Department for Environment Food & Rural Affairs

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Improving air quality in the UK

Tackling nitrogen dioxide in our towns and cities

Technical report

December 2015

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18 January 2016: Table of Changes

Page Number	Change
22	Footnote 26 – broken link updated
100	Table D.5 – PM emissions factors updated

Contents

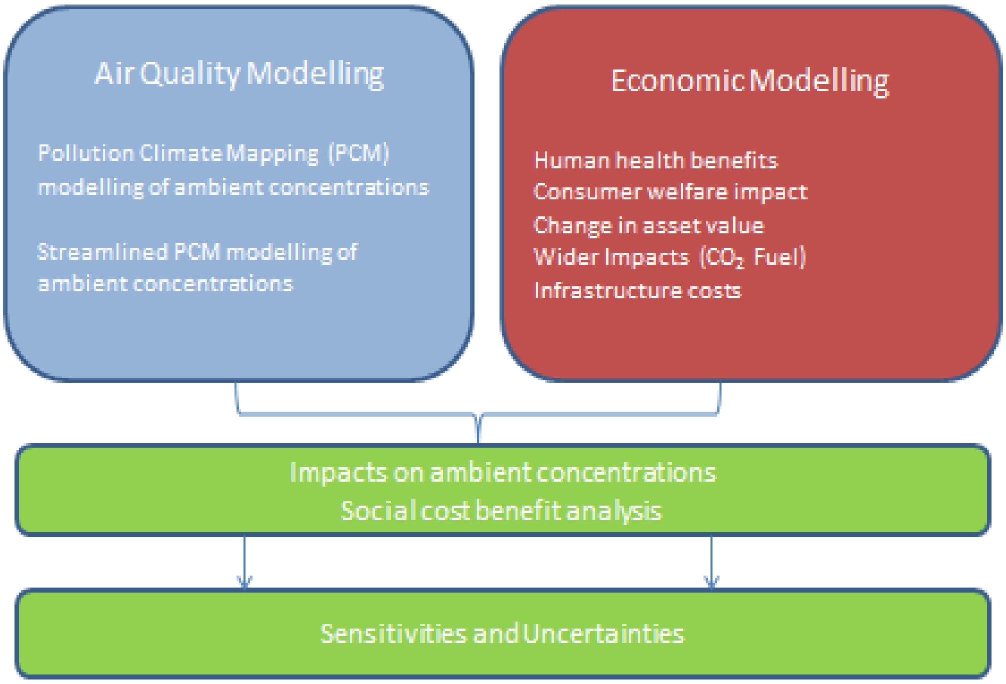
1. Introduction

1. This document provides a detailed account of the technical assessments that have supported the production of the UK air quality plan. Therefore this report should be read alongside the UK overview document, the list of UK and National measures and the air quality plans for each of the 38 UK zones with an exceedance of the nitrogen dioxide (NO_2) limit value in 2013.

2. This technical report explains the modelling and assessment methodologies used in the preparation of the plan. It builds on the Evidence Annex released in September 2015 alongside the consultation on the plan. It expands upon and updates the previous report including full details of the model and methodology used, updated projections, refinement of the appraisal methodology and developments in the plan.

3. Figure 1.1 sets out the overall structure of the analysis used to underpin the development of the plan.

Figure 1.1: Air quality impact appraisal methodology



4. The structure of this report is consistent with Figure 1.1 above. The remainder of this report is split into six sections as follows:

- **Section 2** explains the methodology for the monitoring and modelling used to assess ambient NO_2 concentrations. It outlines both the Pollution Climate Mapping (PCM) model used for national modelling and the streamlined approach used to assess local measures.

- **Section 3** outlines the approach taken to assess the economic and social impacts.
- **Section 4** sets out the scenarios modelled both in the baseline and for the plan measures.
- **Section 5** presents the results of the NO_2 concentration modelling and the economic analysis of the measures in the UK air quality plan.
- **Section 6** sets out quantified and non-quantified sensitivities and uncertainties.

5. There are four annexes that provide supplementary technical detail. Annexes A–C supply additional information on the PCM model, while Annex D provides further technical detail of the Fleet Adjustment model used to assess the costs and benefits.

2. Air quality assessment methodology

6. This section describes the UK's approach to assessing and modelling air quality. The UK is required to report the results of every annual ambient air quality assessment to the European Commission by the end of September the following year. This reporting requirement includes a comparison of ambient air quality for the previous calendar year with the limit values, target values and long term objectives set within the Ambient Air Quality Directive (2008/50/EC)[1] (hereafter called "the Directive") and the 4th Daughter Directive (2004/107/EC)[2].

7. Annex III of the Directive provides information on the locations where air quality should be assessed. The Directive specifies some locations that should be excluded from the assessment. These include '*locations situated within areas where members of the public do not have access and there is no fixed habitation', 'on factory premises or at industrial installations to which all relevant provisions concerning health and safety at work apply'* and *'on the carriageway of roads; and on the central reservations of roads except where there is normally pedestrian access to the central reservation'.* Annex III also states that '*for all pollutants, traffic-orientated sampling probes shall be at least 25m from the edge of major junctions and no more than 10m from the kerbside'*. These requirements apply to both sampling points for assessment by fixed air quality measurements and specific locations where air quality is assessed by modelling.

8. The annual nitrogen dioxide (NO_2) assessment for the UK is based on a combination of measurements from the UK national monitoring networks and the results of modelling assessments, carried out using the Pollution Climate Mapping (PCM) model. The PCM model is a group of models used to calculate pollutant concentrations on a range of geographical scales; for simplicity we will refer to this group of models as 'the PCM model'. Where both measurements and model results are available, the assessment of compliance with the NO_2 limit value for each zone is based on the higher concentration of the two as part of a cautious approach to assessing compliance.

9. The emissions inventory is a key input to this modelling assessment and is provided by the UK National Atmospheric Emissions Inventory (NAEI). Emissions to air are regulated in terms of nitrogen oxides (NO_X), which is the term used to describe the sum of nitric oxide (NO) and nitrogen dioxide (NO_2).

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[1] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:152:0001:0044:EN:PDF
[2] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:023:0003:0016:EN:PDF

10. The modelling assessment to support the UK air quality plan consists of 3 elements:

- The base (reference) year – this is the most recent modelled annual compliance assessment available when the modelling assessment was conducted, and the year for which the model is calibrated using measurement data. For this plan it is 2013.
- The baseline projections – concentrations are projected forward from the base year for 2020, 2025 and 2030. These projections constitute an estimated counterfactual where no further action has been taken. Baseline projections are discussed in more detail in Section 2.6.
- The concentration projections for 2020, 2025 and 2030 are based on implementation of the plan as set out in Section 5.

11. The baseline projections incorporate estimates of emissions from all sources within the emissions inventory, including:

- Transport sources including upcoming Euro standards
- Business emissions including those covered by the Industrial Emissions Directive
- Domestic combustion such as in boilers

12. The PCM model is robust and detailed but this complexity requires significant computation, taking around three months to run scenarios. Therefore, to enable more flexible assessments, supplementary analysis has been undertaken using a simplified version of the full PCM model, known as the Streamlined PCM model (for more details on this model see Section 2.8). The Streamlined PCM model uses the outputs of the full PCM modelling to provide estimates of the impact of different measures by varying the contribution to concentrations from road transport sources.

13. The Streamlined PCM model incorporates direct changes in emissions where vehicle numbers of fleet compositions change; however it does not fully incorporate the complexities of atmospheric science that are available in the full PCM. For example, the Streamlined PCM model does not reflect in detail the knock-on effects of these changes on surrounding roads.

14. A description of UK's air quality monitoring is included in Section 2.1 while the modelling undertaken for compliance assessment is covered in Section 2.2. Section 2.3 provides a summary of the Quality Assurance undertaken for the PCM model. Section 2.4 sets out the annual mean ambient concentrations modelling for 2013 and Section 2.5 focuses on source apportionment for both NO_X and NO_2. Section 2.6 and 2.7 outline the approach for calculating the baseline projections for annual mean and 1-hour limit values. Finally Sections 2.8 and 2.9 look at the Streamlined PCM model in detail.

2.1. Air quality monitoring

15. The NO_2 monitoring data for the UK is delivered through the Automatic Urban and Rural Monitoring Network (AURN), which provides hourly measurements of concentrations of NO_X and NO using the chemiluminescence reference measurement method laid out in the Directive. NO_2 concentrations are calculated within the reference method by subtracting the concentration of NO from the concentration of NO_X.

16. The number of monitoring stations required is defined within the Directive and is dependent on the magnitude of NO_2 concentrations, as assessed against the Upper Assessment Thresholds (UAT) and Lower Assessment Thresholds (LAT) as defined in Annex II of the Directive, and the population of zones and agglomerations.

17. The number of monitoring points is defined in Annex V of the Directive. The Upper and Lower Assessment Thresholds for NO_2 are as follows:

    - Hourly concentrations: UAT of 140 µg/m3 and LAT of 100 µg/m3 not to be exceeded more than 18 times in any calendar year
    - Annual mean concentrations: UAT of 32 µg/m3 and LAT of 26 µg/m3

18. The minimum number of monitoring points required is reduced because of the use of supplementary annual modelling (Article 7, paragraph 3).

19. Hourly NO_X measurements and statistics for all AURN sites, together with those for the separate NO and NO_2 components, can be downloaded in either near-real-time provisional or finally ratified form from the UK-AIR website[3].

20. Annex VI of the Directive defines the reference method for NO_X monitoring, and the procedure for demonstration of equivalence with the reference method. The reference method specified is that developed by CEN (Comité Européen de Normalisation- European Committee for Standardization) and published in the UK through the British Standard BS EN14211: 2012 (NO_X).

21. In compliance with Annex VI, Section D of the Directive, all new equipment introduced into the network complies with the reference method or has been demonstrated to be equivalent to the reference method.

22. The AURN is required to have an established and well-defined quality assurance and quality control (QA/QC) programme to ensure that it achieves the data quality objectives as defined in Annex I of the Directive. Details of this QA/QC programme are published in the network QA/QC manual[4]. The

[3] http://uk-air.defra.gov.uk/data/
[4] http://uk-air.defra.gov.uk/reports/cat13/0910081142_AURN_QA_QC_Manual_Sep_09_FINAL.pdf

programme includes full traceability of all measurements through the use of reference calibration standards, and the participation of the appointed QA/QC institution in the related EU-wide quality assurance programmes.

2.2. Modelling for compliance assessment

23. The PCM model is used to provide information to supplement the annual monitoring assessment, and also to provide the additional information on source apportionment and projections of future concentrations required for the development and implementation of air quality plans. The source apportionment and projections are therefore consistent with the compliance assessments because the same models are used throughout.

24. The PCM model is used to calculate urban and rural background concentrations of NO_2 on a 1 km x 1 km grid. The PCM model is a collection of Geographical Information System (GIS) based models used to estimate ambient concentrations of key pollutants at background and roadside locations throughout the UK. The PCM model is not a full chemistry transport model; it is a collection of various model layers including interpolated measurements, dispersion models and emissions scenarios combined within GIS.

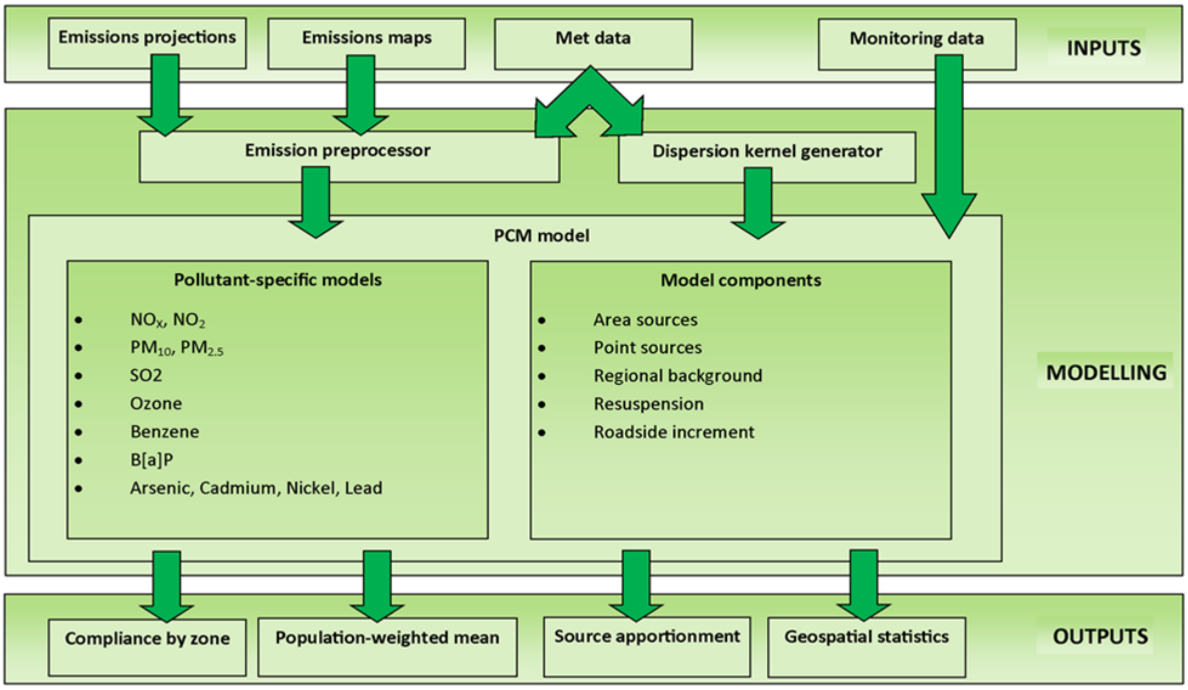
25. The PCM modelling for NO_X and NO_2 is underpinned by NOx emission estimates from the National Atmospheric Emissions Inventory (NAEI). The NAEI provides emissions data from a wide range of sources[5] which are categorised according to whether they are point sources, area sources or local sources. Each category of emissions is mapped across the UK as an individual GIS layer, and a dispersion model is applied to each layer to drive atmospheric mixing and generate background concentrations at 1 km x 1 km resolution. At roadside locations, a roadside increment is modelled as an additional layer. The total modelled concentrations are calibrated against the concentrations measured by the AURN monitoring network.

26. Source apportionment of NO_x contributions from each sector is provided by the PCM model automatically. Concentrations pertaining to different sources are derived based on the emissions data that underpins the PCM model.

27. A flow chart of how the PCM model works is contained in Figure 2.1.

[5] http://naei.defra.gov.uk/

Figure 2.1 PCM modelling process diagram



28. A single representative value is calculated for the traffic location (roadside) concentration adjacent to each of approximately 9000 major road links (A-roads and motorways) in urban areas. A road link is defined as the stretch of road between junctions with other major roads. A traffic count is available for each of the road links. Calculating a single value for each road link means that any additive effect of the contributions to the micro environment at a junction from more than one road is not included. This ensures that the assessment meets the Directive requirement not to assess compliance in the vicinity of major junctions (within 25m).

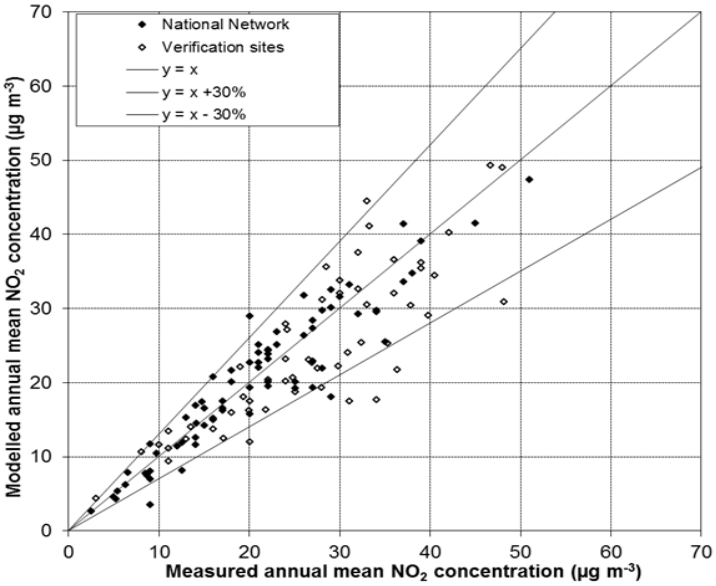
29. Concentrations at traffic locations should be assessed at no more than 10m from the kerbside (AQD, Annex III, Section C). The PCM model for roadside concentrations provides a concentration estimate for a receptor at approximately 4m from the kerbside. This is the average distance from the kerbside for roadside monitoring stations within the AURN. These are the stations that have been used to calibrate the PCM model for roadside locations and thus the model has been calibrated in such a way as to provide estimates of concentrations at this distance from the kerb.

2.3. PCM model quality assurance

30. The PCM model is calibrated for NO_2 concentrations against the measurements from the Automatic Urban and Rural Network (AURN), which ensures alignment between model results and real world monitoring. Figure 2.2 shows a plot of modelled NO_2 background concentrations against NO_2 background concentrations measured at independent verification sites,

demonstrating the equivalence of modelled and measured NO_2 concentrations.

Figure 2.2 Verification of modelled vs measured NO_2 background relationship (2013). Calibrated modelled vs independent measured NO_2 concentrations (verification sites)



31. The PCM model was produced under the Modelling Ambient Air Quality project which is subject to BS EN ISO 9001:2008. It is audited by Lloyds and the Ricardo Energy & Environment internal quality assurance (QA) process. The emphasis of these audits is on document control, data tracking and spreadsheet checking. Model QA is based on the recommendations made in the “Review of the air quality assurance framework of the National Atmospheric Emissions Inventory, Pollution Climate Mapping and Impact Pathway Models” report prepared for Defra under Contract 21366 by Hartley McMaster Limited[6]. The general QA process also takes into account the recommendations from The Aqua book: guidance on producing quality analysis for government (HM Treasury, 2015).

32. The review by Hartley McMaster Limited found that the QA policies and practices adopted by the model builders were evolving during the review, and by the end of the review compared relatively well against three independent sets of best practice guidelines: the Intergovernmental Panel on Climate Change (IPCC) 2006 QA guidelines, the Department of Energy and Climate Change (DECC) QA guidelines, and the guidance within the final report of the Macpherson Review of the quality assurance (QA) of Government analytical

[6] http://uk-air.defra.gov.uk/assets/documents/reports/cat09/1511251152_AQ0962_Review_of_Quality_Assurance_framework_for_models-Final_report.pdf

models. In 2011, an in-depth review and inter-comparison of air quality modelling was conducted. This review identified that the PCM model was suitable for continued use and development.

33. In addition to the national UK Air Quality monitoring networks, local authorities, businesses and academics carry out monitoring and modelling of air quality. In many cases, local monitoring does not meet the strict requirements for compliance assessment.

2.4. Annual mean NO_X and NO_2 modelling for 2013

34. A full description of the original reference year NO_X and NO_2 model for 2013 as used for the compliance assessment reported in September 2014 has been provided in the technical report that accompanies the 2013 air quality assessment[7]. Key information is summarised in this section along with a description of the revisions to the modelling that have been made for the 2013 reference year modelling for the 2015 air quality plans.

35. The GIS based Pollution Climate Mapping (PCM) air dispersion model has been used to estimate annual mean NO_X concentrations at background and roadside locations using emissions estimates from the UK National Atmospheric Emissions Inventory (NAEI). Annual mean NO_2 concentrations were then calculated from the modelled NO_X concentrations. The models have been calibrated using data from the UK AURN. The dispersion kernels used within the PCM model were generated using 2013 meteorological data from RAF Waddington in Lincolnshire.

2.4.1. NO_x emissions

36. The NO_X and NO_2 PCM modelling for 2013 has been based on the 2012 NAEI NO_X emissions estimates[8] and mapped emissions projected forward by one year. This is because 2012 was the most recent year for which emissions estimates were available when the air quality assessment for 2013 was carried out. The largest contributions to total UK NO_X emissions in 2013 were from road transport exhaust emissions and combustion in energy production and conversion (See Annex A).

37. Emissions estimates in the original 2013 compliance assessment were calculated using vehicle emission factors from COPERT 4v10[9] as these

[7] http://uk-air.defra.gov.uk/assets/documents/reports/cat09/1511251423_AQ0650_2013_MAAQ_technical_report.pdf
[8] http://uk-air.defra.gov.uk/assets/documents/reports/cat19/1405130812_UK_IIR_2014_Final.pdf
[9] COPERT 4 v10.0 released in November 2012 and the accompany report "Description of new elements in COPERT 4 v10.0" can be downloaded at http://emisia.com/sites/default/files/COPERT4_v10_0.pdf

represented the best available evidence at the time. Updated emission factors for road traffic have since become available from COPERT 4v11[10]. These updated emission factors have been used in the revised reference year calculation for 2013, and in the projections for future years used in the 2015 plans. The choice of emission factors for Euro 6 cars and LGVs is particularly important for the projections because of the large contribution that these vehicle types make to modelled roadside concentration in the reference year. However, there are still uncertainties in emissions estimates for some current vehicle types and Euro standards. Further information on the approach to vehicle emission factors is provided in Section 2 of the UK overview document.

38. The NAEI emissions mapping method is described in detail in the most recent NAEI UK Emissions Mapping Methodology report[11] and a brief summary is provided here.

39. Emissions maps for non-road traffic area sources within the 2012 NAEI at a resolution of 1 km x 1 km have been calculated for each combination of source (such as domestic combustion, railways or road traffic) and activity (typically fuel, such as diesel, natural gas or coal) using distribution grids that have been generated using appropriate surrogate statistics. These distribution grids include a wide range of data on population, employment and land use amongst others. The emissions for non-road area sources have been projected forwards to 2013 from the 2012 emissions maps for each source and activity combination. Thus the spatial distribution for each source and activity combination in 2013 is assumed to be the same as for that sector in 2012. The individual emissions grids for 2013 were then added together to give sector area source emissions grids for 2013.

40. Emissions maps for road traffic sources in 2013 have been calculated by the NAEI by projecting forwards from a base year of 2012 based on the projected changes in traffic activity and fleet weighed emission factors. These maps include a component for the emissions from vehicles on major roads that has been calculated from traffic count data for individual road links in addition to components from minor roads and cold-starts (starting an engine at the ambient temperature).

[10] COPERT 4 v11.0 released in September 2014 and the accompany report "Update of the Air Emissions Inventory Guidebook – Road Transport 2014 Update" can be downloaded at http://www.emisia.com/sites/default/files/files/COPERT4_v11_0.pdf and emission factors are provided directly via personal communication.

[11] http://uk-air.defra.gov.uk/assets/documents/reports/cat07/1511261130_UK_Emission_Mapping_Methodology_2012_Issue_1.pdf

2.4.2. The PCM model for NO_X

41. Based on the NAEI emissions estimates, a 1 km x 1 km annual mean background NO_X concentration map for 2013 has been calculated by summing the contributions from:

- Large point sources, modelled explicitly using an air dispersion model (ADMS 5.0)
- Small point sources, including estimates for point sources derived from reported CO_2 emissions for plant reporting under the EU Emission Trading System, modelled using a generalised model using dispersion kernels generated using an air dispersion model (ADMS 5.0)
- Distant sources, characterised by the rural background concentration
- Local area sources, modelled using dispersion kernels generated using an air dispersion model (ADMS 5.0) and calibrated using measurement data from the national monitoring network

42. Full details of the modelling method for point and area sources have been provided in the technical report that accompanies the 2013 air quality assessment[12].

43. At locations close to busy roads, an additional roadside contribution has been added to account for contributions to total NO_X from road traffic sources. A revised method, the PCM Roads Kernel Model (PCM-RKM), has been used to calculate this additional roadside contribution for the modelling to support the development of the 2015 air quality plans. The PCM-RKM model uses the ADMS-Roads dispersion model[13] (Version 3.2.4.0). Each model run is parameterised using specific input data for the census point. These inputs are as follows:

Road geometry

44. The modelled concentration at a roadside receptor is influenced by the orientation of the road relative to the prevailing wind direction. The orientation of road links within the PCM model is represented based on the bearing of major road sections relative to due north, based on Ordinance Survey data.

45. Road sources are treated as line sources of variable width, in order to represent the variety of roads (e.g. dual or single carriage way). The model assumes that each lane is 4 metres wide (see Annex B) and the total road width is estimated based on lane counts provided in the census point dataset.

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[12] http://uk-air.defra.gov.uk/assets/documents/reports/cat09/1511251423_AQ0650_2013_MAAQ_technical_report.pdf

[13] http://www.cerc.co.uk/environmental-software/ADMS-Roads-model.html

Traffic speeds, emissions and traffic counts

46. The PCM-RKM uses traffic emissions for major road links in the UK from the NAEI and incorporates vehicle turbulence data calculated by the ADMS-Roads. Traffic flows (annual average daily flows, AADFs) by census point have been aggregated into two vehicle categories (light and heavy duty vehicles) for the calculation of vehicle induced turbulence.

47. Traffic Speed estimates by vehicle category are applied based on categories of UK area type and road type with Department for Transport (DfT) congestion statistics estimating speeds.

48. Emissions vary with time, with weekdays differing from weekend profiles, using the same data as PCM area source model.

Meteorology

49. Hourly sequential meteorological data from Waddington (Lincolnshire) in the reference year (2013) has been used in the setup of the ADMS-Roads model runs. We estimate meteorological conditions at the roads, based on the area type and meteorological site.

Receptor location

50. Model runs are set up so that there is a road source of NOx for each major road link nearest to a census point.

51. This revised method based upon dispersion kernels generated by the ADMS-Roads dispersion model represents a more process-based approach than the previous empirical method. It provides a more robust assessment, whilst retaining the link with measurement data provided by the use of AURN measurement data to calibrate this component of the model. Full details of the PCM-RKM are provided in Annex B.

2.4.3. The PCM model for NO_2

52. Maps of annual mean NO_2 concentrations have been calculated from modelled NO_X concentrations using a calibrated version of the updated oxidant-partitioning model[14]. This model uses representative equations to account for the chemical coupling of ozone (O_3), NO and NO_2 within the atmosphere. A key advantage of this approach for modelling NO_2 concentrations is that the impact of changes in primary NO_2 emissions and/or regional oxidant levels on ambient NO_2 concentrations can be captured. Full

[14] Jenkin, M.E. (2004). Analysis of sources and partitioning of oxidant in the UK-Part 1: the NO_X-dependence of annual mean concentrations of nitrogen dioxide and ozone. Atmospheric Environment, 38, 5117–5129. doi:10.1016/j.atmosenv.2004.05.056

details of the modelling method have been provided in the technical report for the 2013 modelling assessment[15].

53. The primary NO_2 emission fraction (f-NO_2) for each individual road link has been calculated from a combination of traffic counts for each vehicle type and fuel and fleet weighted f-NO_2 values for each vehicle type and fuel. The f-NO_2 values used for this current modelling have been revised to reflect the updated emission factors for NO_X from COPERT 4v11 and f-NO_2 values from the EMEP/EEA Emissions Inventory Guidebook 2013, updated July 2014[16]. The resulting fleet weighted f-NO_2 values for different vehicle types, fuels and different years are presented in Annex C.

2.5. Source apportionment

2.5.1. Source apportionment for NO_X

54. The PCM model for NO_X explicitly includes detailed information on the source apportionment for annual mean NO_X concentrations. This includes the following splits:

- Regional
  - Within member state
  - Transboundary
  - Shipping
- Urban
  - Sectors such as road traffic, industry domestic and others
- Local
  - Including a split into different vehicle classes, such as cars, buses, HGVs

55. Source apportionment for NO_X is presented in the UK overview document and air quality plan for each zone under consideration[17].

2.5.2. Source apportionment for NO_2

56. It is not possible to calculate a precise source apportionment for annual mean NO_2 concentrations because ambient NO_2 concentrations include

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[15] http://uk-air.defra.gov.uk/assets/documents/reports/cat09/1511251423_AQ0650_2013_MAAQ_technical_report.pdf
[16] http://www.eea.europa.eu/publications/emep-eea-guidebook-2013/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-road-transport (Table 3.113)
[17] http://uk-air.defra.gov.uk/library/no2ten/

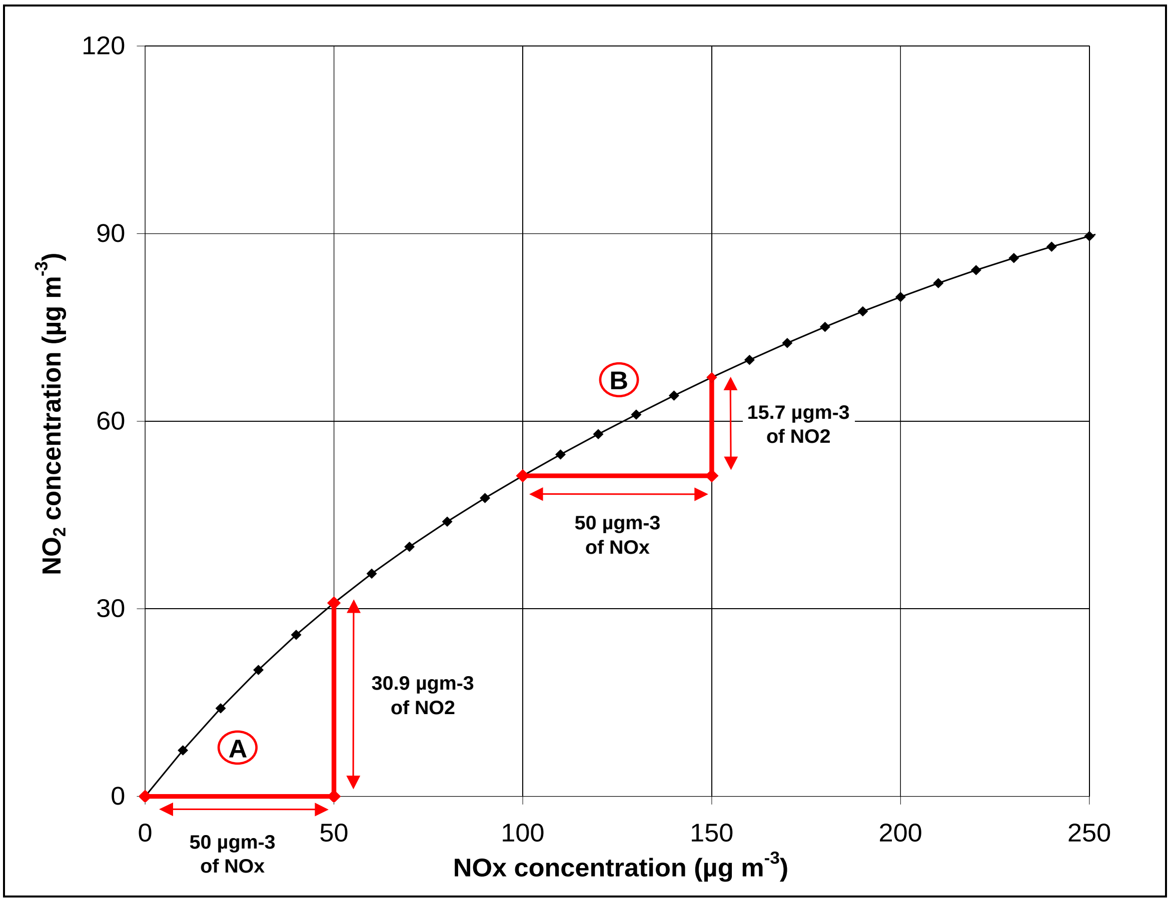
contributions from both directly emitted primary NO_2 and secondary NO_2 formed in the atmosphere by the oxidation of NO.

57. There is no simple linear relationship between NO_2 concentrations and NO_X emissions or concentrations. For a given reduction in NO_X concentration, the corresponding reduction in NO_2 is dependent upon the initial NO_X concentration[18]. This is illustrated by Figure 2.3. Thus, the same reduction in NO_X emissions will have a smaller impact on NO_2 concentrations where those concentrations are already high. This is demonstrated where a reduction of 50 $\mu g/m^3$ NO_X results in a reduction of nearly 40 $\mu g/m^3$ at location A, whereas the same reduction in NO_X concentration at location B only results in a reduction of just under 16 $\mu g/m^3$ in the NO_2 concentration. Likewise, an equal reduction in NO_2 concentrations will require a larger reduction in NO_X emissions where the starting concentration is already high. The complexity is further increased by the variation in primary NO_2 emissions from one location to another, thus the curves are different for different locations.

58. Therefore source apportionment for NO_2 has not been attempted within the modelling work carried out to support the development of the 2015 UK air quality plan. The source apportionment for NO_x is, however, considered to provide a good representation of the sources contributing to ambient NO_2 concentrations.

[18] Jenkin, M.E. (2004). Analysis of sources and partitioning of oxidant in the UK-Part 1: the NO_X-dependence of annual mean concentrations of nitrogen dioxide and ozone. Atmospheric Environment, 38, 5117–5129. doi:10.1016/j.atmosenv.2004.05.056

Figure 2.3. Relationship between NO_X and NO_2 concentrations for a hypothetical site using realistic variables



2.6. Baseline projections for annual mean NO_X and NO_2

59. Baseline projections estimate the likely scale of exceedance in each zone in different years and can be used to estimate a likely timescale to compliance.

60. The PCM projections of future NO_2 concentrations are underpinned by emissions projections, available from the NAEI for 2020, 2025 and 2030. These projections have been calculated from an emissions inventory base year of 2012 and are split by emission source sector (see Annex A).

61. For historic years, the PCM model for NO_2 is calibrated against measured NO_2 concentrations from the AURN for that year. Projected NO_2 concentrations are modelled using a base year (or reference year). The base year of 2013 is used to calibrate the model for the UK air quality plan. This is the most recent year for which an assessment of compliance has been carried out and hence for which a full dataset was available at the time of assessment.

62. The 2013 air quality assessment was reported to the European Commission in September 2014[19]. This data has subsequently been updated to incorporate the latest information on emission factors for road traffic emissions of NO_X and an improved modelling method for traffic (roadside) locations (for further details see Annexes A and B). These updates have only become available since the original assessment for 2013 was reported. These revisions were made in order to ensure that the latest available evidence is used to support the development of the UK air quality plan. The revised 2013 data was recently re-submitted to the Commission.

63. The PCM model's air quality assessment supporting the plan is based on updated emission factors for road transport from COPERT 4v11. The release of COPERT 4 v11 provides updated emission factors for Euro 5/V and Euro 6/VI for cars, LGVs, HGVs and buses/coaches. These updated factors are based on further emissions data collected under European Research Group on Mobile Emissions (ERMES), including real-world tests on around 20 early generation Euro 6 diesel cars.

64. The recent agreement (October 2015) on the Real Driving Emissions (RDE) for Euro 6d vehicles could not be assessed using the PCM model due to time constraints. The PCM model analysis takes three months from start to finish and was underway when the agreement was reached. The impact of RDE was therefore assessed using the Streamlined PCM model as described in Section 2.8.

65. A set of traffic activity projections from the Department for Transport (DfT)[20] and Transport for London (TfL) underpin the NAEI emissions projections. Information on estimates for fleet composition from DfT has also been included, such as uptake rates of low carbon passenger cars and LGVs with electric and hybrid electric propulsion systems; the impact on uptake of announced and committed policies such as new car and new van CO_2 regulations; and impact of Green Bus Fund amongst others.

66. The emissions projections for non-road traffic sources have been calculated by the NAEI based on the Updated Energy Projections 2013 from the Department of Energy and Climate Change (DECC). The projections do not

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[19] Available on the EU Central Data Repository. http://cdr.eionet.europa.eu/gb/eu/aqd/

[20] For Northern Ireland, traffic is assumed to grow at GB average rates for appropriate area types due to lack of suitable traffic projections data for Northern Ireland

include the impact of additional policies and measures that are subject to review and had not yet been implemented into UK law at the time of compilation.

67. Section 4 provides information on the measures that are taken into account in the baseline projections. Further details on the approach and assumptions underpinning baseline projections for NO_X and NO_2 can be found in Annex A.

68. The annual mean NO_2 maps for 2013 for background and roadside (traffic) locations are shown in Figures 2.4 and 2.5. The model results for 2013 in terms of the extent of exceedance of the annual mean limit value for NO_2 within each zone are presented in the air quality plans for each zone.

Figure 2.4. Annual mean background NO_2 concentration, 2013 ($\mu g/m^3$)

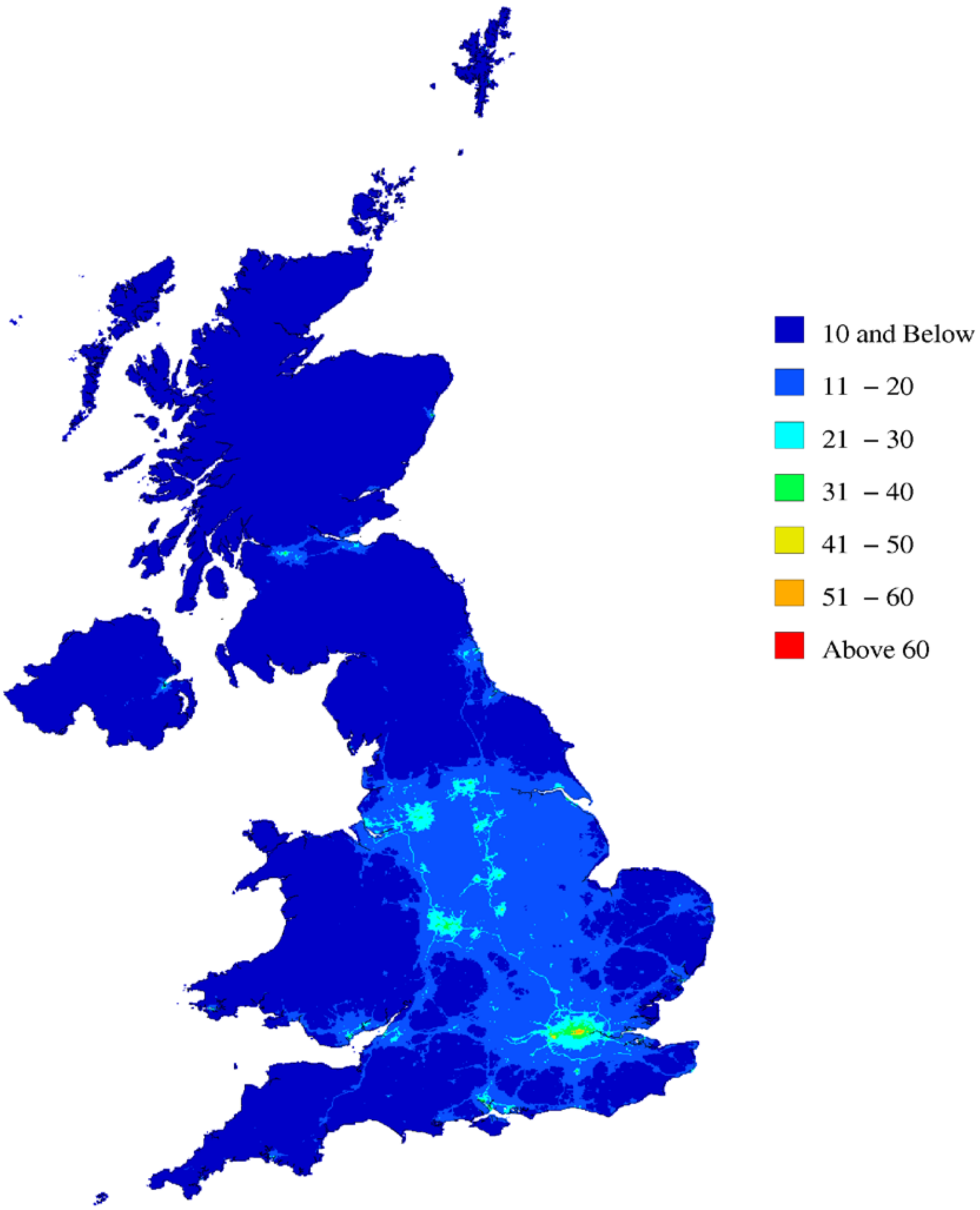
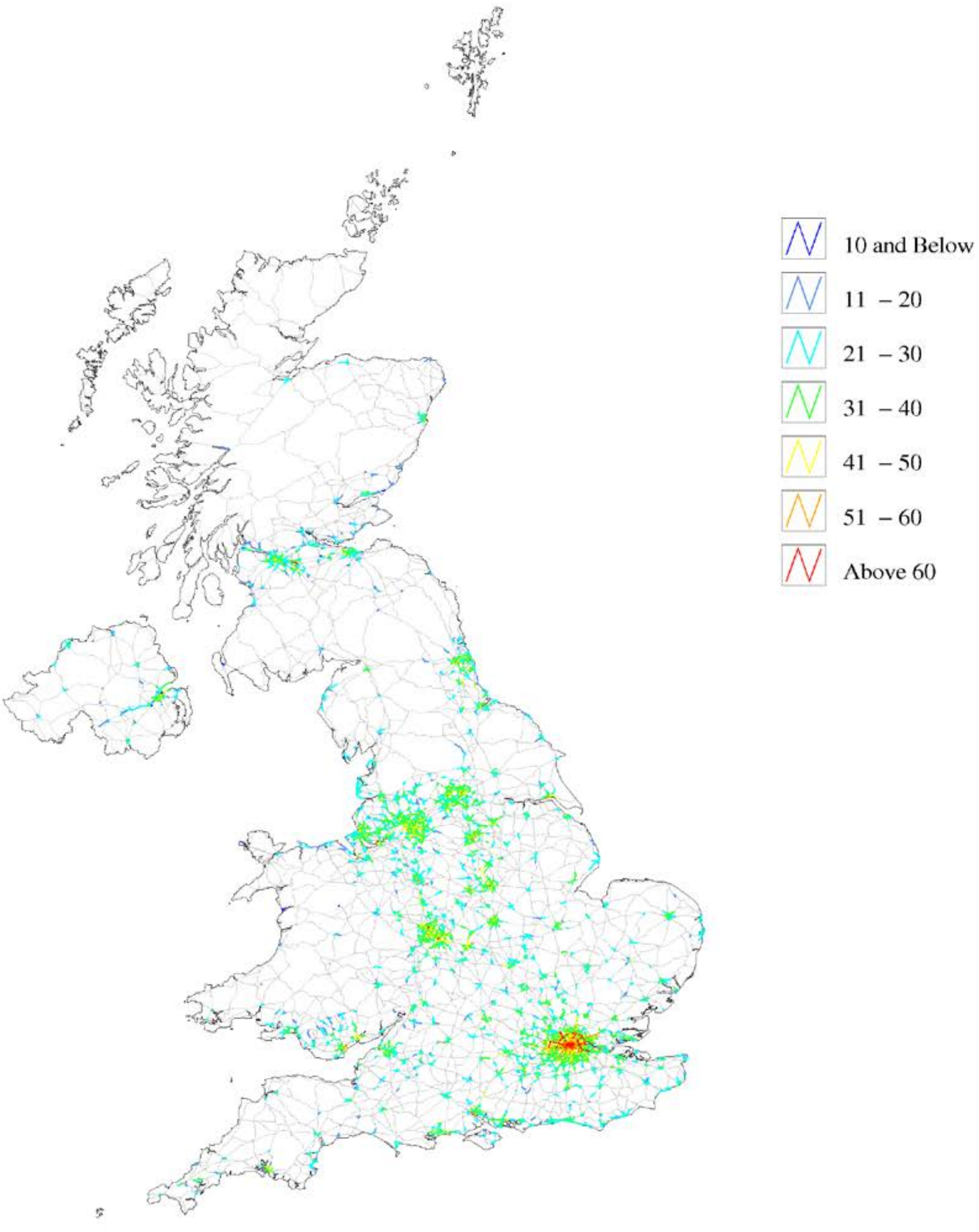


Figure 2.5. Urban major roads, annual mean roadside NO_2 concentration, 2013 (µg/m^3)



2.7. Baseline projections for the 1-hour limit value

69. Modelling of 1-hour NO_2 concentrations for comparison with the 1-hour limit value has not been carried out because of the very large additional uncertainties that would be associated with attempting to model concentrations on an hourly basis using the techniques currently available. The assessment of compliance with this limit value in 2013 has been based on monitoring data only.

70. Projections of compliance with the 1-hour limit value for NO_2 have therefore been derived from model results for annual mean concentrations for the locations of the measured exceedances of the 1-hour limit value in 2013. An annual mean concentration threshold of 40µg/m^3 has been used to be equivalent to compliance with the 1-hour limit value. Thus, for the purposes of this analysis, the hourly limit value will be met at the same time that compliance is achieved for the annual mean limit value. The annual mean limit value is expected to be more stringent than the hourly limit value in the majority of situations (AQEG, 2004)[21], therefore this is a cautious approach. The Air Quality Expert Group (AQEG) found that 94 percent of measured exceedances of the hourly limit value over the period from 1978 – 2001 coincided with exceedances of the annual mean limit value. Analysis of more recent monitoring data has confirmed that exceedances of the 1-hour limit value coincide with annual means greater than 40µg/m^3 in almost all instances[22]. Source apportionment for the 1-hour limit value has been assumed to be the same as for the annual mean concentration at the same location.

2.8. Streamlined PCM model

71. The full PCM model described earlier in this section requires three months to carry out full emissions and concentrations calculations. A streamlined version of this model, the ‘Streamlined PCM model’ was therefore developed. While this tool has reduced functionality compared to the full PCM model, it can estimate the effects of a range of transport scenarios within a much shorter timeframe. The Streamlined PCM model has been used to analyse the impact of local measures and Real Driving Emissions (RDE) testing as described in Section 4.3. The model was built by Ricardo Energy & Environment for Defra.

72. The Streamlined PCM model calculates the projections for NO_X emissions (tonnes of NO_X) and NO_2 concentrations for the years 2020 or 2025, by

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[21] Air Quality Expert Group (AQEG, 2004). Nitrogen Dioxide in the United Kingdom. http://uk-air.defra.gov.uk/library/aqeg/publications

[22] http://uk-air.defra.gov.uk/assets/documents/reports/cat18/0806261511_TG_NO2relationship_report_draft1.pdf

modelling the effect of changes in road traffic (in terms of vehicle numbers, location, speed and number and distance of journeys) across the United Kingdom. The baseline scenario on which the Streamlined PCM modelling is based was derived from a run of the full PCM model.

73. Road traffic composition and flow may be adjusted by vehicle type (passenger cars, all types of light goods vehicles (LGVs), urban buses, articulated and rigid heavy goods vehicles (HGVs), buses, coaches, mopeds and motorcycles), fuel type (petrol or diesel), and Euro Standard[23]. The Streamlined PCM model takes into account the age and composition of the fleet; the size of the vehicle; the emissions standards the vehicles were required to comply with when sold new; abatement technologies used to reduce emissions; the type of fuel used; and trip characteristics (such as length).

74. The Streamlined PCM model estimates changes in emissions on 18,346 road links in 406 local authorities of the United Kingdom and NO_2 annual mean concentrations for approximately 9,000 of these links. These approximately 9,000 roads correspond to urban major roads for which compliance with the annual limit value for NO_2 from the Ambient Air Quality Directive is assessed.

75. In order to enable modelling of localised transport measures, the receptors considered in the Streamlined PCM model are labelled according to their location within 406 local authorities, 20 possible locations of areas in risk of non-compliance with the limit values of the Directive for NO_2, and 12 regions (9 regions in England, the other regions being Scotland, Wales and Northern Ireland)[24]. The areas which include areas at risk of non-compliance have been defined based on natural boundaries such as existing roads or rivers. However in cases where local measures will be implemented, appropriate boundaries would need to be identified by local authorities within scoping studies

76. The Streamlined PCM model consists of two spreadsheets (see figure 2.6):

- The 'Emission Calculation Spreadsheet'. This is a simplified road traffic emissions model which uses emission factor data from the NAEI[25] to calculate NO_X and NO_2 emissions;
- The 'Concentration Calculation Spreadsheet'. This is a simplified version of the PCM model, for ambient concentrations, developed by Ricardo Energy & Environment. This model calculates NO_2 annual mean concentrations and indicates whether or not each link is compliant with

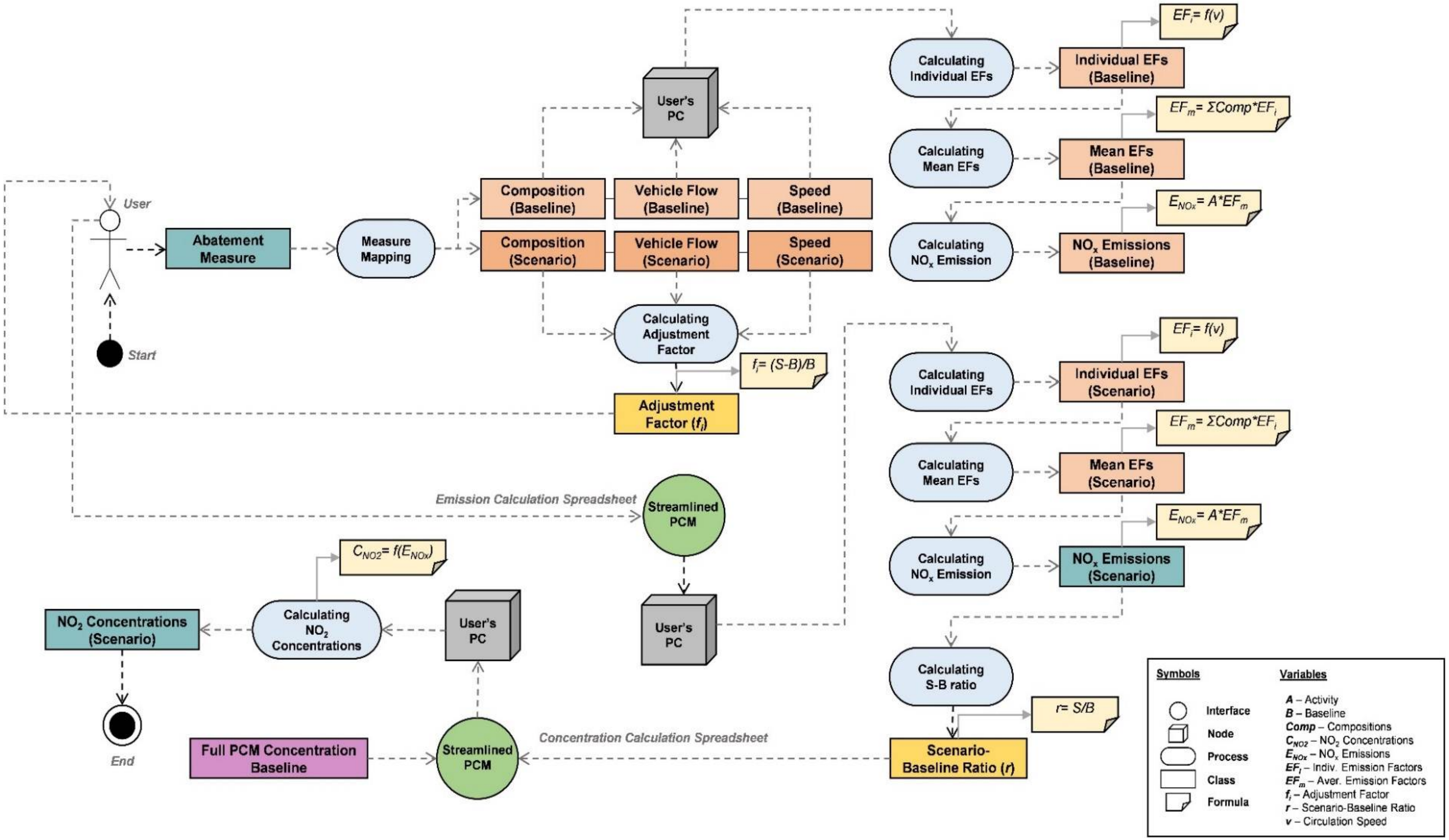
[23] http://ec.europa.eu/environment/air/transport/road.htm
[24] These regions correspond to those previously known as Government Office Regions (GOR) in England
[25] http://naei.defra.gov.uk/

the annual limit value for NO_2 set by the European Commission (Directive 2008/50/EC).

77. Further detail on the Streamlined PCM model is available in the published technical report[26], and the following section describes the quality assurance of this tool, and how it compares with the full PCM model.

[26] http://uk-air.defra.gov.uk/assets/documents/reports/cat09/1511260938_AQ0959_Streamlined_PCM_Technical_Report_(Nov_2015).pdf

Figure 2.6. Schematic flowchart of the Streamlined PCM model



2.9. Quality assurance of the Streamlined PCM model

78. The Streamlined PCM model has been fully quality assured through:

- in-house quality assurance by Defra following the principles of the Aqua book
- testing by Ricardo Energy and Environment
- external peer review by an expert in air quality modelling

79. The Streamlined PCM tool uses information from the PCM model, which for every base year modelling has been calibrated against observations recorded by monitoring stations throughout the UK. The PCM model was produced under the Modelling Ambient Air Quality project and audited by Lloyds. The model has undergone internal quality assurance (QA) as described in Section 2.3. The general QA process also takes into account the recommendations from The Aqua book: guidance on producing quality analysis for government (HM Treasury, 2015).

80. In order to assess the robustness of the tool, results from the Streamlined PCM tool have been compared with equivalent results from the full NAEI emissions and PCM concentrations calculations for four possible scenarios resulting from the implementation of one type of measure (Clean Air Zones) in 2020. For a detailed description of the measure refer to Section 3.5 within the overview of the UK air quality plan. The Streamlined PCM model results compare well with the full PCM model results for each scenario. In terms of the distribution of these differences, there is some variation across roads but the spread is small and provides confidence in the Streamlined PCM tool.

81. The Streamlined PCM model slightly overestimates the impact of the Clean Air Zone measure compared to the full PCM model, with the differences between the mean NO_2 concentrations from the two models ranging from 0.15 – 0.25 $\mu g/m^3$ across the four Clean Air Zone scenarios. This small overestimate is as expected, since the measures will tend to have slightly less impact on gridded major road, minor road and cold-start emissions than on the local major road emissions, particularly for measures involving buses and HGVs, which typically contribute less to minor road than major road emissions and have no cold-start emissions.

82. As expected there are some outliers. In isolated cases where the source apportionment is significantly different in the local roads, for example in roads with very high bus movements, then care needs to be taken as the Streamlined PCM model will tend to overestimate the impact of measures.

83. Defra commissioned an expert in air quality modelling to conduct an external peer review of the Streamlined PCM model, to assess the methodology, robustness and suitability of the model for the purposes of evaluating different policy options. The peer review found the overall concept of the

Streamlined PCM model to be sound, and the methodology and quality assurance proportionate.

3. Economic assessment methodology

84. This section outlines the methodology used to appraise the economic costs and benefits to the UK of the modelled measures as outlined in the UK air quality plan. In addition to reducing NO_2 concentrations, the measures taken will have a range of other impacts. The economic assessment looks to reflect these impacts through cost-benefit analysis.

85. The impact of any measure to address air quality is dependent upon three factors (this is demonstrated with a transport example below):

- What – the level of demand for transport such as the number of journeys undertaken
- How – what technologies are used to service the demand including the vehicle type and technology.
- Where – location of the activity for the higher the population density in which emissions occur will lead to higher exposure.

86. The first stage of the modelling is to establish a baseline. The baseline aims to reflect what would happen if the proposed air quality measures were not implemented. Within the baseline a range of existing measures and assumptions about future activity and emissions have been incorporated as set out in Section 4.2.

87. How these factors change in response to the measure being undertaken in the air quality plan has been quantified. The measures in place are assumed to prompt a behavioural response. This could alter any or all of the three factors set out above.

88. As far as is practical, impacts have been quantified and valued in monetary terms in order to facilitate their comparison. Where impacts are spread over time the values have been converted to present values based on the recommended Green Book guidance[27].

89. Impacts considered as a consequence of the intervention in this economic assessment are:

Benefits

- Health impacts – primarily relating to premature mortality from NO_X exposure,
- Greenhouse gases – reductions in fuel use will reduce GHG emissions.

[27] https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent

- Fuel savings – increasing fleet turnover will increase average fuel efficiency.

Costs

- Welfare cost – incurred by moving users from their preferred outcome to an alternative.
- Lost value of asset – increased turnover will reduce value of older vehicles.
- Implementation costs for local authorities – including infrastructure and scoping studies.

90. A ten year appraisal period has used from 2020 for modelling purposes. Implementation and upfront costs and are assumed to be incurred in 2020. Fuel and carbon impacts associated with local measures are incurred over the 10 year period.

91. This allows the present value of the costs to be compared to the estimated benefits, thereby calculating the net present value and the benefit cost ratio. In this way it has been possible to assess the economic case for the UK air quality plan.

92. It is not possible to quantitatively reflect all potential impacts. The three main uncertainties are around the performance of vehicle emissions standards, health impacts of NO_2, and the valuation of fleet adjustment costs. Where quantification is not possible the assessment has been supplemented with a qualitative description and, where possible, an indication of the potential significance. For more details see Section 6.

93. The rest of this section is structured as follows. Section 3.1 describes the source of benefits – the health impacts of reducing NO_x emissions, and CO_2 savings. Section 3.2 then discusses the costs associated with implementing Clean Air Zones and local measures. The results of the economic impact assessment described in this section are presented in Section 5.3.

94. Further details on the methodology are contained in Annex D.

3.1. Benefits

3.1.1. Health Impacts of NO_2 exposure

95. NO_2 has been associated with hospital admissions for various conditions, effects on lung function and growth, increases in respiratory symptoms, asthma prevalence and incidence, cancer incidence, adverse birth outcomes and mortality (US EPA, 2013; WHO, 2013). However, the evidence has not been regarded, until recently, as sufficient to indicate that NO_2 itself, rather than other co-emitted pollutant(s), was responsible for these health impacts.

96. In recent years the body of evidence for the health impacts of short- and long-term exposure to NO_2 has grown, leading the Committee for the Medical Effects of Air Pollutants (COMEAP) to conclude in 2015[28]:

"Evidence associating NO_2 with health effects has strengthened substantially in recent years and we now think that, on the balance of probability, NO_2 itself is responsible for some of the health impact found to be associated with it in epidemiological studies."

97. Much of the evidence linking health impacts with long-term average NO_2 concentrations has been gathered using observational epidemiological studies. These studies use statistical methods to identify associations between outcomes, such as mortality or ill heath, with external factors, such as modelled or measured pollutants levels, whilst taking into account other variables such as gender and age. Observational epidemiological studies have inherent strengths and weaknesses and are only able to provide evidence on the statistical relationship between risk factors and health outcomes. Therefore, COMEAP also noted that

"…it is possible that, to some extent, NO_2 acts as a marker of the effects of other traffic-related pollutants…"

98. Since publishing this statement in 2015, COMEAP has been considering the evidence linking long-term average NO_2 concentrations with effects on mortality, with a view to recommending methods for quantifying this association and estimating the mortality effect in the UK. The most recent, relevant and best available evidence from single and multi-pollutant analyses will be considered to inform COMEAP's report, and this is anticipated to be available in 2016.

99. On 15 December 2015 COMEAP released a statement that, based on the current best available evidence, a link between NO_2 exposure and mortality should be used for cost benefit analysis[29].

100. As an interim recommendation there are considerable uncertainties around this recommendation. In particular it is highlighted that there is a notable potential overlap between NO_2 and $PM_{2.5}$ mortality. To update this recommendation and set out the uncertainties COMEAP intend on publishing a report in the first half of 2016.

101. The approach taken in this economic assessment considers the reduction in NO_2 attributable to the implementation of Clean Air Zones[30] and local measures as outlined in the UK air quality plan. As these measures will lead

[28] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/411756/COMEAP_The_evidence_for_the_effects_of_nitrogen_dioxide.pdf
[29] https://www.gov.uk/government/groups/committee-on-the-medical-effects-of-air-pollutants-comeap
[30] See Section 3.5 of the overview of the UK air quality plan for more detail on this measure

to some vehicles avoiding the Clean Air Zones, or being diverted to other roads, the change in emissions in areas outside the Clean Air Zone is also considered.

102. In summary, air pollution is associated with a range of health impacts. Changes in these are assessed as follows:

- Change in tonnage of NO_x emissions is calculated using the PCM model, and locations of this change identified
- Public exposure based on location is used to calculate health outcomes, based on the advice from the Committee on the Medical Effects of Air Pollutants;
- Health outcomes are then valued according to Defra guidance[31]

3.1.2. Greenhouse Gas Reductions

103. Increasing turnover in the fleet will reduce the average age of the vehicles and hence increase fuel efficiency. The change in fleet composition will in turn alter overall Greenhouse Gas (GHG) emissions.

104. To assess this impact, CO_2 emissions by Euro standard for the different vehicle types are obtained from the NAEI Road Transport Emission Projections for 2020. Changes in CO_2 emissions are calculated by reference to the expected fleet change occurring as a result of implementing Clean Air Zones. However, the impact on CO_2 is negligible given that some older vehicles (e.g. Euro 4 buses and coaches) emit less CO_2 than Euro 6 vehicles, and for others (e.g. Euro 3-6 LGVs) the impact is constant. While some vehicles (e.g. cars) see improvements with Euro standards, the shift away from diesel cars to petrol (which emit more CO_2 than their diesel counterparts) may lead to net increases in NO_X from cars. Overall, the sum of these impacts means CO_2 emissions experience negligible change between the baseline and policy option.

105. The implementation of signage and re-routing measures may increase mileage and therefore CO_2 emissions, and this has been quantified. The total change in CO_2 emissions in tonnes per year is then multiplied to obtain the lifetime emissions[32]. This figure is valued at the cost per tonne to get the monetised impact of the change in CO_2 emissions.

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

[32] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/360316/20141001_2014_DECC_HMT_Supplementary_Appraisal_Guidance.pdf

3.1.3. Fuel Usage

106. The total distance travelled by each vehicle is assumed to remain unaffected by Clean Air Zones. Therefore, overall there will be a reduction in fuel use as a proportion of the most fuel inefficient vehicles will be scrapped and leave the fleet, and replaced with new vehicles. This is considered a resource saving in our assessment.

107. The implementation of signage and re-routing measures will increase mileage and therefore impact fuel savings and this has been quantified. The annual distance travelled is divided by the fuel efficiency for each vehicle type, to arrive at the annual litres of fuel consumed. The fuel consumed is multiplied by the average residual life remaining for each vehicle type to get the total change.

108. The changes in fuel are then valued at DECC's projected 2025 fuel (resource) price, in order to calculate the total savings.

3.2. Costs

109. The introduction of the proposed transport measures will mean the fleet composition will change across the UK, as some owners affected upgrade to vehicles which meet the specified standards whether purchasing a new vehicle or purchasing a second hand vehicle. Most vehicles are expected to be exempt of the Clean Air Zone charge by 2020, due to natural fleet turnover. Owners of vehicles subject to a charge will have to change their behaviour through either accepting the charge or changing their driving pattern to avoid it, which will impose a social cost.

3.2.1. Welfare loss from fleet upgrade

110. The implementation of Clean Air Zones will have a welfare impact on those vehicle owners who enter a Clean Air Zone with a vehicle below the required Euro standard (as set out in table 4.1). This welfare loss is an economic concept where the consumer is being forced to "pay more" as a result of a restriction. In this case, the vehicle owner is forced to make a choice such as upgrading a vehicle early or changing their driving pattern which costs them more than before the measure was implemented. The forced increase in cost to the vehicle owner counts as a welfare loss.

- These people will have a range of options available to them:
- Avoid driving into the Clean Air Zone
- Continue and pay charge
- Redeploying vehicles subject to the charge outside the Clean Air Zone
- Purchasing a vehicle that is exempt of charge
- Retrofitting existing vehicle

111. **Avoid driving into the Clean Air Zone:** For those who avoid the Clean Air Zone, either by not taking the journey, using a different mode of transport or by driving via a diverted route, there will be an extra cost incurred (either the loss of welfare of not travelling to the destination or from taking a less preferred mode of transport, or the extra fuel costs and lost value of time of taking a diversion). It has not been possible to quantify this cost.

112. **Continue and pay charge:** For those paying the charge, there will be an extra cost every time they enter the Clean Air Zone. This will depend on how frequently drivers enter the Clean Air Zone, and what level the charge is set at. This will be determined via scoping studies. As these factors are unknown, this cost has not been quantified.

113. **Redeployment:** Some businesses and individuals which have a fleet of vehicles may be able to easily reallocate those vehicles that are subject to charge to journeys outside the Clean Air Zones, and reallocate exempt ones to travelling within the Clean Air Zone. We assume this incurs a negligible impact on welfare.

114. **Purchasing an exempt vehicle:** If redeployment is not possible, the decision to purchase a vehicle exempt from the Clean Air Zone charge would often depend on how regularly the vehicle travels within the Clean Air Zone. It will mean that for some vehicle owners paying the charge, it is the most 'economically rational' response. In the case of business owners, the extra cost they incur may be passed on to the end customer.

115. The cost (in terms of welfare loss to owners) of upgrading the fleet ('fleet adjustment cost') is estimated using the consumer surplus approach (see Box 3.1). There is an alternative 'financial cost approach' used in the sensitivity analysis (see Section 6). This method considers a wide range of non-monetised benefits implicitly e.g. the benefits of improved comfort and the wider features of a newer vehicle.

116. **Retrofitting:** The consumer surplus impact of retrofitting is accounted for as a cost to consumer estimated at £17,000 per vehicle[33]. This is because the vehicle owner does not make any gains in welfare from retrofitting their vehicle – there is no change in where vehicles can drive, compared with the baseline, and they will own the same vehicle as previously. As this cost is higher than the consumer welfare loss from upgrading to an exempt vehicle, we assume there will be no retrofitting in the market as we assume vehicle owners act rationally and wouldn't chose to pay above what was required to meet the standards. Any increase in running costs due to operating the retrofit mechanism is considered negligible in our analysis.

[33] Based on retrofitting an HGV.

Box 3.1: The consumer surplus approach

Consumer surplus approach

This method values the lost welfare to society incurred by owners who purchase a new vehicle as a result of the implementation of the charge. In the baseline, a proportion of drivers currently own vehicles which would be subject to a charge. This can be considered their preference for a specific vehicle of a particular Euro standard. However, after the implementation of the Clean Air Zone, the cost of running those vehicles increases due to the introduction of the charge. For a proportion of owners, the preferred response would be to sell this vehicle and upgrade to one which is exempt from the charge. To estimate the lost welfare of having to upgrade, the average vehicle cost of the original vehicle's Euro standard is compared to the cost of the cheapest vehicle of the Euro standard above. This is assumed to be the maximum a consumer would value their own vehicle (and associated Euro standard); as if they were willing to pay more they would already own a newer vehicle. The following costs and benefits are identified and aggregated:

- The difference in cost of purchasing the oldest vehicle in the Euro standard above
- The difference in benefit from the higher resale value of purchasing the oldest vehicle in the Euro standard above

These calculations do not value a range of other benefits of switching to the newer exempt vehicles explicitly (individual fuel savings, lower maintenance costs, better driveability etc.) but these are implicitly incorporated in the consumer surplus estimates. It is assumed that some drivers (likely those with high mileage) are indifferent between owning their current car and the newer alternative whereas other drivers (e.g. those with very low mileage) will not get any non-monetised benefits from moving to a vehicle exempt of charge– e.g. they will experience the full difference in the purchase cost less the resale value of this switch. To account for this the total is divided by two assuming that the value affected owners place on non-monetised costs are evenly distributed between these two extremes. This is then aggregated to get an overall estimate of the societal costs of having to upgrade.

In addition, if the vehicle is scrapped, the residual value of this vehicle is the consumer welfare loss. The cost of retrofitting would be accounted for as financial cost for the purposes of this assessment (however, as explained above no retrofitting is assumed, given this incurs a greater cost than upgrading).

117. Transaction costs associated with the inconvenience of searching for and procuring a new vehicle and risk around quality when buying a second hand vehicle are assumed to be negligible and have not been quantified. This is because the average rate of vehicle turnover is 4 years[34], and it is assumed that the policy will be announced with sufficient advance warning, so therefore within our modelling, drivers are assumed to would not have to switch vehicles before they would previously be upgrading. The only change in behaviour due to the policy is therefore which vehicle they a driver may choose to purchase at the point they would naturally upgrade their vehicle.

3.2.2. Loss of asset value

118. Encouraging the shift towards cleaner vehicles will reduce the value of the most polluting vehicles. Any action that incentivises such a shift will therefore result in disposal of some older vehicles. As the total stock of vehicles is not expected to increase it has been assumed that for any new vehicle entering the fleet an older vehicle will be scrapped as outlined below.

119. The link between new and old vehicles operates through the 'chain of substitution'. In this way the introduction of additional new vehicles puts immediate pressure on vehicles that are a year old; this then has a similar effect on vehicles that are two years old and all the way through to the oldest vehicles. This ripple effect ultimately reduces the value of the oldest vehicle up to the point that it is disposed of.

120. Following this logical approach, the asset value cost to society is the total value of the older vehicles that are ultimately scrapped. These vehicles have been valued at their baseline residual market value before measures were put in place.

3.2.3. Implementation costs to local authorities

121. There will be both set up and ongoing costs to deliver improvements in air quality. Such costs could include:

- Scoping studies
- Infrastructure including installation costs, running costs and IT equipment
- Ongoing communication, enforcement and staff costs.

122. Scoping studies will be essential for local authorities to determine the detailed placement of a Clean Air Zone, assess and mitigate the risk of displaced

[34] RAC (2008) Car ownership in Great Britain, http://www.racfoundation.org/assets/rac_foundation/content/downloadables/car%20ownership%20in%20great%20britain%20-%20leibling%20-%20171008%20-%20report.pdf

traffic, and determine the package of measures that are most cost effective and suitable to local conditions to deliver compliance in all cities. Scoping studies will need to address issues such as the optimal charge level that will prompt the appropriate location-specific behavioural response. They will also need to consider plans for collecting appropriate data to monitor and evaluate the effectiveness of the measures and any unintended consequences.

123. Infrastructure costs have been assessed based on similar traffic control measures. In particular it uses evidence on the implementation costs for automatic number plate recognition (ANPR). These costs are then scaled up based on population and perimeter lengths of the Clean Air Zones in question. This scaling used total population and perimeter lengths of these Clean Air Zones in question, to obtain the costs for each Clean Air Zone under assessment.

124. Finally there will be ongoing costs for the operation of the measures contained within the plan. These costs will include enforcement, running costs of equipment and staffing.

125. Local authorities will earn revenues from the charges collected, from non-compliant vehicles that continue to enter the Clean Air Zone. This revenue will offset a proportion of the running costs although there is expected to be a net cost of administering the Clean Air Zones.

4. Measures modelled for the UK air quality plan

126. The 2015 UK air quality plan sets out how the Government will fulfil its commitment to improve air quality and meet the requirements of the Ambient Air Quality Directive in the shortest possible time.

127. This section sets out the measures from the plan that have been modelled and the assumptions required to underpin both the baseline NO_2 concentration projections and plan projections.

4.1. Introduction

128. The measures contained within the plan have been assessed against a consistent baseline. This baseline reflects the impact over time of a range of measures already in place and developments on road transport and industrial sources.

129. The following are the set of measures that we have modelled against the baseline

- Clean Air Zones for road traffic emissions in specific locations
- London Ultra Low Emission Zone for road traffic emissions
- London Low Emission Zone for Non-Road Mobile Machinery
- London RE:FIT for emissions from domestic combustion
- London RE:NEW for emissions from non-domestic combustion
- Local measures in specific locations

130. The implementation of new procedures for testing of real world driving emissions has also been modelled in certain cases.

131. Not all measures can be easily incorporated into the modelling. There are a number of additional measures in the national overview and zone plan documents that are already planned by local authorities which have not been modelled but could help bring forward compliance.

4.2. Baseline projections

132. The baseline projections are based on projections of different sources and their emissions.

133. The baseline projections also take into account measures in place in the base year, ongoing planned measures, and projections of both road and non-road sources.

4.2.1. Road traffic sources

134. Traffic activity projections include:

- Traffic projections for Great Britain (GB) provided by DfT from the National Transport Model (2013)[35].
- Traffic projections for London provided by TfL (2013)[36].
- For Northern Ireland, traffic is assumed to grow at average rates for Great Britain for appropriate area types due to lack of suitable traffic projections data for Northern Ireland.

135. The uptake rates of low carbon passenger cars and LGVs with electric and hybrid electric propulsion systems were provided by DfT (2013)[37] covering sales and vehicle kilometre projections for the following technologies:

- Petrol/diesel full hybrid cars, petrol plug in hybrid cars and electric cars
- Diesel full and plug-in hybrid LGVs and electric LGVs

136. The baseline also includes the impact of announced and committed policies. These include:

- New car and new van CO_2 regulations, setting targets of 95g CO_2/km in 2020 for cars and 147g CO_2/km for vans, which are assumed to be fully met;
- The Office for Low Emission Vehicles' package of support for ULEVs, announced in 2013 including grant support for new cars and vans as well as recharging infrastructure.
- Existing tax rates not assumed to change or deviate from announced prior to spring 2015.

137. The impact of petrol hybrids on emissions was modelled based on the emission factors recently reviewed and published on the NAEI website

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[35] Traffic projections (unpublished January 2013 version) provided by the Transport Appraisal and Strategic Modelling division at the Department for Transport.
[36] Traffic flow, projected growth factors and fleet composition data for London provided by Transport for London.
[37] Vehicle sales data by vehicle technology provided by the Low Emission Vehicles team at the Department for Transport.

(Murrells and Pang, 2013)[38]. It should be noted that there were no emission factor data on diesel hybrids available at the time of the compilation of the emission inventory, so these were assumed to have the same emission factors as conventional diesel vehicles. All electric vehicle mileages are assumed to be travelled on urban roads.

138. The impact of the Green Bus Fund (GBF) is based on the information provided by DfT on the number of low carbon buses purchased through the last three rounds of GBF. The low carbon buses comprise a mixture of electric buses, hybrids and gas buses. The fourth round of GBF took place in spring 2013 and it has been estimated to fund approximately 225 low carbon buses (a mix of the same technologies as previous rounds, with the majority likely to be hybrids).

139. The impacts of EU Directives on HGV and bus emissions up to Euro VI and motorcycle emissions covering stricter emissions standards have been included.

140. The assumptions of diesel car penetration rates were based on information provided by DfT (2013)[39].

141. Specific information from TfL (2013)[40] on London bus and taxi fleets (which include age-based limit measures for taxis) in London was included. The latest fleet composition data for TfL buses include the following policies:

- 900 Euro III + Diesel Particulate Filter (DPF) buses retrofitted with Selective Catalytic Reduction (SCR)
- 1000 hybrids by end 2016, including around 645 new buses for London (NBL) which have slightly better emissions savings than a conventional hybrid[41]
- Accelerated Euro VI uptake i.e. the remaining ~500 Euro III + DPF buses will be removed early from the fleet and replaced by Euro VI by end 2015
- 200 extra conventional hybrid buses per year from 2013-2016 as agreed in the new TfL business plan commitment

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[38] NAEI data (2013) http://naei.defra.gov.uk/resources/NAEI_Emisison_factors_for_alternative_vehicle_technologies_Final_Feb_13.pdf

[39] Vehicle sales data by vehicle technology provided by the Low Emission Vehicles team at the Department for Transport.

[40] Traffic flow, projected growth factors and fleet composition data for London provided by Transport for London

[41] The actual numbers of hybrids may be greater than this, which will mean the modelling underestimates emissions reductions

142. TfL's fleet composition data for LGVs and HGVs, which includes Low Emission Zone (LEZ) phases 1, 2, 3 and 4, have also been used.

143. Further, a review of cold-start emissions for Euro 6 diesel cars and LGVs was undertaken for the updated emissions projections for road transport[42]. Cold-start emissions represent the additional emissions from vehicles at the start of journeys, when the engine and exhaust treatment equipment has not reached normal operating temperatures. The reconsideration of the cold-start penalty is based on the relative difference in cold-start excess emissions shown by Euro 1 petrol cars with three-way catalysts (TWC) relative to pre-Euro 1 cars, and then applying this relative difference to the current cold-start excess emissions for diesel cars[43]. The fact that a Selective Catalytic Reduction (SCR) system is not as effective as a TWC system was also taken into account, but the warm up time for both systems was assumed to be the same.

144. This leads to Euro 6 diesel cars and LGVs emitting lower levels of cold-start emissions than previously assumed, but still higher than assumed in COPERT4 v11 (which exclude any catalyst warm-up effects on cold-start emissions). As for all other cold-start emissions, the excess emissions are assumed to occur in urban areas where the majority of trips start.

4.2.2. Non road traffic sources

145. The emissions projections for non-road traffic sources have been calculated by the National Atmospheric Emissions Inventory (NAEI) based on the Updated Energy Projections 2013 from the Department of Energy and Climate Change[44].

146. In addition to changes in activity influencing emissions, improvements in abatement measures will also reduce emissions. The implementation of more stringent abatement measures, often the result of established legal requirements, must be considered when estimating future emissions. The relevant emission factors have been adjusted to account for this. The projections do not include the impact of additional policies and measures that are subject to review and had not yet been implemented into UK law at the time of compilation. The regulations that have been taken into account are:

- Industrial Emissions Directive
- International Convention for the Prevention of Pollution from Ships (Marpol) VI
- Sulphur Content of Liquid Fuels Regulations 2007

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[42] Updated NAEI Road Transport Projections; Scenarios 2013D to 2013F -03/03/2015
[43] Method based on NAEI expert judgement
[44] https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2013

- European Directives & UK Regulations on Non-Road Mobile Machinery

4.3. Real Driving Emissions Testing (RDE)

147. On 28 October 2015 the Technical Committee on Motor Vehicles and the Commission reached agreement on the implementation of new procedures for real driving emissions (RDE) for diesel cars. Specifically, the following agreement was reached:

- Step 1: conformity factor of 2.1 for all new model types in September 2017 and all vehicle registrations in September 2019
- Step 2: conformity factor of 1.5 for all new model types in January 2020 and all vehicle registrations in January 2021.

148. As described in Section 2, the full PCM model takes three months to run so modelling was conducted ahead of the agreement on RDE and its impact could not be included in the main model.

149. The impact of RDE was modelled using the Streamlined PCM model (see Section 2.8 for more details on this model) for a small number of locations. For the modelled Clean Air Zones, the RDE requirement will only be applicable to new models entering the fleet after the dates set out above.

4.4. Clean Air Zones

150. A Clean Air Zone is a geographically defined area where action is focussed to improve air quality. A fuller description of these Clean Air Zones is provided in Section 3.5 of the overview document.

151. Table 4.1 sets out the four classes of Clean Air Zone. These classes are defined in relation to the types of vehicles which must meet the standards specified in order to be exempt from the charge. The modelling of controls is assumed to apply in specific locations only, as discussed below.

Table 4.1 Minimum Euro standard exempt from charge by Clean Air Zone type

Clean Air Zone Class	Vehicle Type	Euro Standard
Clean Air Zone Class A	Buses and Coaches	Euro VI
Clean Air Zone Class B	Buses and Coaches	Euro VI
	Heavy Goods Vehicles	Euro VI
Clean Air Zone Class C	Buses and Coaches	Euro VI
	Heavy Goods Vehicles	Euro VI
	Petrol Light Goods Vehicles	Euro 4
	Diesel Light Goods Vehicles	Euro 6
Clean Air Zone Class D (London ULEZ)	Buses and Coaches	Euro VI
	Heavy Goods Vehicles	Euro VI
	Petrol Light Goods Vehicles	Euro 4
	Diesel Light Goods Vehicles	Euro 6
	Petrol Cars	Euro 4
	Diesel Cars	Euro 6

152. Given the lack of availability of petrol LGVs we do not assume that any diesel LGV owner subject to the charge would switch to a petrol LGV. For cars modelled as entering the London Ultra Low Emission Zone there is no strong evidence of switching behaviour, we have applied a working estimate that 75 percent of those who choose to upgrade will switch to a petrol car. We assume this as a second hand petrol car exempt from measures will be considerably cheaper than a diesel car subject to measures.

153. For the purposes of modelling, retrofitted vehicles are assumed to meet the Euro standard requirements for that vehicle type.

4.4.1. Locations of the Clean Air Zones

154. For modelling purposes, the Clean Air Zones in each area included all roads that were projected to exceed the limit values ($40\mu g/m^3$) in 2020. Each Clean Air Zone was defined based on natural boundaries such as existing roads or rivers, or based on existing local authority research where possible. The appropriateness of such boundaries would need to be verified by local authorities via scoping studies.

155. The perimeter of the Clean Air Zone for the Greater London Urban Area is assumed to be same as for the existing London Low Emission Zone[45] . The appropriateness of such boundaries would need to be verified by local authorities via scoping studies. However the approach adopted means that in most cases the modelled areas will represent the greatest likely extent of any actual Clean Air Zone.

156. Table 4.2 indicates the cities where the Clean Air Zones were modelled for this assessment.

[45] https://tfl.gov.uk/modes/driving/low-emission-zone

Table 4.2 Areas in which Clean Air Zones are applied

Zone/Agglomeration (City Clean Air Zone applied within)	Modelled Class
Greater London Urban Area (London)	2020 - D (in ULEZ)/ 2025 - C in Greater London
West Midlands Urban Area (Birmingham)	C
West Yorkshire Urban Area (Leeds)	C
East Midlands (Derby)	B
Nottingham Urban Area (Nottingham)	B
Southampton Urban Area (Southampton)	B

4.5. London

157. A number of factors make London unique, and this is discussed in Section 3.7 of the overview document. To reflect these factors the approach to London is necessarily different from other cities. A number of specific measures are already in place or planned for London (Section 5.2).

158. Additional modelling shows that with these measures London can reach compliance by 2025. The way these measures are accounted for in the modelling has been set out below.

159. Greater London also covers parts of the Eastern air quality zone because the Greater London Authority boundary does not match the boundary of the Greater London agglomeration air quality zone. Measures to address air quality within other zones that fall within the Greater London Authority boundary are included in the London measures.

4.5.1. London Ultra Low Emission Zone

160. Following a public consultation, the Mayor has confirmed the introduction of the Ultra Low Emission Zone (ULEZ) in London from 7 September 2020[46]. The basic standards of the ULEZ are the same as for a Class D Clean Air Zone. The impacts on concentrations of the ULEZ have been modelled using fleet information assumptions provided by TfL.

4.5.2. London Low Emission Zone for Non-Road Mobile Machinery

161. A new Low Emission Zone (LEZ) setting emission requirements for Non-Road Mobile Machinery (NRMM) used on construction sites came into effect in London from September 2015.

162. TfL have provided emission inventory information for NO_X emissions from NRMM in central, inner and outer London that include the impact of the NRMM LEZ. These emissions totals have been used to estimate the impact of this measure on emissions from industrial NRMM in London within the NAEI. Information on NRMM emissions in London in the absence of this measure was not available from TfL. The scaling factors for the impact of this measure as listed in Table 4.3 have been calculated by comparing the trends between 2013 and the relevant projection year in London with those in UK total emissions. This was done for all fuels within the NAEI emission projections. These were derived from the 2012 NAEI and Updated Energy Projections 2013.

Table 4.3. Scaling factors for the impact of London NRMM LEZ

	2020	2025	2030
Central	0.9166	0.8567	0.8064
Inner	0.9871	0.9148	0.8612
Outer	0.8424	0.7807	0.7349

4.5.3. London RE:NEW

163. RE:NEW is the Mayor's programme to help make London's homes more energy efficient. TfL have provided information that this measure will reduce NO_X emissions from domestic natural gas combustion in London by 1.9 percent in 2020 and by 2.2 percent in 2025 and 2030 relative to a baseline that excludes this measure. These reductions have been applied to the total for domestic combustion for all fuels within the NAEI emission inventory for London.

[46] https://tfl.gov.uk/modes/driving/ultra-low-emission-zone

4.5.4. London RE:FIT

164. RE:FIT is the Mayor's programme to help make London's public buildings more energy efficient. TfL have provided information that the impact of this measure will be to reduce NO_X emissions from non-domestic natural gas combustion in London by 0.6 percent in 2020 and by 1.1 percent in 2025 and 2030 relative to a baseline that excludes this measure. These reductions have been applied to the total for combustion in commercial, institutional and agriculture for all fuels within the NAEI to calculate an emission inventory for London.

4.6. Local measures (outside London)

165. In some areas improvements will be delivered through a combination of Clean Air Zones and other local measures or local measures alone. This section sets out how local measures have been incorporated into the compliance modelling outside of London.

166. A large number (around 6000) of additional local measures are set out in the individual zone plans. It is not possible to model the majority of these measures. Moreover, many of the local measures stated within the zone plans have not been implemented at the time of writing and could not be included. A wider discussion of assumptions including their likely impact in concentrations is included in Section 6.

167. The Streamlined PCM model was used to model the impact of signage and re-routing as the most straightforward local measure to model to reach compliance. This modelling is only illustrative of one way the Clean Air Zones can be used in combination with other measures to reach compliance. The scoping studies will be able to provide greater understanding of which measures are most suitable for each individual local authority.

168. Signage and re-routing measures can be defined as the ability to reduce congestion and increase traffic flow on busy roads. This can be achieved in many ways. In this assessment it has been modelled based on evidence from the use of Urban Traffic Management and Control (UTMC) Systems. UTMC use variable message signs to cover key transport corridors and a range of sensors (Bluetooth, ANPR and CCTV cameras) to track traffic flows.

169. It has been assumed that urban traffic re-routing will lead to 10 percent of all vehicles being diverted. This figure is a cautious estimate based on findings from two European studies[47]:

[47] Both studies are outlined in General Guidelines for Active Traffic Management Deployment. Project Title: *Best Practices and Outreach for Active Traffic Management*. Written by: Charles Levecq,

- A study on dynamic re-routing and traveller information in Copenhagen, Denmark, suggested that more travellers followed the alternative route (at least 12 percent of the time) as the displayed travel time between the original and alternate route increased. Uptake could be higher if problems/errors in display systems were resolved.
- In the Netherlands, re-routing information is displayed through full matrix dynamic message sign (DMS) that provides information for drivers. These signs are usually set at entrances of cities. Evidence indicates that after implementation on the Amsterdam ring road, congestion dropped by 25 to 33 percent. In normal conditions, it was found that 8 to 10 percent of drivers were reacting to the information.

170. Signage and re-routing measures have been modelled for Birmingham and Leeds. For both Clean Air Zones, scoping studies would enable local authorities to find the most efficient and cost effective routes to meet this target, however as an example of how this 10 percent reduction in traffic could be implemented:

- In Birmingham, the impacts of signage and re-routing on emissions from two roads in the city centre (the A4400 and A38, a total of 3.2km of exceeding road) and on the roads to which traffic is diverted, primarily the ring road have been modelled. This diversion of traffic onto the ring road will cause drivers to travel further. We have taken into consideration the risk of displaced traffic causing exceedance elsewhere and have modelled the consequential increase in traffic on the ring road to ensure this road will remain in compliance.
- In Leeds, a reduction of 10 percent of the traffic (all vehicle types) from the A58 has been modelled and added to certain sections of the A61 and the M621 with all other roads kept constant. All these road links are within the modelled Leeds Clean Air Zone. With this movement of traffic, drivers will travel further as they will take a less direct route. As a critical exceedance is on the inner ring road, we have assumed the system would need to operate more widely across the city to ensure that traffic was not diverted to cause problems elsewhere. Therefore, all additional vehicle movements occur within the modelled Clean Air Zone.

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Beverly Kuhn, and Debbie Jasek. University Transportation Center for Mobility. October 2011 (Interim Report) Project #10-01-54

5. Modelled Results

171. The results below show the projected impact of the plan on ambient air quality. Section 5.3 looks at the economic impacts of the plan.

5.1. Impacts on Concentrations

172. Table 5.1 shows the baseline projection maximum concentration of NO_X and the resulting maximum modelled concentration once the Clean Air Zone and any other necessary local measures have been introduced. With the measures modelled, all Clean Air Zones outside London will reach compliance at the latest by 2020, with London compliant by 2025. For more detailed results, please refer to the UK overview document.

Table 5.1: Modelled change in NO_2 concentration in priority areas in 2020 (2025)

City	Zone/Agglomeration	Measures Implemented	Baseline projection[48] max concentration µg /m^3	Remaining max concentration µg /m^3
Greater London	Greater London Urban Area (2025)	Type C Clean Air Zone & Local measures & RDE	48	38
Birmingham	West Midlands Urban Area	Type C Clean Air Zone & Local measures & RDE	47	39
Leeds	West Yorkshire Urban Area	Type C Clean Air Zone & Local measures & RDE	47	38
Derby	East Midlands	Type B Clean Air Zone	43	40
Nottingham	Nottingham Urban Area	Type B Clean Air Zone	42	40
Southampton	Southampton Urban Area	Type B Clean Air Zone	41	39
N/A	South Wales	RDE	41	40

[48] Baseline projections are also presented in the overview document in 'Summary of 2013 exceedance of NO_2 limit values and projected dates of compliance' table

5.2. Proposed London measures

173. Transport for London provided emissions information to allow assessment of proposed measures which are otherwise difficult to include in the model. This was used to assess their comparability with those modelled using the PCM model. The primary differences this analysis allowed us to consider are:

- Inclusion of further Zero Emission Capable (ZEC) taxis by 2025; and
- Not implementing further restrictions on light goods vehicles.

174. It is noted that this comparison does not reflect any potential additional NO_x savings from increased enforcement of controls on Non-Road Mobile Machinery (NRMM).

175. In 2025, with the ULEZ and a HGV Clean Air Zone applied, there are just 3 roads remaining above 40µg/m^3. These are all around central London, where taxis contribute a greater proportion of road transport NO_X emissions than at a London-wide level.

176. From 2018 new London taxis will be required to be zero emission capable During scenario testing for the ULEZ, a dispersion model was run to include a ZEC uptake of 79 percent in 2025 (66 percent was modelled for this technical report). This modelling was completed using King's College's London Air Quality Toolkit. This is the same model used for the air quality modelling of the London Atmospheric Emission Inventory (LAEI) and Mayor's Air Quality Strategy (MAQS).

177. This modelling demonstrates that additional ZEC taxi uptake would deliver a similar or greater reduction in concentrations at these locations to create the same compliance outcome in 2025 as a Clean Air Zone including light goods vehicles. The results of these two packages are summarised in table 5.2 below.

Table 5.2: Comparison of modelled Clean Air Zone to GLA London measures

		Van restrictions	ZEC modelling
Road Name	**Road Number**	**Change (µg/m^3)**	**Change (µg/m^3)**
Hammersmith Flyover	A4	-0.8	-0.6
Marylebone Road	A501	-0.3	-1.6
Harrow Road	A4206	-0.8	-2.3
West Way	A40	-0.8	-2.1

5.3. Economic Impact Assessment

178. This section outlines the societal costs and benefits of the modelled measures in the UK air quality plan. These were calculated according to the methodology outlined in Section 3 and Annex D. A summary of the different monetised impacts is contained in Table 5.3 below.

Table 5.3: Estimated impacts of measures (£m, real 2015 prices)

Impact	£million
Benefits	
Health impacts of NO_X reduction inside Zones	2,197.3
Health impacts of NO_X reduction outside Zones	1,435.4
GHG Reduction	393.3
Resource savings from improved fuel efficiency	156.6
Total Benefits (PV)	**4,182.7**
Costs	
Welfare loss from fleet upgrade	-1,062.6
Loss of asset value	-133.4
Implementation costs to local authorities	-58.0[49]
Total Cost (PV)	**-1,254.0**
Net Present Value	**2,928.7**

179. As shown above the health benefits of introducing Clean Air Zones in the cities predicted to exceed limit values in 2020 would deliver a social benefit of £3.6 billion via NO_X emissions reductions. This action would also impose a cost on the users of those vehicles of around £1.2 billion via welfare cost of upgrading and lost value of scrapped vehicles.

180. There are a number of uncertainties which mean that the range of values for quantified impacts can vary significantly depending on the assumptions applied. Section 6 lays out the quantified effect in varying assumptions on the cost of fleet adjustment vehicles and the health impact of NO_2 . There is a range of other factors, detailed in Section 6.5, which are not reflected in this analysis.

[49] This cost is based on a 10 year period going beyond the current spending review

5.4. Distributional impacts

181. This section considers which groups would benefit from improved air quality and how users of different groups might be affected by transport measures based on the ownership profile of different vehicle types. The following section focuses more closely on how businesses may be impacted in terms of costs.

182. Improvements in air quality would benefit those who are more vulnerable to air pollution or who live in areas where there is particularly high air pollution: poor air quality has a disproportionate effect on specific groups: in particular age, income and ethnicity. In children, it can affect lung development and increase likelihood of developing asthma[50]. Adverse health impacts are experienced more commonly by people with pre-existing health conditions such as heart and lung disease; thus older people, being more likely to have an existing medical condition than those in other age groups, are disproportionately impacted[51].

183. Air pollution is also distributed unevenly, with urban areas tending to have higher concentrations of most pollutants. Such areas also contain a disproportionately high proportion of a number of deprived areas and residents with low incomes and from Black and Minority Ethnic (BME) groups[52].

184. The local bus service market is relatively concentrated, with the five largest operators (FirstGroup, Stagecoach, Arriva, Go-Ahead and National Express) having a market share of 71% in 2008/09[53]. If not absorbed by the bus operator, any costs incurred by bus companies could be passed on to its customers, offset through a less frequent or lower quality service or absorbed by the bus operators. Buses are disproportionately used by lower income groups; young adults (17-20 year olds); and single adult households, both with and without children[54].

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[50] Gehring et al (2013) 'Air Pollution Exposure and Lung Function in Children: The ESCAPE Project'
[51] WHO (2013) 'Review of evidence on health aspects of air pollution – REVIHAAP Project' http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/review-of-evidence-on-health-aspects-of-air-pollution-revihaap-project-final-technical-report
[52] Air Quality and Social Deprivation in the UK: an environmental inequalities analysis, 2006 http://uk-air.defra.gov.uk/reports/cat09/0701110944_AQinequalitiesFNL_AEAT_0506.pdf ; and Fecht et al (2014) 'Associations between air pollution and socioeconomic characteristics, ethnicity and age profile of neighbourhoods in England and the Netherland' http://dx.doi.org/10.1016/j.envpol.2014.12.014
[53] http://webarchive.nationalarchives.gov.uk/+/http:/www.competition-commission.org.uk/inquiries/ref2010/localbus/pdf/00_sections_1_15.pdf
[54] Department for Transport National Travel Survey 2013 data tables www.gov.uk/government/collections/national-travel-survey-statistics

185. For operators of small HGV fleets, and single owner-operators, transport measures requiring them to upgrade their vehicle could pose a significant cash flow problem and could lead to an increase in retail prices of the goods they carry. It has not been possible to definitively determine fleet ownership of HGVs; however, West Midlands regional data provided by VOSA shows that 16 percent of HGVs registered in the area are in fleets of just one or two vehicles.

186. Van ownership is very fragmented, especially for older vehicles, which tend to be privately owned. Any actions that target older vans will mostly impact small businesses. Providing a service (involving carriage of equipment) was the most common use of vans reported in the DfT van activity survey 2009[55]; this would include work such as plumbers, builders and plasterers.

187. The impact of any action that targets the existing fleet of cars is likely to fall mainly on private owners. Just over half of new car registrations (54 percent) were made by companies but fewer than ten percent of the whole licensed car stock were company cars (8.6 percent) in 2014[56]. This suggests that cars tend to transition quickly from the company to private market. Private ownership of cars is not distributed evenly by income:

- Lower income groups tend to have marginally older vehicles. 71 percent of household cars in the lowest income quintile are over 6 years old, compared to 50 percent in the highest income quintile.
- Number of trips by car increases with income with the highest income quintile undertaking almost twice the number of journeys of the lowest quintile.
- Proportions of diesel cars are fairly close for all income groups. The middle income group is least likely to own diesel. Overall, around 3 in 10 households own a diesel car.

5.5. Direct costs and benefits to business

188. The enforcement of higher vehicle emission standards will lead to additional costs to businesses, primarily, through the cost of adjusting their fleet to meet the higher emission standards.

189. Some businesses may be able to meet the higher emission requirements by redeploying their existing fleet to a different area. However, where redeployment is not an option, the biggest impact on businesses will

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[55] Van Activity Baseline Survey for England 2008
http://webarchive.nationalarchives.gov.uk/20091003144302/http://www.dft.gov.uk/pgr/statistics/datatablespublications/freight/vanactivitybaseline08/vabs08.pdf

[56] Department for Transport (2015), Vehicle Licensing Statistics Quarter 4 (Oct - Dec)
www.gov.uk/government/uploads/system/uploads/attachment_data/file/421337/vls-2014.pdf

materialise through the need to replace vehicles which do not meet the standards with those that do.

190. The specific impact on individual businesses will depend on fleet composition, in terms of the age and type of vehicles. The impact within the Fleet Adjustment model is calculated for each vehicle type. The overall business costs have been assessed, using the following compositions of business owned and household owned vehicles for each type:

- Cars: Cars are affected in the London Ultra Low Emission Zone which is modelled as a Class D Clean Air Zone. Company registered cars represent 8.6 percent of the total car fleet. It is therefore assumed that an equal proportion of the total cost of upgrading will fall on businesses, which is around £51m (£5m of this is lost asset cost from scrappage). This is likely to be an overestimate, as businesses tend to own newer vehicles (54 percent of all car first registrations were made by companies in 2014). They are therefore less likely to incur costs of upgrading. Businesses are also likely to redeploy cars, which would lower the costs, however this has not been considered here.
- LGVs: DfT data shows LGV ownership is closely split between privately owned (52 percent) and company-registered vans (48 percent). However, the data also shows that the majority of privately owned vans are chiefly used for business purposes. Given this, it is assumed that the full cost of upgrading LGVs that do not meet the standards falls on businesses. This approach may lead to a slight overestimation of the costs to businesses.
- HGVs, buses and coaches: It is assumed all such vehicles are owned by businesses and the full fleet adjustment cost of this category of vehicle is therefore included in the fleet adjustment cost for businesses.

191. See Box 3.1 for details on the consumer surplus approach, which has been used to calculate the cost impact on households and businesses of upgrading the fleet.

192. The consumer welfare losses that businesses are expected to incur occur mainly due to the need to upgrade their vehicles as a result of the assessed measure. This covers both the cost of replacing current vehicle and the lost value of those vehicles which are scrapped, alongside the benefits from owning a newer vehicle. Overall, businesses are expected to incur approximately 43 percent (£455m) of the total fleet adjustment cost (£1bn).

6. Sensitivities and uncertainties

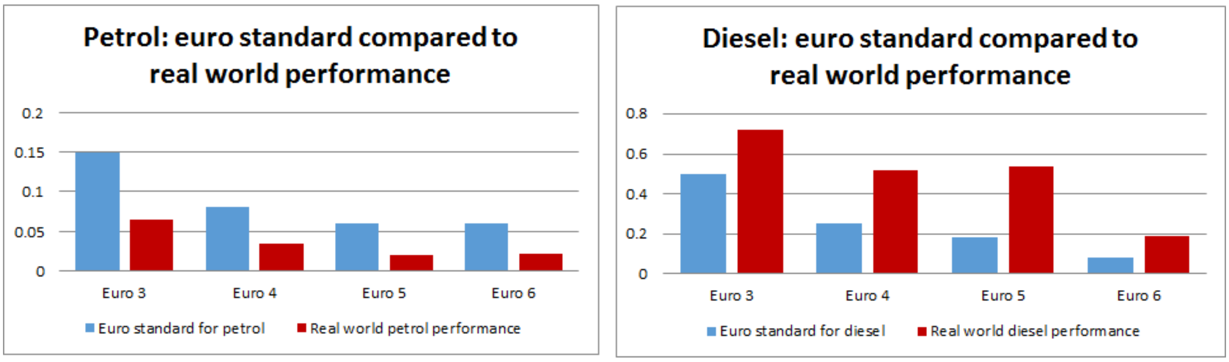
193. The modelling carried out to estimate the impacts of the proposed air quality measures is complex. It takes account of a wide range of variable factors that can affect the overall impact of the UK air quality plan. Inputs and assumptions in the model have been informed by the best available evidence, based on existing data, findings from existing studies, and expert judgement. There is therefore an inherent level of uncertainty associated with these estimates

194. This section sets out some of these inputs and assumptions and discusses both their uncertainties and the effect that this could have on our estimated impacts. Where possible, sensitivity analysis[57] has been carried out (Sections 6.1-6.4) where it was not possible to quantify the impact, these have been qualitatively described.

6.1. Performance of vehicle emissions standards

195. In the past, vehicle performance and emissions in the real world have not corresponded with those measured in European test cycles. This has resulted in NO_X emissions of diesel cars in actual driving conditions being significantly higher than the European standards would suggest, as demonstrated in Figure 6.1

Figure 6.1: Car Euro Standard Compared to Real World Performance. Source: COPERT 4v11 (2014)



196. Whilst emerging data indicates that the real world performance of vehicles is growing closer to European test cycle results, there is still some disparity. The road transport emissions used to inform our analysis are based on the latest data on vehicle NO_X emissions (COPERT 4v11). These COPERT emission factors do include an assessment of non-conformity to account for

57 Sensitivity analysis is used to test the vulnerability of options to unavoidable future uncertainties.

disparity, however, recent evidence from Portable Emissions Measurement System (PEMS) data based on a limited number of Euro 6 diesel passenger cars has indicated that the current COPERT data may underestimate emissions for some vehicles.

197. In order to assess how this disparity may affect our projections, an alternative scenario has been modelled, based assuming emissions to be higher than currently predicted.

198. The results of this modelling are presented in table 6.1. This shows that if emissions from Euro 6 vehicles were higher in reality than expected in our modelling, it could result in up to 22 additional zones being in exceedance of the NO_2 limit values in 2020. This demonstrates the significant impact that performance of emissions standards can have on efforts to reduce NO_2 concentrations.

199. It has not been possible to consider the effect of the future implementation of RDE (as outlined in Section 2) into this alternative scenario. The introduction of RDE is likely to reduce the number of zones which would exceed the limit values in this scenario.

Table 6.1: Number of zones meeting the limit values for NO_2 with different emissions standards performance

	Central estimate of Euro 6 emission standards	If Euro 6 emissions standards do not perform as modelled[1]	Difference
Number of zones meeting the limit value in 2020	35	13	22
Number of zones not meeting the limit value in 2020	8	30	
Total number of zones	43		

[1] Not performing is modelled here with real world emissions 5 times the estimated test emissions.

6.2. Health Impacts of NO_2

200. As stated in Section 3, the quantification of health impacts is based on epidemiological studies which investigate statistical associations between NO_2 concentrations and mortality risk, usually using outdoor air pollution. The studies usually use outdoor air pollution concentrations at the residential addresses as a proxy for personal exposure.

201. The change in mortality associated with exposure to NO_2 concentrations has been valued in our economic assessment (see Section 5.3). However, other

costs including from short-term health impacts on hospital admissions and other health care costs have not been assessed. This is likely to lead to an underestimate of the benefits of reducing NO_2 concentrations.

202. COMEAP noted that as there is no clear evidence for a threshold effect from exposure to NO_2. Therefore in the modelling it has been assumed that mortality and NO_2 exposure change in a linear manner. If there were a threshold effect this would not be expected to have a major impact as the reductions in concentrations are focused on populations with higher exposures.

203. Importantly there is additional uncertainty in assessing the mortality impacts of measures that only reduce NO_2 concentrations, against actions which reduce the whole mix of air pollutants. This is because of both the uncertainty around causality between NO_2 and mortality and the potential overlap between the health effects between PM and NO_2.

204. To reflect the range of the current evidence, the central coefficient (2.5 percent) has been compared against the range of coefficients as recommended by COMEAP (1 and 4 percent). Table 6.2 shows the results of this comparison. Using COMEAP's lowest coefficient of 1 percent, the benefits of reducing NO_2 are 60 percent lower than the central estimate. The maximum coefficient leads to estimated benefits that are 65 percent higher than the central estimate.

Table 6.2: Monetised health benefits of reduction in NO_2 from proposed measures

NO_2 Impact (£million)	
Central	3,634
High	5,876
Low	1,453

6.3. Health Impacts of PM

205. There is likely to be substantial overlap between the mortality impacts of $PM_{2.5}$ and NO_2 concentrations when single pollutant models are used in the same analysis. To address this point the health impacts of changes in exposure to PM have been excluded entirely in the central scenario. However, the potential additional benefit of PM reduction is quantified below. This is the extreme scenario assuming no overlap exists between the two pollutants.

Table 6.3: Monetised health benefits of reduction in PM from proposed measures

PM Impact (£million)	
Central	0

High	347

6.4. Fleet adjustment costs

206. In order to explore any sensitivity in our initial assessment of the financial cost of upgrading from a vehicle that does not meet the Clean Air Zone standard to one that does, this cost has been assessed using an alternative approach (see box 6.1). Under both methodologies there will be a cost to vehicle owners who choose to purchase a new vehicle to avoid paying a charge to enter the Clean Air Zone. Costs and benefits valued in this methodology are the following:

- The extra cost of purchasing a vehicle that would not be subject to a Clean Air Zone charge (i.e. the cheapest second hand vehicle that meets requirements)
- The benefit gained by selling your alternative vehicle (residual value)
- The benefit of the improved characteristics of a vehicle that is not subject to the charge (e.g. fuel savings)

BOX 6.1: The financial cost approach

This method considers the full financial cost of the vehicle that the affected owner pays if they chose to upgrade to a vehicle exempt from the charge.

As with the previous approach, in the baseline vehicle owners demonstrate a preference for certain types of vehicles. If a Clean Air Zone was implemented some of these would be subject to a charge. Vehicle owners now facing this extra cost may choose to upgrade to an exempt vehicle to avoid the charge. To do this, they will need to pay the market value of the vehicle. It is assumed the consumer would pick the cheapest exempt alternative, in order to avoid unnecessary costs. This method calculates the full financial cost of the new vehicle.

It is assumed the consumer will sell their current vehicle to drivers unaffected by the Zone and receive the market (residual) value to partially offset the cost of the new vehicle, unless the current vehicle is scrapped or they choose to retrofit. The net impact of these two factors gives the upfront financial cost. This is then adjusted to account for the improved fuel efficiency of the newer vehicle. The fuel savings are quantified and valued as a resource cost.

The non-monetised benefits of owning a newer vehicle are not accounted for in this methodology. Most importantly this approach does not account for the cost of the vehicle that would have been purchased in the absence of air quality measures.

207. This method does not account for the opportunity cost of that investment[58] for vehicle owners and ignores the non-monetised benefit you get from owning a newer vehicle such as potential additional vehicle features. These characteristics are incorporated in the consumer surplus approach, as outlined in Box 3.1

208. If a vehicle is scrapped, the cost of the cheapest vehicle exempt from the charge is the cost that those choosing to upgrade will incur (as the owner receives no residual value for their vehicle).

209. The cost of retrofitting is accounted for as the entire financial cost. While there may be an increase in running costs of retrofitted vehicles, these are considered to be negligible.

210. The results of this methodology are outlined in Table 6.4. This approach does not estimate the positive impact on owners who operate outside the Clean Air Zones. These owners will be able to purchase vehicles which do not meet Clean Air Zone standards at a lower price, and sell vehicles exempt from a Clean Air Zone charge for a higher price to those drivers who do enter the Zones.

211. The table below compares the different cost methodology results. Our central approach shows a cost of £1bn whereas when considering the financial costs only there is a cost of £9bn. This is because none of the non-monetised benefits nor the costs of the alternative vehicle purchased in the baseline are considered in this approach. As a result this alternative approach is not as useful for economic analysis, though is useful to demonstrate what the lifetime costs of exempt vehicles will be.

Table 6.4: Sensitivity analysis around the Consumer Fleet Adjustment Costs

Table 6.4. Fleet adjustment cost (£million)	
Central- Consumer Surplus approach	1,063
Alternative Model- Financial Cost approach	6,157

6.5. Non-quantified sensitivities and uncertainties

212. The previous sub-sections in Section 6 set out and attempt to quantify the key uncertainties around the impact of the air quality plans. Tables 6.5 and 6.6 provide an overview of a range of other relevant assumptions and associated uncertainties that it has not been possible to quantify.

[58] By purchasing an exempt vehicle, the owner will have lost the opportunity to purchase the vehicle of their choice (i.e. there will be an opportunity cost of the change in vehicle). This is the cost of upgrading over and above the cost of the vehicle they would have upgraded to in the absence of the policy (including interest that would have accrued from any alternative investment).

Table 6.5: Assumptions and associated uncertainties around NO_2 benefits

Assumption	Associated uncertainty
The implementation of Real Driving Emissions (RDE) has been modelled for a few specific Clean Air Zone s, as detailed in Section 2.	If RDE were modelled for the rest of the UK, it is likely that overall emissions would be lower, as demonstrated in the modelled Clean Air Zones.
The model assumes that the fraction of NO_X emitted from vehicles as NO_2 remains constant over time.	Previous abatement measures have resulted in an increase in the proportion of NO_X emitted as NO_2. Our modelling may therefore overestimate reductions in NO_2 concentrations from this perspective.
Lack of robust studies on actual behavioural responses to Clean Air Zone-type measures means this assumption is based on assessment of the number of vehicles available and expert judgement on people's and businesses' responses.	Depending on how people and businesses behave in response to measures, there could be a larger or smaller change in NO_2 concentrations compared to the modelling predictions.
The Clean Air Zone delivers a 90 percent reduction in the distance travelled within the zone by vehicles that would otherwise be subject to a charge for HGVs, LGVs and cars; and a 100 percent reduction in the buses and coaches.	In reality, there may be a higher or lower proportion of vehicles subject to a charge that continue to enter the Clean Air Zone. This would alter that the estimated reduction in NO_2 concentrations although it is not possible to assess the direction or scale.
Some local measures have been modelled by the Streamlined PCM model, which slightly overestimates reductions in concentrations of NO_2 compared to the full PCM model as background concentrations are not taken into account.	In the case of measures which simply divert traffic to a nearby area, emissions from these vehicles could therefore result in smaller reductions in NO_2 concentrations than the streamlined PCM modelling predicts, due to the potential presence of higher background concentrations.
Some local measures have not been included in the modelling.	There are a large number of additional measures in the national overview and zone plan documents that are already planned by local authorities which could not be modelled but may lead to greater NO_2 reductions that in our analysis, and potentially more quickly (particularly if those measures impact NO_2 concentrations of non-compliant roads)

Evidence on Urban Traffic Management and Control (UTMC) systems are used to inform assumptions on potential impacts of signage and rerouting. It is assumed these divert 10% of the vehicles to other roads given this evidence.	These studies consider the impacts of UTMC when applied to congestion, and are not based on air quality directly. This may have implications for the efficacy of signage and re-routing in cases where journey time is not reduced.
The modelling assumes that the number of trips and distance travelled by those who purchase new vehicles will not change from how frequently and far they travelled with their older vehicle.	Owners of newer vehicles in general drive them more often or further than older vehicles. If purchasing new vehicles results in their owners driving more, then the predicted reduction in NO_2 concentrations would be overstated.
While the modelling takes into account DfT fleet change projections, local growth conditions have not been considered in the modelling.	Areas may experience economic growth which could increase traffic and congestion. This is not taken into account in the analysis.

Table 6.6: Assumptions and associated uncertainties around impacts

Assumption	Associated uncertainty
DfT GPS Journey information has been used to identify the number of unique vehicles that are likely to enter different networks of Clean Air Zones. This tracks a sample of around 160,000 vehicles travelling around the UK, and identifies where they enter multiple cities. This dataset has been combined with data from the London LEZ, which identifies the total number of unique vehicles entering London in a year.	The sample of vehicles in the GPS sample is not derived statistically, and may be biased towards newer vehicles. Therefore, the sample may overestimate the number of unique vehicles entering Clean Air Zones. Reduced vehicle numbers entering Clean Air Zones would reduce both costs and benefits of measures compared with our calculations.
Only the mortality impacts of exposure to NO_2 have been quantified and valued.	The morbidity impact of exposure to NO_2 would be expected to increase the overall health impact. However without direct quantitative links it is not possible to assess the scale of this potential gap.

Fuel consumption data is only available for cars and diesel LGVs. There is no data available for other vehicle types so it is assumed that there are no improvements in fuel efficiency for these vehicles.	We expect that newer vehicles experience greater improvements in fuel efficiency and savings in CO_2.
The provisional Clean Air Zone perimeters used in the modelling were based on the inclusion of areas in exceedance of the 40 ug/m^3 limit, and following realistic and easily identifiable existing boundaries.	This may mean the perimeters of the Clean Air Zones change considerably compared to the modelled version, which would have an impact on infrastructure costs, and also number of vehicles, and population affected.
Maintenance and upkeep costs of existing vehicles are not accounted for in the costings analysis.	Given limited data on maintenance and insurance costs, changes in these factors have not been considered in the calculations.
The second hand value of vehicles is based upon depreciation rates of the most popular cars and vans. All depreciation rates are contained in Annex D.	There is uncertainty around the actual depreciation rates of vehicles, which generates uncertainty on the cost of purchasing second hand vehicles. This means that more or fewer second hand vehicles may be purchased than expected.
Consumers are assumed to be 'economically rational'. It is also assumed that consumers on average replace their vehicles every four years, and the introduction of Clean Air Zones is announced four years before implementation, therefore consumers will not experience any additional transaction costs.	Removing these assumptions may mean costs of upgrading may be greater than modelled.

Annex A- Baseline NO_X and NO_2 projections for 2020, 2025 and 2030

1. NO_X emissions

1.1. Introduction

213. Emissions projections are available from the National Atmospheric Emissions Inventory (NAEI) for 2020, 2025 and 2030. These projections have been calculated from an emission inventory base year of 2012. The projections split by emission source sector are illustrated in Figure A.1. Table A.1 provides a more detailed description of the coding used for each sector. The values for intermediate years shown in this figure have been calculated by interpolation i.e. by extending the trend between the years for which emissions estimates are available (2012, 2015, 2020, 2025 and 2030).

Figure A.1. Total UK NO_X emissions for 2012 and emissions projections up to 2030 by source sector for point and area sources from NAEI 2012

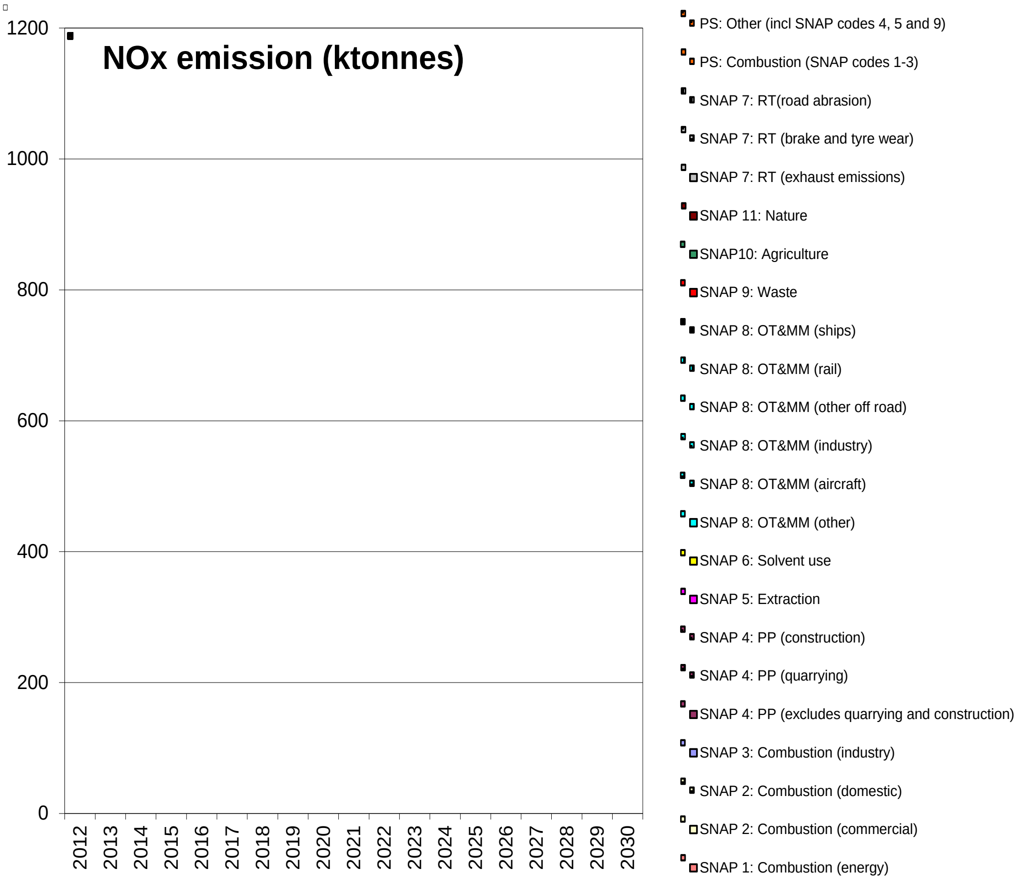


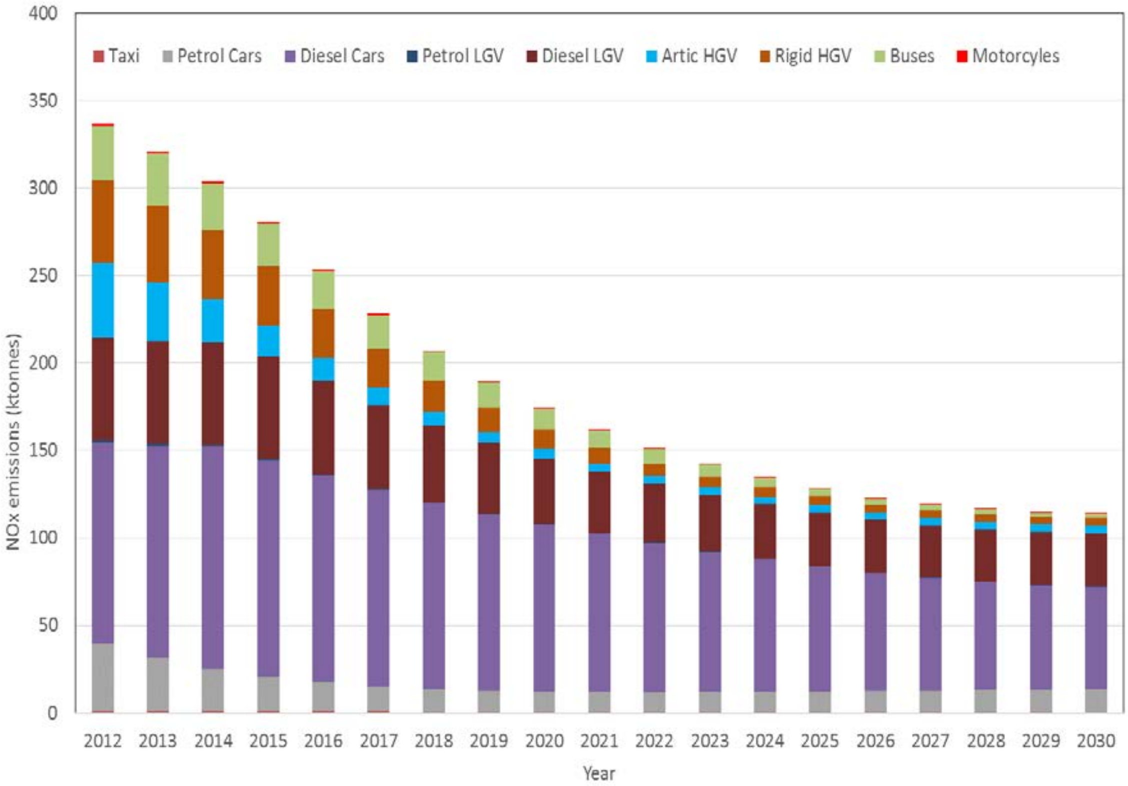
Table A.1 - Description of Standardised Nomenclature for Air Pollutants (SNAP) sector coding

Short code	Description
SNAP 1: Combustion (energy)	SNAP 1: Combustion in energy production & transformation
SNAP 2: Combustion (commercial)	SNAP 2: Combustion in commercial, institutional & residential & agriculture (excludes domestic)
SNAP 2: Combustion (domestic)	SNAP 2: Combustion in commercial, institutional & residential & agriculture (domestic only)
SNAP 3: Combustion (industry)	SNAP 3: Combustion in industry
SNAP 4: PP (excludes quarrying and construction)	SNAP 4: Production processes (excludes quarrying and construction)
SNAP 4: PP (quarrying)	SNAP 4: Production processes (quarrying)
SNAP 4: PP (construction)	SNAP 4: Production processes (construction)
SNAP 5: Extraction	SNAP 5: Extraction & distribution of fossil fuels
SNAP 6: Solvent use	SNAP 6: Solvent use
SNAP 8: OT&MM (other)	SNAP 8: Other Transport & mobile machinery (other)
SNAP 8: OT&MM (aircraft)	SNAP 8: Other Transport & mobile machinery (aircraft)
SNAP 8: OT&MM (industry)	SNAP 8: Other Transport & mobile machinery (industry off road mobile machinery)
SNAP 8: OT&MM (other off road)	SNAP 8: Other Transport & mobile machinery (other off road mobile machinery)
SNAP 8: OT&MM (rail)	SNAP 8: Other Transport & mobile machinery (rail)
SNAP 8: OT&MM (ships)	SNAP 8: Other Transport & mobile machinery (ships)
SNAP 9: Waste	SNAP 9: Waste treatment and disposal
SNAP10: Agriculture	SNAP10: Agriculture forestry & land use change
SNAP 11: Nature	SNAP 11: Nature
SNAP 7: RT (exhaust emissions)	SNAP 7: Road transport (exhaust emissions)
SNAP 7: RT (brake and tyre wear)	SNAP 7: Road transport (brake and tyre wear)
SNAP 7: RT(road abrasion)	SNAP 7: Road transport (road abrasion)
Point source: Combustion (SNAP codes 1-3)	Combustion point sources (SNAP codes 1-3)
Point Source: Other (incl SNAP codes 4, 5 and 9)	Other point sources (including SNAP codes 4, 5 and 9)

1.2. Road traffic sources

214. Figure A.2 shows the projections for UK total road traffic NO_X emissions split by vehicle type and fuel. The largest contributions are from diesel cars and diesel LGV.

Figure A.2 Total UK road traffic NO_X emissions projections to 2030



215. The original 2013 compliance assessment (submitted in September 2014) used an earlier set of road transport emissions projections for NO_X, which was based on COPERT 4 v10 emission factors[59]. The release of COPERT 4 v10 was to provide 'representative' NO_X emission factors for Euro 5 diesel cars, in response to their known exceedance of NO_X emission limits in real-world driving COPERT 4v10 provided interim emission factor estimates while awaiting results from emissions measurements of Euro 5 vehicles that were being co-ordinated in the framework of the European Research Group on Mobile Emissions (ERMES) activity at the time.

[59] COPERT 4 v10.0 released in November 2012 and the accompanying report "Description of new elements in COPERT 4 v10.0" can be downloaded at http://emisia.com/sites/default/files/COPERT4_v10_0.pdf

216. Updated emission factors for road transport have since become available from COPERT 4v11[60]. These updated emission factors have been used in the revised reference year calculation for 2013 and in the projections for future years for the 2015 NO_2 air quality plan.

217. The release of COPERT 4 v11 provides updated emission factors for Euro 5/V and Euro 6/VI for cars, LGVs, HGVs and buses/coaches. These updated factors are based on further emissions data collected under ERMES, including real-world tests on around 20 early generation Euro 6 diesel cars. It should be noted that the factors for Euro 6 may potentially be biased by samples, including premium class models, performing potentially better than the fleet average.

218. COPERT 4v11 also provides emission factors for the second stage of Euro 6 vehicles, referred to as Euro 6d, based on a prognosis of the likely technological approaches required to conform to the real-world test procedures to be introduced for this standard. Euro 6d vehicles will be subject to more stringent test procedures to ensure exhaust control systems perform under a broad range of different operating conditions (although the exact test procedure and implementation timing was still under discussion at the time of the compilation of the emissions projections). The impact of the Euro 6d standards has not been included in the baseline projections modelling for the 2015 plan, due to the uncertainties surrounding the exact specification and timing of these standards at the time that the baseline projections modelling was carried out (spring 2015). Following the new Real Driving Emissions (RDE) announcement in October 2015, a separate model assessment was conducted using a streamlined version of the PCM model (see Section 2.8 of the Technical Report).

219. The information on and assumptions for fleet composition included in the baseline projections are outlined in Section 4.2 of the Technical Report.

[60] COPERT 4 v11.0 released in September 2014 and the accompanying report “Update of the Air Emissions Inventory Guidebook – Road Transport 2014 Update” can be downloaded at http://www.emisia.com/sites/default/files/files/COPERT4_v11_0.pdf and emission factors are provided directly via personal communication.

2. The PCM model for baseline NO_X projections

2.1. Introduction

220. The 2013 reference year model has been used to calculate the baseline NO_X concentration projections for 2020, 2025 and 2030 to provide the information required to develop the air quality plan. Meteorological data for 2013 was used for each projections year, along with emissions projections for the relevant year. Thus the weather in each projection year was assumed to be the same as in the reference year, but the expected changes in emissions (based on NAEI emissions projections) for each projection year were taken into account.

2.2. Road traffic sources

221. The emissions from road traffic sources have been mapped in detail for each projection year. These projections incorporate activity projections for each vehicle type in each of nine former Government Office Regions in England and projections for Scotland, Wales and Northern Ireland. The emissions for each of the individual major road links have been calculated for the projection years based on the:

- 2012 traffic counts for each vehicle type
- Traffic activity projections in the projection year for each vehicle type and fuel for the relevant region
- The fleet weighted emission factor in the projection year for the vehicle type and fuel.

222. The contributions from emissions from traffic on minor roads and from cold-starts were then added in order to calculate the total road traffic emissions for each of the 1 km x 1 km grid squares across the UK. The emissions projections for road traffic NO_X emissions are based on COPERT 4v11 and include the expected impact of Euro 6 standards for diesel cars and LGVs, but do not include the impact of Euro 6d standards for these vehicles. The impact of the Euro 6d standards have not been included due to the uncertainties surrounding the exact specification and timing of these standards at the time that the baseline projections modelling was carried out (spring 2015).

2.3. Non-road traffic area sources

223. The emissions for non-road area sources have been projected forwards from the 2012 emissions maps for each source and activity combination. Thus the

spatial distribution for each source and activity combination in the projection year is assumed to be the same as for that sector in 2012.

2.4. Point sources

224. The emissions estimates for each point source for the projection years were estimated by scaling the 2012 emissions estimates. Scaling factors were derived for each individual source code. Thus the proportional change in emissions for each plant within the same source code (such as iron and steel - combustion plant or incineration) were assumed to be the same. Plants that are expected to close during the period covered by the projections were specifically omitted from the point source projections for the years after the expected closure date.

2.5. Regional background

225. The maps of regional NO_X concentrations for the projection years have been calculated from the 2013 map of regional background concentrations. The 2013 map has been split into three components:

- Regional NO_X concentration from UK sources
- Regional NO_X concentration from non-UK European sources
- Regional NO_X concentration from maritime sources

226. This source apportionment has been carried out using projected 2010 concentrations from European Monitoring and Evaluation Programme (EMEP) grids (Tim Oxley pers. comm., 2006) for these sources. The contribution from UK sources has been scaled forward according to the NAEI projections of total UK NO_X emissions. The contribution from EU sources has been scaled forward according to the International Institute for Applied Systems Analysis (IIASA) projections compiled for the European Commission's Thematic Strategy on Air Pollution (TSAP) 2014 for a Current Legislation (CLE) scenario for the EU27 (less the emissions estimate for the UK)[61]. The contribution from maritime sources has been scaled forward using emissions projections for shipping from VITO, which were also compiled for TSAP 2014[62].

[61] from report TSAP #14 table 3.1 http://www.iiasa.ac.at/web/home/research/researchPrograms/MitigationofAirPollutionandGreenhousegases/TSAP-reports.en.html

[62] http://www.iiasa.ac.at/web/home/research/researchPrograms/MitigationofAirPollutionandGreenhousegases/Final_Report_VITO_International_Shipping-main-16042013.pdf

3. The PCM model for baseline NO_2 projections

227. The 2013 reference year PCM model has been used to calculate the baseline NO_2 concentration projections for 2020, 2025 and 2030. The primary NO_2 emission fraction, f-NO_2, has been recalculated for each road link for the projection years based on the NO_X emissions and a fleet weighted f-NO_2 value for the relevant year for each vehicle type and fuel. The trends in f-NO_2 by vehicle type and fuel are presented in Annex C.

228. The regional oxidant concentration has been assumed to remain unchanged from the 2013 value in the projection years on the basis of projections presented by Derwent et al[63]. An analysis of trends in background ozone concentrations at Mace Head in Ireland also suggests that there has been little change in concentration since about 2000[64].

[63] Derwent, R.G., Simmonds, P.G., O‟Doherty, S., Stevenson, D.S., Collins, W.J., Sanderson, M.G., Johnson, C.E., Dentener, F., Cofala, J., Mechler, R. and Amann, M. (2005). External influences on Europe‟s air quality: baseline methane, carbon monoxide and ozone from 1999 to 2030 at Mace Head, Ireland. Atmospheric Environment, 40, 844-855. doi:10.1016/j.atmosenv.2005.09.077
[64] Air Quality Expert Group. Ozone in the United Kingdom (2009): http://archive.defra.gov.uk/environment/quality/air/airquality/publications/ozone/documents/aqeg-ozone-report.pdf

Annex B- The PCM Roads Kernel Model

1. Description of the model

229. The Pollution Climate Mapping Roads Kernel Model (PCM-RKM) has been set up to calculate roadside concentrations of NO_2, NO_x, PM_{10}, $PM_{2.5}$ and benzene on urban major roads. The model uses the Atmospheric Dispersion Modelling System (ADMS) Roads dispersion model[65] (Version 3.2.4.0). Individual model runs are carried out for the approximately 9000 census points covering UK urban major roads. Model runs are parameterised using the following input data for each census point:

- Road geometry
- Traffic speeds, emissions and traffic counts
- Meteorology
- Receptor locations

1.1. Road geometry

230. The PCM model uses a line coverage[66] to represent the layout of UK major roads, in combination with the census point dataset which describes the traffic flows on these roads. There is one census point per major road, located between junctions with other major roads. The traffic flow between major road junctions is assumed to be constant based on the assumption that the majority of traffic joins or leaves major roads at junctions with other major roads.

231. An assessment of variation in modelled concentrations with road orientation (not detailed here) suggests that differences in road orientation can make an approximately +/- 40% change for a receptor at 4 m from the roadside. This assessment evaluated the relative change in concentration modelled for receptors at various distances from the road for all road links. For each census point, the concentration modelled for a receptor at particular distance from the roadside was compared to the concentration modelled for an identical road link aligned due north at the same distance from the road. The relative change is largely independent of road type, traffic flow and road width; hence the orientation of a particular road is important to the modelled concentration that results. This difference is driven by the orientation of the road relative to the prevailing wind direction.

232. The orientation of roads within the PCM model can be described at three levels. The coarsest level is the census point level where multiple UK major road sections are associated with each census point. This level of detail

[65] http://www.cerc.co.uk/environmental-software/ADMS-Roads-model.html
[66] A set of lines within Geographical Information System

corresponds to the end nodes of the road links. The major road sections level data set, which comes from Ordnance Survey data, contains major road links but has nodes at junctions with both major roads and minor roads. Finally there is the x, y coordinate level, where the coordinates of each arc of every link which makes up the major roads GIS dataset are available. Therefore there are several grid references corresponding to each link.

233. The number of road links for each census point means that the stretches of road are too long to be accurately described by one orientation calculated from the end nodes of the full length of road. To best represent the road orientation, the x, y coordinate level would be most accurate. However this would produce approximately 40 records for each census point, and it would be unfeasible to resolve variations in roadside concentrations down to this level when the underlying traffic data is represented at a much coarser level. Hence to represent the orientation of road links associated with each census point, the end nodes of the major road sections have been used to calculate the bearing of the road link with respect to due north. The nearest UK major road section associated with the census point is used to define the orientation for all sections associated with that census point, given that it most closely represents the situation at the census point.

234. Road sources within ADMS-Roads are treated as line sources of variable width. To represent road widths as accurately as possible for all roads within the UK urban major roads coverage, the width has been estimated based on lane counts provided in the census point dataset. Road widths have been calculated assuming an average width of 4 metres per lane for urban single and dual carriageway A-roads and urban motorways. The 4 metre lane width assumption corresponds to those recommended by the Design Manual for Roads and Bridges (DMRB, 2005)[67], where a lane width of 3.65 metres is more typical and the difference in lane width takes into account the hardstrip for urban A-roads.

235. To provide confidence in the lane counts from the census points dataset and the lane widths calculated, these were verified for a subset of road links for the following cases:

- Where lane counts were not available
- Where only a single lane was indicated
- For road links with the highest traffic flows
- For road links where predictions indicated the highest concentrations in a zone

[67] DMRB (Design Manual for Roads and Bridges), 2005, Volume 6, Section 1, Part 2, TD 27/05, "Cross-Sections and Headrooms", http://www.dft.gov.uk/ha/standards/dmrb/vol6/section1/td2705.pdf

236. Excluding those road links where only a single lane was indicated, for the assessed road links an average of 4 metres per lane was typical. Wider and more varied widths were observed for roads with only single lanes but these are not characteristic of the complete dataset, typically being slip roads or small urban A-roads carrying the least traffic (these represent less than 0.5% of the census points).

237. All road sources are set up as line sources of length 2000m. For road links that have not been assessed and a lane count has not been provided, road widths have been assumed as shown in Table B1 along with the other default characteristics.

Table B1 – Default road source characteristics

Road type	Assumed number of lanes in each direction	Total width (m)	Length (m)
Single carriageway A-road	1	8	2000
Dual carriageway A-road	2	16	2000
Motorway	3	32	2000

1.2. Traffic speeds, emissions and traffic counts

238. ADMS-Roads uses traffic speeds and flows by vehicle category to estimate vehicle induced turbulence. The PCM-RKM uses traffic emissions for major road links in the UK provided directly by the National Atmospheric Emissions Inventory (NAEI) and incorporates the vehicle induced turbulence as calculated by ADMS-Roads. Unitary emissions of 1 g/km/s are applied such that output concentration profiles can be treated as kernels providing weightings for the pollutant specific road link emissions from the NAEI. The roadside increment concentration is calculated by multiplying concentrations modelled for unit emissions by the emissions rate for each road link. Traffic flows (annual average daily flows, AADFs) by census point have been aggregated into two vehicle categories i.e. light and heavy duty vehicles for the calculation of vehicle induced turbulence.

239. Traffic speed assumptions by vehicle category have been applied following categories based upon UK area type and road type following a methodology similar to the NAEI, and taking data from DfT congestion statistics to estimate the speeds. The categories, the data source used to develop the assumptions and the methodology applied are summarised in Table B.2. The

spatial distribution of the area types is illustrated in the technical report that accompanies the 2013 air quality assessment[68].

240. Emissions are assumed to be time varying, with a weekday temporal profile varying by hour of the day including separate profiles for Saturday and Sunday. The time varying emissions profiles for traffic are the same as those used for treating area source emissions from traffic in the PCM area source model[69], which were obtained from a distribution of all traffic in the United Kingdom by time of day (DETR, 2000)[70].

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68 http://uk-air.defra.gov.uk/assets/documents/reports/cat09/1511251423_AQ0650_2013_MAAQ_technical_report.pdf

69 http://uk-air.defra.gov.uk/assets/documents/reports/cat09/1511251423_AQ0650_2013_MAAQ_technical_report.pdf

70 Department of Environment, Transport and Regions (DETR, 2000). Personal communication from Sandra Simoni, August 2000.

Table B.2 – Summary of the categories, data sources and methods applied to estimate vehicle speeds, and estimated speeds in PCM-RKM

Description	Classification (based on UK area type, and road type)	Data Source and methodology	LDV[71] Speed (km/h)	HDV[72] Speed (km/h)
Central London A roads	1_Urban_Major_Principal	DfT's "Congestion on local authority managed 'A' roads: 2010/11"[73] linked table CGN0201a. No split by vehicle type, flow weighted and based on weekday morning peak. Averaged across 2006/7 to 2010/11 and assumed City of London corresponds to central London (assumed area type 1).	15	15
Inner London A roads	2_Urban_Major_Principal	DfT's "Congestion on local authority managed 'A' roads: 2010/11" linked table CGN0201a. No split by vehicle type, flow weighted and based on weekday morning peak. Averaged across 2006/7 to 2010/11 inner London boroughs excluding City of London (assumed area type 2).	21	21
Outer London A roads	3_Urban_Major_Principal	DfT's "Congestion on local authority managed 'A' roads: 2010/11" linked table CGN0201a. No split by vehicle type, flow weighted and based on weekday morning peak. Averaged across 2006/7 to 2010/11 Outer London boroughs (assumed area type 3).	29	29
Local authority A	4,5_Urban_Major_Principal	DfT's "Congestion on local authority managed 'A' roads: 2010/11" linked table CGN0201a. No split by vehicle type, flow weighted and based on weekday morning	40	40

[71] Light Duty Vehicles (cars and LGV)
[72] Heavy Duty Vehicles (HGVs and buses)
[73] http://webarchive.nationalarchives.gov.uk/20121107103953/ http:/www.dft.gov.uk/statistics/releases/congestion-on-local-authority-managed-a-roads-2010-11/

Description	Classification (based on UK area type, and road type)	Data Source and methodology	LDV[71] Speed (km/h)	HDV[72] Speed (km/h)
roads		peak. Averaged across 2006/7 to 2010/11 and England (assumed area type 4,5).		
Local authority A roads	6,7,8,9_Urban_Major_Principal	DfT's "Congestion on local authority managed 'A' roads: 2010/11" linked table CGN0201a. No split by vehicle type, flow weighted and based on weekday morning peak. Averaged across 2006/7 to 2010/11 and England (assumed area type 6,7,8,9).	40	40
Inter urban trunk roads	4,5_Urban_Major_Trunk (single carriageway)	For single carriageway A-roads in urban areas the speed limit has been applied.	48	48
Inter urban trunk roads	6,7,8,9_Urban_Major_Trunk (single carriageway)	For single carriageway A-roads in urban areas the speed limit has been applied.	48	48
Rural A roads	10_Rural_Major	DfT's free flow vehicle speed statistics, GB 2010[74], Table SPE0101, flow weighted average across vehicle types, assuming single carriageway roads.	76	72
Inter urban trunk roads	4,5_Urban_Major_Trunk	DfT's "Congestion on inter-urban roads, for the year ending December 2010"[75] linked table CGN0103. No split by vehicle type, not flow weighted, average of monthly average speeds for trunk A roads, Mar 2008-Nov 2010.	82	82
Inter urban trunk roads	6,7,8,9_Urban_Major_Trunk	DfT's "Congestion on inter-urban roads, for the year ending December 2010" linked table CGN0103. No split by vehicle type, not flow weighted, average of monthly average speeds for trunk A roads, Mar 2008-Nov 2010.	82	82
Urban motorways	3_Urban_Motorways	DfT's "Congestion on inter-urban roads, for the year ending December 2010" linked table CGN0103. No split by vehicle type, not flow weighted, average of monthly	95	95

[74] http://webarchive.nationalarchives.gov.uk/20121107103953/http:/www.dft.gov.uk/statistics/releases/free-flow-vehicle-speeds-in-great-britain-2010/
[75] http://webarchive.nationalarchives.gov.uk/20110314114542/http:/dft.gov.uk/pgr/statistics/datatablespublications/roads/congestion/

Description	Classification (based on UK area type, and road type)	Data Source and methodology	LDV[71] Speed (km/h)	HDV[72] Speed (km/h)
		average speeds for motorways, Mar 2008-Nov 2010.		
Urban motorways	4,5_Urban_Motorways	DfT's "Congestion on inter-urban roads, for the year ending December 2010" linked table CGN0103. No split by vehicle type, not flow weighted, average of monthly average speeds for motorways, Mar 2008-Nov 2010	95	95
Urban motorways	6,7,8,9_Urban_Motorways	DfT's "Congestion on inter-urban roads, for the year ending December 2010" linked table CGN0103. No split by vehicle type, not flow weighted, average of monthly average speeds for motorways, Mar 2008-Nov 2010	95	95
Rural motorways	10_Rural_Motorways	DfT's free flow vehicle speed statistics, GB 2010, Table SPE0101, flow weighted average across vehicle types, motorway non built up roads even though "urban" area type	111	91

1.3. Meteorology

241. Hourly sequential meteorological data from Waddington (Lincolnshire) in the reference year has been used in the setup of the ADMS-Roads model runs. Table B.3 shows the other assumptions applied for the meteorological conditions at the roads, which are dependent on the area type and meteorological site. These are in common with the setup for the area source dispersion kernels in the PCM model.

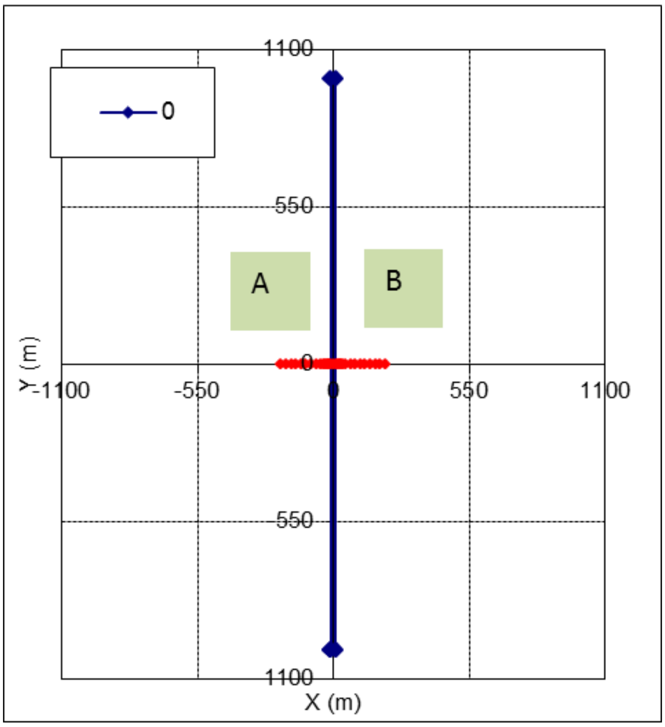
Table B.3 - Summary of meteorological parameters applied by area type

Area types (from Table A2)	Types of location	Minimum Monin–Obukhov length (m)		Surface roughness (m)	
		Dispersion site	Meteorological site	Dispersion site	Meteorological site
1,2,4	Conurbation	25	10	0.5	0.1
3,5,6,7,8	Smaller urban	20	10	0.5	0.1
9,10	Rural	10	10	0.5	0.1

1.4. Receptor locations

242. Model runs are set up with a road source for each major road link nearest to a census point. This road source represents the link at the road angle determined from the coordinates of its end nodes. Concentrations are modelled for 49 receptors, with one at the road centre line of the road link, and 24 each side, perpendicular to the road link. Close to the road, receptors are spaced at 1m intervals; past 15m from the roadside the receptor spacing progressively increases, to a maximum of 200m from the roadside. A diagram illustrating the position of receptors and road source is given in Figure B1.

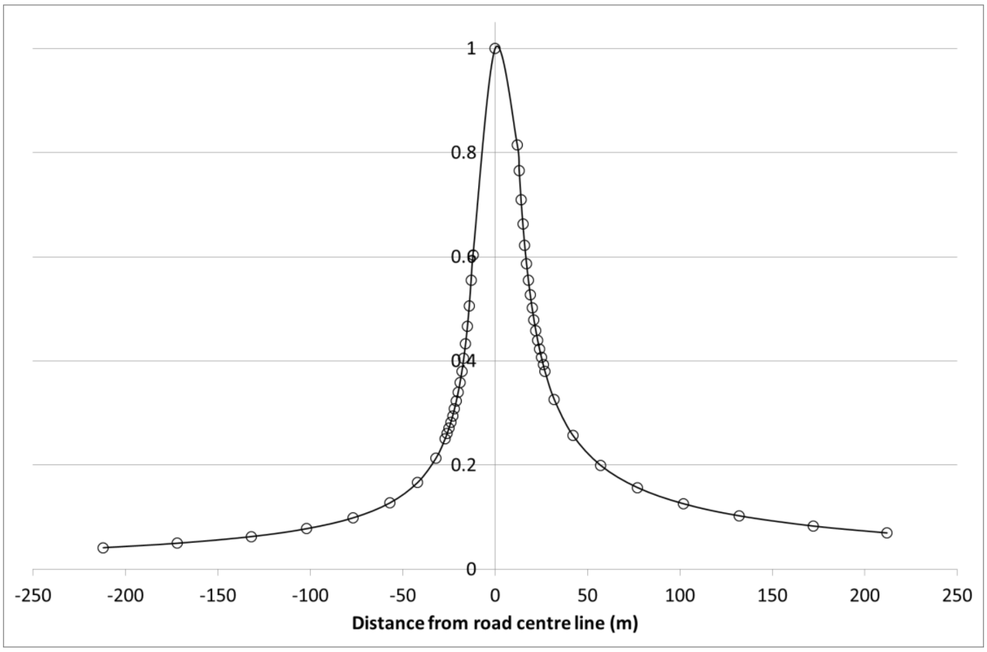
Figure B.1 – Schematic diagram of road source (blue) and receptors (red)



2. Model outputs

243. Modelled concentrations can be derived from the ADMS-Roads model outputs for all receptor locations specified. In the PCM-RKM modelling for 2013 the average concentration across each side of the road at a distance of 4m from the kerb for all census points has been selected for comparison with the measured concentrations at roadside (traffic) stations for model calibration. The same output has also been used for the compliance assessment for roadside (traffic) concentrations. To illustrate the variation in concentration modelled with distance from the road, a normalised concentration profile is presented in Figure B2.

Figure B.2 – Example normalised concentration profile



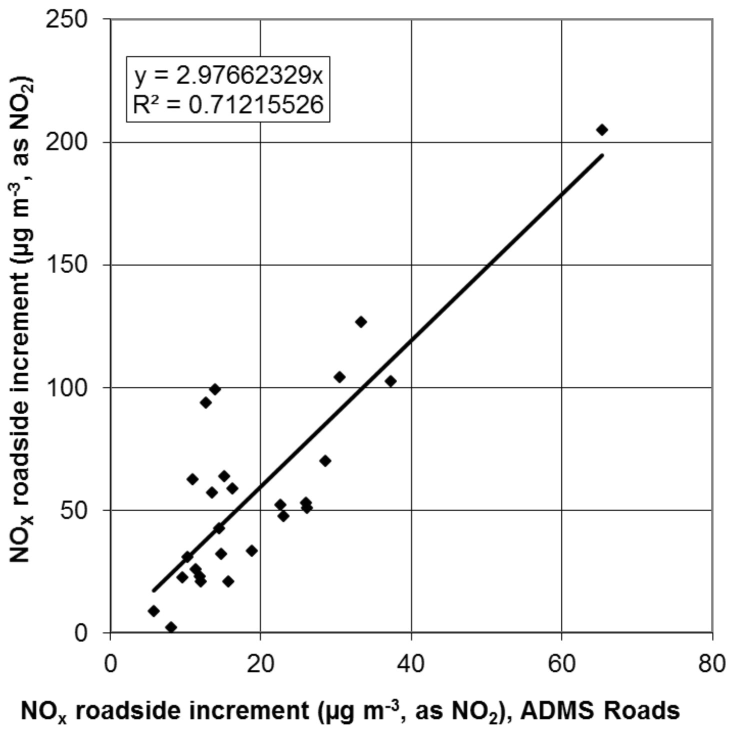
3. Model calibration

244. The PCM-RKM uses the PCM roadside increment approach for the prediction of the local contribution to total concentrations at the roadside. As such the annual mean concentration at roadside locations has been assumed to be made up of two parts: a background concentration (excluding local sources) and a roadside increment.

Roadside concentration = background concentration + roadside increment.

245. To calibrate the model, modelled concentrations are compared to measured roadside increment concentrations (i.e. measured roadside concentration minus modelled background concentration) at Automatic Urban and Rural Network (AURN) roadside traffic stations. Figure B3 presents the calibration plot for NO_X for 2013 for the PCM-RKM.

Figure B3 - Calibration of NO_X roadside increment model, 2013 (µg/m^3, as NO_2) – PCM-RKM



3.1. Adjustment factors applied to road link emissions

246. The effect of street canyons has not been explicitly included in the PCM-RKM model. However, the model calibration based on the comparison of

measured and modelled roadside concentration increments implicitly includes some influence of street canyon effects, dependent on how much the local environment of the AURN road traffic stations used to calibrate the model can be characterised as street canyons. Street canyons are typically characterised in terms of aspect ratio, the ratio of the road width to the height of buildings lining the road. Vardoulakis et al. (2003)[76] characterised avenue canyons as those with aspect ratios (AR) < 0.5, and deep canyons as those where AR = 2.

247. Motorways are expected to have a more open aspect than the urban streets where the AURN road traffic stations used to calibrate the model are situated. An adjustment factor has therefore been derived for motorways. The AURN road traffic stations used to calibrate the model have been characterised in terms of AR from estimates of the average road widths (building façade to building façade) and average building heights determined by examining the roads within ArcMap, Google Earth and Google Streetview.

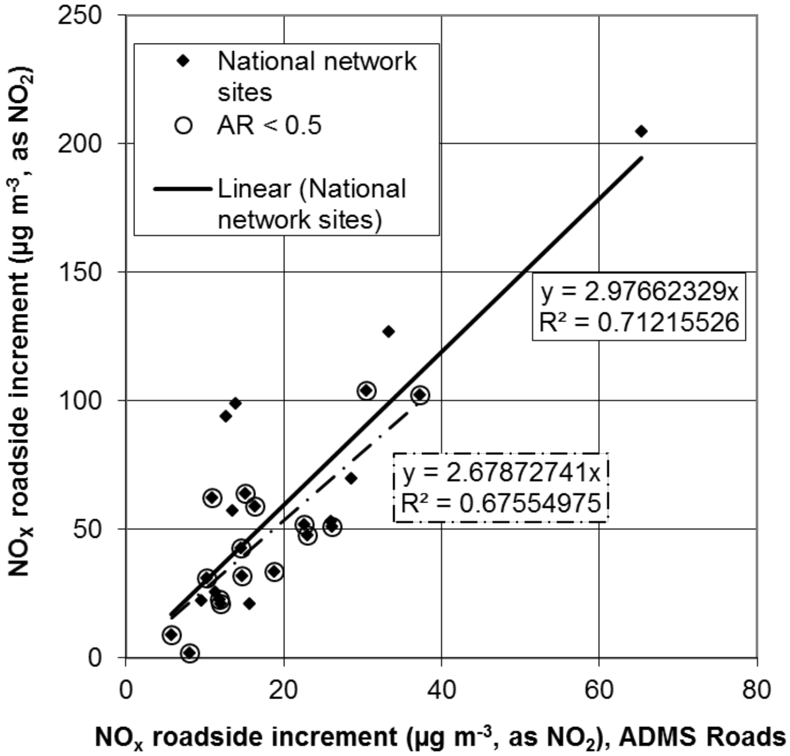
248. The motorway adjustment factor has been derived from the ratio of the NO_X calibration factor for traffic stations where AR < 0.5, to the NO_X calibration factor for all AURN traffic stations:

$$\boldsymbol{F} = \frac{C_{AR<0.5}}{C_{All}}$$

249. The determination of the motorway adjustment factor is illustrated in Figure B.4.

[76] Sotiris Vardoulakis, Bernard E.A Fisher, Koulis Pericleous, Norbert Gonzalez-Flesca, Modelling air quality in street canyons: a review, Atmospheric Environment, Volume 37, Issue 2, January 2003, Pages 155-182, ISSN 1352-2310,

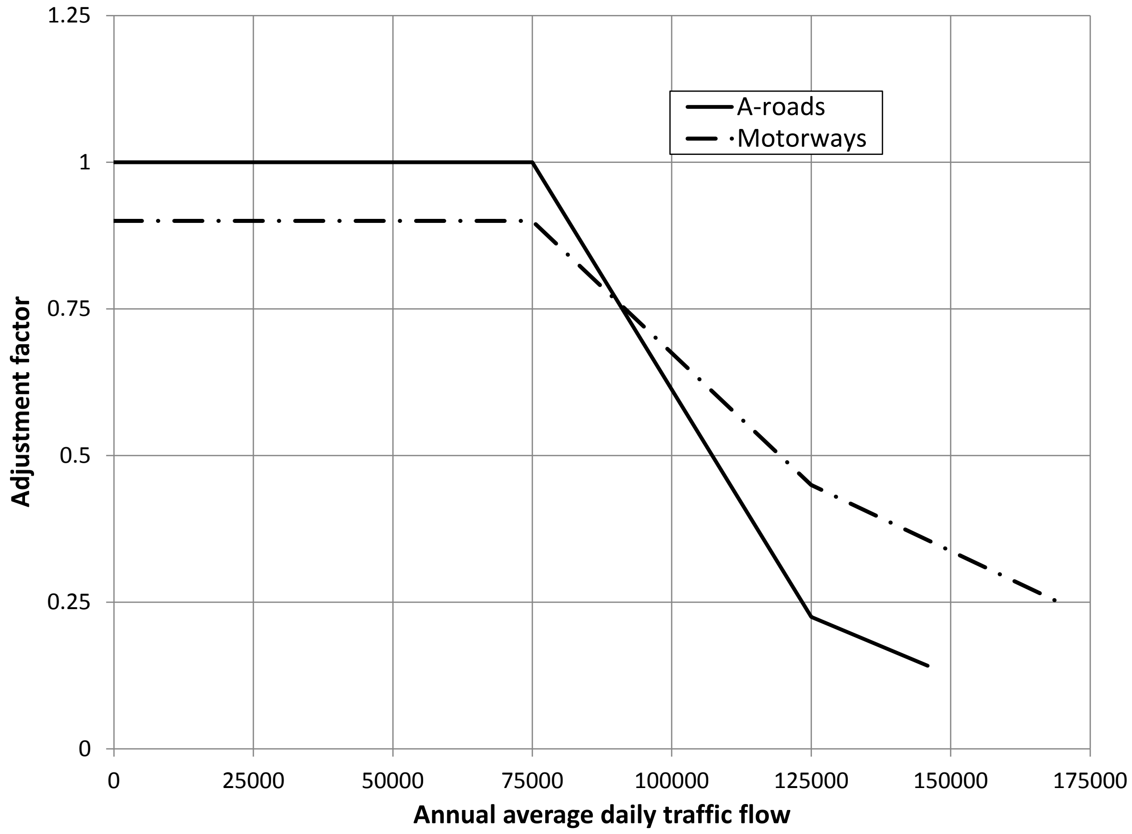
Figure B.4 – Determination of motorway adjustment factor



250. In development of the PCM-RKM, comparison of roadside modelling results to the previous PCM model output indicated significant increases in the modelled concentrations for roads with high traffic flows predicted by using ADMS-Roads. These increases are not thought realistic, and indicate under-prediction of dispersion for the widest and highest flow roads since dispersion is likely to be most efficient on these roads. To address this, in addition to the general scaling applied to road link emissions for motorways, further adjustment factors have been developed to apply to the road link emissions for motorways and A-roads where the traffic flow exceeds an annual average daily flow of 75,000.

251. The combined traffic flow and motorway adjustment factors as a function of traffic flow are presented in Figure B.5.

Figure B.5 – Combined adjustment factors applied to road link emissions



4. Model verification

252. Figures B.6 and B.7 present verification plots for NO_X and NO_2 for the year 2013 for the PCM-RKM method. Both national network sites used in the model calibration and verification sites (monitoring sites not in the national network) are shown. Lines representing y = x – 30 % and y = x + 30% are also shown - these represent the Air Quality Directive (AQD) data quality objective for modelled annual mean NO_2 and NO_X concentrations). There is no requirement under the AQD to report modelled annual mean NO_X concentrations for comparison with limit values for the protection of human health. However, comparisons of modelled and measured NO_X concentrations and of the modelled NO_X concentrations with the data quality objectives are presented here, along with the comparisons for NO_2 to allow a full comparison of the PCM-RKM outputs with measurements. The NO_X results provide an additional check on the reliability of the modelled estimates of NO_2 because the non-linear relationships between NO_X and NO_2 tends to cause modelled NO_2 concentrations to be relatively less sensitive to differences between measured and modelled values of NO_X.

253. Summary statistics for the comparison between modelled and measured NO_X and NO_2 concentrations for the PCM-RKM are listed in Table B.4. The percentages of monitoring sites for which the modelled annual mean concentrations fall outside the data quality objectives is generally greater for NO_X than for NO_2, for the reasons discussed above.

Figure B.6 - Verification of roadside annual mean NO_X model 2013 – PCM-RKM

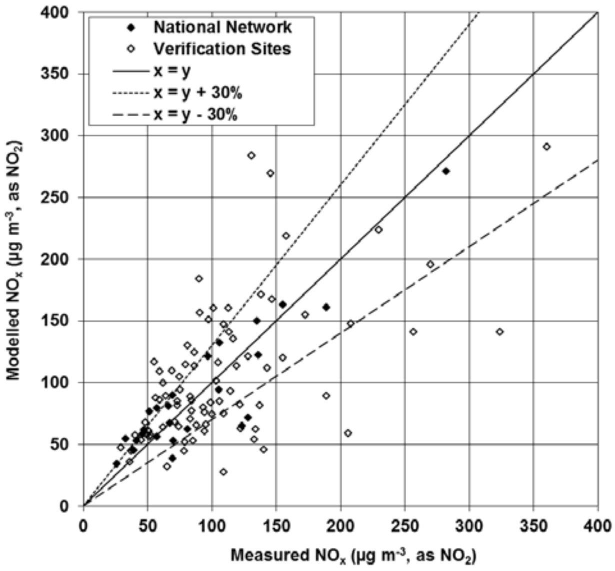


Figure B.7 - Verification of roadside annual mean NO_2 model 2013 – PCM-RKM

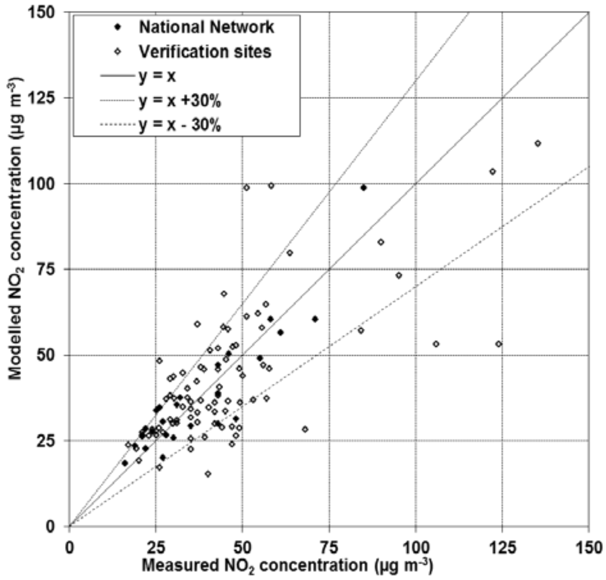


Table B.4 - Summary statistics for comparison between modelled and measured NO_X and NO_2 concentrations at roadside sites (μg/m³, as NO_2)

		Mean of measurements (μg/m³, as NO_2)	Mean of model estimates (μg/m³ as NO_2)	R^2	% outside data quality objectives	Number of sites in assessment
NO_X	National Network	89.0	88.9	0.83	34.6	26
	Verification Sites	110.8	106.5	0.44	50.6	83
NO_2	National Network	36.9	37.4	0.84	15.4	26
	Verification Sites	45.3	43.2	0.47	33.7	83

Annex C- Primary NO_2 emission fractions ($f\text{-}NO_2$)

1. Introduction

254. Local oxidant is calculated in the updated oxidant-partitioning model used by the PCM model as:

Local oxidant = f-NO_2.[NO_X]

255. Where *f-*NO_2 is the fraction of NO_x emissions emitted as primary NO_2 (by volume). Therefore, to calculate local oxidant levels, the *f-*NO_2 levels from different local sources need to be understood. In general it is possible to make a distinction between *f-*NO_2 from road traffic sources and *f-*NO_2 from non-road traffic sources. *f-*NO_2 from road traffic sources is thought to have risen since the early 2000s, although this trend displays considerable variation with location (AQEG, 2007[77]; Carslaw et al., 2011[78]). In contrast, *f-*NO_2 from non-traffic sources has remained relatively constant with time.

256. The f-NO_2 values for road traffic sources have been revised for the 2013 reference year and projections modelling for the 2015 air quality plan from those previously used[79]. This is to reflect the updated emission factors for NO_X from COPERT 4v11 and f-NO_2 values from the EMEP/EEA Emissions Inventory Guidebook 2013, updated July 2014[80]. The revised values are presented below.

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[77] Air Quality Expert Group (AQEG 2007). Trends in Primary NO_2 in the United Kingdom. http://www.defra.gov.uk/environment/quality/air/airquality/publications/primaryno2-trends/index.htm

[78] Carslaw, D. C., Beevers, S. D., Westmoreland, E., Williams, M. L., Tate, J. E., Murrells, T., Stedman, J., Li, Y., Grice, S., Kent, A., and Tsagatakis, I. (2011). Trends in NO_X and NO_2 emissions and ambient measurements in the UK. Version: July 2011. http://uk-air.defra.gov.uk/library/reports?report_id=673

[79] http://uk-air.defra.gov.uk/assets/documents/reports/cat09/1511251423_AQ0650_2013_MAAQ_technical_report.pdf

[80] http://www.eea.europa.eu/publications/emep-eea-guidebook-2013/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-road-transport/view

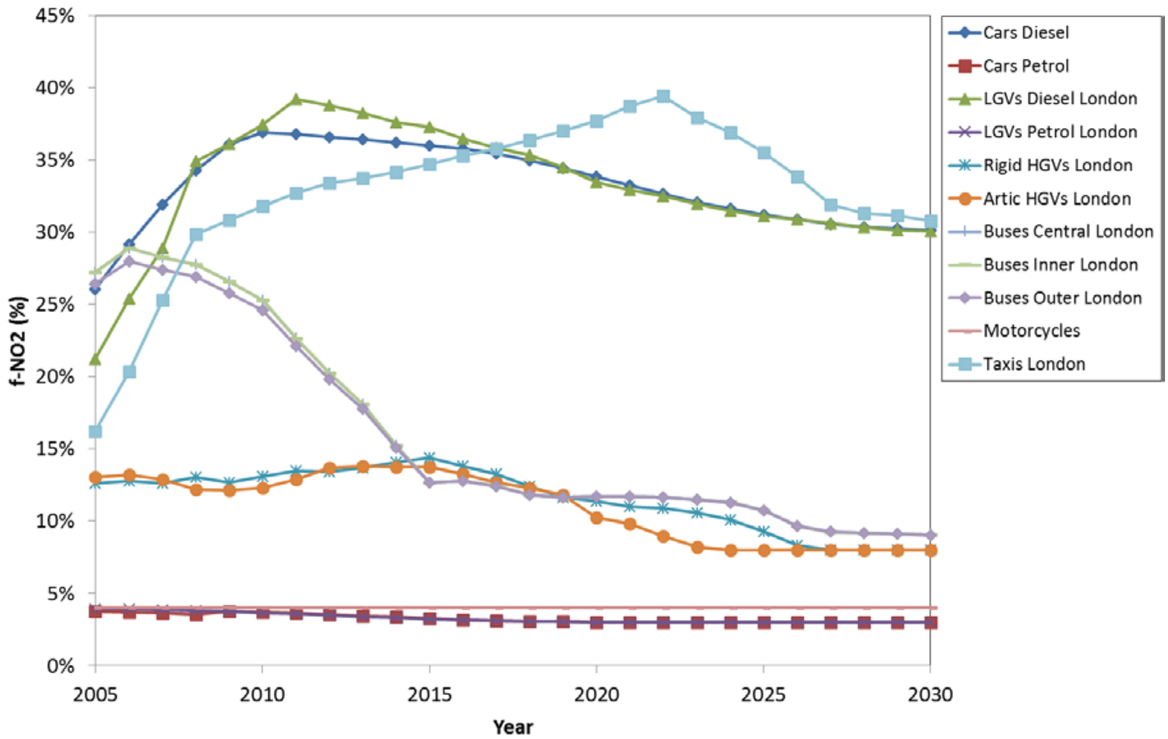
2. f-NO_2 for road traffic sources on individual road links

257. Figure C.1 shows fleet average f-NO_2 projections by vehicle type for London and the rest of the UK used for the modelling to support the development of the 2015 air quality plan.

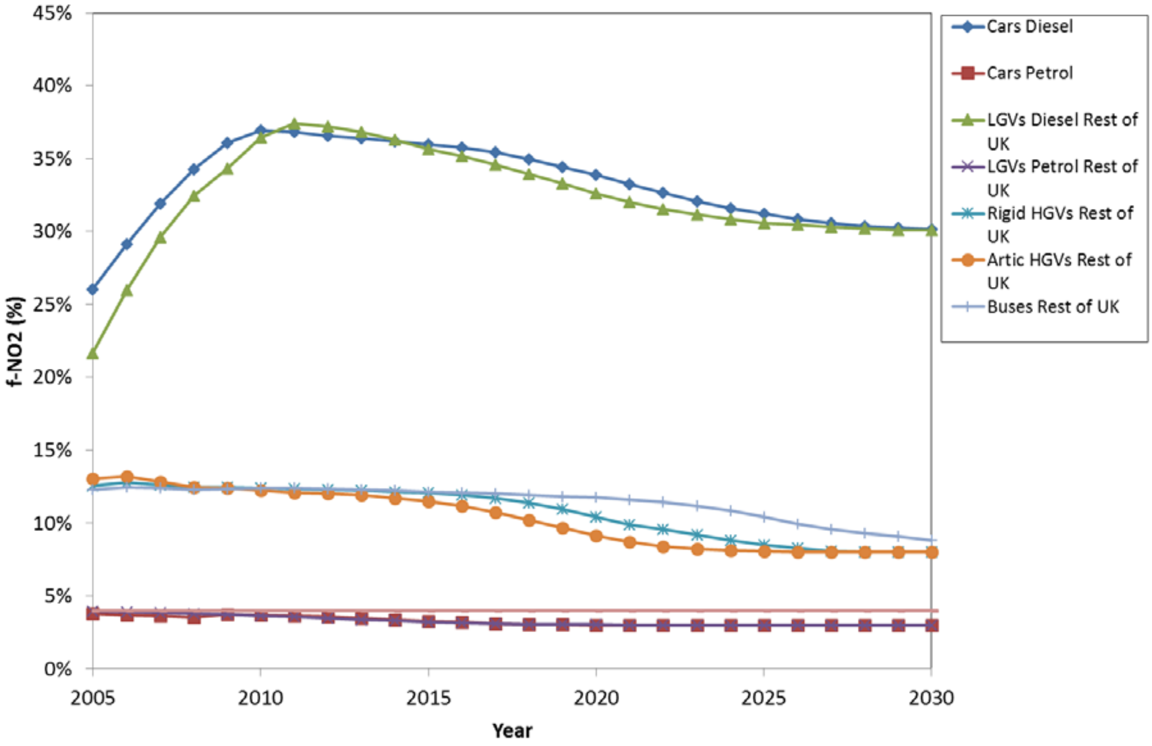
258. f-NO_2 for all petrol vehicles is very low (less than 5%). f-NO_2 for diesel cars and LGVs is greater and rose steeply from 26% to 37% between 2005 and 2010, declined somewhat from 2010 onwards and is expected to be 31% by 2025. A gentle decline in f-NO_2 is expected for HGVs and buses outside London from about 2015. Buses in London had higher f-NO_2 than in the rest of the UK in 2005 and this decline will be similar to the rest of the UK by about 2015. f-NO_2 for London taxis is expected to peak in about 2020.

Figure C.1 - Fleet average f-NO_2 projections by vehicle type for a) London and b) rest of the UK

a) London



b) Rest of the UK



3. f-NO_2 for background sources

259. Table C.1 shows the f-NO_2 values used for background sources in 2013. The non-road f-NO_2 values used for background calculations in Table C.1 have been taken directly from Jenkin (2004)[81]. There is little evidence that this has changed significantly over the past years or is likely to change in the future. The road traffic f-NO_2 values for background calculations have been calculated using the average of the major road link f-NO2 values for each area type.

260. Table C.2 shows the road f-NO_2 for background concentrations for 2020, 2015 and 2030. Large changes in f-NO_2 are not expected between 2013 and 2030. Many locations show an increase between 2013 and 2020 followed by a gradual decline with the largest increase being in rural areas. However Central London shows an initial decline.

Table C.1 – Primary NO_2 emission fractions (f-NO_2) for background concentrations in 2013

DfT Area type	Location	Non-road *f-NO_2* for background calculations (%)	Road *f-NO_2* for background calculations (%)
1	Central London	0.140	0.231
2	Inner London	0.128	0.237
3	Outer London	0.093	0.248
4	Inner Conurbations	0.093	0.238
5	Outer Conurbations	0.093	0.247
6	Urban (population > 250,000)	0.093	0.248
7	Urban (population > 100,000)	0.093	0.251
8	Urban (population > 25,000)	0.093	0.253
9	Urban (population > 10,000)	0.093	0.254
10	Rural	0.093	0.253

[81] Jenkin, M.E. (2004). Analysis of sources and partitioning of oxidant in the UK-Part 1: the NO_X-dependence of annual mean concentrations of nitrogen dioxide and ozone. Atmospheric Environment, 38, 5117–5129. doi:10.1016/j.atmosenv.2004.05.056

Table C.2 - Primary NO_2 emission fractions (f-NO_2) for background concentrations for road sources in 2020, 2025 and 2030

DfT Area type	Location	2020 (%)	2025 (%)	2030 (%)
1	Central London	0.211	0.222	0.213
2	Inner London	0.230	0.237	0.229
3	Outer London	0.251	0.248	0.236
4	Inner Conurbations	0.260	0.250	0.240
5	Outer Conurbations	0.271	0.255	0.244
6	Urban (population > 250,000)	0.269	0.254	0.242
7	Urban (population > 100,000)	0.273	0.256	0.243
8	Urban (population > 25,000)	0.274	0.257	0.244
9	Urban (population > 10,000)	0.276	0.259	0.246
10	Rural	0.279	0.259	0.245

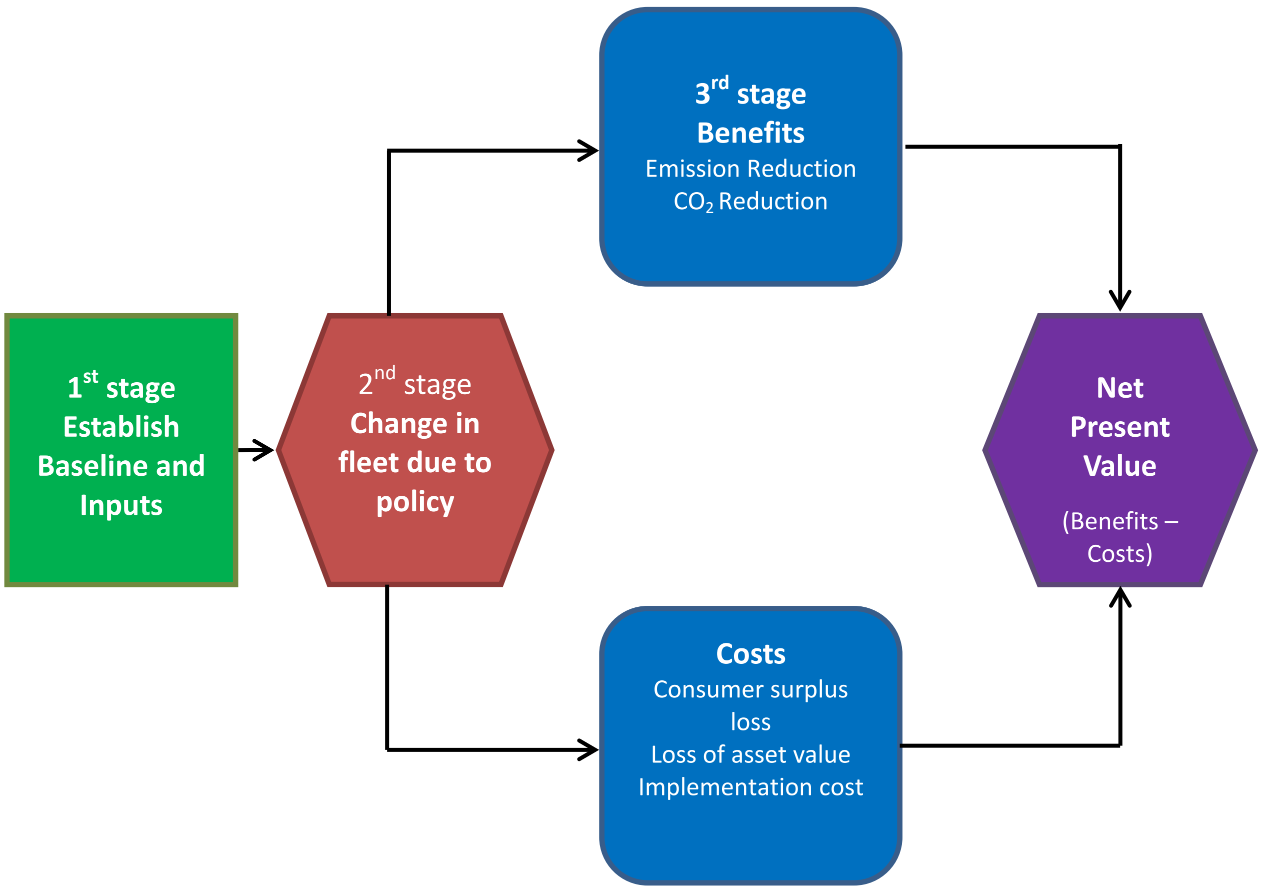
Annex D- Fleet Adjustment Model - Technical Documentation

1. Overview

261. The Fleet Adjustment model quantifies the societal costs and benefits associated with changes in UK vehicle fleet. This fleet change may be triggered by a number of different policies. In this case it has primarily been used to assess impact of a Clean Air Zone as set out in the UK air quality plan.

262. The Fleet Adjustment modelling approach follows a number of sequential stages as outlined in Figure D.1 below. Sections 2-6 of this annex elaborate on the assumptions and approach taken in each of these stages.

Figure D.1 Flow diagram of the assessment of costs and benefits in the fleet adjustment model



263. In the first stage, the baseline scenario establishes the vehicle fleet in different years prior to the implementation of any adjustments. The baseline is established via two key inputs:

- The fleet composition (number of vehicles by age and vehicle type - Buses, coaches, taxis, HGVs, LGVs and cars);

- The number of vehicle kilometres driven by each type of vehicle, inside and outside of the proposed Clean Air Zone and their location.

264. More information on the definition of the baseline is set out in Section 3.

265. The second stage introduces measures which have an impact on the vehicle fleet. It models individual owners' specific responses to the measures introduced. The responses will depend on the costs of different options available and the nature of the measure. In this example, some vehicle owners may choose to upgrade vehicles or avoid the restricted zone, triggering changes in the fleet composition and to the proportion of time older vehicles spend driving in different locations. The detailed assumptions are set out in Section 4.

266. The third stage then quantifies and values the main societal impacts of the changes in fleet relative to the baseline. Some examples of these impacts are the loss of asset value from vehicles scrapped, the cost to society of upgrading to a vehicle exempt from the charge, and the health benefits attributable to the resulting reductions in NO_X, PM and CO_2 pollution. The methodology and assumptions are set out in Section 5 of this annex.

267. Finally all the impacts are then discounted and total costs are subtracted from total benefits providing a resulting net present value (NPV), in 2015 prices. Full details are outlined in Section 6.

2. Model design

268. The primary application of the Fleet Adjustment model is to assess the societal impact of changes in the UK fleet. As set out in the main body of the Technical Report, this modelling has primarily been used to assess four types of Clean Air Zone as set out below.

- Type A – Buses, coaches and taxis only
- Type B – Buses, coaches, taxis and heavy goods vehicles (HGVs)
- Type C – Buses, coaches, taxis, HGVs and light goods vehicles (LGVs)
- Type D – Buses, coaches, taxis, HGVs, LGVs and cars

269. The Fleet Adjustment model calculates the monetised social impact of measures over a ten year period. For the purpose of the Clean Air Zone policy appraisal outside of London and within the Ultra Low Emission Zone (ULEZ), this period is 2020-2029 as 2020 represents the latest date by which Clean Air Zones may be implemented. For the Greater London area excluding the ULEZ a 10 year appraisal period from 2025 is assumed. In reality Clean Air Zones may be implemented earlier which may mean the analysis slightly underestimates both the benefits and costs of the policy. The monetised social impact is intended to inform policy design to ensure value for money.

2.1. Model Design Principles

270. The assessment has been made in line with best practice as set out in the HM Treasury Green Book[82]. This is supported with the following Green Book supplementary guidance:

- Valuing impacts on air quality: Defra Supplementary Green Book Guidance (2013)[83] and interim guidance on valuing oxides of nitrogen[84]
- Web-based Transport Analysis Guidance: WebTAG (2014)[85]
- DECC Valuation of energy use and greenhouse gas emissions for appraisal (2014)[86]

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[82] https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent
[83] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/197893/pu1500-air-quality-greenbook-supp2013.pdf
[84] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/460401/air-quality-econanalysis-nitrogen-interim-guidance.pdf
[85] https://www.gov.uk/transport-analysis-guidance-webtag
[86] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/360316/20141001_2014_DECC_HMT_Supplementary_Appraisal_Guidance.pdf

271. The Fleet Adjustment model works alongside the Pollution Climate Mapping (PCM) model. (Full details in Section 3 of the main body of the Technical Report and in Annexes A-C). The models use consistent input sources where applicable, e.g. National Atmospheric Emissions Inventory (NAEI) projections data on vehicle compositions and kilometres travelled by each vehicle type.

3. Establishing the baseline

272. Fleet composition data and vehicle usage data provide the baseline scenario against which any changes are modelled.

273. Fleet composition projections by vehicle type and emission standard for years 2020-2029 is sourced from the national transport model produced by DfT. This tracks both current levels and forecast vehicle composition by stock and distance travelled measured in vehicle kilometres (vkm). The following vehicle types are included in the model. Impacts on taxis are modelled as impacts on diesel cars.

- Bus
- Coach
- Articulated HGV
- Rigid HGV
- Diesel LGV
- Petrol LGV
- Diesel Car
- Petrol Car

3.1. Inputs

274. The inputs described within Table D.2, Table D.3 and Table D.4 are used when quantifying the impacts of the implementation of Clean Air Zones.

275. Table D.2 describes the inputs defined as vehicle characteristics within the implementation of policy in Section 5.

Table D.2 Vehicle characteristics used within the Fleet Adjustment model

Input	Source
Average vehicle age	Euro standards relate to vehicle age, for example a diesel van registered from 2006-2009 is a Euro 4 standard. Automobile Association (AA) data is used for the years when each Euro standard comes into effect. An average of the range is used as the average age for each Euro standard. The average vehicle age is used to calculate value of vehicles using depreciation rates.

<table>
<tr><td>Vehicle depreciation rates</td><td>Depreciation rates are attributed to each vehicle type over a ten year period. Depreciation rates for cars were estimated based upon the depreciation rates of the most popular 10 cars sold in the UK in 2014. Van depreciation rates were estimated looking at published data on resale values. After three years the annual rate of depreciation is assumed to remain constant for all vehicle types.

Depreciation rates are assumed to be as below. These are the percentage of value lost per year.

<table>
<tr><th>Year</th><th>Cars</th><th>Other vehicle types</th></tr>
<tr><td>1</td><td>0.37</td><td>0.35</td></tr>
<tr><td>2</td><td>0.18</td><td>0.18</td></tr>
<tr><td>3+</td><td>0.16</td><td>0.18</td></tr>
</table></td></tr>
<tr><td>Vehicle annual distance travelled</td><td>Vehicle annual distance data is sourced from the National Atmospheric Emissions Inventory[87]. It provides an average annual distance travelled according to vehicle type. The distance travelled is assumed to remain constant over the ten year period of the policy.</td></tr>
<tr><td>Average length of vehicle ownership</td><td>Length of vehicle ownership is broken down by vehicle type. This data has been sourced from the RAC[88].</td></tr>
</table>

[87] http://naei.defra.gov.uk/

[88] http://www.racfoundation.org/assets/rac_foundation/content/downloadables/car%20ownership%20in%20great%20britain%20-%20leibling%20-%20171008%20-%20report.pdf

276. **Table D.3** describes the inputs which are defined as local authority characteristics within the implementation of policy in Section 5.

Table D.3 Local authority characteristics used within the Fleet Adjustment model

Input	Source
Zone perimeters and population (Local authority characteristics)	For modelling purposes, the Clean Air Zone border perimeters in each area were defined to include all roads that were projected to exceed the limit values (40µg/m^3) in 2020. Each Clean Air Zone was defined based on natural boundaries such as existing roads or rivers, or based on existing local authority research where possible. The population within these areas has been provided from Ricardo Energy & Environment using Office of National Statistics (ONS) data. This data is used to calculate the set up and running costs of Clean Air Zones.
Fraction of time spent within the zones	Fraction of time spent within the network varies by vehicle type and the data is sourced from Ricardo Energy & Environment. The average time spent within the proposed Clean Air Zones is presented as a percentage of total km driven. This data is used to calculate the impact on emissions inside and outside the Clean Air Zone.
Unique vehicle entries	Vehicle entries into Clean Air Zones by vehicle type are provided by Trafficmaster sourced from DfT GPS Journey information. Only a sample of these figures was provided and so they were scaled based on empirical data on unique vehicles from one location. Vehicles, which enter more than one Clean Air Zone are only counted once to mitigate double-counting (a driver will only need to upgrade a vehicle once). The aim of this calculation is to calculate unique vehicle entries into each Clean Air Zone. Unique vehicle entries are then calculated over the assessment period.

277. Table D.4 outlines all inputs which are not defined under vehicle characteristics or local authority characteristics but which are used to calculate impacts within the implementation of policy in Section 5.

Table D.4 Additional inputs used within the Fleet Adjustment model

Input	Source
Fuel Costs	Petrol and diesel fuel costs are annual average values. Fuel costs up to 2013 are observed, whereas values from 2014 onwards are projections based on the central fossil fuel price scenario published in October 2014 by the Department of Energy and Climate Change (DECC). These are used to estimate the fuel efficiency savings when using the financial cost approach method (for more details see Section 5.1)
Fuel consumption	Fuel consumption is broken down by vehicle type and Euro standard. WebTAG guidance provides data on light vehicle fuel consumption. All other vehicle types are assumed to have no change in fuel consumption across Euro standards; this is in line with DfT fuel consumption analysis. These are used to estimate the fuel efficiency savings when using the financial cost approach method (for more details see Section 5.1)
Air quality damage costs	NO_X and PM damage costs (£/tonne) are sourced from Green Book and Defra guidance[89]. These vary depending on location to reflect population density. As far as possible the damage costs have been matched to the location of the emissions for example inside Clean Air Zones, the inner conurbation damage cost is used (or London, inner for London). For outside Clean Air Zone emissions the rural transport average is used. Damage costs are assumed to remain constant in real terms and are therefore not adjusted for inflation. However there is a health uplift of 2% applied to account for higher willingness to pay for healthcare.
Greenhouse gas abatement costs	As vehicle emissions are not included in the European Trading Scheme (ETS), an average CO_2 non-traded central carbon price for the assessment period is used, (£71.6/tonne in 2015 prices) provided by DECC, published in October 2014, to calculate the impact of a change in CO_2 emissions.
Fleet emission	Emission factors are split by each vehicle type and emission

[89] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/460398/air-quality-econanalysis-damagecost.pdf

factors	standard for CO_2 and PM as shown in Table D. The PM factors are derived by the NAEI based on the most recent dataset of vehicle composition. These are estimated from vehicle sales, survival rates, age-related vehicle mileage and information from Automatic Number Plate Recognition (ANPR) data. Emission rates are taken from COPERT 4v11 in the National Atmospheric Emissions Inventory. The CO_2 emission factors are sourced from Transport Research Laboratory (TRL). CO_2 is the only Greenhouse Gas (GHG) that is produced by vehicles considered within DECC guidance[90] published in December 2014, and as a result, no equivalent tonnes of CO_2 need to be accounted for.

Table D.5 Vehicle exhaust emission factors

Emission Factors	Petrol Cars	Diesel Cars	Petrol LGVs	Diesel LGVs	RHGVs	AHGVs	Buses	Coaches
PM (mg/km)								
Euro 3	1.07	32.92	1.06	58.87	93.45	139.59	127.41	127.41
Euro 4	1.07	25.45	1.06	30.75	24.49	33.68	31.21	31.21
Euro 5	1.38	1.80	2.48	0.96	27.73	38.33	37.30	37.30
Euro 6	1.42	1.20	2.48	0.96	2.57	3.32	3.60	3.60
CO_2 (g/km)								
Euro 3	163.19	149.25	220.27	236.34	619.39	978.36	686.29	686.29
Euro 4	150.37	141.52	220.27	236.34	579.35	908.23	647.83	647.83
Euro 5	131.91	123.70	220.27	236.34	587.79	922.00	662.75	662.75
Euro 6	116.34	108.61	220.27	236.34	587.79	922.00	662.75	662.75

278. The above table reports the emission factors for exhaust emissions only, and does not account for PM emissions from tyre and brake wear.

279. Note the NO_X vehicle emission changes are taken directly from the PCM model which are unavailable for PM and CO_2.

90 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/360316/20141001_2014_DECC_HMT_Supplementary_Appraisal_Guidance.pdf

4. Modelling changes in the fleet

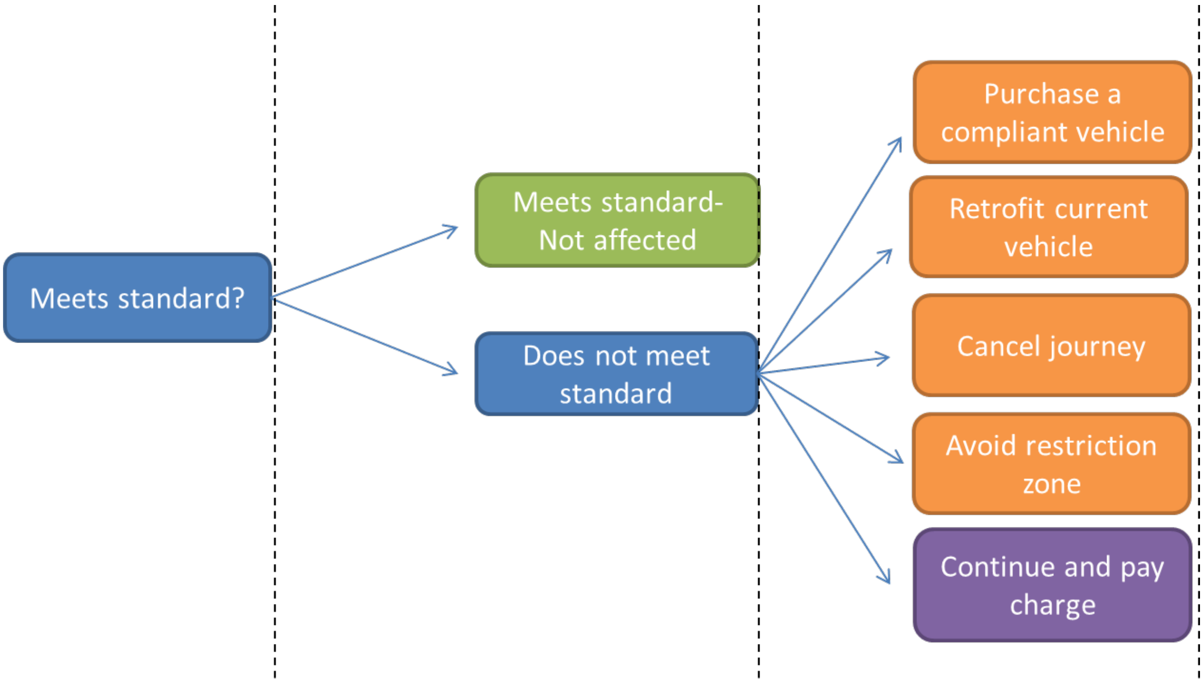
280. This section sets out how changes in the fleet have been modelled to reflect measures taken. Assumptions around the behavioural responses of vehicle owners are applied to model the resulting change in fleet. Changes in total annual distance travelled by each vehicle type and vehicle kilometres travelled within and outside the Clean Air Zone are then estimated. More details on the behavioural assumptions are outlined below.

4.1. Behavioural response of owners with vehicles subject to charge

281. Individuals or businesses who own vehicles subject to the charge are assumed to have the following choices within the model as demonstrated in Figure D.2:

   i. Replace current vehicle with a vehicle exempt from the charge - this will enable the new vehicle owner to continue to drive in restricted areas without charge.
   ii. Retrofit existing vehicle – retrofitting to the required standard allows vehicle owners to continue driving in restricted areas without charge
   iii. Cancel journeys – some owners will choose to cancel or shift trips into the Clean Air Zone where restrictions apply.
   iv. Avoid restriction areas– some owners may divert their journeys around traffic restricting areas.
   v. Pay a charge for entering the Clean Air Zone – some drivers will choose to pay a charge for entering restricted areas instead of purchasing a vehicle exempt from the charge. This may be the most cost-effective option for drivers that enter these Clean Air Zones infrequently.
   vi. Redeployment of existing fleet – users with multiple vehicles may be able to redeploy their fleet to use cleaner vehicles within restricted areas. The costs of such changes are assumed to be negligible and therefore not considered in the model.

Figure D.2 Decision tree for road transport users



282. The response functions are for vehicles which are subject to the charge. They are based upon the best available data from similar schemes. Given the limited data and the assumption that drivers response functions may vary from Clean Air Zone to Clean Air Zone, there are uncertainties surrounding these responses which are discussed in Section 6 of the main body of the Technical Report. However it is assumed that if a local authority were to implement a Clean Air Zone, it would conduct a detailed scoping study to identify the optimal charge to yield a behaviour change response equivalent to that laid out below.

283. The assumed proportions of vehicle owners who respond according to the different options available is summarised in Table D.6.

Table D.6 Proportions of vehicle owners which choose certain behavioural responses

	Petrol Cars	Diesel Cars	Petrol LGVs	Diesel LGVs	RHGVs	AHGVs	Buses	Coaches
Pay charge	24%	24%	1%	1%	2%	2%	0%	2%
Avoid Zone	8%	8%	24%	24%	26%	26%	0%	26%
Retrofit vehicle	0%	0%	0%	0%	0%	0%	0%	0%
Replace Vehicle	68%	68%	75%	75%	72%	72%	100%	72%

284. It is also assumed an additional 25% of those vehicle owners which would upgrade will scrap their vehicles. The charge is estimated to lead to 24% of unique vehicles entering the Clean Air Zones choosing to pay the charge. As these are the least frequent Clean Air Zone users, this translates to 10% of vehicle kilometres travelled within the Clean Air Zone and therefore 90% of vehicle kilometres would not happen as a consequence. The behavioural responses are consistent with those used within the PCM concentrations modelling.

5. Quantifying the impacts

285. The model assesses several impacts resulting from the modelled change in the fleet. The following costs and benefits are calculated:

   a. **Loss of consumer welfare/ financial cost of upgrading**

      Consumers who upgrade their vehicle as a result of traffic restrictions will incur a cost of doing so. The model calculates this via two alternative methods.

   b. **Loss of asset value**

      A certain proportion of the oldest vehicles in the fleet will be scrapped as their value falls to zero. This will incur a loss of asset value as their value was greater than zero in the baseline.

   c. **Infrastructure implementation and running cost**

      Costs are incurred by local authorities from setting up the infrastructure of Clean Air Zones and running these.

   d. **Emission change impacts**

      A change in emissions will change the health and environmental impacts on society.

286. These impacts are assessed consistently with the baseline modelling. The detailed inputs to the model are set out in Section 3 with corresponding headings to those in the calculation flow charts within Section 5.

5.1. Cost of upgrading

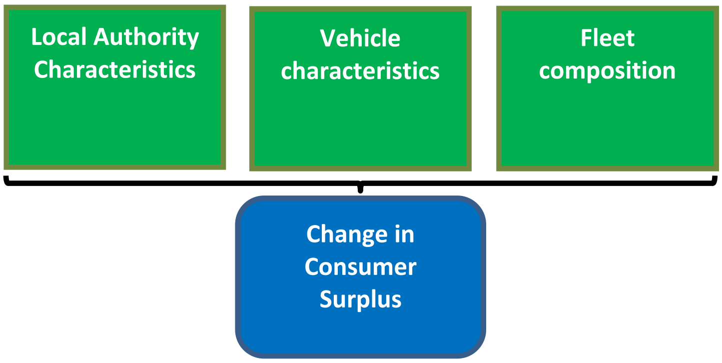
287. The different vehicle response functions are explained in Section 4.1. The response with the most significant impact on societal welfare will be on consumers that choose to upgrade to a vehicle exempt from the charge, which leads to their old vehicle being either scrapped or sold on. We have only quantified the impacts for retrofitting the vehicle, entering the Clean Air Zone and replacing the vehicle, as it is not possible to quantify the impacts of all the other behaviour changes, due to a lack of available case studies. The cost implications of the various other behaviour responses are also expected to be relatively small; for example, changing route does not put a financial burden on drivers unlike upgrading a vehicle.

288. There are two ways in which the societal cost impact from upgrading from a vehicle subject to the charge to a charge exempt vehicle has been measured; the consumer surplus approach and the financial cost approach.

5.1.1. Consumer surplus approach

289. Figure D.3 demonstrates the inputs that feed into the consumer surplus calculation (please see Table D.2, Table D.3 and Table D.4 for a full list of inputs). More detail on methodology is set out below.

Figure D.3 Inputs to consumer surplus calculation



290. The consumer surplus approach is based on the following three assumptions:

a. Owners of vehicles value them differently. It is assumed the levels at which the vehicles are valued is equally distributed between the minimum value (i.e. market price) and the maximum (i.e. minimum price of a vehicle one Euro standard above).

b. The market price is the minimum value that owners would value their vehicle at. This is assumed on the basis that otherwise they would sell their vehicle in the baseline.

c. The maximum value placed on a vehicle is the value of a vehicle one Euro standard above. This is because it is assumed that people always prefer newer vehicles, and if they are willing to pay more for a vehicle, they would purchase the higher Euro standard in the baseline.

291. Based on the three assumptions above, the loss of surplus from selling their old vehicle is calculated (See Box D.1 for an economic explanation of consumer surplus).

Box D.1: Consumer surplus – economic explanation

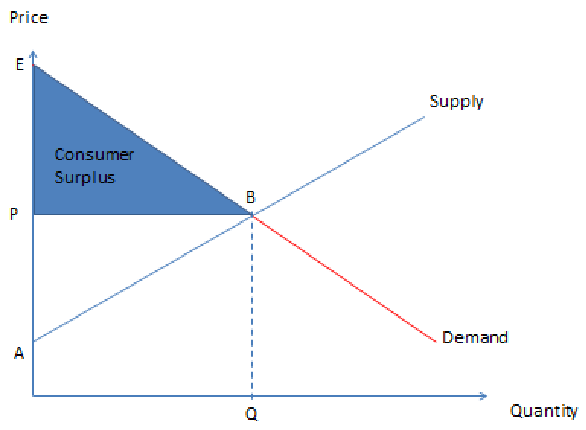
The value a consumer puts on a vehicle over the price they paid for it is called the consumer surplus. For example, if an owner perceives that they can make an extra £3,000 a year by owning a van as they can access more customers, while the costs of purchase loan repayments and running the van total just £2,000 a year, the van owner makes £1,000 consumer surplus from owning the van.

Given this, the loss to the business of getting rid of this van cannot be assessed as the value of their vehicle at the market price alone. It would be the difference between their valuation (£3,000 in this case) and the market price.

Graphically, this can be shown through a supply and demand graph (below). The value of consumer surplus can be estimated by identifying the maximum price consumers are willing to pay for the vehicle (point E, or £3,000 in the case of the van driver) and the market price (point P; or £2,000); this is then multiplied by the number of individuals affected (Q).

This figure would provide the aggregate consumer surplus if all owners valued the vehicle equally. However, as it is assumed owners of vehicles value them differently and the levels at which they are valued is equally distributed between the maximum (i.e. price of a vehicle one Euro standard above) and minimum value (i.e. market price) this total figure is then divided by 2 to attain the total consumer surplus for the market (the blue triangle below).

Figure D.4 Simplified illustration of consumer surplus



292. In addition to there is a transaction cost associated with, searching for and buying a new vehicle. It is assumed any implementation of new vehicle emissions guidelines will be announced 4 years in advance, as households and businesses own cars for an average of 4 years, there should not be a difference in the effort required to purchase a new vehicle, whether or not a new measure is implemented.

293. It should be noted that there will be a shift in demand from vehicles subject to a charge to exempt vehicles. This would increase the number of available vehicles subject to the charge in the market, leading to a decrease in the value of such vehicles, which will negatively impact owners of vehicles subject to a charge. It is, however, not possible to forecast this change in the market price and this impact is therefore not assessed. The degree to which this will impact the results will depend upon the percentage of the UK fleet which is affected by the traffic restrictions. The impact is expected to be relatively small.

294. Additionally, it is assumed that in the model no corresponding non-monetised benefits are accrued via retrofitting. Therefore, the cost of doing so is the entire financial cost (c. £17,000 to retrofit an HGV/ bus). However non-monetised benefits are incurred when vehicles are traded for newer vehicles, therefore consumer surplus losses are much lower, and always below £17,000 for all vehicles. As a result, no drivers are assumed to choose to retrofit if the consumer surplus approach to valuation is taken.

295. Note when using the consumer surplus approach we do not value the fuel savings separately as this saving is considered to be implicitly accounted for in the consumer surplus calculation.

5.1.2. Financial cost approach

296. Vehicle owners which upgrade will incur monetary costs from purchasing a newer (and therefore more expensive) vehicle. Therefore, costs and benefits valued in this methodology are the following:

- The extra cost of purchasing a vehicle exempt from the charge (i.e. the cheapest second hand exempt vehicle, or new vehicle in 25% of cases)
- The benefit gained by selling the baseline vehicle (residual value)
- The benefit of fuel savings from owning a more efficient vehicle

297. If a vehicle is scrapped, the cost of the cheapest exempt vehicle is the cost that will be paid (as the owner receives no residual value for their vehicle). It is also assumed that 25% of vehicles will be bought new (to replace the scrapped vehicles), with corresponding cost of doing so.

298. The cost of retrofitting is accounted for as the entire financial cost. While there may be an increase in running costs, these are considered to be negligible.

299. This approach does not estimate the additional impact on owners who operate outside the Clean Air Zones. These owners will be able to purchase vehicles which do not meet standards at a lower price, and sell vehicles which do for a higher price to those drivers who do enter such Clean Air Zones.

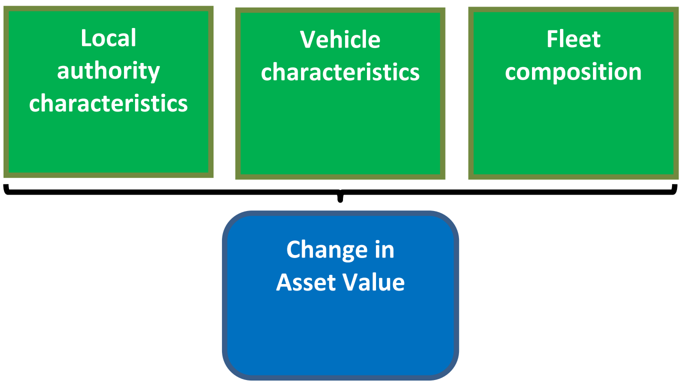
300. Vehicle owners are also assumed to have a rational option of retrofitting as the financial cost of upgrading to an exempt vehicle is higher than £17,000 for some HGVs/ buses.

301. Vehicle owners will recoup some of the costs of purchasing a newer vehicle via fuel savings. As the measure will lead to a shift from older vehicles to newer, more fuel efficient vehicles, consumers are likely to experience a fall in running costs due to savings on fuel expenditure. The final value for savings is based on the resource cost of fuel, which excludes duty and VAT. The total distance travelled by each vehicle is assumed to remain unaffected by the Clean Air Zones, and any fuel efficiency savings incurred by vehicle owners from upgrading vehicles will be implicitly captured in the consumer surplus calculation. However, for England as a whole there will be a reduction in fuel use given that a proportion of the most fuel inefficient vehicles have been scrapped and left the fleet, and replaced with vehicles which meet the standard. This translates into a resource saving from reduced expenditure on fuel.

5.2. Change in asset cost

302. The following flow chart demonstrates the specific inputs which are used as part of the change in asset cost calculation. The detailed breakdown of this calculation is laid out in the paragraphs below.

Figure D.5. Flow of inputs to Change in Asset Value



303. A proportion of the upgrading vehicle owners will buy a new vehicle. As total fleet in operation will not increase and assuming that the market for vehicles operates efficiently, it follows that a similar number of the oldest, most

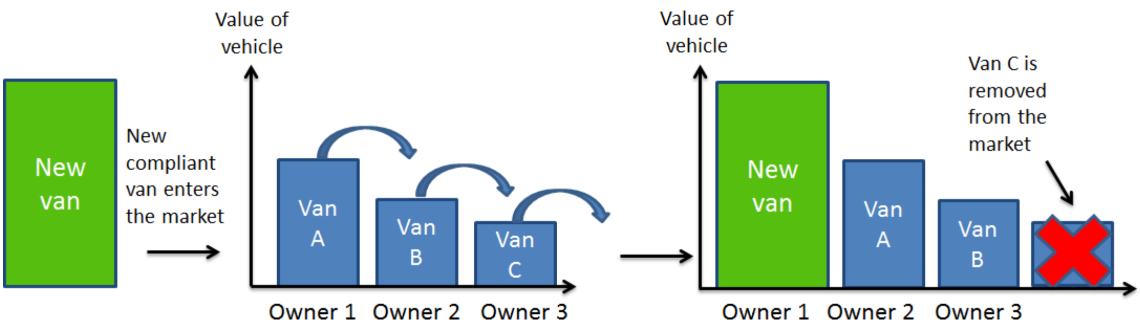
polluting vehicles will exit the market and be scrapped, as demand for such vehicles falls to zero, resulting in the deteriorating value of these vehicles.

304. Of the group who choose to upgrade their vehicle subject to a charge, it is assumed a minority will opt to purchase a new vehicle. The remainder will purchase a second hand exempt vehicle, and sell their vehicle subject to the charge to a buyer unaffected (or minimally affected) by the access restriction. It is assumed the total number of vehicles in the market does not change; therefore a proportion of old vehicles are scrapped. The number of scrapped vehicles will equal the number of new vehicles entering the market.

305. The entrance of new vehicles to the market and subsequent knock-on effects on the rest of the vehicles in the market can be demonstrated in Figure 5.4 below. For example, if van A is a Euro 5 diesel, owner 1 can sell this to owner 2, who does not travel frequently into the restricted area and owns van B, a Euro 4 diesel. Owner 2 in turn will sell on van B to owner 3, and van C (a Euro 2 diesel) will be scrapped, as its value would fall to zero.

306. However, if the access restriction had not been introduced, all vans of Type C in the market would have a value greater than zero, and would have remained in the market. The introduction means that this value is lost as demand would fall for this vehicle type, and therefore there is an additional cost to society.

Figure D.6 Fleet turnover process



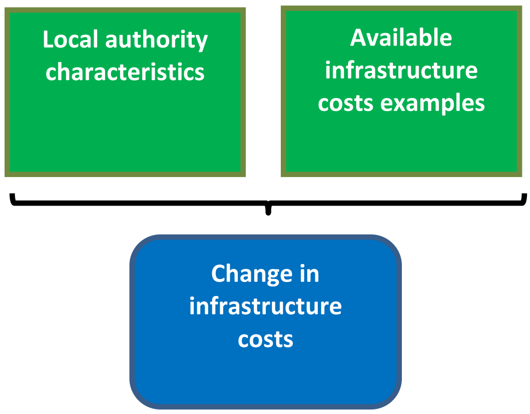
307. The number of vehicles scrapped depends upon the number of vehicles who face the charge and the behavioural assumption that a percentage, based upon the vehicle type, will be scrapped as a result of Clean Air Zones.

308. The residual value of the vehicles scrapped prior to the introduction of Clean Air Zones has been calculated based on the age of vehicle and depreciation rates over time. For example, a vehicle with a limited operational life remaining but which is scrapped earlier is valued at the estimated price of a vehicle of that type and age. The total residual value of the vehicles scrapped is considered to be the loss of asset value to society as a result of the introduction of Clean Air Zones.

5.3. Change in infrastructure costs

309. The following flowchart highlights which specific inputs are used to calculate the change in infrastructure costs. The full process is detailed below.

Figure D.7 Inputs to infrastructure capital and running costs



310. Clean Air Zones which are included in the network will incur costs of setting up and for enforcement of vehicle emission standards. Such costs could include the following:

311. General infrastructure and implementation costs (e.g. signage, monitoring compliance)

312. Automatic Number Plate Recognition system (e.g. ANPR camera and installation costs, running costs, IT equipment) however, other systems may be more appropriate for the area in question

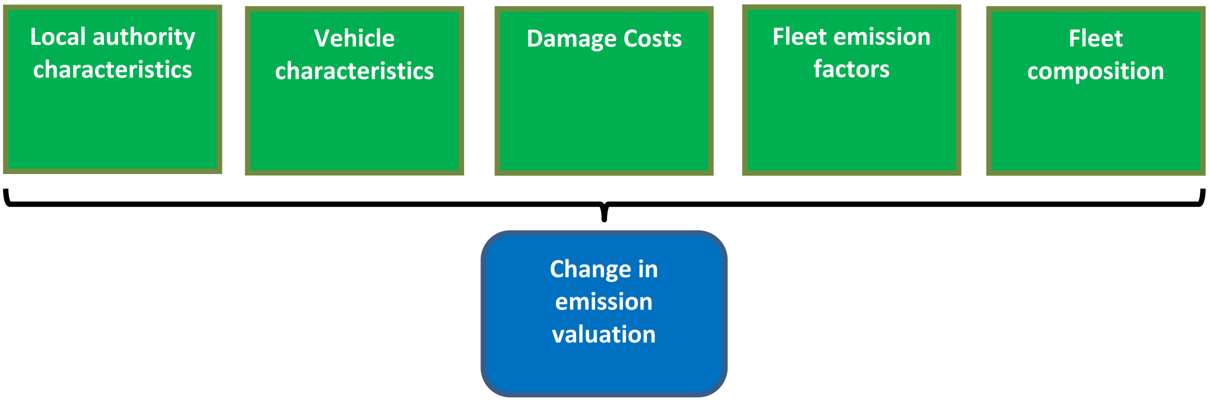
313. Ongoing communication, enforcement and staff costs

314. Defra have scaled costs of implementation from available data on similar schemes. To estimate the costs that will be incurred within the restricted areas considered in the model, these costs were scaled up depending on the total population and perimeter lengths of the Clean Air Zones to obtain the costs for each Clean Air Zone under assessment.

5.4. Emission change impacts

315. The following flowchart highlights which specific inputs are used to calculate the emission changes as a result of Clean Air Zone implementation. The full process is detailed below.

Figure D.8 Inputs to emissions change



316. The tonnage of NO_X emission reductions inside Clean Air Zones is provided from the PCM model runs for 2020, 2025 and 2030 and extrapolated for other years. Reductions will decrease with time as the fleet naturally upgrades to cleaner vehicles exempt from the charge.

317. A change in NO_X and PM emissions is expected outside the Clean Air Zones. Some drivers subject to the charge will divert journeys to avoid the Clean Air Zone. This will increase the emission levels outside the Clean Air Zone. Other vehicles subject to the charge will be sold outside the Clean Air Zone when drivers upgrade to vehicles exempt from the charge, however it is assumed this would still be an upgrade from an older vehicle, therefore reducing the emissions outside of the Clean Air Zone. The overall change can be calculated by adding the vehicle kilometres of vehicles avoiding the Clean Air Zone and then taking away the emissions savings produced from the newer vehicles bought outside the Clean Air Zone.

318. For those vehicles scrapped, as a result of the Clean Air Zones, a calculation has been made to account for the emissions savings that would have been incurred over the ten year assessment period. The distance travelled by each scrapped vehicle per annum and the emissions produced as a result, is multiplied by the remainder of each scrapped vehicles expected lifetime within the assessment period. This provides the expected emissions which are no longer produced on the roads by scrapped vehicles, as a result of the traffic restrictions.

319. The PCM does not provide estimates of CO_2 changes. CO_2 emission factors for different vehicle types and Euro standards are obtained from Transport Research Laboratory. As the fleet upgrades to newer, more fuel efficient vehicles and a proportion of the fleet is scrapped, there will be a reduction in CO_2 emissions. From the data available on number of vehicles, Euro

standard and distance travelled, it is possible to approximate the reduction on emissions due to the upgrade in fleet. It is also able to calculate the fuel cost savings, using projections of diesel and petrol prices from DECC[91].

[91] https://www.gov.uk/government/publications/fossil-fuel-price-projections-2014

6. Calculating net present value

320. For ongoing benefits, a 10 year appraisal period is used from 2020 outside London and in the ULEZ, and from 2025 for the Greater London area excluding the ULEZ. For analysis purposes, costs incurred with implementation and upgrading are upfront costs and are assumed to be incurred in 2020. Fuel, NO_x and CO_2 impacts associated with local measures are incurred over the 10 year period.

321. As outlined previously, total benefits include emission damage cost reduction and fuel savings, while total costs include asset loss, consumer welfare loss and infrastructure costs.

322. After obtaining the total quantified cost and benefit figures, the present value of the differences between the costs and benefits is calculated to provide the NPV discounted to 2015 prices.