Pre Euro IV HGV Euro VI	0.4	0.01	0.0	0.0	0.1	0.0
2016 Pre Euro IV bus and HGVs to Euro VI	2.4	0.05	0.2	0.2	0.3	0.2
2016 10% reduction in cars	0.6	0.04	0.0	0.1	0.2	0.2
2021 fuel split	2.3	0.01	0.2	0.2	0.1	0.1
2021 All buses to Euro VI	2.0	0.02	0.2	0.2	0.1	0.1
2021 All HGVs to Euro VI	0.9	0.01	0.1	0.1	0.0	0.0
2021 All bus and HGVs to Euro VI	3.0	0.03	0.2	0.3	0.2	0.2
2021 All vans to Euro 6	0.3	0.01	0.0	0.0	0.0	0.0
2021 All pre Euro V buses to Euro VI	1.0	0.02	0.1	0.1	0.1	0.1
2021 All pre Euro V HGV to Euro VI	0.0	0.00	0.0	0.0	0.0	0.0
2021 All pre Euro V bus and HGVs to Euro VI	1.0	0.02	0.1	0.1	0.1	0.1
2021 10% reduction in cars	0.4	0.03	0.0	0.0	0.2	0.2
2016-2021 fuel split	16.3	0.22	1.3	1.5	1.2	1.1
2016-2021 all buses Euro VI	23.2	0.29	1.9	2.1	1.6	1.5
2016-2021 all HGVs Euro VI	10.4	0.11	0.9	0.9	0.6	0.5
2016-2021 all buses and HGVs Euro VI	33.7	0.40	2.8	3.0	2.2	2.0
2016-2021 all vans Euro 6	4.3	0.12	0.4	0.4	0.7	0.6
2016-2021 10% reduction in cars	2.9	0.21	0.2	0.3	1.2	1.1

Table B4: Reduction in the number of years lost over 100 years for measures in the Bradford Outer Ring Road

Scenario	Emission reduction, tonnes		Number of life years lost over 100 years			
			NO_x		PM	
	NO_x	PM	No lag	40 year lag	No lag	40 year lag
Per tonne	**1**	**1**	**0.082**	**0.089**	**5.438**	**5.003**
2016 fuel split	46.4	1.00	3.8	4.1	5.4	5.0
2016 all buses Euro VI	22.8	0.28	1.9	2.0	1.5	1.4
2016 all HGV Euro VI	24.7	0.24	2.0	2.2	1.3	1.2
2016 all bus and HGVs Euro VI	47.5	0.52	3.9	4.2	2.8	2.6
2016 All vans Euro 6	17.3	0.50	1.4	1.5	2.7	2.5
2016 Euro II &Euro III retrofit	4.4	0.14	0.4	0.4	0.7	0.7
2016 all Pre Euro IV buses Euro VI	8.3	0.15	0.7	0.7	0.8	0.7
2016 all Pre Euro IV HGV Euro VI	3.8	0.09	0.3	0.3	0.5	0.5
2016 Pre Euro IV bus and HGVs to Euro VI	12.1	0.24	1.0	1.1	1.3	1.2
2016 10% reduction in cars	8.5	0.6	0.7	0.8	3.4	3.2
2021 fuel split	33.8	0.16	2.8	3.0	0.9	0.8
2021 All buses to Euro VI	8.0	0.09	0.7	0.7	0.5	0.4
2021 All HGVs to Euro VI	8.6	0.07	0.7	0.8	0.4	0.4
2021 All bus and HGVs to Euro VI	16.6	0.16	1.4	1.5	0.9	0.8
2021 All vans to Euro 6	4.9	0.09	0.4	0.4	0.5	0.4
2021 All pre Euro V buses to Euro VI	4.0	0.05	0.3	0.4	0.3	0.3
2021 All pre Euro V HGV to Euro VI	0.2	0.00	0.0	0.0	0.0	0.0
2021 All pre Euro V bus and HGVs to Euro VI	4.3	0.05	0.3	0.4	0.3	0.3
2021 10% reduction in cars	6.2	0.6	0.5	0.6	3.1	2.8
2016-2021 fuel split	240.6	3.48	19.7	21.4	18.9	17.4
2016-2021 all buses Euro VI	92.5	1.10	7.6	8.2	6.0	5.5
2016-2021 all HGVs Euro VI	99.8	0.94	8.2	8.9	5.1	4.7
2016-2021 all buses and HGVs Euro VI	192.3	2.03	15.8	17.1	11.1	10.2
2016-2021 all vans Euro 6	66.4	1.75	5.4	5.9	9.5	8.7
2016-2021 10% reduction in cars	44.0	3.6	3.6	3.9	19.5	18.0

Public Health England, Leeds City Council, Bradford Metropolitan District Council have prepared a separate health impact assessment (HIA) for the West Yorkshire Low Emission Zone feasibility study. The health impact assessment calculates the number of deaths attributable to particulate air pollution using the impact pathway approach. The main differences in the assessment of the number of deaths attributable to the reduction in PM2.5 emissions are as follows:

1) The HIA compares scenarios with the 2012 baseline, whereas this cost benefit assessment (CBA) compares scenarios with the business as usual case for the same year. The CBA thus considers the benefits from the LEZ measure alone.

2) The CBA considers the impact of the emission reductions within the ring roads whereas the HIA compares the impact of the emission reductions across the whole of the council areas.

3) The HIA uses a local dispersion model and population density statistics whereas the CBA uses the results of the national area source dispersion model and typical population densities corresponding to an inner conurbation.

The following like-for-like comparison has been made for the scenario All Pre Euro V buses to Euro VI by 2021. Leeds City Council provided an estimate of 26.4 tonnes per year for the change in $PM_{2.5}$ emissions from the 2012 baseline for the Leeds All Urban Area.The damage cost methodology used in this CBA gives 144 life years lost per year as the saving for this emission reduction. Assuming 11 life years lost per attributable death (COMEAP) this gives 13 attributable deaths avoided per year. This is comparable with the 15 attributable deaths avoided given in the HIA for this scenario.

RICARDO-AEA

The Gemini Building
Fermi Avenue
Harwell
Didcot
Oxfordshire
OX11 0QR

Tel: 01235 75 3000
Web: www.ricardo-aea.com