Department for Environment Food & Rural Affairs

Department for Transport

UK Plan for tackling roadside nitrogen dioxide concentrations

Technical report

July 2017

Scottish Government
Riaghaltas na h-Alba
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Department of Agriculture, Environment and Rural Affairs
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Any enquiries regarding this publication should be sent to us at

Joint Air Quality Unit
Area 2C
Nobel House
17 Smith Square
London
SW1P 3JR

Email: 2017airqualityplan@defra.gsi.gov.uk

www.gov.uk/defra

Contents

Executive summary

The air quality challenge

The quality of our air is important for public wellbeing. Over recent decades, air quality has improved significantly. For example, total UK emissions of NO_x fell by almost 70 per cent between 1970 and 2015 and by over 19 per cent between 2010 and 2015. However, there is increasing evidence to suggest that air quality can adversely affect health, the environment, and economic performance. Poor air quality is the largest environmental risk to public health in the UK.

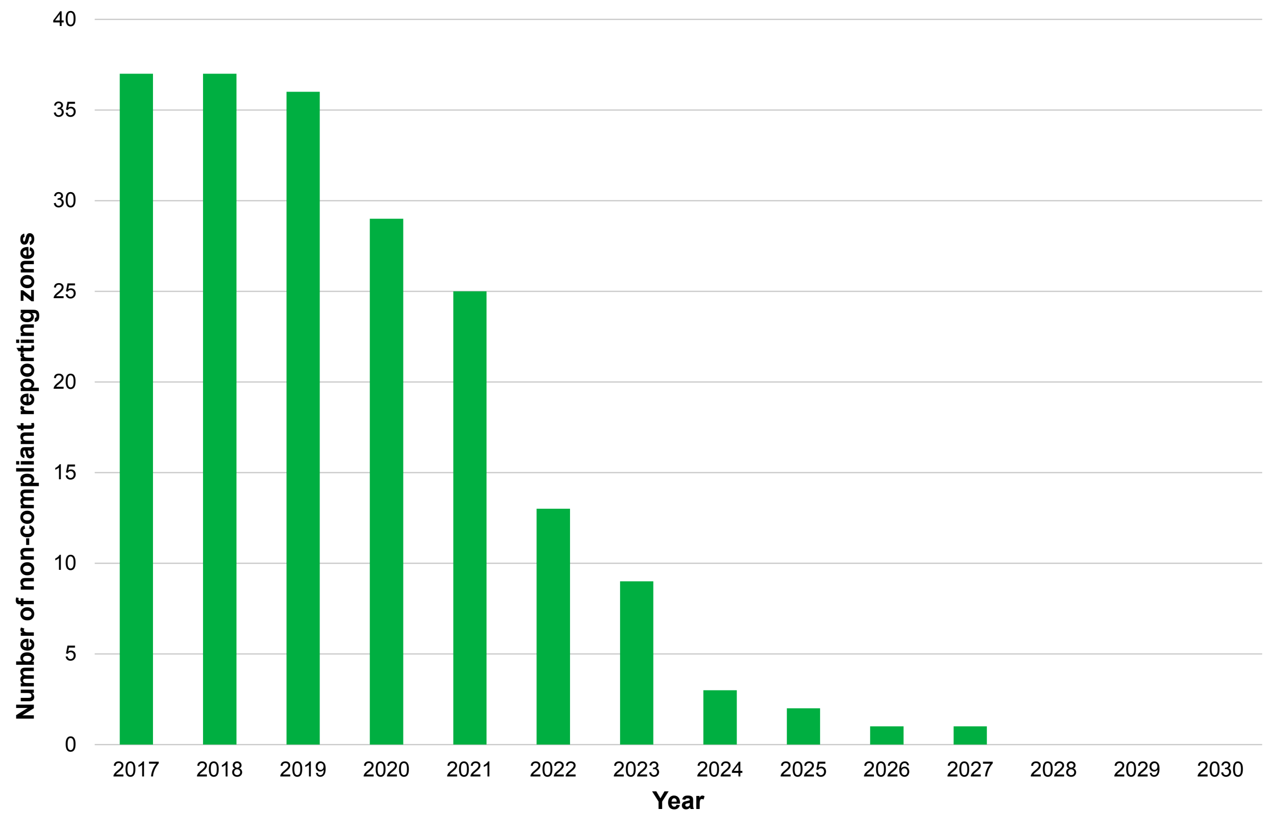
The most immediate action required on poor air quality is tackling nitrogen dioxide (NO_2) concentrations around roads - the only statutory air quality limit that the UK currently fails to meet. Tackling the problem is challenging because of uncertainty in the evidence about current and future air quality and its effects on human health. Previous standards to control emissions from cars have not performed as expected, which has led to revised emission projections revealing more areas with high NO_2 than previously modelled. Pollution from traffic is also mainly a local environment problem that requires local evidence to design effective solutions.

This technical report presents the evidence that was used to develop and assess the UK Air Quality Plan for tackling nitrogen dioxide (hereafter referred to as 'the Plan'). It is important to note that whilst this national assessment describes one route to compliance with NO_2 limit values it is unlikely to exactly reflect the eventual, locally developed plans. Supported by central guidance, local feasibility studies will use locally-specific modelling and knowledge to help design schemes which fit the local circumstances, and ongoing data collection will inform an adaptive approach that adjusts solutions as evidence emerges and uncertainty is reduced. The modelling in this report therefore provides a benchmark against which to assess local authority measures required by the Plan.

Under existing legislation, the annual average concentration of NO_2 in the air must be no higher than $40\mu g/m^3$ across a calendar year in every assessed location in each of the 43 air quality reporting zones of the UK. Additionally, an hourly average concentration over $200\mu g/m^3$ must not be reached more than 18 times in a year. The UK assesses air quality, as well as legal compliance with these obligations, via a combination of monitoring data and modelling. National estimation of background concentrations produces a result for each 1km grid square and each of 9,000 major road links in the UK, which are used to assess compliance.

As well as assessing the current situation, the same modelling processes are used to project into the future. Figure **Ex.1** presents the projected number of reporting zones estimated not to be in compliance with the annual NO_2 requirement between 2017 and 2030 if no further action is taken. The improving trend is caused by the expected benefits to air quality of stricter emission standards in new vehicles as they replace older, poorer performing vehicles. It is important to stress that these estimates of future air quality are subject to a level of uncertainty. These national modelling results are used to identify places where action is required with the objective to improve on this trend and bring these zones into compliance as quickly as possible. Local authorities will undertake their own, more locally-specific, modelling to determine suitable measures for their local plans.

Figure Ex.1 The estimated number of reporting zones projected to be non-compliant without further action



Notes: The UK is divided into a total of 43 reporting zones.

Figure **4.4** provides an estimate of the uncertainty around these projections

Assessing the Plan

In order to make a national assessment of the impact of the measures presented in the Plan it has been necessary to make significant modelling assumptions about how these measures will be delivered. These are used to assess the potential impact of the Plan on air quality, to provide a cost-benefit analysis and to investigate the effect across different sectors of society.

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These modelling assumptions do not necessarily reflect the approach that the relevant local authorities will ultimately need to take in order to deliver compliance with legal limits in the shortest possible time, and different local authorities will identify suitable approaches based on the specific nature of the exceedance(s) in their area. Annex K of the Plan sets out all local authorities with roads shown by national modelling to have NO_2 levels above legal limits. It also shows the projected levels of those roads in future years and when, in the absence of further action, they would be expected to come within legal limits.

Those areas with the greatest problem, with exceedances projected beyond the next three to four years, will be required to develop local plans. Other areas will also be expected to take steps now to reduce emissions if there are measures they could take to bring forward the point where they meet legal limits and government will take steps to support them.

To deliver compliance in the shortest possible time the Plan sets out measures covering four main strands:

- Baseline scenario - reflecting existing or ongoing action to improve air quality.
- Clean Air Zone scenario[1] - modelling an assumed network of Clean Air Zones (CAZs) in urban areas where the most serious problems occur. The assessment of these solutions assumes that work begins immediately (if not already underway) with CAZs designed and implemented locally by 2020 and 2021. This provides a benchmark against which local plans can be compared.
- Additional abatement measures - roads that are not suitable for a CAZ are more likely to need to be tackled locally through a range of solutions and the Plan does not prescribe what these might be. As such, this report only makes a high-level estimate of the potential effects because it is not possible to predict what effects different control measures might have in advance and at a national scale. The Plan requires a local assessment of these roads to be undertaken and measures which are most likely to be effective to be implemented.
- Supporting measures - which would either further improve air quality or mitigate the costs of the other measures.

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[1] Charging Clean Air Zones have been modelled to assess one potential route to compliance. However, local feasibility studies will use locally-specific modelling and knowledge to help design schemes which fit the local circumstances. Charging Clean Air Zones should only be used where no other equally effective solution is identified.

In assessing the measures in the Plan it has only been possible to model the first three strands. In the case of the additional abatement measures, only an indicative assessment of the air quality impact is presented. Supporting measures in the final strand are not assessed because they are either primarily targeted on supporting the transition to delivering the change or at present are not developed to the point at which they can be nationally assessed.

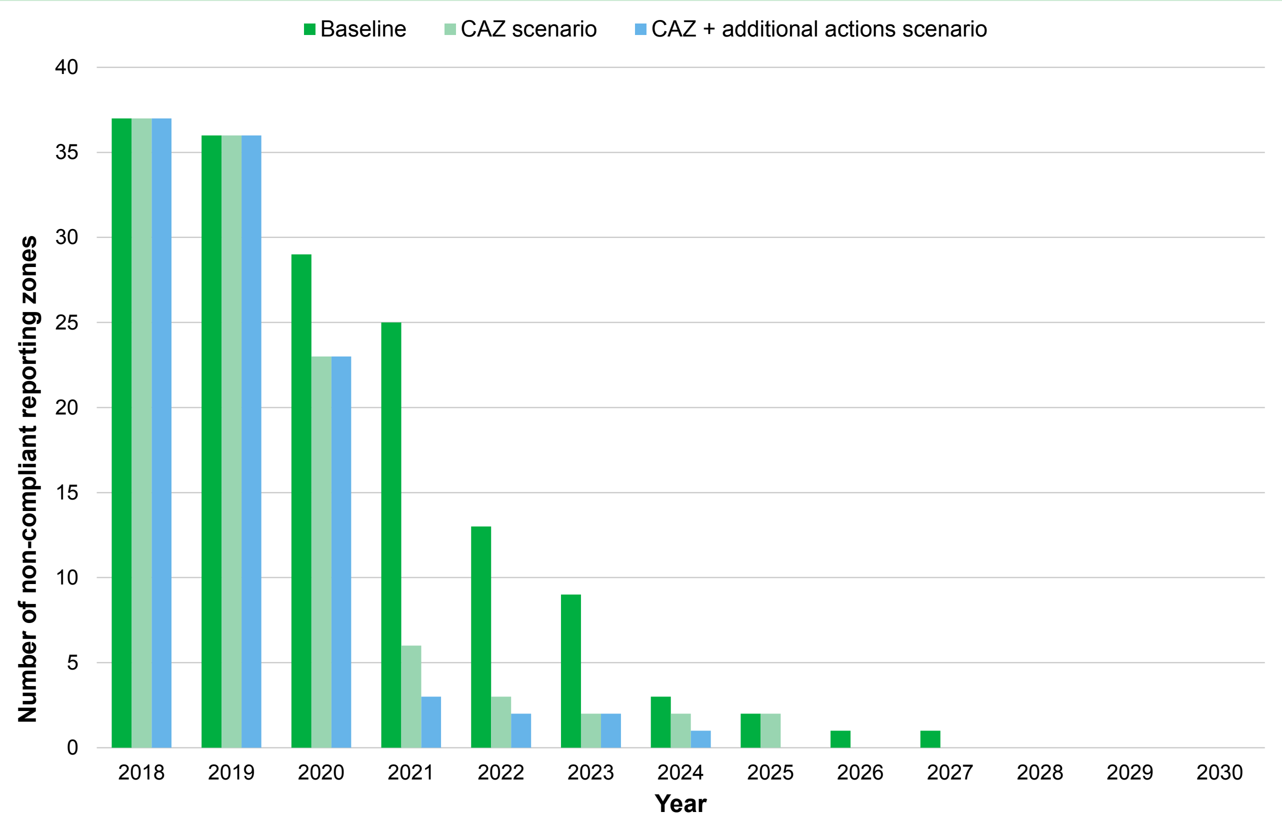
Implementation of local plans will be supported by a Clean Air Fund which will allow local authorities to bid for additional money to support the implementation of measures to improve air quality. Government will also consult on broader measures that could help mitigate the impact of local plans on businesses, residents and those travelling into towns and cities to work. Such measures are primarily intended to tackle distributional concerns. Any air quality impacts that they have are, therefore, overlapping with the measures assessed in this report and as such their impact on air quality has not been assessed.

Conclusion

The modelling results show that there is potential for local plans to bring forward compliance with statutory limits on NO_2 concentrations (Figure **Ex.2**). The framework for implementing a set of measures in practice is set out in the accompanying Air Quality Plan. The measures modelled in this report provide a benchmark against which local plans can be compared so that the most effective action can be determined. This benchmark assumes a network of CAZs, which would impact a small but significant proportion of road users.

The evidence base is subject to a substantial degree of uncertainty and so it is important to keep these results and conclusions under review to quantify the outcomes of implementing plans and, if necessary, change the measures being used.

Figure Ex.2: Comparison of the number of reporting zones projected to be non-compliant with no further action (baseline), with the modelled CAZ (CAZ scenario) and with additional abatement (CAZ + additional actions scenario)



Note: Figure **4.4** provides an estimate of the uncertainty around these projections

1. Introduction

This technical report accompanies the UK Plan for tackling roadside nitrogen dioxide concentrations (hereafter referred to as ‘the Plan’) and provides a benchmark against which to assess local authority measures required by the Plan.

1.1 The air quality challenge

Over recent decades, air quality has improved significantly. For example, total UK emissions of NO_x fell by almost 70 per cent between 1970 and 2015 and by over 19 per cent between 2010 and 2015.[2] However, evidence continues to build that air quality has an important effect on public health, the economy, and the environment.[3] Poor air quality is the largest environmental risk to public health in the UK.[4] Older people, children, people with pre-existing lung and heart conditions, and people on lower incomes may be most at risk.[5]

Air quality has a wide range of impacts and it is difficult to quantify and value them fully. These impacts can be separated into four broad categories: health, productivity, subjective wellbeing, and ecosystems. Only a subset of these impacts can currently be quantified and valued but a fuller picture will emerge as the evidence grows.

The negative link between long-term exposure to air pollution and chronic mortality is long-recognised. The total mortality impact of air quality is subject to notable uncertainties as set out in this report. Refined recommendations from the Committee on the Medical Effects on Air Pollutants (COMEAP) on the link between NO_2 and mortality are included in Annex **A**.

Short-term exposure to high levels of air pollution can cause a range of other adverse health effects including exacerbation of asthma, effects on lung function, increases in hospital admissions and mortality. Studies show that long-term exposure to air pollution reduces life expectancy by increasing deaths from lung, heart, and circulatory conditions.

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[2] National Statistics (2016) Emissions of air pollutants in the UK, 1970 to 2015 <www.gov.uk/government/statistics/emissions-of-air-pollutants>

[3] See, for example, Department for Environment, Food and Rural Affairs and Public Health England, ‘*Air Quality: A Briefing for Directors of Public Health’,* 2017 <https://laqm.defra.gov.uk/assets/63091defraairqualityguide9web.pdf>

[4] Public Health England, ‘*Estimating local mortality burdens associated with particulate air pollution*’, 2014 <www.gov.uk/government/publications/estimating-local-mortality-burdens-associated-with-particulate-air-pollution>

[5] World Health Organization, ‘*Review of evidence on health aspects of air pollution – REVIHAAP Project*’, 2013 <www.euro.who.int/__data/assets/pdf_file/0004/193108/REVIHAAP-Final>

There is emerging evidence of possible links with a range of other adverse health effects including diabetes, cognitive decline and dementia, and effects on the unborn child.[6] [7]

Air quality can also have notable impacts on economic performance through its effect on both human and natural capital. It is estimated that in 2012 poor air quality had a total productivity cost of up to £2.7 billion.[8] In addition, ozone damages the rural economy through its impact on agriculture (crop production has been found to be reduced by up to nine per cent in years with high ozone).[9]

Recent research has found a strong link between NO_2 exposure and self-reported life satisfaction after controlling for a range of other economic, social, and environmental factors including health.[10] Survey evidence also suggests that air quality causes stress and anxiety that can lead people to have diminished life experiences.

In addition, air quality also impacts the environment. Between 2013 and 2015, 44 per cent of sensitive habitats across the UK were estimated to be at risk of significant harm from acidity and 63 per cent from nitrogen deposition.[11] It has also been found that ozone affects ecosystems (by reducing carbon uptake and biomass in sensitive plants and trees).

Further research continues to improve our understanding of the health, economic and environmental effects of air pollution meaning the evidence is subject to change. Nevertheless, the currently available evidence indicates it is an important issue that requires action.

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[6] Ibid.

[7] Royal College of Physicians, '*Every breath we take: the lifelong impact of air pollution*', 2016 <www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution>

[8] Department for Environment, Food and Rural Affairs, '*Valuing the impacts of air quality on productivity*', 2015 <https://uk-air.defra.gov.uk/assets/documents/reports/cat19/1511251135_140610_Valuing_the_impacts_of_air_quality_on_productivity_Final_Report_3_0.pdf>

[9] Ozone factsheets produced by the Natural Environment Research Council, Centre for Ecology and Hydrology and the Science and Technology Facilities Council are available at <www.ozone-net.org.uk/factsheets>

[10] Knight and Howley, '*Can clean air make you happy? Examining the effect of nitrogen dioxide (NO_2) on life satisfaction*', 2017 <www.york.ac.uk/media/economics/documents/hedg/workingpapers/1708.pdf>

[11] Based on a 2013-2015 three-year average. Department for Environment, Food and Rural Affairs, '*Provision of Mapping and Modelling of Critical Loads and Critical Levels Exceedance 2016-19*', 2016.

1.2 Sources of air pollution

Air pollution comes from many sources and is made up of many different pollutants. These pollutants behave differently when in the atmosphere and can undergo chemical reactions with each other (Box **1.1**).

Box 1.1: An overview of the health effects of the main air pollutants
Nitrogen oxides (NO_x) NO_x emissions are made up of both nitrogen dioxide ('primary' NO_2) and nitric oxide (NO) and are released from the combustion processes from domestic (boilers, wood burners), industrial (manufacturing and construction) and road transport (engines). NO reacts with oxidants such as ozone to form NO_2 in the atmosphere ('secondary NO_2'). Short-term exposure to concentrations of NO_2 higher than 200µg/m^3 can cause inflammation of the airways. NO_2 can also increase susceptibility to respiratory infections and to allergens. It is difficult to identify and quantify the direct health effects of NO_2 at ambient concentrations because it is emitted from the same sources as other pollutants such as particulate matter (PM). The evidence associating NO_2 with health effects has strengthened substantially in recent years. Studies have found that both day-to-day variations and long-term exposure to NO_2 are associated with increased mortality and morbidity. Evidence from studies that have corrected for the effects of PM is suggestive of a causal relationship, particularly for respiratory outcomes.
Particulate matter (PM_{10} and $PM_{2.5}$) 'Primary' PM is produced by combustion in industry and road transport, particularly from diesel vehicles (PM_{10}). 'Secondary' PM is formed by the chemical reaction of other pollutants, such as NO_x, sulphur dioxide or ammonia (NH_3). Fine particulate matter can penetrate deep into the lungs and research in recent years has strengthened the evidence that both short-term and long-term exposure to $PM_{2.5}$ are linked with a range of adverse health outcomes including (but not restricted to) respiratory and cardiovascular effects.
Sulphur dioxide (SO_2) Emitted primarily as a result of combustion of sulphur containing fuels in power stations (for heat and electricity). A respiratory irritant that can cause constriction of the airways. People with asthma are considered to be particularly sensitive. Health effects can occur very rapidly, meaning short-term exposure to peak concentrations can have significant effects.

Ozone (O_3) A respiratory irritant formed by reactions between non-methane volatile organic compounds and nitrogen oxides in the presence of sunlight. Ozone reacts with NO to form NO_2. Short-term exposure to high ambient concentrations of O_3 can cause inflammation of the respiratory tract and irritation of the eyes, nose, and throat. High levels may exacerbate asthma or trigger asthma attacks in susceptible people and some non-asthmatic individuals may also experience chest discomfort whilst breathing. Evidence is emerging of negative health effects due to long-term exposure. In addition, ground-level O_3 is a greenhouse gas contributing to climate change.
Non-methane volatile organic compounds (NM-VOCs) Emitted to air from the use of solvents (such as in paints, fuel and pesticides), extraction and distribution of fossil fuels and from combustion processes primarily from domestic wood burning, but are also emitted from diesel exhaust. Significantly, NM-VOCs react with NO_x in the presence of sunlight to form ground-level O_3. The health effects of volatile organic compounds themselves (putting aside their role in O_3 formation) can vary greatly according to the compound, which can range from being highly toxic to having no known health effects.
Sources: Adapted from Air pollution in the UK 2015[12] and the National Atmospheric Emissions Inventory webpages.[13]

Many normal activities contribute to poor air quality so tackling air quality means changing the way people have become used to living and working. Each pollutant is produced in different proportions by different sources. Road vehicles contribute about 80 per cent of NO_x pollution at the roadside. Growth in the number of diesel cars and vans,[14] coupled with the failure of vehicle manufacturers to ensure that they replicated laboratory test-based emissions performance (Euro standards) in real world driving conditions, has exacerbated this problem because of the NO_x they emit (Figures **1.2** and **1.3**).

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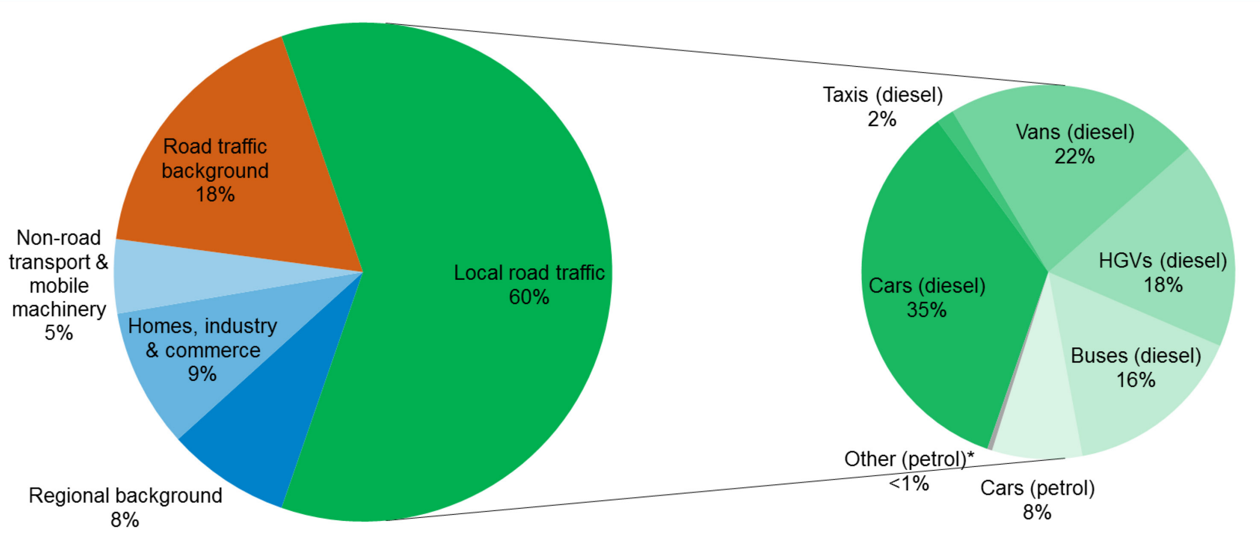
[12] Department for Environment, Food and Rural Affairs, *'Air pollution in the UK 2015'*, 2016 <https://uk-air.defra.gov.uk/library/annualreport/viewonline?year=2015_issue_1>

[13] National Atmospheric Emissions Inventory, Overview of air pollutants, <http://naei.defra.gov.uk/overview/ap-overview>

[14] Between 2000 and 2016 the number of diesel cars in Great Britain increased from 3.2 million to 12.1 million and diesel vans increased from 1.8 million to 3.6 million. Department for Transport, *'Vehicle Licensing Statistics: Quarter 4 (Oct – Dec) 2015'*, 2016 – car statistics tables <www.gov.uk/government/uploads/system/uploads/attachment_data/file/516429/vehicle-licensing-statistics-2015.pdf>

Figure 1.2: UK national average NO_x roadside concentration apportioned by source of NO_x emissions, 2015



Source: National modelling 2017

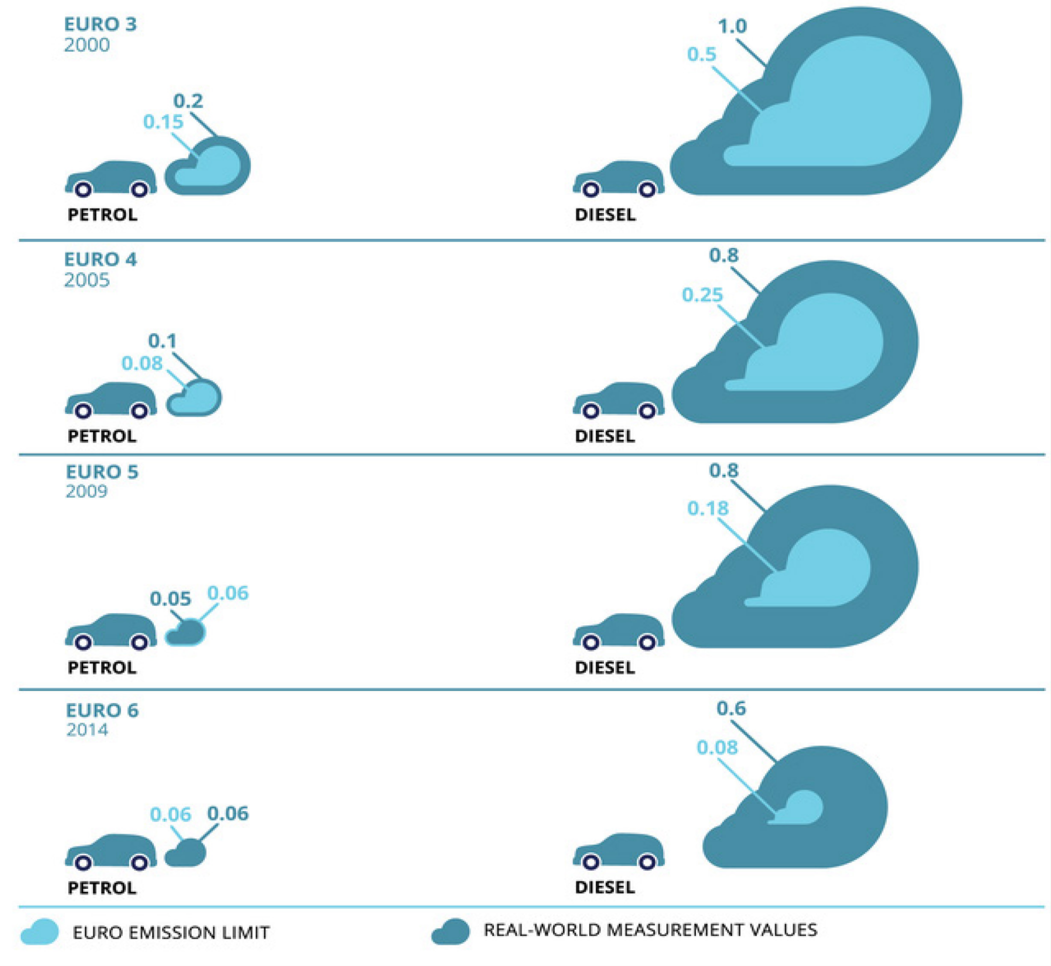
Note: 'Local road traffic' in the large pie chart is the estimate of the proportion of local NOx roadside concentrations contributed by traffic on that road and is shown in greater detail in the smaller pie chart. 'Road traffic background' is the estimate of NOx concentrations contributed by traffic on other roads.

Note: Figures may sum to more than 100% due to rounding.

Note: HGVs = Heavy Goods Vehicles.

* Other (petrol) is made up of petrol vans and motorcycles.

Figure 1.3: Comparison of NO_x (g/km) emission standards for different car Euro standards, by emission limit and real-world performance



Source: Adapted from a report by the European Environment Agency.[15]

1.3 Regulatory framework

The UK has national and international obligations that require control of air pollution.[16] The legal requirement for NO_2 stipulates that the annual average concentration of NO_2 must be no more than 40µg/m^3 across a whole year within all 43 reporting zones of the UK (Figure **1.4**). Additionally, an hourly average concentration over 200µg/m^3 must not be

[15] European Environment Agency (EEA), *'Explaining road transport emissions – A non-technical guide'*, 2016 <www.eea.europa.eu/publications/explaining-road-transport-emissions>

[16] See the Air Quality Standards Regulations 2010 (SI 2010/1001), the Air Quality Standards (Scotland) Regulations (SSI 2010/204), the Air Quality Standards (Wales) Regulations 2010 (SI 2010/1433) and the Air Quality Standards Regulations (Northern Ireland) 2010 (SR 2010 No 188), as amended.

reached more than 18 times in a year.[17] One requirement of the legislation is the publication of information on the UK's climate, topography and population, which can be found in Annex **B**.

The system used to report air quality information and to assess legal compliance has been approved by the European Commission. Many other European countries use denser networks of monitoring stations than are used in the UK because these countries choose not to use supplementary modelling. Consequently, those countries report empirical data whereas the UK reports the outputs of models alongside monitoring data. The modelling approach is used in the UK because it provides a more complete assessment of all relevant locations. It also enables added consistency for modelling future scenarios of air quality, which is integral to assessing the impact of measures presented in this Plan. However, the use of a model based on monitoring observations does introduce a degree of uncertainty about historical pollution levels compared to obtaining further empirical data.

In 2015 (the latest year for which a compliance assessment is available), 37 of the 43 air quality reporting zones exceeded the statutory annual mean limit of 40µg/m^3 for NO_2.

[17] The annual average requirement is widely accepted to be a more stringent requirement than the hourly average. This is illustrated by the fact that the latest compliance modelling shows that 37 zones are not compliant with the annual average requirement but only two do not meet the hourly average. Therefore the plan focuses on the annual average as the more challenging requirement.

Figure 1.4: UK air quality reporting zones; for monitoring and reporting air pollution the UK is divided into agglomeration zones (major urban areas) and non-agglomeration zones

1.4 Actions to improve air quality

The Plan focuses on how to reduce concentrations of NO_2 to meet the legal limits in the shortest time possible. The measures modelled in this report are not intended to dictate the single way in which government believes compliance with these limits can be achieved. Assessments by local authorities may reveal alternative approaches – informed by specific local knowledge – which would enable compliance to be achieved as, or more, quickly. However, the limitations of national modelling and the data available on local circumstances means it is not possible to model such interventions centrally. As such this technical report provides an assessment of the benchmark against which local plans will be measured and assesses the impacts of key measures identified in the Plan, including an assessment of the differential impacts of the measures on different parts of society. Once local modelling and feasibility studies have been completed it will become clearer what measures are required at a local level.

1.5 Uncertainties

There are important uncertainties surrounding the modelling and forecasting of air quality impacts, as well as the estimation of the associated costs and benefits. These uncertainties arise for a variety of reasons, including limited availability, or consistency, of evidence and data, and inherently unpredictable factors associated with forecasting. This report makes explicit the uncertainties that exist in the evidence about the measurement and modelling of air quality and its impacts, primarily on human health.

An Air Quality Review Group was established by the Defra Chief Scientific Advisor to provide wider assurance of the evidence as it was developed for the Plan. A particular consideration has been how to take account of, and communicate, the uncertainties related to the evidence. The group recommended that the assessment of uncertainties should be aligned with guidance from the Intergovernmental Panel on Climate Change (IPCC).[18] This has been done to enable consistent communication of how different sources of uncertainty compare.

Two expert panels were convened to provide independent guidance on the two key areas of uncertainty: air quality modelling and cost-benefit analysis. These panels were asked to identify and assess, quantitatively where possible and qualitatively where not, the elements of the analysis that are subject to greatest uncertainty and that have a material impact on the results.

The output from this exercise provides valuable context for the analysis overall. It underlines the importance of interpreting the results in this report with caution and the need to undertake continuous evaluation of real-world outcomes in order to adapt plans made based on this evidence. The identification of these uncertainties is not a justification for inaction but a rationale for swift implementation and ongoing evaluation of policies. There are areas of high uncertainty around some of the inputs and assumptions and for many of these it will take years of research to reduce the uncertainties. Some of the uncertainties can only be reduced by implementing the Plan, measuring the outcomes and then, where necessary, adapting the policies in the future based on increased knowledge of how well they have performed against expectation. To that end, systematic evaluation of the performance of interventions to control air quality will be used to adjust and improve the range of controls and thereby incrementally build confidence in which methods are most effective.

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[18] Mastrandrea, M.D. et al., '*Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties*' (2010) Intergovernmental Panel on Climate Change <www.ipcc.ch/pdf/supporting-material/uncertainty-guidance-note.pdf>

1.6 Building on the existing evidence base

The draft Plan technical report[19] investigated the impacts of a range of potential policy options and presented them for consultation. The evidence in that report established that:

- All roads come into compliance eventually due to the natural upgrade of the national fleet to cleaner models.
- A Network of Clean Air Zones (CAZs) is the most effective route to compliance[20] for the majority of exceedances. The design will be determined by local feasibility studies and could include access restrictions on vehicles, such as charging zones.
- The impact of measures targeting the most polluting vehicles is likely to be distributed unevenly and there are ways that these impacts could be mitigated.
- Some national actions on government vehicles and vehicle labelling standards could deliver a small but cost effective improvement.
- No general solution was identified to address exceedences that cannot be tackled with a CAZ (for example on motorways and roads outside of urban areas). Therefore local bespoke solutions would need to be considered.

This report does not repeat the content of the technical report that accompanied the draft Plan but builds on it to show the cumulative impact of the measures presented in the Plan and how it has been assessed.

This is done by explaining the analysis methods used, presenting the results, discussing the uncertainties and looking at the next steps in building the evidence base for tackling the NO_2 problem on the UK's roads.

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[19] Department for the Environment, Food and Rural Affairs, '*Draft UK Air Quality Plan for tackling nitrogen dioxide – Technical Report*', 2017 <www.gov.uk/government/consultations/improving-air-quality-reducing-nitrogen-dioxide-in-our-towns-and-cities>

[20] Effectiveness was assessed against three critical success factors: air quality impact, timing to impact and deliverability.

2. Assessment methods

This section describes the methods used to assess air quality in the UK, the results of that assessment and the methods used to assess the measures in the Plan. Emphasis is placed on describing changes introduced since the draft Plan technical report.[21]

2.1 Air quality assessment

A robust assessment of the state of the current and projected air quality in the UK, and the impact this has across the population, is important as the starting point for the Plan. Understanding the impact of policy options on air quality provides evidence for the actions identified in the Plan.

2.1.1 Air quality assessment methods

The draft Plan technical report provides details of the methods used to model and monitor air quality to assess compliance with NO_2 limits and to model future concentrations.

In brief, emissions from the National Atmospheric Emissions Inventory (NAEI)[22] are mapped across the UK within a Geographic Information System (GIS). Deterministic dispersion models specific to each pollutant are used to simulate atmospheric mixing and to generate background concentrations for different pollutants. The modelled results are then calibrated against measured concentrations from the national monitoring network and then verified. This modelling provides an estimate of the distribution of atmospheric pollutants including NO_2 on a 1km x 1km grid and for individual roads. Collectively, this is known as the Pollution Climate Mapping (PCM) model and is operated on behalf of Defra by Ricardo Energy & Environment.

Statistical analysis of the model results and independently measured NO_2 concentration data (Section **4.1.1**) estimates that the PCM model has an overarching uncertainty of ±29 per cent.

2.1.2 Air quality compliance

The latest historical assessment of UK air quality is for 2015 and shows 37 of the 43 reporting zones exceed the 40µg/m^3 annual mean NO_2 limit value in at least one location. In the same year only two of these 37 zones also exceeded the hourly average NO_2 limit value (Greater London Urban Area and South Wales).

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[21] Department for the Environment, Food and Rural Affairs, '*Draft UK Air Quality Plan for tackling nitrogen dioxide – Technical Report*', 2017 <www.gov.uk/government/consultations/improving-air-quality-reducing-nitrogen-dioxide-in-our-towns-and-cities>

[22] National Atmospheric Emissions Inventory <http://naei.defra.gov.uk/>

2.1.3 Air quality projections

The draft Plan technical report was based on the best projections of future NO_2 concentrations available. Since then, new projections of future NO_2 concentrations have been updated using the PCM model.

The new projections use the most recent historical assessment (2015) as the base year. As such, these projections use the latest available input data including 2015 road transport figures from the Department for Transport (DfT), the 2015 calibration of the PCM model with measurement data from the Automatic Urban and Rural Network (AURN), and the latest emission factors from COPERT 5.[23]

The latest PCM modelled projections provide annual average projected NO_2 concentrations for all years from 2017-2030 inclusive, with road transport NO_x emissions modelled discretely for each individual year. This is the first time that NO_2 projections have been modelled with this level of temporal detail.[24] The highest estimated concentration found in each reporting zone in each year up to 2030 is provided in Annex **C**.

Figure **2.1** compares the number of zones projected to exceed the NO_2 limit value without further action used both in the draft Plan and for this final Plan. Even accounting for uncertainties, the effects of currently implemented measures to control air pollution produce a substantial and progressive decline in the number of zones in exceedance. The latest information suggests slightly less improvement at the reporting zone level in the short term (2017 to 2021). However in the longer term an increased number of zones are expected to become compliant in the period from 2022 to 2026.

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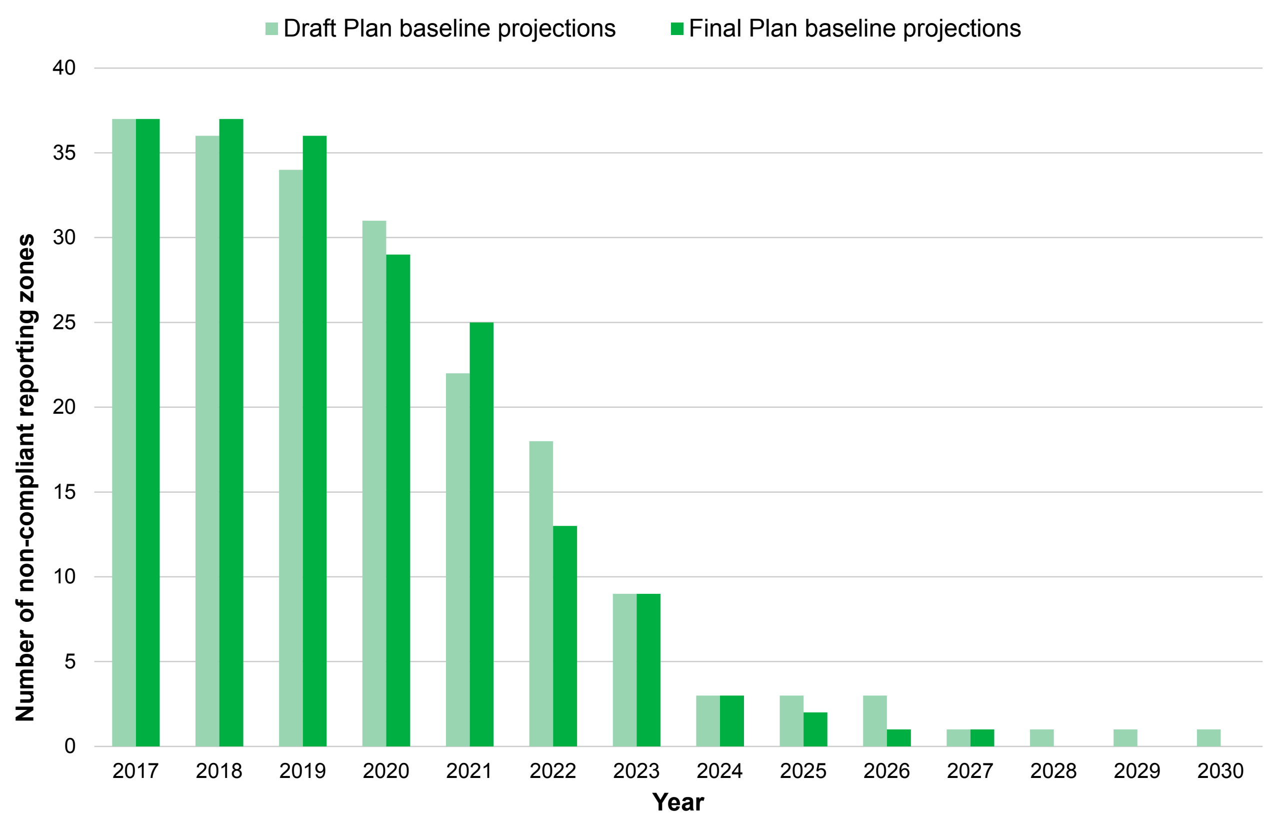
[23] COPERT (Computer Program to calculate Emissions from Road Transport) NO_x emission factors are combined with road traffic numbers to estimate national emissions. Version 5 was published in September 2016 and takes into account real-world driving conditions emissions testing conducted in the UK and other European countries.

[24] The 2015 Plan presented projected concentrations modelled at five year intervals. The draft 2017 Plan presented projected concentrations for the years 2017-2030, but these were provided based on modelling five year intervals and linear interpolation.

Figure 2.1 Comparison of the number of reporting zones projected to be non-compliant without further action (baseline) in the draft and final 2017 Plans.



Note: Figure **4.4** provides an estimate of the uncertainty around these projections

The differences between these two sets of projections arise from the following changes:

- **Base year**

  The draft Plan used the previous historical assessment (2013) as the base year with adjustments to account for the shift from COPERT 4.11 to COPERT 5. This represented the most up-to-date modelling at the time of the draft Plan. The final Plan uses the most recently available historical assessment from the full modelled process (2015) as the base year.

- **Data input updates**

  The final Plan projections include updates in data inputs including to traffic flow data (2015 rather than 2013), COPERT emission factors (version 5 within the baseline rather than version 4.11) and model calibration (with measurements from 2015 rather than 2013). These are all fully incorporated throughout the NAEI, PCM model, and Streamlined Pollution Climate Mapping (SL-PCM) model.

- **Modelled years**

  The final Plan includes modelled projections for individual years from 2017 to 2030, rather than interpolated projections between modelled projections of five-yearly intervals as in the draft Plan.

- **New policies**

  The final Plan baseline includes the effects of certain measures that were not included in the draft Plan projections. Most notable is the progress that has been made introducing the Ultra Low Emission Zone (ULEZ) in central London. This means that the UK is now projected to reach compliance by 2028 in the baseline scenario (Figure 2.1).

Although the updated projections impact compliance in some specific areas they do not alter the overall scale of the challenge or the range of options needed to tackle it.

2.1.4 Assessing the impact of air quality across the population

Building on the draft Plan technical report, evidence on the distributional impacts of NO_2 has been drawn from peer-reviewed papers, Defra-commissioned research and reviews.

The assessment (full details in Annex **D**) suggests that in England NO_2 concentrations are highest where the most deprived populations live, but both the least and most deprived groups live in neighbourhoods with higher concentrations than those in the middle of the deprivation distribution. This broadly reflects the population living in urban centres. Higher concentrations of NO_2 have also been found in ethnically diverse neighbourhoods.

2.1.5 Assessing the impact of policy options on air quality

The Streamlined Pollution Climate Mapping (SL-PCM) model is a rapid assessment tool, based on the outputs of the full PCM model, used to analyse the impact of policy options on air quality. For the draft Plan, technical report analysis was conducted with the latest version of the SL-PCM model available at the time.

Since then new SL-PCM models have been produced based on the latest full PCM modelling set out in Section **2.1.3**. They are now consistent with the latest PCM modelling: the SL-PCM model projections are based on a 2015 base year and one model has been developed for each of the projected years 2018-2030 inclusive. That means that, unlike previous modelling, modelling is conducted for each year separately and no interpolation is required. These have been used to estimate the air quality impact of the measures with more accuracy in these years. An independent quality assurance review of the models (Box **2.2**) was conducted before analysis began.

Box 2.2 SL-PCM model Independent Quality Assurance Review

Scope of review

Independent air quality experts Prof Paul Monks, Dr Mathew Heal and Dr Chun Li. carried out a Quality Assurance (QA) review of the latest SL-PCM model in May 2017. This review covered two key aspects:

- Detailed model function checks (checking that links and code contained within the model work correctly)
- Higher level 'sense checks' testing that when certain parameters are changed the model behaves as it should.

Key findings

Overall, the review concluded that the SL-PCM model is fit for purpose. It did not reveal any results that raise concern over the validity of the model for delivering what it is designed to do.

The detailed inspection of the content and links between spreadsheet columns and tabs revealed one finding that was not as expected. Modelling results were not affected because that part of the model is not used in the new version of the SL-PCM model. For completeness, and in line with best practice, Ricardo will correct this in a future version of the SL-PCM model.

Model sensitivity runs yielded findings qualitatively in line with expectations.

Due to the nature of the review and the model, it was not possible to verify the accuracy of underlying data. The reviewers therefore noted that the validity of the SL-PCM model outputs is intrinsically reliant on the validity of the full PCM model under the given scenario and that users are required to have a good understanding of the model in order to use it accurately.

2.2 Economic assessment

In addition to reducing NO_2 concentrations, the Plan will have a range of other impacts. The economic assessment attempts to reflect these impacts through cost-benefit analysis and distributional analysis. The methods described in the draft Plan technical report have been used with a number of improvements and updates, which are described in this section.

The cost-benefit analysis focuses on the most significant direct impacts as required by government best practice appraisal guidance.[25] The impacts that have been assessed fall into the following categories:

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[25] HM Treasury, '*The Green Book: appraisal and evaluation in central government*', <www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent>

- Air quality – reflecting the reduced impacts from health problems, productivity and the environment linked to reduced concentrations of NO_2
- Greenhouse gas emissions – valued according to government appraisal guidelines
- Social impact – reflecting the direct costs and benefits of the given action to society
- Government impact – including implementation and set-up costs
- Traffic flow impacts – for CAZs, monetising the value of the time saving resulting from fewer vehicles on the road

The NO_2 baseline projections produced by the PCM model (Figure **2.1**) include the impacts of the London ULEZ. This is because the latest fleet composition data include these impacts. For the purposes of the economic assessment, the effects of the ULEZ have been removed from the baseline projections[26] so that they can be included in the effects of the Plan. This is consistent with the approach taken for the 2015 Plan and the draft 2017 Plan, ensuring that the impacts of both plans are brought together and that London is treated in the same way as other urban areas.

The various policies in the Plan will have different implementation dates and since PCM results are available until 2030 a consistent appraisal period of 2018-2030 has been used. Some costs and benefits will continue after this period, and the residual value of infrastructure at the end of the period has not been included, but these are not expected to affect the cost-benefit results significantly. Once estimated these impacts have been discounted using the social discount rate of 3.5 per cent and summed to calculate the net present value (NPV) of the Plan. All estimates use 2017 as the price base year as well as the present value base year.

2.2.1 Assessing health impacts

A key consideration of the cost-benefit analysis is the health improvement expected as a result of the measures in the Plan. The Committee on the Medical Effects of Air Pollutants (COMEAP) provides independent advice to UK government departments on how air pollution impacts on health. Where evidence is well developed, a quantitative relationship is established linking a given reduction in concentrations of a pollutant to the resulting reduction in risk of the health impact occurring. Economic methods to value health outcomes can then be applied to monetise the health benefit. Where the evidence is not sufficient to produce a quantitative estimate a qualitative assessment of possible health benefits is produced instead.

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[26] The baseline projections were adjusted by taking the higher of the concentration values in the draft and final Plan baseline projections for roads in London. These adjusted baseline projections are a modelling construct and not used outside the economic assessment.

Evidence linking air pollution with adverse effects on health continues to accumulate but quantification of its effects remains challenging. Attributing effects to individual pollutants is particularly difficult because a number of pollutants are emitted from the same sources and so their distribution tends to be similar.[27] This makes it difficult to disentangle their effects. There are therefore a range of estimates of the link between NO_2 and mortality. There is good mechanistic evidence to indicate a causal role for particulate pollution, but there is also increasing evidence suggesting some direct effects of NO_2 itself, particularly effects on lungs.[28 29]

COMEAP continues to work in this area and recently wrote to ministers explaining its latest advice on quantifying mortality effects associated with long-term average concentrations of NO_2 (Annex **A**). The letter explains the uncertainties and recommends methods for quantifying the mortality benefits expected from measures that either:

- remove or reduce all traffic-related pollutants, including NO_2, or
- reduce NO_2 concentrations primarily by targeting reductions in NO_x emissions

For measures that remove or reduce all traffic-related pollutants COMEAP recommended that a coefficient[30] of 1.023 per 10μg/m^3 NO_2 could be used in cost-benefit analysis (with a 95 per cent confidence interval of 1.008–1.037) to reflect associations between long-term average concentrations of NO_2 and all-cause mortality.

COMEAP recognised that this could overestimate the effects associated with NO_2 due to potential confounding by $PM_{2.5}$ and other pollutants. Therefore, for interventions that primarily target emissions of NO_x, like those in the Plan,[31] COMEAP recommends that just

[27] Committee on the Medical Effects of Air Pollutants, *'Interim statement on quantifying the association of long-term average concentrations of nitrogen dioxide and mortality'*, 2015 <www.gov.uk/government/uploads/system/uploads/attachment_data/file/485373/COMEAP_NO2_Mortality_Interim_Statement.pdf>

[28] Committee on the Medical Effects of Air Pollutants, *'Statement on the evidence of health effects from exposure to nitrogen dioxide'*, 2015 <www.gov.uk/government/publications/nitrogen-dioxide-health-effects-of-exposure>

[29] World Health Organization, '*Review of evidence on health aspects of air pollution – REVIHAAP Project'*, 2013 <www.euro.who.int/__data/assets/pdf_file/0004/193108/REVIHAAP-Final>

[30] The analysis in this report uses coefficients which link changes in concentrations of pollutants with changes in mortality. As an example, a coefficient of 1.05 means that for every 10μg/m^3 increase or decrease in pollutant concentrations there will be a five per cent increase or decrease in associated mortality.

[31] The Plan is expected to have a mixture of effects, including reducing all traffic-related pollutants and specifically targeting NO_x emission reduction (for example cancelled journeys and upgraded vehicles respectively – see Section **3** for more details). It has not been possible to assess these as separate components so to avoid overestimation the Plan is treated as primarily targeting NO_x emissions.

25-55 per cent of the coefficient be used to take account of possible overestimation. The mid-point of this range (40 per cent) gives a central adjusted coefficient of 1.0092 per 10μg/m^3 NO_2. This means that for every 10μg/m^3 increase or decrease in NO_2 exposure there is predicted to be a 0.92 per cent increase or decrease in the risk of mortality. This coefficient is applied for the central analysis in this technical report.

COMEAP recommends that an unadjusted coefficient of 1.06 per 10μg/m^3 $PM_{2.5}$ should be used in cost-benefit analysis (with a 95 per cent confidence interval of 1.04–1.08), to reflect associations between long-term average concentrations of $PM_{2.5}$ and all-cause mortality. Road transport emissions of primary PM are highly correlated with NO_x emissions. As the PM coefficient is not adjusted to take into account possible confounding by other pollutants, including NO_2, quantifying the mortality impacts of reductions in primary PM alongside those of reductions of NO_2 in the same assessment could lead to an overestimate. Therefore, as in the draft Plan analysis, and following COMEAP's advice, the central analysis of this report does not quantify the mortality impact of primary PM reductions. It should be noted that, as the measures in the Plan are likely to lead to reductions in primary PM, not quantifying these effects is likely to underestimate the total impact of the measures.

As secondary PM is produced from NO_x some distance from the source and is unlikely to be highly correlated with NO_2 concentrations, COMEAP advise that the mortality impacts of secondary nitrates (for example secondary PM formed from NO_x emissions) can be quantified. The impacts of secondary PM formed from emissions of NO_x have therefore been incorporated into the cost-benefit analysis.

This latest advice on the relationship between long-term exposure to NO_2 and $PM_{2.5}$ and all-cause mortality is being used to update government's air quality damage costs. Damage costs seek to estimate the cost to society of a change in the emission of a given pollutant. They can be provided by pollutant and source, as well as location. Box **E.5** provides further detail on how the damage costs have been used in the analysis using the Fleet Adjustment Model.

Other updates to the damage costs include:

- **Dispersion modelling**

  Improved understanding of the dispersion of NO_x emissions (i.e. the relationship between NO_x emissions and NO_2 concentrations), specifically taking account of NO_x to NO_2 chemistry as modelled in the PCM, is now incorporated in the damage costs. This has reduced all NO_x sector-specific damage costs, with a relatively more significant impact on road transport damage costs.

- **PM and chronic bronchitis**

  The impacts of PM emissions on chronic bronchitis have also been incorporated into the damage costs following the recommendations laid out in the 2016 COMEAP report on this relationship.[32] In that report COMEAP recommended that the association between long-term exposure to ambient air pollution and chronic bronchitis was not included in core health impact assessments, because the available evidence did not sufficiently establish causality. However, an approach to estimating the possible change in cases as a result of reduced pollution levels, if the relationship were causal, was proposed for use in sensitivity calculations. COMEAP did not assign a monetary value to these effects but did include further considerations and guidance as to how analysts could transform estimates of changes in the prevalence into a monetised effect. The methodology used in the updated set of damage costs reflects COMEAP's guidance. The inclusion of chronic bronchitis considerably increases the PM specific damage costs.

- **New impact pathways**

  In addition to the impact pathways previously monetised (mortality impacts, hospital admissions, material damage, etc.) and the newly quantified chronic bronchitis impacts, the updated damage costs also monetise new productivity and ecosystems impact pathways. These additional pathways are included in the central analysis in this report with, as stated above, the chronic bronchitis impacts of PM included in sensitivity analyses.

- **Data inputs**

  Routine updates to baseline population and health impact data.

There is evidence that improving air quality by reducing the emissions of air pollutants has a range of other positive outcomes that cannot currently be quantified and monetised. Although it is often not possible to disaggregate the impacts of NO_2 from those of other pollutants, including $PM_{2.5}$, there is emerging evidence of possible links with:

- Cognitive decline and dementia, which have been linked to traffic-related air pollutants[33]

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[32] Committee on the Medical Effects of Air Pollutants, '*Long-term exposure to air pollution and chronic bronchitis*', 2016 <www.gov.uk/government/uploads/system/uploads/attachment_data/file/541745/COMEAP_chronic_bronchitis_report_2016__rev_07-16_.pdf>

[33] M. C. Power et al., 'Exposure to air pollution as a potential contributor to cognitive function, cognitive decline, brain imaging, and dementia: A systematic review of epidemiological research', *Neurotoxicology*, 2016 Sep (2016), pp.235-253 <www.ncbi.nlm.nih.gov/pubmed/27328897>

- Lower lung function in early life, which has been linked to exposure during pregnancy[34]

- Exacerbation of existing cases of asthma from traffic-related pollutants[35]

- An increased risk of developing type-2 diabetes[36]

- Self-reported life satisfaction, which can be considered an indicator of an individual's overall wellbeing and has been linked to NO_2 (after controlling for other economic, social and environmental factors)[37]

2.2.2 Assessing other societal impacts

In addition to health impacts, each of the actions modelled has been assessed for any other significant societal costs and benefits using consistent valuation approaches.

The most sophisticated of these valuation processes uses the Fleet Adjustment Model (FAM) to assess the impacts of changes in the UK fleet in response to charging CAZs. Other actions have been assessed using simpler, but consistent, approaches that are described alongside the results in Section **3**.

The non-health impacts the FAM quantifies are:

- **Public costs**

  Owners of vehicles below the required Euro standard may change their behaviour in response to a CAZ. The new action is favoured less than their baseline behaviour (otherwise they would have been doing it already); hence these vehicle owners will incur an additional cost, termed welfare loss in economics. Where a CAZ is modelled to include a charging element, this is made up of either the explicit monetary cost of having to pay any charge or the implicit cost of having to change their behaviour so as to not pay the charge.

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[34] Morales et al., 'Intrauterine and early postnatal exposure to outdoor air pollution and lung function at preschool age.', *Thorax*, 70 (2015), pp.64-73 <www.ncbi.nlm.nih.gov/pubmed/25331281>

[35] Royal College of Physicians, '*Every breath we take: the lifelong impact of air pollution*', 2016 <www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution>

[36] Ibid.

[37] Knight and Howley, Can clean air make you happy? Examining the effect of nitrogen dioxide (NO_2) on life satisfaction, 2017 <www.york.ac.uk/media/economics/documents/hedg/workingpapers/1708.pdf>

- **Traffic flow improvements**

  Alongside changes in the fleet, additional impacts may be felt from changes in the behaviour of vehicle owners. Vehicle owners who choose not to make their journey will be reducing the number of vehicles on roads within each of the CAZs leading to faster journey times for other users.

- **Government costs**

  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 and IT equipment and ongoing running costs such as communication, enforcement and staff costs.

- **Change in greenhouse gas emissions**

  Reductions in CO_2 emissions are valued when the fleet is reduced (other greenhouse gases emitted by vehicles are not valued in government guidance). Where owners replace vehicles with a compliant vehicle a CO_2 emission saving is not expected, as the vehicle is sold to another user who will continue to use it (unless it is scrapped). Where vehicles are scrapped there will be a CO_2 saving. These savings have been valued using an average CO_2 non-traded central carbon price for the appraisal.[38]

Since publication of the draft Plan technical report, the FAM has been improved enabling it to deal with CAZs being implemented in multiple years – accounting, for example, for the cumulative impact of CAZs on owner behavioural choices. Additionally, where more up to date information has become available the input data for the FAM has been updated. Full details of the FAM and the latest changes are included in Annex **E**.

2.2.3 Assessing the impact of the Plan across the population

Geographical analysis has been used to better understand the patterns of NO_2 concentrations and populations in the places with the biggest air quality challenge: the towns and cities modelled as CAZs in the analysis.

To understand how the costs of CAZs fall across the population, analysis has been conducted covering travel behaviours; vehicle use, ownership and sales; and individuals' income and expenditure. Additionally, the potential beneficiaries of mitigations and how they might compare to affected groups has also been considered.

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[38] Table 3: Carbon prices and sensitivities 2010-2100 for appraisal, 2015 £/tCO_2e <www.gov.uk/government/uploads/system/uploads/attachment_data/file/483282/Data_tables_1-20_supporting_the_toolkit_and_the_guidance.xlsx>

2.2.4 Assessing cumulative impacts

The effects of some measures will be additive; that is, their effects are independent of each other so can be added cumulatively when packaged together. For instance, the impacts of implementing a CAZ that charges buses to enter a city and introducing traffic management on a motorway outside the city could be added together because they do not overlap in terms of vehicle type or location.

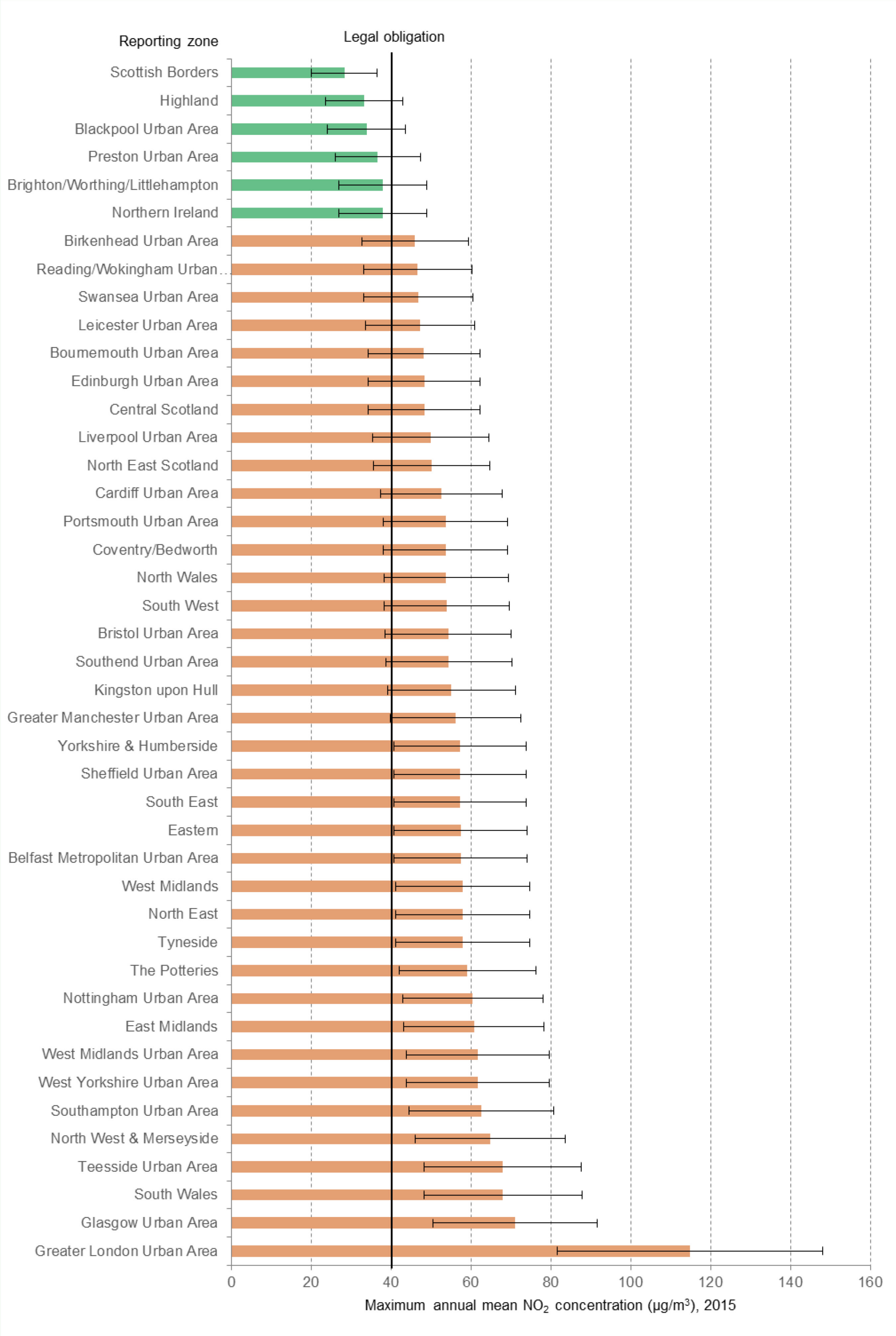
On the other hand, the total impacts of some measures taken in isolation cannot be combined completely. An example of this would be the implementation of a bus and HGV charging CAZ and a bus retrofit scheme in the same city. Because both policies would bring about an improvement in the emissions of the bus fleet, there would be significant overlap in their impacts.

To avoid double counting, the overlaps between policies being modelled have been accounted for based on where the policies would apply, the sequence in which it is likely they will be introduced and by taking a conservative approach to their impact. Details of the assumptions made about each measure, including their interaction with other measures, follow in Section **3**.

2.3 Conclusion

The assessment of the UK's air quality, whilst uncertain, shows there are some significant challenges associated with meeting our NO_2 limits (Figure **2.3**). With no further action expected changes in the vehicle fleet are projected to bring zones into compliance (Figure **2.1**). The Plan to tackle these issues will improve air quality more quickly as well as having economic impacts that can be assessed. The Plan, the assumptions made to model it, and the results of the assessment are described in Section **3**.

Figure 2.3: Maximum average NO_2 concentrations (µg/m^3) and compliance (green = compliant, orange = non-compliant) for each UK reporting zone in 2015 with error bars showing the overarching uncertainty in the modelling.



3. Policy assessment design and results

This section presents the design and results of an assessment of the measures in the Plan using the methods described in Section **2.2**.

3.1 Policy assessment design

The draft Plan technical report[39] investigated the impacts of a range of potential policy options and presented them for consultation. Based on that evidence, and the consultation responses received, Section 7 of the final Plan lists a range of measures. At the heart of the Plan is a requirement that the local authorities listed in Section 7.4 must carry out feasibility studies in order to produce a local plan, which will set out the measures the local authority will take to reduce NO_2 concentrations to below the legal limits in the shortest possible time.

Government will provide local authorities with the necessary technical and financial support to carry out these studies and to implement the measures they identify in their local plan. The exact nature the policies implemented in individual locations as part of the Plan will vary depending on the specifics at those locations and the solutions available to a local authority in that area. A local plan will only be approved by government, and thus be considered for appropriate funding support, if it can show that:

- It is likely to cause NO_2 levels in the area to reach legal compliance within the shortest time possible (and provides a route to compliance which reduces exposure as quickly as possible);
- The effects and impacts on local residents and businesses have been assessed, including on disadvantaged groups, and there are no unintended consequences;
- Proposals that request UK government funding support demonstrate value for money; and,
- The local measures have been carefully analysed using detailed local evidence together with local air quality modelling tools and analysis methods, improving on the analysis at national level.

[39] Department for the Environment, Food and Rural Affairs, '*Draft UK Air Quality Plan for tackling nitrogen dioxide – Technical Report*', 2017 <www.gov.uk/government/consultations/improving-air-quality-reducing-nitrogen-dioxide-in-our-towns-and-cities>

To provide a national assessment,[40] an indicative package of policy solutions has been modelled (see also Section **6**). This will provide a benchmark for the Plan following the principle that compliance must be brought forward in the shortest possible time. This modelling includes assumptions regarding the broader government intervention set out in the Plan, which will help to improve air quality at the national level, such as support for low-emission vehicles. Some of the policies assumed to be implemented in this package are likely to be different to those taken forward, particularly where they relate to actions at the local level. Regardless of the specific approach that is actually taken in individual areas, local plans will need to be developed and implemented at pace so that air quality limits are achieved within the shortest possible time.

The following sets out the key measures in the Plan and how their impacts were modelled and accumulated in the modelling (Annex **G** provides further detail of the modelling methodology). These measures are presented in the order in which they were modelled, not in order of importance:

- **Government Buying Standards for vehicles**

  The update to Government Buying Standards for vehicles is assumed to come into force before CAZs and is a national action in England. As such, its effects on the UK's fleet composition, and consequent air quality and economic impacts, have been taken into account before the effects of the other measures.

- **CAZs**

  CAZs that include charging are the measure that can be modelled nationally (referred to as the 'CAZ scenario')[41] to provide the benchmark for achieving statutory NO_2 limit values in towns and cities in the shortest possible time. Government will place legal duties on relevant local authorities in England requiring them to develop and implement a plan designed to deliver compliance in the shortest possible time and will work closely with each of them to ensure that it does so. In particular, while local authorities are encouraged to consider alternative approaches, any alternative will need to deliver compliance as quickly as a charging CAZ if it is to be preferred for inclusion in the plans which local authorities develop. For the purposes of modelling a benchmark, it has been assumed that charging CAZs are implemented in all towns and cities where they are considered feasible and where they would bring forward compliance. This includes towns and cities

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[40] Policy responsibility for air quality in Scotland, Wales and Northern Ireland is devolved. However, responsibility for air quality evidence is UK-wide. In particular, a single assessment of air quality is made across the UK for compliance reporting. Modelling of options in this technical report is UK-wide but ultimately the relevant administrations will each decide on the policies to improve air quality in their areas.

[41] Charging CAZs have been modelled to assess one potential route to compliance. However, local feasibility studies will use more specific local modelling and knowledge to help design schemes which fit the local circumstances. Charging CAZs should only be used where no other equally effective solution is identified.

across the UK but in practice the Plan sets out the measures which have been adopted by each of the Devolved Administrations.

- **Measures for exceedances not suitable for a CAZ**

  Modelling was conducted on the air quality impact of actions on roads still in exceedance after the implementation of CAZs. Because of the weak evidence base around the effectiveness of these measures the results are only incorporated in an additional scenario (the 'CAZ plus additional actions scenario'), not the main CAZ scenario. A cost-benefit assessment has not been conducted. These are localised actions so there is little or no overlap between them.

- **London Zero Emission Zone**

  In June 2017 the Mayor of London published a draft transport strategy proposing to implement a Zero Emission Zone in central London in 2025.[42] This measure is still in an embryonic stage so its exact details are unclear. However, it is expected to have a significant impact on air quality in London so an indicative analysis of some of the potential air quality improvements that may result have been modelled. As with the measures for exceedances not suitable for a CAZ, the results of this analysis are not incorporated in the CAZ scenario.

- **Supporting measures**

  Other measures in the Plan are not modelled either to avoid double-counting their impact, or because this impact is negligible, or not possible to assess due to lack of information. Their economic impacts are assumed to be negligible, captured in other measures or to result in a transfer of costs.

The descriptions that follow detail the assumptions required for modelling purposes and are provided in the order in which they were modelled to avoid double counting their impacts.

3.1.1 Government Buying Standards for vehicles

Government Buying Standards (GBS) include mandatory and best practice standards for central government procurement and are best practice for the wider public sector. Updating the GBS for vehicles to include NO_x and PM impacts will lead to the promotion of low NO_x and PM alternatives (where possible), such as petrol over diesel fuelled vehicles, reducing government's air quality impact.

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[42] Mayor of London's Draft Transport Strategy, June 2017, p.99: <https://consultations.tfl.gov.uk/policy/mayors-transport-strategy/user_uploads/mts_main.pdf>

This policy has not changed since the draft Plan but there have been improvements to the modelling assumptions to reduce uncertainty. An increase in the sample size of government vehicles analysed has led to an increase in the assumed annual average number of vehicles procured and the distance they travel. Analysis of the distribution of government vehicles by their average annual mileage and evaluation of the percentage of vehicles that would have an economic case to switch based on running costs has increased the assumed switch rate from diesel to petrol from 30 to 43 per cent.

It is important to note that switching to petrol is only one of the possible responses to the implementation of the update to GBS. Other responses include switching to hybrid or electric vehicles but due to limited evidence on future fleet requirements and composition, a simple approach assuming a switch from diesel to petrol has been taken.

3.1.2 Clean Air Zones

It is for local authorities to develop innovative local plans that will achieve NO_2 concentrations below statutory limit values within the shortest possible time. The UK government will require the local authorities with persistent exceedances as listed in the Plan to undertake local assessments to consider the best option to achieve NO_2 concentrations below the statutory limit values within the shortest possible time. The UK government has identified CAZs that include charging as the measure it is able to model nationally which will achieve statutory NO_2 limit values in towns and cities in the shortest possible time. Therefore, this measure is included in the analysis as a benchmark against which local plans can be compared.

CAZs focus action to improve air quality in a particular location. Evidence in the draft Plan technical report[43] suggested that they were the quickest, most cost-effective way of meeting NO_2 limit values on the majority of urban roads. They also only target the places that need action, reducing the burden on the population as a whole.

CAZs fall into two categories:

- **Non-charging CAZs**

  Defined geographic areas used as a focus for action to improve air quality. This action can take a range of forms such as facilitating the use of ultra-low emission vehicles (ULEV)[44] and encouraging businesses to clean up their vehicle fleets,[45] but does not include the use of charge-based access restrictions.

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[43] See Section 4 of Department for the Environment, Food and Rural Affairs, '*Draft UK Air Quality Plan for tackling nitrogen dioxide – Technical Report*', 2017 <www.gov.uk/government/consultations/improving-air-quality-reducing-nitrogen-dioxide-in-our-towns-and-cities>

[44] An ultra-low emission vehicle is one that emits less than 75g/km of CO_2 and includes electric vehicles and hybrids, among others.

- **Charging CAZs**

  Areas that, in addition to the above, vehicle owners are charged to enter or to move within if they are driving a vehicle that does not meet the required standard. Charging CAZs would only be expected where equally effective non-charging approaches are not identified.

Given the potential impacts on individuals and businesses, when considering between equally effective alternatives to deliver compliance, the UK government believes that if a local authority can identify measures other than charging zones that are at least as effective at reducing NO_2 and are at the same or lower cost, those measures should be preferred as long as the local authority can demonstrate that this will deliver compliance as quickly as a charging CAZ. The local modelling undertaken by local authorities will help to identify what other measures could be taken.

Therefore, for the purpose of modelling the Plan, all of the modelled CAZs have been assumed to be charging CAZs, given that the Plan requires relevant local authorities in England to implement a plan which will achieve compliance in the shortest possible time (see paragraph 95, Section 7.4 of the Plan).The impact of charging CAZs containing only a charge-based access restriction can be modelled by making assumptions about the behavioural impacts of a charge, how this affects the vehicles that enter a zone, and on this basis the resultant NO_2 impacts. Once relevant local authorities have undertaken detailed local modelling they will have a better idea of what measures can be taken at a local level. Subject to the requirement to achieve compliance in the shortest possible time, they can opt to pursue an alternative approach, such as a non-charging CAZ, which implements one or more alternative measures to reduce NO_2 in the area. The possible impacts of some of these options are discussed further in Section **3.1.5**, together with other abatement measures. In order to assess a non-charging CAZ, a detailed consideration of each of the links within the area and the potential abatement options would be required. In the next stage of the work local authorities will undertake this analysis through local feasibility studies which will include more granular modelling of each local area.

The Clean Air Zone Framework for England defines four classes of access restriction targeting particular vehicle types (Table **3.1**). The sequence of different CAZ classes (from A to D) progressively targets more vehicle types, starting with the most polluting vehicles first.

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[45] See the Clean Air Zone Framework.

Table 3.1: Charging CAZ classes set out in the 2015 Plan for NO_2	
CAZ class	**Vehicles included**
A	Buses, coaches and taxis
B	Buses, coaches, taxis and heavy goods vehicles (HGVs)
C	Buses, coaches, taxis, HGVs and light goods vehicles (LGVs)
D	Buses, coaches, taxis, HGVs, LGVs, cars, motorcycles and mopeds[I]

[I] The impact of including motorcycles and mopeds in CAZs have not been modelled. These vehicles only represent a small proportion of total NO_x emissions so it is not expected that they will be included in the access restrictions for the majority of zones.

Vehicles that do not meet certain emission standards must pay to enter charging CAZs. The proposed Euro standard requirements, set out in Table **3.2**, are generally the most stringent for that vehicle type. The CAZ framework commits government to setting a timetable for tightening these standards, but the analysis in this report assumes that they do not change over time.

Table 3.2: Compliant Euro standards for charging CAZs by vehicle type	
Vehicle type	**Compliant Euro standards**
Cars and taxis	Euro 6 diesel / Euro 4-6 petrol
LGVs	Euro 6 diesel / Euro 4-6 petrol
HGVs, buses and coaches	Euro VI diesel
Motorcycles and mopeds [I]	Euro 3 diesel / petrol

[I] The impact of including motorcycles and mopeds in CAZs have not been modelled. These vehicles only represent a small proportion of total NO_x emissions so it is not expected that they will be included in the access restrictions for the majority of zones.

Charging the most polluting vehicles should lead to behavioural changes amongst vehicle owners. Changes in the distances driven within the zones by different standards of vehicle have been used to determine the air quality impact using the SL-PCM model, and changes in the numbers of vehicles of different standards have been used to assess costs using the FAM.

The following behavioural changes are modelled, using the proportions in Table **3.3**:

- **Upgrade to an exempt vehicle**

  The most frequent travellers into the zone will have a strong incentive to upgrade their vehicles, because it will be cheaper over time than paying the charge. This results in a shift from non-compliant to compliant vehicle kilometres within the zone. There will also be an increase in non-compliant vehicle kilometres outside the zone because non-compliant vehicles are redeployed or sold to others there.

- **Cancel trip**

Some trips may be cancelled. If businesses choose to cancel a journey into a CAZ, it is assumed that an equivalent business with a compliant vehicle will enter the zone to replace it. This assumption applies to all vehicles except privately owned cars and replaces non-compliant vehicle kilometres with compliant vehicle kilometres, resulting in no change in distance travelled by these vehicle types. Cancelled private car journeys are assumed not to be replaced. There will be a resulting overall reduction in vehicle kilometres within the zone.

- **Change mode**

Some vehicle owners may choose to use other modes of transport in place of certain car trips. It is assumed this will lead to a net reduction in emissions because the major shift is likely to be towards public transport,[46] which is assumed to have sufficient capacity to absorb these trips without needing to run more services. This is felt to be a reasonable assumption given the relatively modest assumed percentage increases in journeys on public transport as a result of CAZs.

- **Avoid the zone**

Vehicle owners passing through a CAZ may choose to drive around it to avoid the charge leading to a reduction in vehicle kilometres within the zone and a consequent increase outside the zone. Emissions outside the zone are assumed to be partially offset by reduced emissions inside the zone.

- **Continue and pay charge**

Depending on their circumstances and trip purpose, some travellers into a zone will not be incentivised to change their behaviour and may choose to continue to enter and pay the charge. There will be no impact on kilometres travelled for these vehicles.

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[46] Balcombe et al., '*The demand for public transport: a practical guide*', 2004 <www.trpa.org/documents/rseis/New%20References%20for%20Final%20EIS/Balcombe%20et%20al%202004.pdf>

Table 3.3: Proportions of non-compliant vehicle kilometres (VKM) and non-compliant vehicles (V) by response to the presence of a charging CAZ										
Response	**Cars**		**LGVs**		**HGVs**		**Buses**		**Coaches**	
	VKM	**V**	**VKM**	**V**	**VKM**	**V**	**VKM**	**V**	**VKM**	**V**
Upgrade	64%	22%	64%	25%	83%	44%	94%	62%	72%	41%
Cancel	7%	16%	6%	12%	4%	13%	6%	38%	13%	26%
Change mode	11%	23%	2%	4%	0%	0%	0%	0%	0%	0%
Avoid	11%	23%	8%	17%	4%	13%	0%	0%	0%	0%
Pay	7%	16%	20%	42%	9%	29%	0%	0%	16%	32%
Note: Vehicle kilometre proportions are based on unpublished evidence from Ultra Low Emission Zone stated preference research (1,200 participants) and TfL response modelling, modified to the characteristics of CAZs. Vehicle numbers based on the same stated preference research combined with Global Positioning System (GPS) trip data has been used to identify the number of vehicles that will have to trade up to meet the change in trip rates identified. Because vehicles that enter a zone more often are more likely to be upgraded, the proportion of vehicles that are replaced is lower than the proportion of vehicle kilometres that are replaced.										

To determine where to model an illustrative network of charging CAZs, the SL-PCM model was used to assess the impact of these behaviour changes for each of the four classes of CAZ across the whole country. This identified which roads would be brought into compliance by which class. The results were mapped and 17 urban areas were identified where, on the basis of illustrative modelling, CAZs could make improvements to air quality. Annex **F** provides more detail on the principles used to identify indicative CAZ boundaries. This sets a benchmark against which measures identified by local authorities will be assessed.

The boundaries were applied to GPS tracking data in order to ascertain the number of trips made into the zones, the time spent within them, and the proportions of vehicles that make frequent visits. This data was used to build a better picture of the fleet of vehicles that travel within the network of CAZs and would therefore be most impacted by the introduction of CAZs.

The five cities that were identified in the 2015 Plan (Birmingham, Derby, Leeds, Nottingham and Southampton), and London, are assumed in the modelling to implement their CAZs by 2020 because of the progress they have already made. All other urban areas are assumed to implement by 2021.

In addition to the primary impacts expected from these behavioural responses, there are a number of potential secondary impacts (Box **3.4**).

Box 3.4: Secondary impacts of CAZs
Impact of vehicle upgrades on air quality outside CAZs It is anticipated that a national network of charging CAZs would significantly reduce emissions of pollutants from the UK's vehicle fleet as vehicle owners choose to upgrade to less polluting vehicles to avoid paying charges. Hence the overall UK fleet is likely to become cleaner. Therefore, the secondary effects of the CAZ network on the UK fleet as a whole have been estimated and the resultant air quality benefits have been modelled on all UK roads outside of CAZs. This reduces the NO2 concentrations of some non-compliant roads outside of CAZs, bringing some into compliance. Consequently, there is an impact on the number and scale of the policies needed to bring forward compliance outside of CAZs.
Impact of vehicle upgrades on the second-hand car market Because the CAZ charges are expected to lead to increased demand for both newer and petrol vehicles there is a danger that there will be insufficient vehicles available for sale to satisfy this demand. Analysis has been conducted to project the likely number of vehicles required as well as the supply of compliant second-hand vehicles in the UK. The results suggest that sufficient vehicles are available (approximately ten times as many as required) to satisfy the expected level of demand.
Impact of 'avoid' behaviour on air quality on alternative routes Some vehicle owners will respond to the CAZ charges by avoiding the CAZs and taking alternative routes. These alternative routes could see increased concentrations of NO_2 leading to further compliance issues. To mitigate this, the concentrations on potential alternative routes were taken into account when drawing indicative CAZ boundaries with the aim of ensuring that they do not cause other roads in surrounding areas to become non-compliant. The Joint Air Quality Unit (JAQU) will work with local authorities as they conduct feasibility studies to make sure this issue is considered locally before implementation. Alternative routes could also be longer, increasing CO_2 emissions. It has not been possible to quantify this or include it in the analysis.
Impact on road traffic background emissions Concentrations of NO_2 are affected by a variety of sources including the (background) emissions from the surrounding area (Figure **1.2**). The SL-PCM is unable to calculate the effects of reduced emissions in the surrounding area because it looks at each road in isolation. This is unlikely to be an issue except in areas where emissions from the surrounding area are a major cause of NO_2 concentrations on a road (as is the case in central London). It has not been possible to account for the reductions in background emissions that will result from the measures in the Plan.

London

London contains many of the highest NO_2 exceedances in the country and, without policy interventions, is not expected to come into compliance with annual average NO_2 limits until 2030. Its plans to tackle its exceedances are more developed than most local authorities and so they can be modelled in a less generic way. London's most significant policy is the Ultra Low Emission Zone (ULEZ), which is equivalent to a charging CAZ. The ULEZ is expected to be implemented in three stages:[47]

- **Stage 1: Introduction for central London in 2019**

  The ULEZ in central London is broadly the same as a Class D CAZ in terms of the vehicles that face charges. It has therefore been assessed in the same way as a Class D CAZ for both air quality and cost-benefit analysis. It has been modelled as being implemented in 2019 in Central London.

- **Stage 2: Expanding the ULEZ to the whole of greater London for buses and HGVs in 2020**

  The expansion to wider London is broadly equivalent to a Class B CAZ and has been modelled as being implemented from 2020.

- **Stage 3: Expanding the ULEZ up to the North & South Circular for cars and LGVs in 2021**

  The expansion for cars and LGVs is modelled as a Class D CAZ. While this policy is expected to be brought in by 2021, it has been modelled as being implemented in 2020 for consistency with the other CAZ analysis. As London is not expected to reach compliance with NO_2 limits within the North and South Circular until 2025, this assumption will not have an impact on compliance.

Unlike the rest of the UK, some vehicles in London already face a charge based on their emissions. In the Low Emission Zone (LEZ) which covers the Greater London area, heavy vehicles that are Euro 3 or older, and LGVs that are Euro 2 or older already face a charge. Therefore, the behavioural change assumptions for CAZs modelled in London have only been applied to vehicles which do not currently face a charge but will do following the introduction of the CAZ. This is because there will not be any change in costs for vehicles which are already non-compliant with LEZ standards.

3.1.3 Exceedances not suitable for a CAZ

Local authorities will determine whether a CAZ is the best solution and, if so, what its shape and class should be. However, it is likely that some roads that are in exceedance will not be suitable for inclusion in a CAZ. Based on indicative CAZ modelling there are 15 roads (totalling 40 exceedances) outside of those areas that may require further action. These are listed in Annex **F** alongside the principles used to map illustrative CAZs.

[47] Mayor of London, *'Mayor plans to introduce ULEZ in April 2019'*, 2017 <https://tfl.gov.uk/info-for/media/press-releases/2017/april/gla---mayor-plans-to-introduce-ulez-in-april-2019>

Based on previous work, consultation with experts and a review of relevant literature (Annex **H**), it is assumed that for these roads a number of options are possible, depending on local conditions. The following list is not comprehensive and local assessments may identify further possibilities:

- **Traffic management**

  This measure would seek to smooth traffic, reduce average speeds and influence driver dynamics (for example, reducing levels of acceleration that can lead to higher NO_x emissions) on roads where the current driving conditions are contributing to the exceedance.

- **Signage and rerouting**

  Diverting some of the traffic on a road could lower concentrations. However, this measure is not feasible where there are no realistic alternative routes, or where diverting traffic could create congestion problems or risks of non-compliance on nearby roads.

- **Targeted eco-driving courses**

  This measure would aim to deliver free courses on eco-driving (teaching people to drive more smoothly and with more anticipation) for frequent users of a road in exceedance. However, there is limited evidence on the extent to which this measure can reduce NO_x emissions (in contrast to strong evidence about CO_2 emissions) and levels of uptake are highly uncertain.

- **Fleet turnover**

  All roads come into compliance eventually due to the natural upgrade of the national fleet to cleaner models. CAZs aim to accelerate this turnover and are modelled to bring concentrations closer to compliance on roads across the country. The majority of exceedances that may not be suitable for a CAZ, excluding London, become compliant by 2022 due to fleet turnover, with only one other exceedance remaining (in South Wales) in 2024 and 2025. Most other measures will take some time to implement and so would only be in effect for a small number of years before the road becomes compliant anyway.

Based on the uncertainty about the effectiveness of these options and the need for more bespoke local assessments to determine the most appropriate action, there is no single measure that could be applied to all of the residual exceedances. Therefore, measures are only modelled for these roads as part of the CAZ plus additional actions scenario.

A 10 per cent emissions reduction has been modelled to provide an illustrative estimate of the extent of improvement on these roads assuming that some measure is implementable on each. This figure was considered to be a conservative assumption within the range of estimates identified in the review of evidence on potential measures (Annex **H**). However, there is a wide range of possible emissions reductions depending on the particular measure adopted – a 10 per cent reduction provides only an illustration. This scenario is not likely to reflect the true situation, since roads will differ in terms of whether and which measures are feasible, but it gives a sense of a best-case scenario. It is not costed in the economic assessment.

This emissions reduction was applied in the SL-PCM model to roads that remain in exceedance after modelling the impact of CAZs and the impact of fleet turnover induced by CAZs.

The introduction of measures for these exceedances was modelled for 2021. This is because it is expected to take some time to conduct local feasibility studies and then implement particular measures. Given the scale of the challenge, it is unlikely that a single measure will bring compliance on its own but more likely a range of measures will be used, or else one larger measure. Detailed development of a package of interventions will be necessary and the local modelling of interventions and option assessment may therefore be required. This could take as long as a CAZ feasibility study (to the end of 2018). Schemes would still require procurement, installation and some behaviour change interventions to support implementation. These measures are considered to remain in development through part of 2020, such that it is not realistic to assume that annual average concentrations would be below the limit in that year. Where an infrastructure improvement is the best measure to tackle air quality in a particular location in the shortest possible time, the government anticipates that it could take 18-24 months after the feasibility study is complete for the improvement to be implemented.

It is assumed that these measures are kept in place until each of the roads become compliant in the baseline. This is because these measures are expected to be temporary interventions which would be lifted once they were no longer required.

A key limitation of this approach is that it does not account for diversion of traffic. Traffic management, signage, and rerouting could displace traffic onto other roads. It is assumed that a local assessment of abatement options would determine whether or not potential displacement in a given location would introduce additional compliance risks, and that these measures would not go ahead where this was the case.

3.1.4 London Zero Emission Zone

The Mayor of London has proposed implementing a Zero Emission Zone (ZEZ) in central London in 2025.[48] This proposal is at an embryonic stage, thus there are few details as to what it would entail. It is expected to be similar to a CAZ with charges levied on vehicles that are not zero-emission capable. Purely for the purposes of this analysis, an indicative policy has been modelled to estimate the potential impacts of a ZEZ. However, this should

[48] Mayor of London's Draft Transport Strategy, June 2017, p.99: <https://consultations.tfl.gov.uk/policy/mayors-transport-strategy/user_uploads/mts_main.pdf>

not be taken as a guide to the eventual policy design. Instead, it should be treated as an indication of the potential air quality improvements that such a policy could make.

The indicative estimate of the potential impacts of a ZEZ has been modelled using the following assumptions:

- The zone is assumed to cover central London and to be implemented in 2025.
- The bus fleet is assumed to be upgraded to zero emission by 2037 in line with the proposal set out in the Mayor of London's Draft Transport Strategy.[49]
- All zero-emission capable taxis are assumed to be compelled to operate in zero-emission mode within the ZEZ. As a result of London's policy that all new taxis bought after 2020 must be zero-emission capable, a substantial proportion of the taxi fleet is expected to be zero-emission capable by the time the ZEZ is assumed to be implemented in 2025.
- Because zero-emission variants are more readily available for light than for heavy vehicles, it is assumed that cars and LGVs will be included in the scope of the ZEZ but that HGVs and coaches will not. It has been assumed that the ZEZ will be able to reduce car and LGV emissions by 10 per cent through a combination of the behavioural changes used to model CAZs: change mode, cancel, avoid and a small number of upgrades to zero-emission vehicles.

As there are few details of this policy at the current time, it has not been possible to quantify the potential economic impacts from a ZEZ.

3.1.5 Supporting measures

Chapter 7 of the Plan includes several other measures that support those listed above. Supporting measures can broadly be separated into two groups:

- Additional abatement measures, which will further improve air quality, such as additional support for ULEVs.
- Mitigation measures, which look to support the transition to the measures in the new Plan, which could include initiatives supported by the Clean Air Fund.

Supporting measures are not modelled as separate components of the indicative modelling because their effects are all either: captured via the modelling of another component, likely to have a negligible impact at the roadside in the short-term, treated as a transfer of costs with no overall impact, or too under-developed to be modelled.

[49] Ibid. p.96

Actions to improve vehicle emission testing are accounted for in the SL-PCM model, which has separate vehicle standard categories for newer Euro standards subject to real driving emissions tests.

Vehicle labelling complements other air quality policies by increasing the information available to consumers but is not expected to have a significant impact in isolation (as demonstrated in the draft Plan technical report[50]). Therefore, it has been assumed that there will be no additional impacts from this action beyond those from the other components of the modelling.

Adoption of ULEVs is a key driver of long-term air quality improvements in the UK. Promotion of ULEVs through government schemes such as the Plug-In Car Grant helps to support economic growth, cut consumer fuel costs and decrease all vehicle emissions including CO_2 and NO_x. 2016 saw levels of new ULEV car sales at around 1.5 per cent of total sales, including around 10,000 pure electric vehicles, a large increase from 2015. With a government target for all new cars and vans to be a zero emission vehicle by 2040 and for almost every car and van to be a zero emission vehicle by 2050, the number of ULEVs on the road is set to grow quickly. In the medium-long term, widespread use of ULEVs will lead to radically improved air quality throughout the UK, as older, more emitting vehicles are replaced with cleaner electric vehicles.

In the short-term ULEV uptake alone is unlikely to be able to provide an effective mechanism to achieve NO_2 compliance in the shortest time possible. Air quality modelling suggests that following implementation of the Plan, a large number of pure electric vehicles would still be needed to achieve compliance earlier. For example, by taking the last non-compliant road in London and applying the reduction needed to achieve compliance there to the wider Low Emission Zone area, we would need to replace 3.2m cars with pure electric vehicles. To obtain more accurate estimations of the number of pure electric vehicles needed, full transport modelling would have to be conducted.

The consultation that accompanied the draft Plan set out that the UK's legal obligations must be delivered as quickly as possible but that

> '*this must not be done in a way that unfairly penalises ordinary working families who bought diesels in good faith as a direct result of tax changes made by previous governments that focused on fuel economy and CO_2 emissions*'.

We will not know the degree to which local plans will impact residents and individuals until local authorities come forward with their plans. In the meantime, the government will work with local authorities and others to consider how to help minimise the impact of such measures on local businesses, residents and those travelling into towns and cities to work

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[50] Department for the Environment, Food and Rural Affairs, '*Draft UK Air Quality Plan for tackling nitrogen dioxide – Technical Report*', 2017 <www.gov.uk/government/consultations/improving-air-quality-reducing-nitrogen-dioxide-in-our-towns-and-cities>

where such action is necessary; and will issue a further consultation in autumn to aid development and assessment of options. The measures considered in that consultation will include options to support motorists: in particular private car drivers on lower incomes, or those who may have to switch to a cleaner vehicle. Options considered could include retrofitting, subsidised car club membership, exemptions and discounts from any restrictions, permit schemes for vans or concessionary bus travel.

A targeted scrappage scheme will also be considered in this consultation focussing on certain groups of drivers who most need support (such as those on lower incomes or those living in the immediate vicinity of a Clean Air Zone) and providing an incentive to switch to a cleaner vehicle.

The air quality impacts of these mitigation options have not been modelled because it has been assumed that they have no additional air quality impacts above the operation of a charging CAZ (which is the principal mitigation option that has been modelled). This is a conservative assumption as it is likely to underestimate the air quality benefits of the air quality plan.

3.2 Results

Results follow of three scenarios modelled using different components from the measures described in Section **3.1**:

- **Baseline scenario:** actions already taken or in progress. This represents the expected compliance levels in every year up to 2030 in the absence of any further action.

- **CAZ scenario:** actions that are known to be possible. This primarily includes illustrative charging CAZs, but also incorporates updated Government Buying Standards.

- **CAZ plus additional actions scenario:** additionally includes actions which may be possible but for which assessment is highly uncertain. This includes potential action on exceedances on roads that are not suitable for a CAZ and a Zero Emission Zone in London, in addition to the measures in the CAZ scenario.

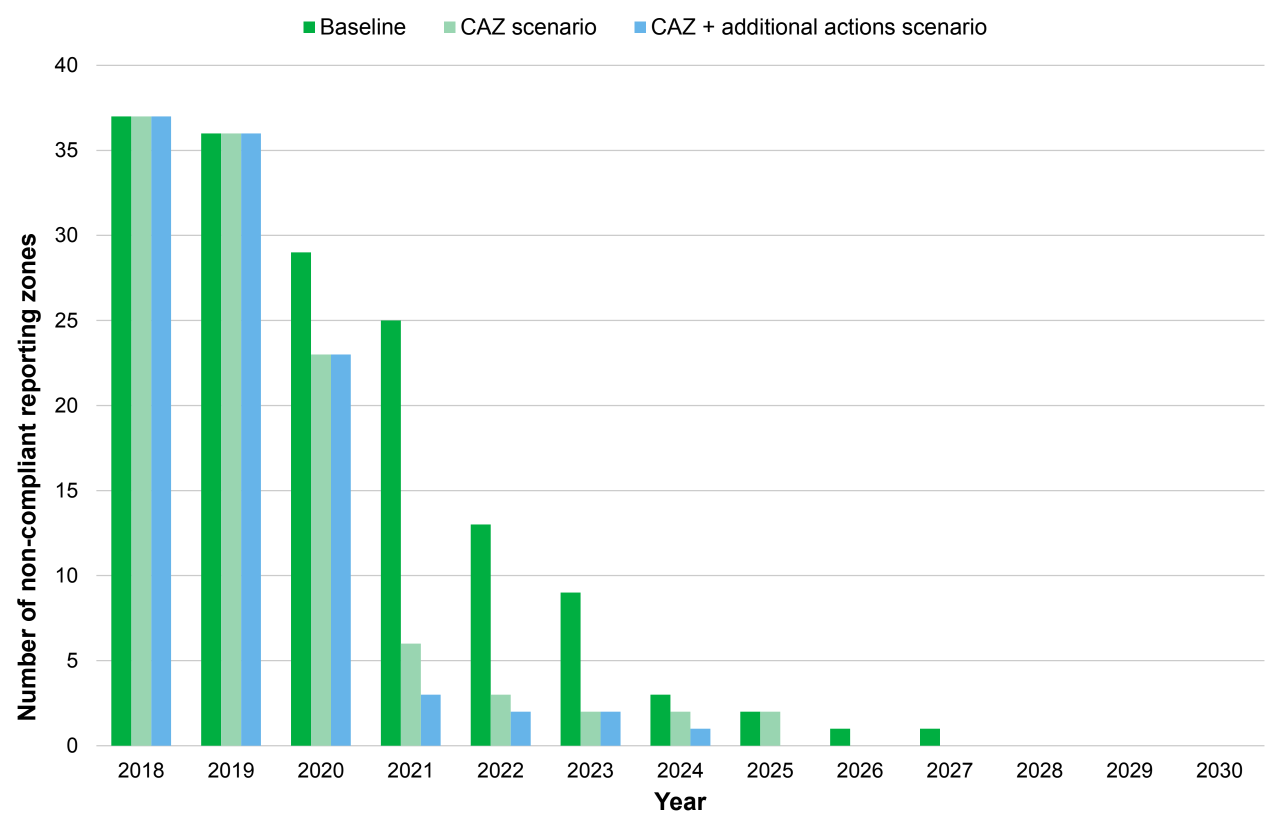
Cost benefit analysis was undertaken for the CAZ scenario only. This is because the illustrative measures in that scenario are relatively well understood and considered implementable. The additional measures in the CAZ plus additional actions scenario carry a much greater degree of uncertainty (Sections **3.1.3** and **3.1.4**) so cost-benefit analysis for these measures was not considered. Table **3.5** sets out the scenarios and the measures they include.

Table 3.5: Measures included in each scenario			
Measure	**Baseline scenario**	**CAZ scenario**	**CAZ + additional actions scenario**
Actions already taken or underway			
Government Buying Standards			
Illustrative charging CAZs			
Action on exceedances not suitable for a CAZ			
London Zero Emission Zone			
Supporting measures	Not included (see Section **3.1.5**)		

3.2.1 Air quality compliance

Figure **3.6** illustrates the estimated impact of the scenarios on achieving compliance with NO_2 concentration limits over time by reporting zones. In the CAZ scenario the majority of reporting zones are predicted to be brought into compliance by 2021, with all zones expected to be compliant by 2028. In the additional actions scenario, which includes modelling for exceedances not suitable for a CAZ and a Zero Emission Zone in London, some exceedances are likely to persist in 2021. Note that uncertainty within the prediction model means there will be variance around all these results.

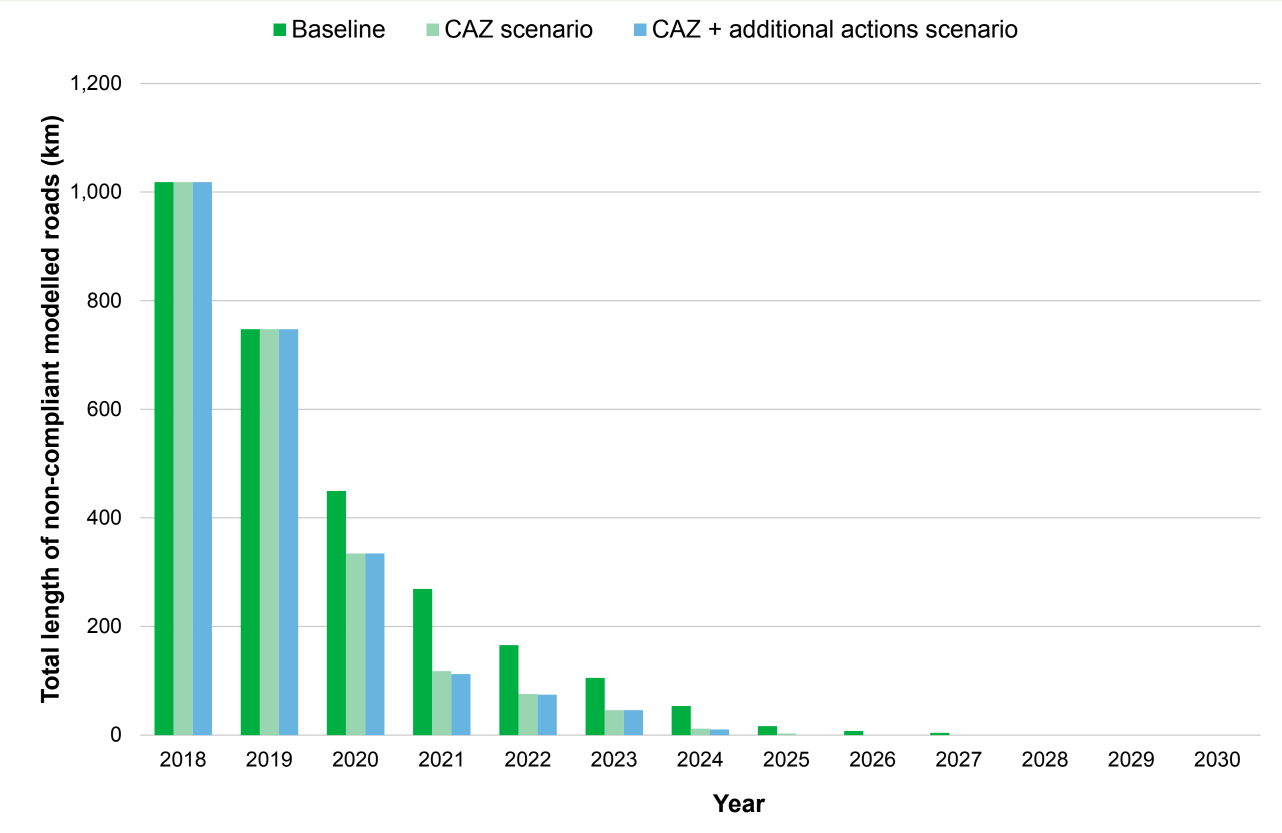
Figure 3.6: Comparison of the estimated number of reporting zones projected to be non-compliant with no further action (baseline), with the modelled CAZs (CAZ Scenario) and with additional abatement (CAZ + additional actions scenario)



Note: Figure **4.4** provides an estimate of the uncertainty around these projections

For individual roads the results (Figure **3.7**) show a similar, but smoother, decline. The difference between the CAZ scenario and the CAZ plus additional actions scenario is estimated to be less pronounced.

Figure 3.7: Comparison of the estimated total length of modelled road (km) projected to be non-compliant with no further action (baseline), with the modelled CAZ (CAZ scenario) and with additional abatement (CAZ + additional actions scenario)



3.2.2 Cost benefit analysis

The results of the cost-benefit analysis of the CAZ scenario, based on a range of assumptions, are set out in Table **3.8**. More information on the ranges of costs and benefits that make up this analysis are provided in the comments, and in Section **4**.

Table 3.8: Summary of the economic impacts of the CAZ scenario

Impacts	Low	Central	High	Comments
Health impact	£2.8m	£400m	£2,400m	The net monetised impact of the change in NO_x emissions resulting from the CAZ scenario. The uncertainty range is based on the range of coefficients linking NO_2 and mortality set out in Section **4.2.5**.
Government impact	-£410m	-£250m	-£230m	The cost to government of setting up and administering the CAZs over the ten-year period. The uncertainty range is based on the Green Book guidance for optimism bias for a non-standard civil engineering project (Section **4.2.11**).
Public impact	-£2,000m	-£1,200m	-£500m	The net of the costs of lost welfare and asset value with the benefits in traffic flows. The uncertainty range is based on removing and doubling the welfare impacts (Section **4.2.7**) only (loss of asset value and benefits in traffic flows remain constant across the range presented).
Greenhouse gas emissions impact	£7.7m	£15m	£23m	The net monetised impact of the change in CO_2e emissions. The uncertainty range is based on government's carbon price range (Section **4.2.12**).
Economic growth impact	Positive and negative impacts			Positive impacts through improved air quality and higher new vehicle purchases. Negative impacts through increased costs to businesses.
Overall NPV	-£1,800m	-£1,100m	+£1,000m	This uncertainty range is based on the overarching uncertainty in the cost-benefit analysis (Section **4.1.2**). This is not the sum of all of the uncertainties set out in Section **4** or those above but instead represents the highest and lowest NPVs generated by the individual sensitivities run on the cost-benefit analysis. This is consistent with the advice from the cost-benefit analysis uncertainty panel.

Note: All monetised impacts are present values, discounted to 2017 prices, appraised over 2018-30. Positive values indicate a benefit. All monetised impacts are rounded to the nearest two significant figures, totals may therefore not sum to the total of the rounded figures.

The overall net present value (NPV) of the measures in the central CAZ scenario is -£1.1 billion, within the range of -£1.8 billion to +£1 billion.

Recent changes to the evidence base (Section **2.2.1**) have the effect of reducing the quantifiable value for money of taking action to reduce emissions. However, these estimates are only able to reflect a proportion of the actual impact, excluding a range of impacts on public health, welfare, economic performance and the environment. Furthermore, the need to take action to deliver compliance in the shortest possible time does not diminish. It also doesn't alter the range of options available to deliver against this objective or their relative cost-effectiveness, meaning this remains the lowest-cost solution.

3.2.3 Distributional analysis

Full details of the distributional analysis are provided in Annex **D**.

Analysis of populations living in CAZs confirms that the areas of towns and cities covered by the modelled zones in England have a larger proportion of the comparatively deprived population than the population outside CAZs. The relationship between deprivation and air quality in England is also confirmed by the analysis, particularly for NO_2: air quality tends to be poorest in areas of high comparative deprivation, both within and outside the proposed CAZs. The introduction of CAZs as modelled therefore has the potential to improve air quality for some of the most deprived areas of the UK and for some of those that risk the greatest exposure. Equally, other local authority action to deliver compliance in the shortest possible time will have the same impact.

The analysis undertaken looking at the financial impact of CAZs on businesses suggests that there would be additional costs as well as changes to customer behaviour for individual businesses to cope with. However, overall there is little evidence that there would be a significant impact. Small businesses may have less financial resilience; however evidence of the impact is limited. One review of the London congestion charging zone has suggested that it had a broadly neutral impact on the business economy of central London. [51] Plans developed by local authorities will have to assess the economic effects and impacts on local businesses and show there are no unintended consequences.

Analysis of the financial impact of CAZs on individuals suggests that in general terms individuals living in and around the zones that are on lower incomes and have non-compliant vehicles are most at risk of being adversely affected by vehicle charging. However, they may also benefit more than others may from any investments in alternatives (for example improved public transport) if these enable them to avoid running a vehicle and from the health benefits that result from action to improve air quality (see also Section **2.2.3**). However, it should be noted these are not part of the central case and cost-benefit analysis. Individual circumstances will strongly influence an individual's ability to cope with the introduction of a charge, including their access to alternatives, reliance on the non-compliant vehicle and the impact of potential mitigation measures.

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[51] See discussion in Annex **D.3**, and also Transport for London, '*Central London Congestion Charging Impacts Monitoring Fourth Annual Report*', 2006 <http://content.tfl.gov.uk/fourthannualreportfinal.pdf>

Discussion of mitigation measures highlights their potential to help alleviate the adverse impacts of CAZs where these occur but also highlights that their success will depend on how they are targeted. Targeting based on vehicle age (or Euro standard), geography, zone use, and income could all be important.

4. Sensitivities and uncertainties

This section presents the results of a review of the uncertainties in the analysis performed for the Plan. Following the guidance of the Air Quality Review Group established by Defra's Chief Scientific Advisor, expert panels were convened to provide an independent assessment of uncertainty. The methodology and key conclusions of these panels are detailed in Section **4.1**. Output from the panels has been used to inform a range of sensitivity scenarios presented in Section **4.2**.

4.1 Uncertainty assessment

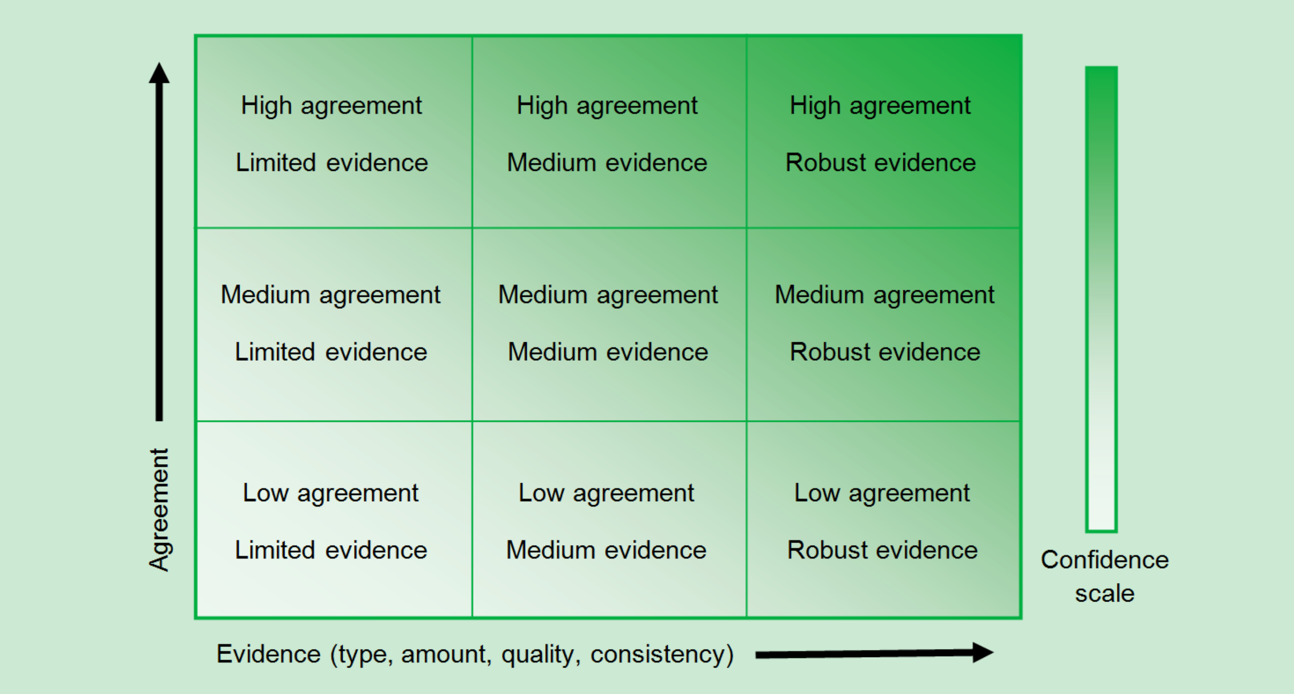
Two expert panels were convened in order to provide an independent assessment of the degree of uncertainty in the analysis conducted for the Plan. A panel chaired by Defra's Chief Scientific Advisor (composed of Professors David Carslaw, Paul Monks and Ricardo Martinez-Botas) focused on air quality modelling. The other, chaired by Defra's Chief Economist (composed of Professor Sir David Spiegelhalter, Dr Heather Walton, Dr Jacopo Torriti, Dr Risa Morimoto and Mr John Henderson), focussed on cost-benefit analysis.

The format of the panels was based on guidance from the IPCC.[52] Before convening, panel members were provided with the available evidence and asked to independently identify the key uncertainty-propagating assumptions in the analysis. They were also asked to prepare a quantitative description of the uncertainty around each assumption if possible and, if not, to take a qualitative approach based on IPCC guidance. The IPCC qualitative approach is based on two metrics: 'Evidence' (type, amount and quality) and 'Agreement' (within the body of evidence). These are combined to give an overall 'Confidence Level' (Figure **4.1** and Table **4.2**).

The panels began with a discussion of the overarching uncertainty in their area of analysis (i.e. air quality modelling or cost-benefit analysis) and how this could be best estimated using available evidence. After this, they agreed on quantitative or qualitative uncertainty descriptions for each of the key assumptions they had identified. In addition, they debated which assumptions were the most significant contributors to the uncertainty in the analysis.

[52] Mastrandrea, M.D. et al., '*Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties*' (2010) Intergovernmental Panel on Climate Change <www.ipcc.ch/pdf/supporting-material/uncertainty-guidance-note.pdf>

Figure 4.1: Evidence and agreement statements and their relationship to confidence[53]



Note: Confidence increases towards the top-right corner as suggested by the shading.

Table 4.2: Methodology for the assignment of confidence terms[54]

Term	Evidence and agreement levels
Very low confidence	Low agreement and limited evidence
Low confidence	Medium agreement and limited evidence Low agreement and medium evidence
Medium confidence	High agreement and limited evidence Medium agreement and medium evidence Low agreement and robust evidence
High confidence	High agreement and medium evidence Medium agreement and robust evidence
Very high confidence	High agreement and robust evidence

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53 Ibid.

54 Wuthrich, N., '*Conceptualizing Uncertainty: An Assessment of the Uncertainty Framework of the Intergovernmental Panel on Climate Change*' (2016) London School of Economics and Political Science <http://personal.lse.ac.uk/WUETHRIC/EPSA15_Wuethrich.pdf>

4.1.1 Air quality modelling

The key uncertainty-propagating assumptions identified by the air quality modelling panel are summarised in Table **4.3**, together with the panel's quantitative or qualitative description of the degree of uncertainty and the range of possible values for that assumption. Note that the assumptions are ordered from those that the panel felt had the greatest impact on the overall uncertainty to those that they felt had the least impact. Annex **I.1** contains a full summary of the panel's discussion. In addition to those suggested by the panel, JAQU has conducted two additional sensitivity studies around key areas of uncertainty (Section **4.2**). The quantitative ranges employed in these studies are also included in Table **4.3**.

Table 4.3: Uncertainty-propagating assumptions in the air quality modelling, with quantitative and qualitative descriptions

Assumption	Quantitative description	Qualitative description
Emission factors	Light duty diesel vehicles: ±60% (standard deviation)* *HBEFA emission factors as an alternative source*†	Low confidence (Medium agreement and limited evidence)
Dispersion modelling (including the inability to reflect the 'canyon effect')	-	Very low confidence (Limited agreement and limited evidence)
Primary NO_2 fraction	Ambient measurements suggest c.40% lower‡	Low confidence (Medium agreement and limited evidence)
Traffic composition	*DfT National Transport Model high and low traffic forecasts***	Medium confidence (Medium agreement and medium evidence)
Use of annual average meteorological data from a single site	-	High confidence (High agreement and medium evidence)
Relationship between traffic speed and emissions	-	High confidence (High agreement and medium evidence)

Note: Quantitative ranges not provided by the panel are included, but italicised.

Note: See Annex **I.1** for further details on these assumptions.

[I] The 'canyon effect' is the effect whereby streets flanked by buildings serve to decrease dispersion and hence increase the concentration of pollutants.

* Source: Department for Transport, Vehicle Emissions Testing Programme (2016)

† Source: Institute for internal combustion engines and thermodynamics, Graz University of Technology, 'Update of Emission Factors for EURO 4, EURO 5 and EURO 6 Diesel Passenger Cars for the HBEFA Version 3.3' (2017)

‡ Source: Carslaw D.C. et al, 'Have vehicle emissions of primary NO_2 peaked?', *Faraday Discussions* (2016)

** Source: Department for Transport, Road Traffic Forecasts 2015 (2015)

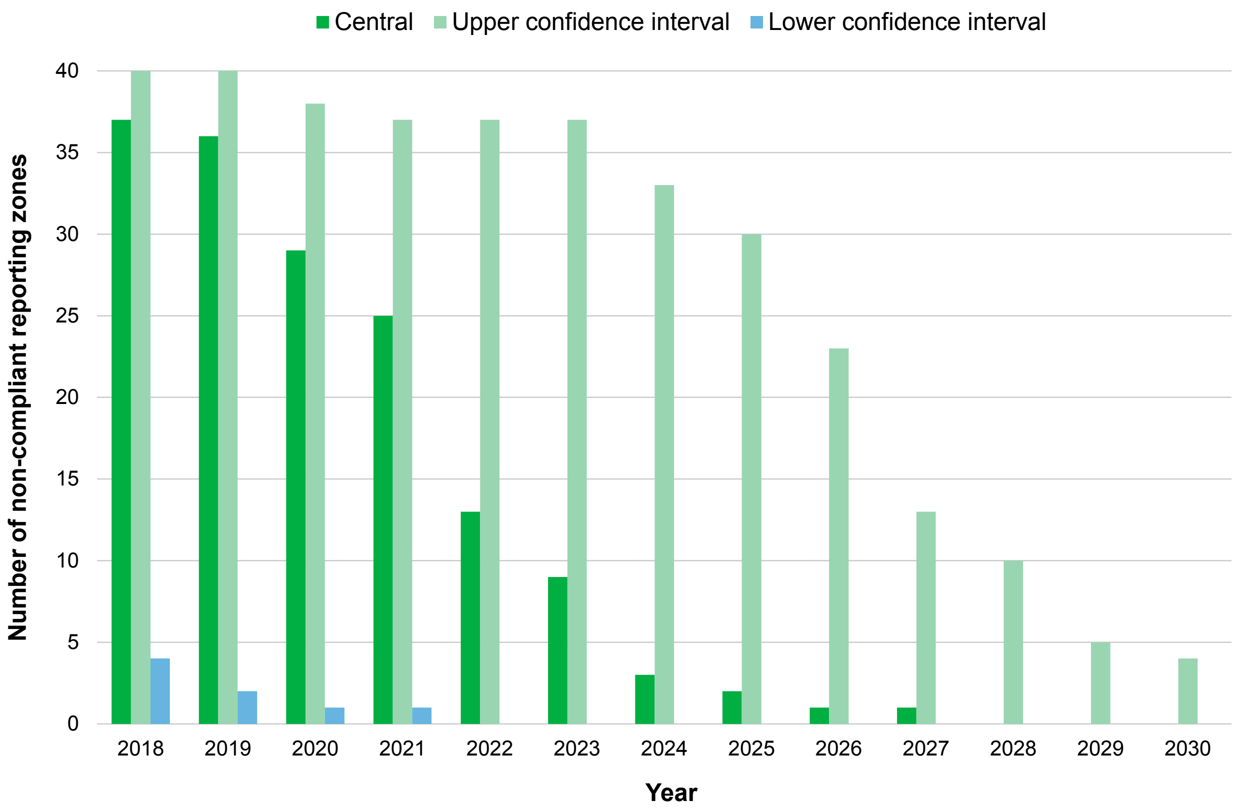
The panel suggested that a comparison of modelled versus independently measured NO_2 concentration data can be used to estimate the overarching uncertainty in the PCM model. They recommended a statistical analysis of this data in order to obtain a quantitative uncertainty estimate. JAQU has undertaken such an analysis, comparing annual average measured concentrations from 82 independent[55] roadside sites with PCM model outputs for the same year for the corresponding road links. A confidence interval analysis (at a 95 per cent level) has been undertaken through a consideration of the standard error in the difference between the modelled and measured annual average concentration for each site. Through this process, an estimate of ±29 per cent for the overarching uncertainty in the air quality modelling conducted for the Plan has been obtained. That means that there is 95 per cent confidence that the true outcome is within this range. This is comparable with the data quality objectives defined in Annex I, Section A of the Ambient Air Quality Directive.

Analysis has been undertaken in order to demonstrate the possible effect of this overarching uncertainty on the NO_2 concentration projections in the Plan. The number of non-compliant reporting zones has been calculated for the PCM model's baseline for the cases of concentrations being at the high and low ends of the uncertainty range (Figure **4.4**). In the central case, all zones are compliant by 2028. In the low scenario, this is achieved by 2022 while in the upper scenario 4 zones remain non-compliant in 2030.

The overarching uncertainty estimate of ±29 per cent and the study presented in Figure **4.4** suggest that the scale of the challenge faced and the ability of the measures presented in the Plan to tackle the challenge is highly uncertain. However, the measures will be implemented in such a way that discrepancies in the modelling conducted for this Plan are accounted for. All local authorities with persistent exceedances will undertake feasibility studies and as such, will perform their own local air quality modelling. This will indicate whether JAQU's modelling constituted an overestimate or underestimate of concentrations within the local area and local plans can be adapted to reflect this. To support this, the UK government will consider further steps to ensure that air quality improves in areas that are modelled to be below but close to the legal limit and to ensure that forecast levels remain compliant. These steps could include preferential access to funding and government support to access and build on best practice.

[55] Independently measured data is defined here as data which has not been used in the calibration of the model.

Figure 4.4: The estimated number of non-compliant reporting zones in the baseline at the upper and lower confidence intervals of the PCM model, compared to the central estimate



Note: Upper and lower confidence interval estimates have been calculated by adding and removing 29% (respectively) from road-level concentration outputs from the PCM model's baseline.

4.1.2 Cost-benefit analysis

The key uncertainty-propagating assumptions identified by the cost-benefit analysis panel are summarised in Table **4.5**, together with the panel's quantitative or qualitative description of the degree of uncertainty and the range of possible values for that assumption. Annex **I.2** contains a full summary of the panel's discussion. Note that the panel discussed the relationship between NO_2 and mortality concluding that it may be the most significant source of uncertainty but no attempt was made to order the other assumptions in terms of significance. In addition to those suggested by the panel, JAQU has conducted a number of additional sensitivity studies around key areas of uncertainty (Section **4.2**). The assumptions tested by these studies and the quantitative ranges used are also included in Table **4.5**.

Table 4.5: Uncertainty propagating assumptions in the cost-benefit analysis, with quantitative and qualitative descriptions		
Assumption	**Quantitative description**	**Qualitative description**
NO_2 – mortality relationship	Central: 0.9%* COMEAP range: 0.2%-2%* *WHO value: 5.5%*† *Low benefit sensitivity: 0%*	-
NO_2 – morbidity relationship (lack of treatment in CBA)	-	Medium confidence (Medium agreement and medium evidence)
Valuation of health impacts	Central: £37,353‡ *CAFE VOLY: £62,428*** *CAFE VSL: £203,817***	-
Exposure (modelled based on concentration outside of place of residence)	-	-
Cost associated with upgrading vehicle	Central: Welfare cost halfway between no cost and full cost *High cost sensitivity: Full cost* *Low cost sensitivity: No cost*	-
Benefits of CAZs (no treatment of health impact due to increased walking/cycling)	-	-
Behavioural response to CAZs	*High cost sensitivity: All upgrade* *Low cost sensitivity: All continue*	Low confidence (Medium agreement and limited evidence)
Number of days spent in a CAZ	Central: Mean of data *Sensitivity: Median of data*	-
Particulate matter health impact	Central: No PM health impact *Sensitivity: PM health impact included*	-
Optimism bias	*High cost sensitivity: +66%* *Low cost sensitivity: -6%*	-
Greenhouse gas impacts	*High benefit sensitivity: High carbon price forecast* *Low benefit sensitivity: Low carbon price forecast*	-

Note: Assumptions and quantitative ranges not provided by the panel are included, but italicised.

Note: For three assumptions the panel felt there was insufficient evidence to produce even a qualitative description.

Note: See Annex **I.2** for further details on these assumptions.

* Source: See Annex **A**

† Source: World Health Organization, 'Health risks of air pollution in Europe – HRAPIE project' (2013)

‡ Source: Department for Environment, Food and Rural Affairs, 'Valuation of the health benefits associated with reductions in air pollution' (2004)

** Source: AEA Technology, Methodology for the Cost-Benefit analysis for CAFE: Volume 2: Health Impact Assessment (2005)

The panel noted that there was insufficient quantitative information to perform a Monte Carlo-type calculation of the overarching uncertainty in the cost-benefit analysis.[56] As such, it was suggested that a range could be estimated by taking the highest and lowest NPVs from the sensitivity scenarios suggested by the panel (Section **4.2**). These were the WHO NO_2-mortality coefficient and the zero mortality coefficient scenarios respectively (Section **4.2.5**). By taking these values, a range of -£1,800m to +£1,000m has been derived around the central NPV of -£1,100m (Table **4.6**).

Table 4.6: Cost-benefit analysis overarching NPV uncertainty range (with the sensitivity scenarios from which the range has been derived)

Scenario	**NPV** (£m)
Central	-1,100
High (WHO NO_2-mortality coefficient)	+1,000
Low (high welfare cost of upgrading)	-1,800
Note: NPVs rounded to 2 significant figures.	

4.2 Sensitivity scenarios

Several sensitivity scenarios have been modelled in order to demonstrate the effect of key assumptions on air quality modelling and cost-benefit outputs. The scenarios were selected through an internal review, largely informed by the recommendations of the uncertainty panels (Section **4.1**).

4.2.1 Light duty diesel vehicle emission factors

Emission factors were identified by the air quality modelling panel as the most significant source of uncertainty (Section **4.1.1**). Consequently, sensitivity scenarios have been run in order to test the SL-PCM model's response to higher or lower emission factors than those employed in the CAZ scenario. The sensitivity scenarios focus on light duty Euro 6, Euro 6d-temp and Euro 6d diesel vehicles.[57] Euro 6 diesel vehicles are known to show greater variability in their emissions than their older counterparts as highlighted in the recent diesel emissions issue. Consequently, in order to provide 'worst case' sensitivities, the variability in emissions shown by Euro 6 vehicles has been extrapolated to all Euro 6 vehicles.

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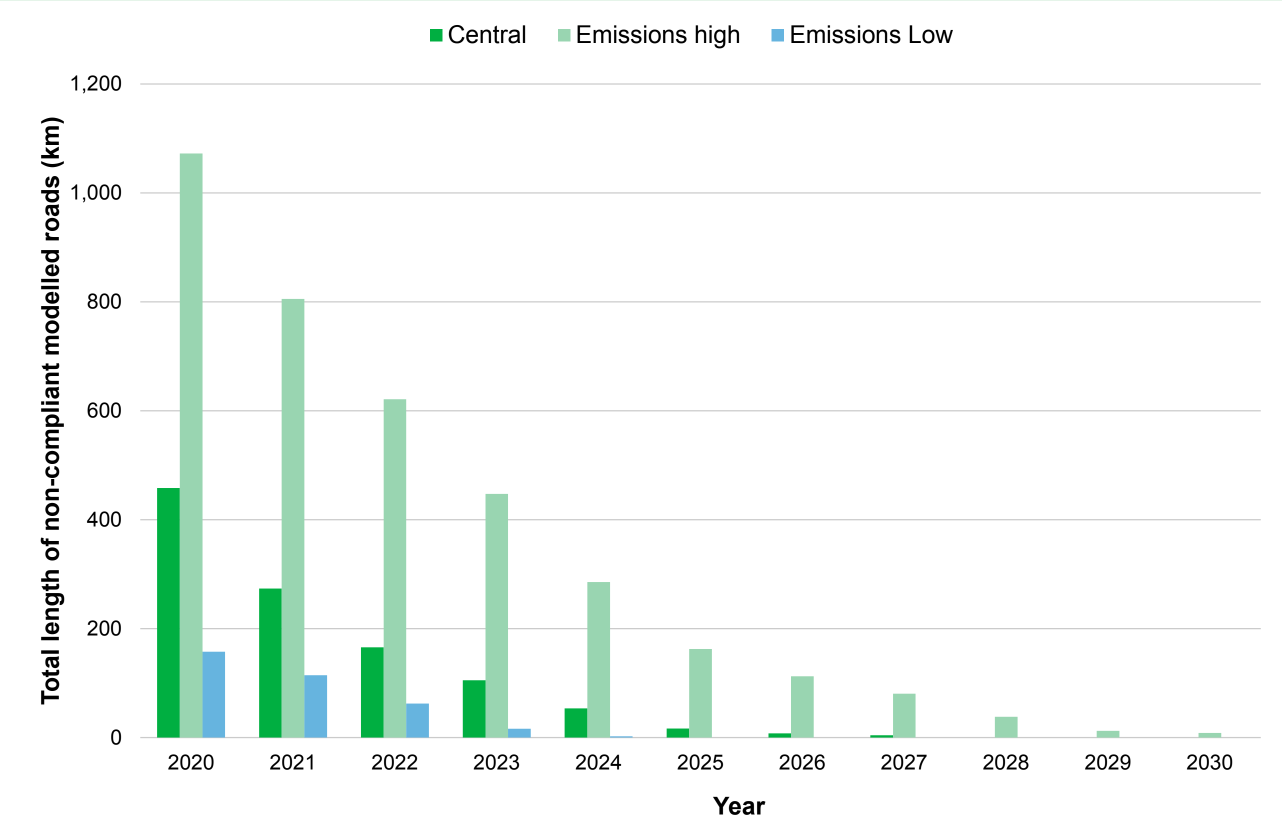
[56] Monte-Carlo analysis is a mathematical method used to combine a number of key uncertainties into a single encompassing measure of uncertainty.

[57] For diesel cars, new type approvals must comply with the Euro 6d-temp standard from January 2017 and all new diesel cars must comply from January 2019. The Euro 6d standard applies from September 2020 for new type approvals and September 2021 for all new diesel cars.

Real Driving Emissions (RDE) data for a set of 19 diesel vehicles has been used to derive high and low emissions scenarios.[58] The standard deviation within this dataset has been determined as a percentage of the mean (±60 per cent). This percentage has been applied to Euro 6 (all three iterations) diesel car and diesel LGV emission factors within the SL-PCM model (for the model's baseline) to produce high and low scenarios. The model was run for 2020, 2025 and 2030, with concentrations for interim years being inferred by linear interpolation. The scenarios are, in effect, examining the effect on NO_2 concentrations if all Euro 6 diesel cars and LGVs were among the worst emitters in the class or among the best emitters in the class. In the central scenario, all modelled roads are compliant by 2028, while in the low scenario 100 per cent compliance on modelled roads is achieved by 2025 (Figure **4.7**). In the high emissions scenario, a number of road links remain non-compliant in 2030.

[58] Department for Transport, Vehicles Emissions Testing Programme (2016) <www.gov.uk/government/uploads/system/uploads/attachment_data/file/552439/vehicle-emissions-testing-programme-print.pdf>

Figure 4.7: Comparison of the estimated total length of modelled road (km) projected to be non-compliant (for the baseline) for central, high and low light duty diesel vehicle emission factor scenarios[59]



Note: The high and low scenarios have been calculated using the SL-PCM model (for the baseline). The central has been calculated using the PCM model (for the baseline).

4.2.2 The Handbook of Emission Factors for Road Transport emission factors

Emissions from future vehicle types not yet present on UK roads remain a central assumption in air quality projections around which there is considerable uncertainty. The evidence regarding emissions for future Euro 6 diesel cars (Euro 6d-temp and Euro 6d) is continuing to emerge. COPERT (Computer Program to calculate Emissions from Road Transport) emission factors are developed by Emisia, a member of the European Research on Mobile Emission Sources (ERMES) group. Use of these emission factors is best practice across most of Europe. Handbook Emission Factors for Road Transport

[59] All of the air quality modelling sensitivities have been presented in terms of total length of non-compliant modelled roads rather than number of non-compliant reporting zones. This is because some scenarios have a limited impact on the number of non-compliant zones within a given year. Therefore, to provide a clearer picture (and to ease comparison between scenarios) the total length of non-compliant modelled roads has been used.

(HBEFA) is an alternative source of emission factors produced by another ERMES partner, TU Graz. COPERT and HBEFA both include estimated emission factors for Euro 6d-temp and Euro 6d vehicles.

The latest update to HBEFA (Version 3.3) was initially released on 25th April 2017, with the final report published on 1st June 2017 (and as such, there was time only for the indicative analysis detailed here).[60] This update was analogous to COPERT's Version 5 in that it took account of real-world driving conditions emissions testing on diesel passenger cars conducted in the UK and across Europe. However, as HBEFA and COPERT incorporated this data into their modelling using different methodologies, the resulting emission factors are different. HBEFA has also introduced a new ambient temperature correction to account for the fact that colder temperatures lead to higher NO_x emissions.

The sensitivity of the modelled projections to alternative emission factors for Euro 6d-temp and Euro 6d (as well as Euro 5 and 6) has been tested by running the SL-PCM model (for the baseline) with adjusted emission factors. An adjustment factor was derived for each Euro standard by comparing COPERT and HBEFA emission factors over a range of driving speeds (12 to 90 kph) representative of a combination of urban, rural and motorway driving at a typical ambient temperature of 12.5°C (Table **4.8**). The model was run for 2020, 2025 and 2030, with concentrations for interim years being inferred by linear interpolation. Use of HBEFA emission factors results in a 10-20 per cent decrease in the total length of non-compliant roads in 2020-2023 compared to the central (COPERT) scenario (Figure **4.9**). It also leads to 100 per cent compliance on modelled roads being achieved in 2027, a year earlier than in the central scenario.

Table 4.8: HBEFA and COPERT emission factors for Euro 5 and Euro 6 diesel passenger cars[61]

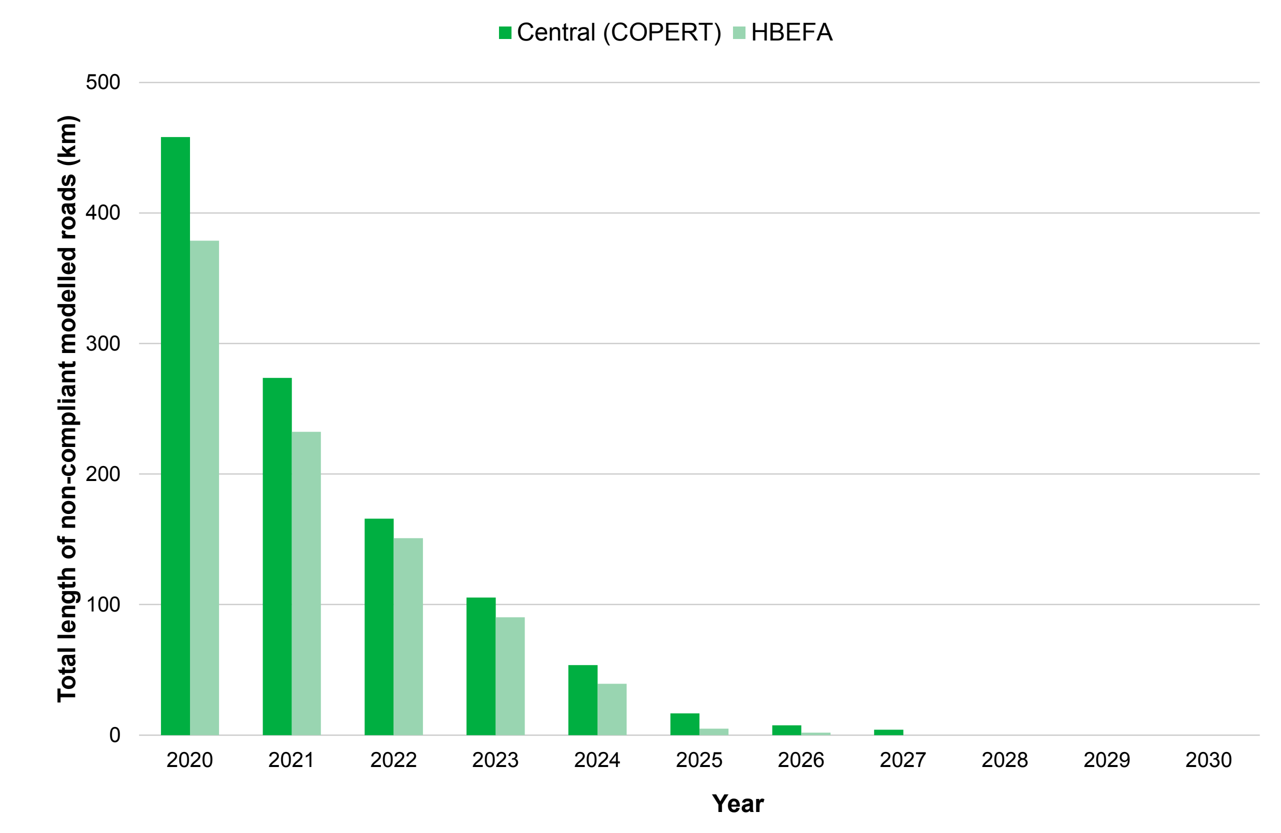
	COPERT (g/km)	**HBEFA** (g/km)	**Difference**
Euro 5	0.647	0.846	+31%
Euro 6 (2015-2017)	0.533	0.470	-12%
Euro 6d-temp (2017-2020)	0.407	0.162	-60%
Euro 6d (2020+)	0.198	0.108	-45%

Note: These are representative emission factors for a journey covering a range of driving speeds (12 to 90 kph) representative of a combination of urban, rural and motorway driving at a typical ambient temperature of 12.5°C.

[60] Institute for internal combustion engines and thermodynamics, Graz University of Technology, 'Update of Emission Factors for EURO 4, EURO 5 and EURO 6 Diesel Passenger Cars for the HBEFA Version 3.3' (2017)

[61] From communication with Leonidas Ntziachristos (Emisia)

Figure 4.9: Comparison of the estimated total length of modelled road (km) projected to be non-compliant (for the baseline) for central (COPERT) and HBEFA emission factor scenarios

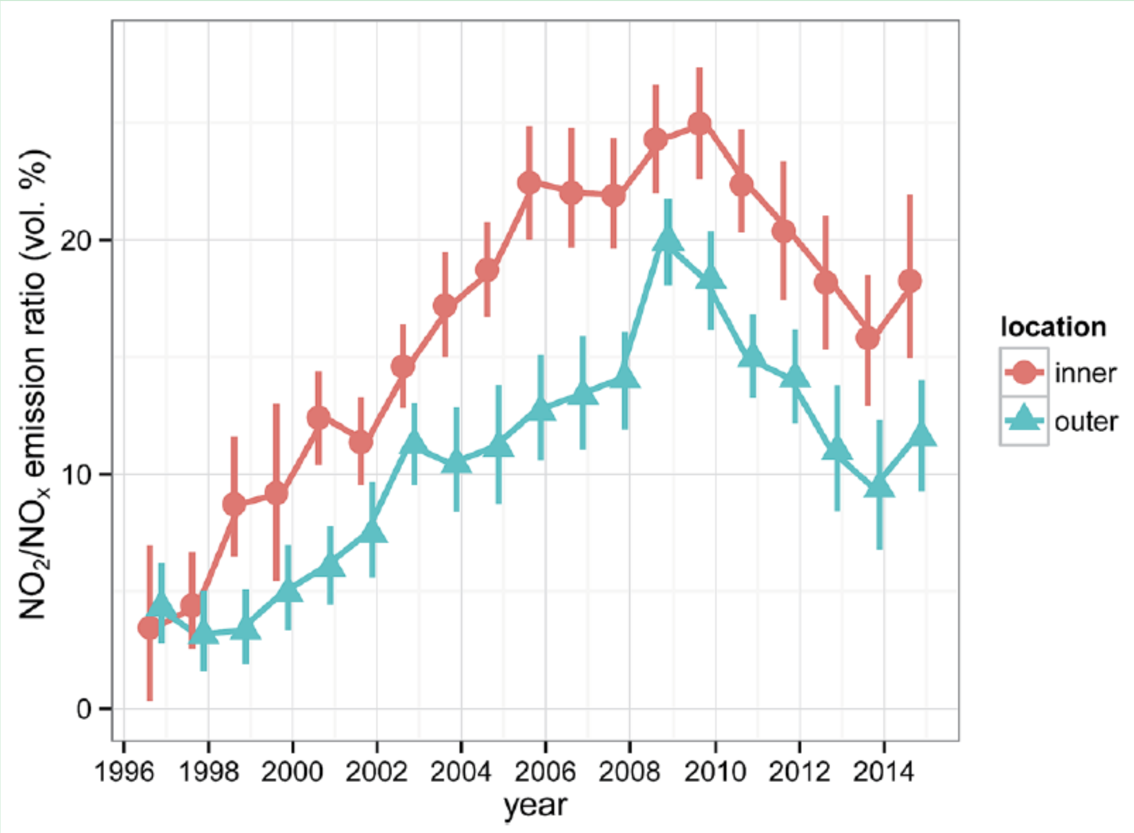


Note: The HBEFA scenario has been calculated using the SL-PCM model (for the baseline). The central has been calculated using the PCM model (for the baseline).

4.2.3 Primary NO_2 fraction

Based on guidance from the air quality modelling uncertainty panel (Section **4.1.1**), sensitivity scenarios have been modelled around primary NO_2 fraction (f-NO_2). The central scenario modelled for the Plan uses 2015 NAEI f-NO_2 values. This gives an average f-NO_2 of 0.25 in 2015 for UK major roads (and varying from 0.24–0.26 for future years). However, analysis of ambient measurements taken on UK roads suggests a value of 0.15 for 2015 (Figure **4.10**).

Figure 4.10: Annual average estimated fraction of primary NO_2 calculated from data from ambient monitoring sites in London[62]



Note: The ratio has been calculated separately for inner and outer London. The error bars represent 95% confidence in the mean estimates. The data for 2015 only includes the first 3 months of the year.

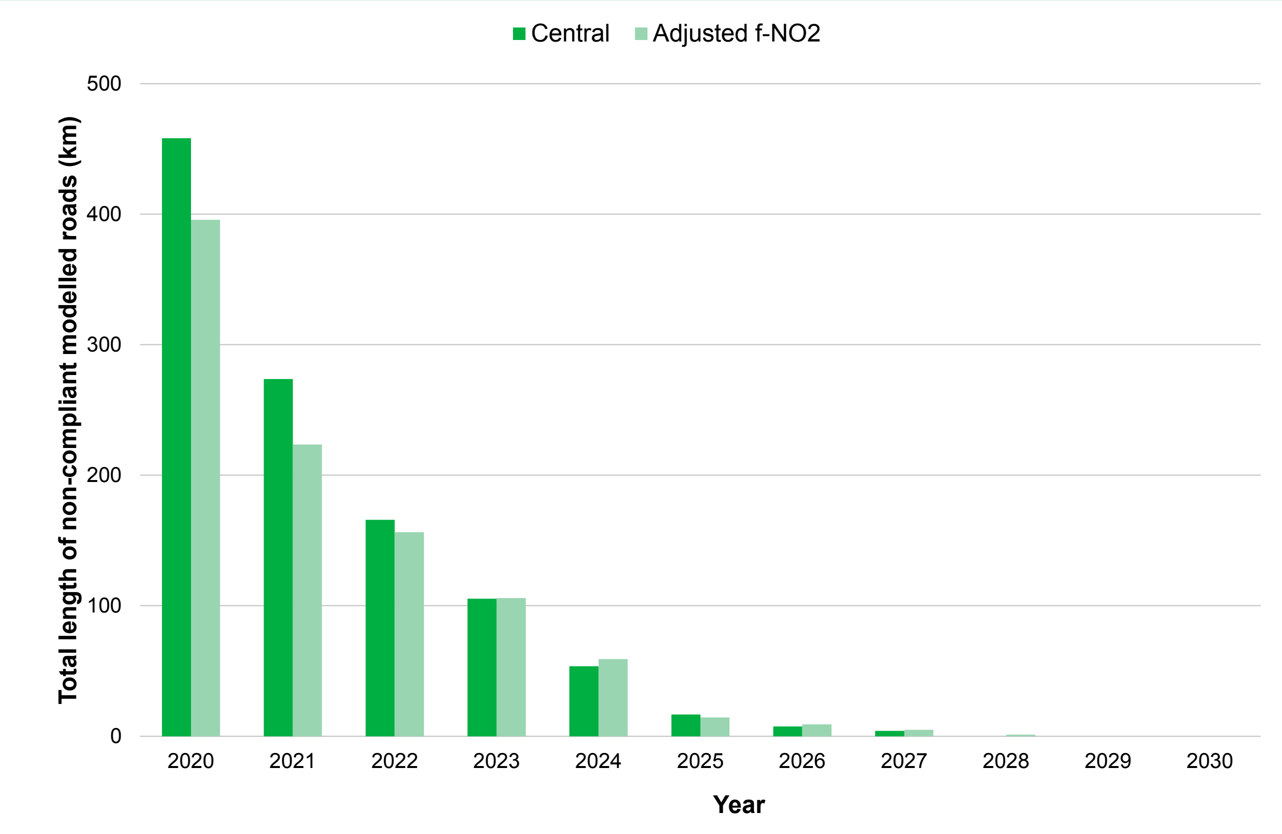
A sensitivity scenario has been modelled based on this alternative f-NO_2 value using the SL-PCM model (for the baseline) for 2020, 2021, 2025 and 2030, with concentrations for interim years inferred by interpolation. The sensitivity has been parameterised through a recalibration of the model's oxidant partitioning model, adjusting f-NO_2 down by 40 per cent (based on the difference between the 2015 NAEI f-NO_2 and the average measured 2015 f-NO_2 value).

The response of the model to the decrease in f-NO_2 is rather complex, with a decrease in the total length of non-compliant roads in some years and an increase in others (Figure **4.11**). This is a consequence of the non-linear relationship between NO_x and NO_2. In response to a decrease in f-NO_2, road links with higher NO_x concentrations decrease in NO_2 concentration while those with lower NO_x concentrations increase in NO_2 concentration. Therefore, the total length of non-compliant road can increase or decrease

[62] Carslaw D.C. et al, 'Have vehicle emissions of primary NO_2 peaked?', *Faraday Discussions* (2016)

with respect to the central scenario depending on which links are moving into compliance within a given year.

Figure 4.11: Comparison of the estimated total length of modelled road (km) projected to be non-compliant (for the baseline) for central and adjusted fraction of primary NO_2 scenarios



Note: The f-NO_2 scenario has been calculated using the SL-PCM model (for the baseline). The central has been calculated using the PCM model (for the baseline).

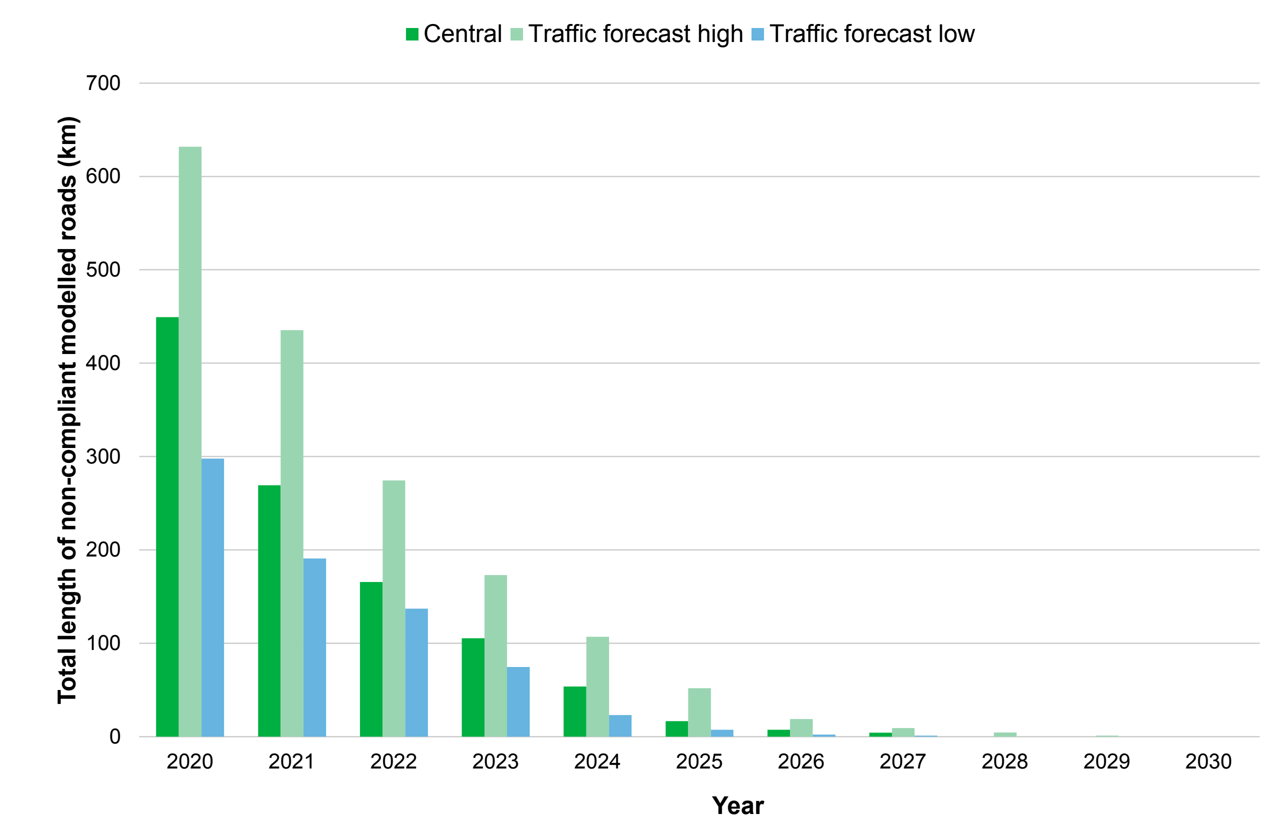
4.2.4 Traffic forecasting

Although the air quality modelling uncertainty panel did not explicitly recommend a sensitivity study around the traffic forecast employed in the Plan, they assigned a relatively poor qualitative estimate of ‘medium confidence’ (to the area which they described as ‘traffic composition’). As such, JAQU has calculated sensitivity scenarios based on the high and low traffic mileage forecasts from the National Transport Model (the central forecast from this model was used in the CAZ scenario).[63] The scenarios have been run using the SL-PCM model (for the model’s baseline) for 2020, 2025 and 2030, with data for interim years being inferred by linear interpolation.

[63] The high forecast shows a mean difference in vehicle kilometres driven of +8% in 2020, +10% in 2025 and +12% in 2030 compared to the central forecast. The low forecast shows a mean difference in vehicle kilometres driven of -7% in 2020, -9% in 2025 and -11% in 2030 compared to the central forecast.

The results of this sensitivity study suggest that traffic forecasting is a fairly significant source of uncertainty in the modelling (Figure **4.12**). For 2020, the high and low scenarios show a difference in total length of non-compliant roads of approximately ±40 per cent with respect to the central forecast. In the high scenario, 100 per cent compliance is achieved one year later than in the central scenario and in the low scenario one year earlier.

Figure 4.12: Comparison of the estimated total length of modelled road (km) projected to be non-compliant (for the baseline) for central, high and low traffic forecast scenarios



Note: The high and low scenarios have been calculated using the SL-PCM model (for the baseline). The central has been calculated using the PCM model (for the baseline).

4.2.5 Relationship between NO_2 and mortality

The cost-benefit analysis uncertainty panel noted that the relationship between NO_2 and mortality was an important uncertainty. As such, four sensitivity scenarios have been modelled around the treatment of this relationship in the analysis conducted for the Plan, which uses a 0.9 per cent change in mortality per 10µg/m^3 annual average change in NO_2 concentration. A high scenario (2 per cent) and a low scenario (0.2 per cent) have been derived from COMEAP guidance.[64] An additional high scenario has been modelled based

[64] The central estimate of 0.9% has been derived by taking the central coefficient of 1.023 and applying an adjustment of 40%. The central coefficient has a 95% confidence interval of 1.008-1.037 and the adjustment

on the WHO's recommended coefficient of 5.5 per cent[65] and a further low scenario has been modelled by assuming that NO_2 has no mortality impact (a coefficient of 0 per cent).

The results of this sensitivity confirm that the relationship between NO_2 and mortality is a highly significant area of uncertainty (Figure **4.13**). Applying COMEAP's recommended range around the central estimate gives NPVs £300m lower and £530m higher than the central NPV (both still negative). The wider sensitivities show that if there is no impact of NO_2 on mortality, the NPV falls to -£1,500m while if the WHO coefficient[66] is applied, the NPV rises by a considerable margin to +£1,000m.

Table 4.13: NO_2 and mortality cost-benefit sensitivity scenarios

Scenario	Percentage change per 10µg/m^3 annual average change in NO_2 concentration	NPV (£m)
No impact	0.0%	-1,500
COMEAP low	0.2%	-1,400
COMEAP central	0.9%	-1,100
COMEAP high	2.0%	-570
WHO	5.5%	+1,000
Note: NPVs have been rounded to 2 significant figures.		

4.2.6 Valuation of health impacts

To value the mortality impacts of exposure to NO_2, the estimated number of life years lost due to exposure (the difference between predicted life expectancy with and without exposure) has been combined with a monetary impact value, the value of a life-year lost

factor range recommended by COMEAP was 25-55%. It is important to note that this range is not a continuum with an obvious mid-point. Rather it is the result of different assumptions being given different weight within a process of expert judgement. The high scenario has been derived by taking the upper confidence interval and applying the upper adjustment factor and the low scenario in the corresponding fashion. Section **2.2.1** discusses COMEAP's advice in more detail.

[65] World Health Organization, *'Health risks of air pollution in Europe – HRAPIE project'* (2013) <www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/health-risks-of-air-pollution-in-europe-hrapie-project.-new-emerging-risks-to-health-from-air-pollution-results-from-the-survey-of-experts>

[66] It should be noted that the WHO coefficient has a recommended cut-off for quantification of 20µg/m^3 and is based on a meta-analysis where some of the studies include cohorts which may not be representative of the wider population, for example cohorts defined by pre-existing conditions.

(or VOLY).[67] The impact values used to monetise changes in life-years lost in the CAZ scenario were originally estimated by Chilton et al. (on behalf of Defra).[68] This study estimated a VOLY associated with a life-year spent in good health of £27,630 (2002 prices), uprated to £37,353 (2017 prices) for use in the Plan.

Two sensitivities around this central VOLY figure have been modelled. Firstly, the Clean Air for Europe (CAFE) recommended VOLY figure (widely used across Europe) of €52,000 (2000 prices)[69] has been used, though uprated and converted to £62,428 (2017 prices). Additionally, the value of a statistical life year (VSL)[70] estimate produced by CAFE[71] has been converted into VOLY figures and used as a second sensitivity. Both of these approaches result in higher values being used; no lower alternatives are available.

These scenarios reinforce the outputs of the NO_2 and mortality relationship sensitivities in confirming that health impacts and their valuation are the most significant source of uncertainty in the cost-benefit analysis (Table **4.14**). Of note is the result for the CAFE VSL scenario, which produces a positive NPV.

Table 4.14: Health valuation cost-benefit sensitivity scenarios

Scenario	**Monetary impact value** (£, 2017 prices)	**NPV** (£m)
Central	37,353	-1,100
CAFE VOLY	62,428	-780
CAFE VSL (converted to VOLY)	203,817	+740
Note: NPVs have been rounded to 2 significant figures.		

4.2.7 Welfare cost of upgrading

Welfare cost has been defined in the modelling as the difference between an individual's normal (baseline) actions and their less preferred actions in response to a CAZ, in this

[67] VOLY is derived through a consideration of individuals' or society's willingness to pay for an increase of one additional year of life expectancy.

[68] Department for Environment, Food and Rural Affairs, '*Valuation of the health benefits associated with reductions in air pollution*', 2004, <http://webarchive.nationalarchives.gov.uk/20130403215617/http://archive.defra.gov.uk/environment/quality/air/airquality/publications/healthbenefits/airpollution_reduction.pdf>.

[69] AEA Technology, '*Methodology for the Cost-Benefit analysis for CAFE: Volume 2: Health Impact Assessment*', 2005 <http://ec.europa.eu/environment/archives/cafe/pdf/cba_methodology_vol2.pdf>

[70] VSL is derived through a consideration of individuals' or society's willingness to pay for a lower risk of mortality, divided by that risk reduction.

[71] Ibid.

case the cost of upgrading a vehicle earlier than in the baseline. The modelling has assumed an average welfare cost of halfway between zero and the full cost of upgrading. A more complete explanation of how the welfare cost of CAZs is monetised is given in Annex **E.** There is limited available research in this area and as such the valuation approach for this welfare cost is subject to a degree of uncertainty. Sensitivity scenarios have therefore been modelled using the full cost of continuing into the zone and zero as the welfare cost. The impact on NPV is approximately ±70 per cent with respect to the central scenario (Table **4.15**).

Table 4.15: Welfare cost of upgrade sensitivity scenarios

Scenario	**NPV** (£m)
Central	-1,100
Full cost (high)	-1,800
Zero cost (low)	-320
Note: NPVs have been rounded to 2 significant figures.	

4.2.8 Behavioural response to CAZs

The cost-benefit uncertainty panel suggested that application of Transport for London research on response to the presence of a CAZ to the rest of the UK was a source of uncertainty (Table **3.3**). To test the sensitivity of the analysis to this assumption, scenarios have been modelled by taking the extreme examples of 100 per cent of non-compliant vehicles upgrading and 100 per cent of non-compliant vehicles paying the charge to continue entering the zone (these outcomes are extreme would not be expected in practice). In this case, results have been presented for cost only, rather than overall NPV (Table **4.16**)[72] and do not assume any changes in charging levels, which is unlikely in practice.

The effect is significant, of the order of several hundred million pounds. However, the change in NPV from the central estimate would be lower due to the effect on benefit. For example, if 100 per cent of vehicles upgraded then health benefit would increase somewhat, offsetting some of the increased cost associated with this scenario. The significant difference in cost occurs because the owners of non-compliant vehicles who elect to continue and pay the charge transfers this money from themselves to the relevant local authority. Therefore continuing into the zone and paying the charge is taken in this national model to be cost neutral, local authorities as part of their feasibility studies will consider any distributional impacts of the CAZ charges.

[72] These scenarios would also have an impact on benefit. An assessment of the impact on benefit would require further air quality modelling and as such, due to time constraints, only analysis of the effect on cost has been performed.

Table 4.16: Behavioural response to CAZs economic sensitivity scenarios	
Scenario	**Cost** (£m)
Central	2,100
100% upgrade	3,400
100% continue	240
Note: Costs have been rounded to 2 significant figures and represent the net public cost rather than the cost to individuals.	

4.2.9 Number of days in CAZ

The Trafficmaster dataset, sourced from DfT GPS journey information, contains estimates on the number of days spent in each zone split by vehicle-type. This is used to calculate annualised costs that are based on the number of days a vehicle would enter a zone. Examination of this data showed that a small proportion of vehicles drove into the CAZ network a disproportionately large number of times compared to the rest of the sample. For cars and, to a lesser extent, vans these vehicles are likely to be private hire vehicles or similar which are far more likely to drive into the CAZ network. These vehicles served to skew the mean upwards, giving a larger number of average days in the zone than would be expected.

The central cost-benefit analysis therefore uses the median number of days spent within a CAZ as an input. This has been chosen as it reduces the skewing effect caused by the small number of vehicles which enter the CAZ network very regularly. In order to test the sensitivity of the model to this, an alternative scenario NPV has been calculated by using the mean number of days spent within a CAZ. This scenario results in an increase in cost of approximately 30 per cent, leading to a £600m lower (more negative) NPV (Table **4.17**).

Table 4.17: Number of days in CAZ economic sensitivity scenario	
Scenario	**NPV** (£m)
Median (central)	-1,100
Mean	-1,700
Note: NPVs have been rounded to 2 significant figures.	

4.2.10 Particulate matter health impact

The health benefit calculated in the Plan considered only the impact of NO_2 on mortality, although in reality there would be an additional health benefit due to the reduction in particulate matter (PM). This was not included in the central analysis following advice from COMEAP. As road traffic emits multiple pollutants (including NO_2 and PM) it is difficult to quantify the extent to which the reported associations of mortality represent the same overall effect of the pollution mixture, or the “overlap” of effects. COMEAP provide coefficients for both NO_2 and PM but, as the PM coefficient is not adjusted to take into account possible confounding by effects of NO_2, recommend that these are not combined (as doing so could overestimate the combined mortality effects). Therefore, as in the draft Plan analysis, the central analysis of this report does not quantify the mortality impact of primary PM reductions. However, as the measures are expected to lead to reductions in primary PM, this is likely to mean health benefits are being underestimated.

In order to assess the effect of including the impact of PM on the cost-benefit analysis, a sensitivity scenario has been modelled. The effect of vehicle upgrade (in response to the measures being implemented) on PM emissions has been modelled by altering emission factors.[73] The consequent health benefit of this reduction in PM emissions has been calculated through application of the updated PM damage costs and added to the health benefit from the NO_2 emissions reduction. The inclusion of the impact of PM reduction results in an increase in NPV of £160m (Table **4.18**).

Table 4.18: PM health impact economic sensitivity scenario

Scenario	**NPV** (£m)
Central	-1,100
PM health impact included	-940
Note: NPVs have been rounded to 2 significant figures.	

4.2.11 Optimism bias

The cost-benefit uncertainty panel did not suggest any sensitivity scenarios to be run around the costs to government from the measures. However Treasury guidance recommends adjusting costs to account for optimism bias.[74] Optimism bias describes the tendency for costs to be underestimated and benefits to be overestimated when appraising projects involving capital expenditure. Therefore the high and low scaling factors for non-standard civil engineering capital costs[75] have been used as sensitivity scenarios for the costs to government. The high sensitivity increases government costs by around £160m and the low reduces them by around £20m (Table **4.19**).

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[73] The effect of cancelled or rerouted journeys on PM has not been considered due to time constraints. As well as the impact these responses would have on exhaust PM emissions within CAZ areas, there would be an additional impact on PM from tyre and brake wear. Consequently, the possible impact of a separate consideration of PM health effects has likely been underestimated in this sensitivity scenario.

[74] HM Treasury, '*The Green Book: appraisal and evaluation in central government*', <www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent>

[75] HM Treasury, '*Public Sector business cases using the five case model: updated guidance*', 2015, <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/469317/green_book_guidance_public_sector_business_cases_2015_update.pdf>

Table 4.19: Optimism bias economic sensitivity scenarios		
Scenario	**Government impact** (£m)	**NPV** (£m)
Central	-250	-1,100
High (+66%)	-410	-1,200
Low (-6%)	-230	-1,000
Note: Prices have been rounded to 2 significant figures.		

4.2.12 Greenhouse gas impacts

A sensitivity scenario around the greenhouse gas impact of the CAZ scenario was modelled using the Department for Business, Energy and Industrial Strategy's high and low carbon price forecasts.[76] The effect on the greenhouse gas impact is approximately ±50 per cent, although given that this is a relatively minor aspect of the cost-benefit analysis, the consequent impact on NPV is negligible (Table **4.20**).

Table 4.20: Greenhouse gas economic sensitivity scenarios	
Scenario	**Greenhouse gas impact** (£m)
Central	15
High carbon price forecast	23
Low carbon price forecast	7.7
Note: Prices have been rounded to 2 significant figures. As there is no impact to 2 significant figures, NPVs have not been included.	

4.2.13 Exposure modelling

In calculating the health impacts of change to air quality, personal exposure to NO_2 has been estimated based on the estimated NO_2 concentration outside of the place of residence. This has notable merit as it forms the basis of much of the evidence used in epidemiological studies to assess the links between air quality and health. Intuitively it is reasonable as the residence is the location where individuals spend the majority of their time.

While this is a reasonable assumption it is well recognised that the actual exposure depends on time spent in a variety of places, including at work and in transport, as well as the NO_2 concentrations in those locations. This means that individual exposure could vary

[76] Department for Business Energy and Industrial Strategy, '*Data tables 1-19; supporting the toolkit and the guidance*', 2017 <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/602657/5._Data_tables_1-19_supporting_the_toolkit_and_the_guidance_2016.xlsx>

significantly between people, depending on their personal activity.[77] One study of the discrepancy between residence-based and mobility-based estimates of individual exposure to NO_2 found that residence-based estimates substantially underestimated the true exposure.[78] Other studies have shown that individuals who commute to the workplace can be exposed to approximately twice the amount of NO_2 compared to those who work from home.[79]

This is especially important for this Plan where geographically targeted measures may change public exposure in urban areas but have a limited impact on residential concentrations. In such a situation the reduction in actual individual exposure would be higher than implied by residence-based exposure models. Therefore, the health benefits that have been estimated may be understated in this respect.

It has not been possible to quantify the impact of this uncertainty. It is however possible that this could be significant given that a notable proportion of public exposure is likely to occur within urban areas.

4.3 Discussion

This Plan has been developed using the best available evidence and expert judgement in both its air quality modelling and its cost-benefit analysis. However, an important step in developing any plan that relies on modelling is to recognise and analyse the uncertainties propagated by the assumptions made. This develops an understanding of the strengths and weaknesses of the approach taken and leads to a robust, well-informed decision-making process.

The treatment of uncertainties has been expanded through the establishment of two expert panels, who provided an independent assessment of the uncertainty in the air quality modelling and cost-benefit analysis (Section **4.1**). These panels identified the key areas of uncertainty within the two analytical domains, proposed a means of estimating overarching uncertainty, and provided indicative quantitative ranges where possible. JAQU has acted on the panels' suggestions by providing estimates of overarching uncertainty and by modelling a range of sensitivity scenarios based on the key areas of uncertainty which they identified (Section **4.2**). The overarching uncertainty estimates are ±29 per cent for

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[77] Steinle et al., Quantifying human exposure to air pollution: moving from static monitoring to spatiotemporally resolved personal exposure assessment (NERC Centre for Ecology & Hydrology, 2013) <http://nora.nerc.ac.uk/20732/1/N020732PP.pdf>

[78] Setton et al., 'The impact of daily mobility on exposure to traffic-related air pollution and health effect estimates', *Journal of Exposure Science and Experimental Epidemiology* (2011) <https://www.nature.com/jes/journal/v21/n1/full/jes201014a.html>

[79] See for example, NERC Centre for Ecology & Hydrology, Integration of modelling and personal exposure monitoring of air pollution (2014) <www.gla.ac.uk/media/media_363829_en.pdf>

the air quality modelling (Section **4.1.1**) and -£1,800m to +£1,000m around the central NPV of -£1,100m for the cost-benefit analysis of the CAZ scenario (Section **4.1.2**). There are additional potential impacts from improving air quality that are not possible to monetise (for example, the effect on subjective wellbeing) and, therefore, are not included in this NPV range. As a result, the overall NPV is likely to be underestimated.

In many cases, the modelled sensitivities present highly different results compared to the central scenario (Section **4.2**). However, it is important to note that the scenarios are largely indicative and the estimates produced from them should not be interpreted as a statistically derived range. Rather, they are extreme examples, designed to test the model's response to a particular parameter. As such the overarching uncertainty in the cost-benefit analysis which has been derived from these sensitivities should also be treated as an indicative range only.

The uncertainties identified underline the importance of interpreting the results in this report with caution and of undertaking continuous evaluation of real-world outcomes in order to adapt plans that have been made based on this evidence. JAQU will continue to work with the aforementioned uncertainty panels and with the wider academic community in order to improve the evidence base upon which its air quality, health and economic modelling rests. In this way, uncertainties can be reduced and intervention measures can be implemented with increased confidence. Details about future steps which will be undertaken can be found in Section **5**.

5. Next steps

Action to tackle NO_2 on urban roads does not stop with the publication of this Plan. Further evidence will be required to support the implementation of the measures outlined in the Plan and to evaluate its success in achieving its aims.

Work is also ongoing to refresh government's Air Quality Strategy, which will require robust evidence to support strong action targeted in the most important areas.

5.1 Plan implementation and support for local authorities

The next step in implementing the measures identified in the Plan will require new legislation under which the Secretary of State would be able to require particular local authorities to implement their plans for a charging CAZ (following relevant feasibility studies). The current ambition is to lay any Statutory Instrument before Parliament in September 2017.

Individual local authorities will also be required to conduct feasibility studies with accompanying business cases. The government has previously said that relevant local authorities will have up to 18 months to produce their plans. We will now require local authorities to set out initial plans within 8 months, by the end of March 2018. These will be followed by final plans by the end of December 2018.

Work has already begun on feasibility studies with the five cities which were required to introduce CAZs in the 2015 Plan and following central government guidance on modelling and economic assessment. Central government has used feedback from these initial cities to consider ways to improve assistance to local authorities. It is committed to making the process as simple and fast as possible for local authorities by doing what it can to facilitate feasibility studies.

The UK government is conscious that some local authorities are projected to have air quality concentrations which are close to, but below air quality limits in 2021. The government will consider further steps to ensure that air quality in these areas improves and to ensure that forecast levels remain compliant. These steps could include preferential access to funding and government support to access and build on best practice.

Central government will work with the local authorities to review what tools and support can be made available. Significant additional resources have been allocated both to support the local authorities in this area and to develop the evidence more broadly.

5.2 Adaptive management

Given the uncertainties set out in Section **4**, it will be important to use an adaptive approach to implementation whereby the impact of the measures is monitored and they are adjusted as necessary based on emerging evidence. The experience of the five cities required to introduce CAZs in the 2015 Plan can be used to inform the approach taken by other local authorities.

By adopting a flexible approach to implementation and integrating robust measurement and evaluation of the performance of these interventions to control air quality, measures can be adjusted based on an improving evidence base. In this way, the Plan is able to respond to the uncertainty in a constructive manner and incrementally build confidence in which methods are most effective, thus driving continuous improvement.

To make sure the right evidence is available to use an adaptive management approach to the implementation of the measures set out in the Plan, consideration is being given to:

- The design of proportionate evaluation processes that will measure the impacts of the measures and compare them to ‘control areas’ where there have been no interventions
- Setting up appropriate monitoring and data collection processes
- Conducting feasibility studies in urban areas that are implementing local plans to improve evidence on a local level and increase confidence that the design of their plan is correct to deliver the desired impact
- Ensuring robust appraisals of any local measure funding to allow for evaluation of associated air quality, health and economic consequences
- Additional evaluation of data collected, widening the evidence base for measures that work effectively with regards to improving air quality
- Adaptation of national and local actions to optimise the range of interventions in use

Data collection by local authorities with exceedances, along with appropriate data about other components of the measures, will be integral to assessing the success of different interventions to control air quality. Consideration is being given to whether sufficient value will be obtained from commissioning an evaluation contractor to collect primary data and conduct a more in-depth review.

It will be necessary to consider the evaluation methods, data collection requirements and stakeholder feedback mechanisms that will be necessary to conduct the review. Some important principles for monitoring and evaluation of the measures are:

- Establishing a baseline for the analysis (ideally establishing one full year of data collection before the policies are introduced)
- Taking a centralised approach to make sure results are consistent and comparable
- Seeking efficiencies, such as using local authority monitoring sites, where possible

- Monitoring in such a way as to develop a greater indication of source categories and apportionment
- Focusing on areas affected by the measures implemented

5.3 Wider air quality strategy

The focus of this technical report is on reducing local NO_2 concentrations, which is where our immediate challenges lie and where immediate action is needed. As the Plan notes, the UK government has adopted ambitious, legally-binding targets for 2020 and 2030. These ceilings will require significant reductions in emissions of the five main air pollutants NO_x, $PM_{2.5}$, SO_2, NH_3 and NM-VOCs) (Table **5.1**).

Table 5.1: UK emission reduction commitments, the percentage reduction in emissions from 2005 levels required over time

	NO_x	**$PM_{2.5}$**	**SO_2**	**NH_3**	**NM-VOCs**
2020-29	-55%	-30%	-59%	-8%	-32%
2030 onwards	-73%	-46%	-88%	-16%	-39%

Over the medium and longer term, additional action will be required to meet the emission reductions set out above. This will require measures that cut across all sectors of the economy in addition to the planned measures to address local NO_2 concentrations, which have a road transport focus.

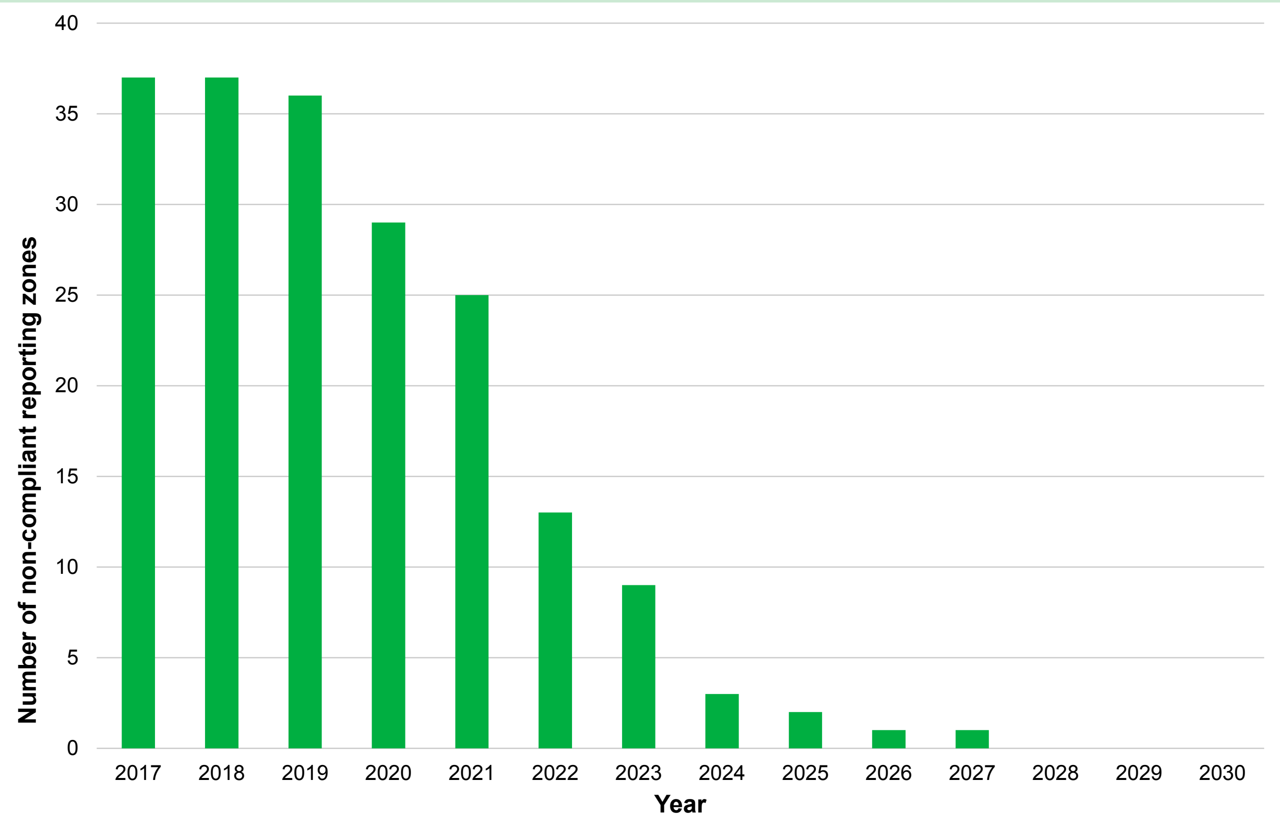
Evidence will play an important role in identifying where emission reductions come from and at what cost, helping to ensure reductions are achieved cost-effectively and without disproportionate impacts on individual sectors. Understanding the way pollutants react with one another in the atmosphere helps identify unintended consequences; for example, a reduction in one pollutant's concentrations leading to a rise in another's. This evidence base is being developed and will be informed by evidence gathered for this NO_2 Plan.

6. Conclusion

This technical report accompanies the UK Air Quality Plan for tackling nitrogen dioxide and provides a benchmark against which to assess local authority measures required by the Plan. This technical report presents the evidence that was used to develop and then assess the Plan. It is important to note that whilst this national assessment describes one route to compliance with NO_2 limit values it is unlikely to represent the eventual, local plans. Local feasibility studies will use local knowledge to help design schemes and ongoing data collection will inform an adaptive approach that adjusts solutions as evidence emerges and uncertainty is reduced. This technical report therefore provides a benchmark against which to assess local authority measures required by the Plan.

While notable progress has been made in improving air quality the UK remains non-compliant with its obligations for ambient concentrations of NO_2. The latest historical assessment of UK air quality is for 2015 and shows 37 of the 43 reporting zones exceeded the 40µg/m^3 annual mean NO_2 limit value in at least one location. With no further action compliance is not expected to be delivered for a decade (Figure **6.1**).

Figure 6.1: The estimated number of reporting zones projected to be non-compliant without further action



Note: Figure **4.4** provides an estimate of the uncertainty around these projections

To deliver compliance in the shortest possible time the Plan sets out measures covering four main strands:

- Existing or ongoing action to improve air quality. This is assessed in the baseline scenario

- Local plans to be developed and implemented at pace so that air quality limits are achieved within the shortest possible time. The benchmark modelled to assess the plans against assumes a number of CAZs are introduced. This is assessed in the CAZ scenario.

- Additional abatement measures (such as traffic management, signage and rerouting) in areas where a CAZ would not be appropriate or where opportunities are identified to further reduce the period of non-compliance. This is assessed in the CAZ plus additional actions scenario.

- Undertaking supporting measures which would either further improve air quality or mitigate the costs of the other measures.

In assessing the measures in the Plan it has only been possible to model the first three strands and in the case of the third, only an indicative assessment of the air quality impact is presented. Supporting measures in the final strand are not assessed because they are either primarily targeted on supporting the transition to delivering the change or at present are not developed to the point at which they can be nationally assessed.

Table 6.2: Comparison of the estimated number of reporting zones projected to be non-compliant without further action (baseline), following implementation of illustrative CAZs (CAZ scenario) and with additional abatement measures (CAZ + additional actions)*							
	2018	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Baseline	37	36	29	25	13	9	3
CAZ scenario	37	36	23	6	3	2	2
CAZ + additional actions	37	36	23	3	2	2	1
	2025	**2026**	**2027**	**2028**	**2029**	**2030**	
Baseline	2	1	1	0	0	0	
CAZ scenario	2	0	0	0	0	0	
CAZ + additional actions	0	0	0	0	0	0	

Note: There are 43 UK reporting zones in total. Figure **4.4** provides an estimate of the uncertainty around these projections.

* Additional abatement measures include an assumed 10 per cent reduction in emissions in areas not suitable for a CAZ and the implementation of the zero emission zone in London in 2025.

Table **6.2** shows that the modelled benchmark is expected to bring forward compliance significantly with a notable improvement in 2020 when the first round of CAZs are introduced, and in 2021 when the second round of modelled CAZs are operational. Overall the CAZ plus additional actions scenario has been modelled to reduce the remaining estimated duration of non-compliance by around a third.[80]

National compliance is reached in 2026 in the CAZ scenario. Additional actions may bring national compliance forward. They may also increase the number of compliant reporting zones compared to the CAZ scenario from 2021 onwards, reducing the number of zones in non-compliance each year by a seven more than the CAZ scenario.

It is important to stress that these projections of future air quality are subject to uncertainty. As a measure of the overall uncertainty: comparisons between modelled and measured data vary by ±29 per cent. There is a 95 per cent likelihood that the true outcome is within this range. This uncertainty is not a justification for inaction but a rationale for swift implementation and ongoing evaluation of policies. Some of the uncertainties can only be

[80] The duration of non-compliance can been measured in the number of years each zone is non-compliant as set out in table 6.1. In the baseline from 2018 there are 156 zone years of non-compliance which is reduced to 112 for the CAZ scenario and 105 after additional actions.

reduced by implementing the Plan, measuring the outcomes and then, where necessary, adapting the policies in the future based on increased knowledge of how well they have performed against expectation. To that end, systematic evaluation of the performance of interventions to control air quality will be used to adjust and improve the range of controls and thereby incrementally build confidence in which methods are most effective.

Cost benefit analysis was undertaken for the CAZ scenario only. This is because these measures are considered possible and are well understood. Updated advice on impacts and valuation since the publication of the draft Plan has the effect of reducing the overall quantifiable economic value (the net present value) of the measures assessed. Annex **J** reproduces the analysis from the draft Plan technical report using the latest advice, showing a reduction in impacts across the board.

The net present value of the CAZ scenario is estimated at - £1.1billion over the period 2018-2030, however this is subject to a significant degree of uncertainty. Taking into account a range of factors that may alter the costs and benefits of the assessed measures, there is a range of possible net present values of -£1,800m to +£1,000m around the central NPV of -£1,100m. This net present value excludes a range of potential benefits that could not be quantified and is, therefore, likely to be an underestimate.

The negative net present value of the assessed measures does not diminish the need to take action. The measures that have been identified and assessed illustrate one route for reaching compliance with statutory limits in the shortest possible time; however, local assessments may identify equally effective means at lower cost.

Overall, the evidence presented in this technical report illustrates that there is potential for local plans to bring forward compliance with statutory limits on NO_2 concentrations. The framework for implementing a set of measures in practice is set out in the final Plan that this technical report accompanies. The modelled measures in this report provide a benchmark against which local plans can be compared so that the most effective action can be determined. The evidence base is subject to a substantial degree of uncertainty and so it is important to keep these results and conclusions under review.

Annex A – Refined COMEAP recommendations letter

c/o COMEAP Secretariat
Air Quality and Public Health Group
Public Health England
Chilton
Didcot
Oxfordshire

Dr Thérèse Coffey MP
Parliamentary Under Secretary of State for the Environment and Rural Life Opportunities
Department for Environment, Food & Rural Affairs
Nobel House
17 Smith Square
London
SW1P 3JR

14 July 2017

Dear Dr Coffey

Refined COMEAP recommendations for quantifying mortality effects on the basis of long-term average concentrations of nitrogen dioxide (NO_2)

This letter summarises current thinking of the Committee on the Medical Effects of Air Pollutants (COMEAP) on the association between long-term average concentrations of nitrogen dioxide (NO_2) and mortality risk. We previously (July 2015) provided interim recommendations to assist Defra when developing plans to improve air quality. This letter presents updated recommendations that arose from discussion at the COMEAP meeting held on 24 February 2017.

Summary

1. Population-based studies following people's health over several years show statistical associations between higher long-term average concentrations of ambient NO_2 where people live and increased mortality risk. It is likely that some of this effect is due to NO_2 itself. However, as other co-emitted pollutants, e.g. from traffic, are also high in the same places, these could also be responsible to some extent. In our view, the available evidence and methods do not allow us to make a reliable assessment of the size of the effect which is attributable to NO_2 itself.

2. We therefore recommend two different approaches for assessing the mortality benefits of interventions intended to reduce NO_x emissions from traffic:

☐ For interventions which reduce all traffic-related air pollutants, use the statistical association obtained from population studies. In this case, NO_2 is regarded as acting as a marker for the effects of the traffic pollutant mixture overall, including NO_2.

☐ For interventions which primarily target emissions of NO_x, use 25-55% of the statistical association obtained from population studies. This is, in our judgement, the likely extent to which this association represents effects causally related to NO_2. This is more uncertain than assessing traffic pollutants as a mixture.

Background

3. In our March 2015 *Statement on the evidence for the effects of nitrogen dioxide on health*[81] we noted the strengthening evidence linking NO_2 with health effects. We concluded that:

i. Evidence of associations of ambient concentrations of NO_2 with a range of effects on health has strengthened in recent years. These associations have been shown to be robust to adjustment for other pollutants including some particle metrics.

ii. Although it is possible that, to some extent, NO_2 acts as a marker of the effects of other traffic-related pollutants, the epidemiological and mechanistic evidence now suggests that it would be sensible to regard NO_2 as causing some of the health impact found to be associated with it in epidemiological studies.

4. At that stage, we did not draw conclusions on specific health outcomes nor look in detail at the methodological issues relevant to quantification of effects associated with ambient NO_2.

5. We were subsequently asked to propose approaches to quantifying mortality associated with long-term average concentrations of NO_2. This was primarily needed to provide Defra with a method for assessing the potential mortality benefits of measures to reduce NO_2 concentrations, to assist with the development of plans to improve air quality. In July 2015, a COMEAP working group provided interim recommendations to your predecessor as Parliamentary Under Secretary, Mr Rory Stewart. As well as recommending an interim recommendation for a coefficient, the letter explained that:

"…there is uncertainty in the extent to which the association between long-term average concentrations of NO_2 and mortality is causal. It is likely that some of the effect is due to NO_2, but other co-emitted pollutants could also be responsible to some extent. Therefore, the uncertainty in applying a coefficient to assess the health benefit of measures to reducing NO_2 will depend on the extent to which the measure is specific to NO_2, or also reduces concentrations of other coemitted pollutants. There is likely to be more uncertainty when the measure is specific for a reduction in NO_2, compared to when an intervention aims to reduce the whole mixture of air pollutants."

6. In our *Interim statement on quantifying the association of long-term average concentrations of nitrogen dioxide and mortality* published in December 2015[82], we

[81] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/411756/COMEAP_The_evidence_for_the_effects_of_nitrogen_dioxide.pdf

explained the additional work that we were undertaking to refine our recommendations. These included carrying out a systematic review and meta-analysis of epidemiological studies of long-term average concentrations of NO_2 and all-cause mortality. We noted that, in interpreting these, a number of scientific and methodological challenges needed to be considered, including the extent of independence of the associations of mortality with NO_2 and $PM_{2.5}$. We also noted the uncertainty in the extent to which the association between long-term average concentrations of NO_2 and mortality was causal.

Recommendations arising from COMEAP meeting held on 24 February 2017

7. We have discussed these complex scientific and statistical issues on several occasions since the publication of our interim statement. The Committee has not been able to come to a consensus view on how the epidemiological associations between NO_2 and mortality can be used to either predict the benefits of interventions to improve air quality or to estimate the current mortality burden imposed on the UK population by air pollution.

8. Some Members are doubtful that the evidence is sufficient to allow a robust recommendation for quantification to be made. This is particularly the case for effects likely to be caused by NO_2 itself. Others think it important to make an estimate of the possible mortality benefit from reducing NO_2 concentrations. They note that to recommend against undertaking quantification would have the same consequence, for policy development, as assuming that there would be no mortality benefit, which they do not consider to be likely.

9. We last discussed this issue as a Committee at a meeting held on 24 February 2017. We considered possible uses of the epidemiological associations (coefficients) between long-term average concentrations of NO_2 and mortality effects. For assessment of the benefits (impacts) of interventions to reduce emissions, we discussed the use of these coefficients to:

a. Predict the benefits of interventions which reduce all traffic-related air pollutants

b. Predict the benefits of interventions which primarily target emissions of nitrogen oxides (NO_x)

10. For both these types of intervention, we also discussed (c) assessing the benefits associated with reductions in secondary nitrate concentrations arising from reductions in NO_x emissions.

11. We also discussed

d. Estimating the mortality burden attributable to current concentrations of air pollutants

a. Predicting the benefits of interventions which reduce all traffic-related air pollutants

12. We have derived a summary coefficient linking long-term average concentrations of NO_2 with all-cause mortality, by undertaking a meta-analysis of associations reported in cohort studies. We used associations from single-pollutant models (ie with no attempt to adjust for effects associated with correlated pollutants) in this analysis. This summary

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[82] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/485373/COMEAP_NO2_Mortality_Interim_Statement.pdf

coefficient reflects the effect of NO_2 and also, to some extent, other pollutants with which NO_2 is correlated. These include $PM_{2.5}$, other fractions of particulate matter (PM), and other components of the air pollution mixture. In particular, associations with NO_2 are likely to reflect the effects of the mixture of traffic-related pollutants.

13. Interventions that would reduce traffic movements, or remove traffic altogether, would reduce the whole mixture of traffic-related pollutants. Some other interventions, such as replacing Euro 3/III vehicles by Euro 6/VI, would also reduce emissions of a number of other potentially causal pollutants/metrics (eg volatile organic compounds, aldehydes, organic compounds bound to primary PM) as well as reducing NO_x emissions.

14. We recommend that the summary unadjusted NO_2 coefficient of 1.023 (95% CI: 1.008, 1.037) per 10 µg/m^3 annual average NO_2 is used to estimate the effect on mortality of reductions in the whole pollution mixture.

15. Furthermore: as these measures will also reduce PM concentrations, an alternative calculation of benefits associated with this reduction, using an unadjusted $PM_{2.5}$ coefficient can also be undertaken. Discussion at the meeting held on 7 June 2017 confirmed that our recommendation is to use a coefficient of 1.06 (95%CI: 1.04 - 1.08) per 10µg/m^3 annual average $PM_{2.5}$ derived from a meta-analysis of single pollutant studies (Hoek et al, 2013)[83]. As either of these calculations is likely to underestimate the likely benefits of interventions, the higher of the two values calculated from these two approaches can be used as the most appropriate estimate of the predicted benefits.

b. Predicting the benefits of interventions which primarily target emissions of NO_x

16. Some interventions are primarily targeted at reducing NO_x emissions, and would have little impact on emissions of other traffic-related pollutants. Using the unadjusted coefficient to predict the mortality benefits of these interventions would produce an over-estimate.

17. We have discussed whether it would be possible to use epidemiological associations for NO_2 reported from two-pollutant models (with PM) to refine the summary coefficient. These coefficients would be adjusted, as far as possible, for effects associated with PM, especially $PM_{2.5}$. In our view, the available evidence and methods do not provide a satisfactory basis on which to reliably propose an adjusted coefficient. It should be noted that even a coefficient adjusted for effects more closely associated with $PM_{2.5}$ concentrations than with NO_2 would not reliably reflect the size of the causal effect of NO_2 itself: the adjusted coefficient would also reflect effects of other pollutants which are more closely spatially correlated with NO_2 than with $PM_{2.5}$, such as ultrafine particles, primary combustion particles, volatile organic compounds etc.

18. The majority of Members therefore considered it preferable to use expert judgement to make a recommendation as to how the benefits of interventions that primarily target NO_x could be estimated. We considered it likely that the effect of NO_2, itself, on mortality was likely to be in the range of 25 – 55 % (mid-point of range 40%) of the unadjusted coefficient of 1.023 (95% CI: 1.008, 1.037) per 10µg/m^3 annual average NO_2, and recommend that this be used in assessments of interventions that primarily target NO_x

[83] Hoek, G., Krishnan, R. M., Beelen, R., Peters, A., Ostro, B., Brunekreef, B. & Kaufman, J. D. 2013. Long-term air pollution exposure and cardio- respiratory mortality: a review. *Environ Health*, 12, 43.

emissions. This is equivalent to reducing the unadjusted coefficient by 20% (an approximate adjustment for effects associated with $PM_{2.5}$ concentrations, based on two-pollutant models) and applying expert judgement, inferred from other types of evidence, suggesting that 30-70% of this adjusted coefficient may be caused by NO_2 itself, rather than other correlated (e.g. co-emitted) pollutants.

c. Assessment of effects associated with secondary nitrate

19. For both types of intervention, we consider it appropriate to, additionally, assess mortality benefits associated with reductions in secondary nitrate concentrations arising from the reductions in NO_x emissions. Because secondary nitrate concentrations occur some distance from the source of NOx emissions, effects associated with them would not be represented by the NO_2 coefficient.

20. We recommend using the unadjusted coefficient 1.06 (95%CI: 1.04 - 1.08) per $10 \mu g/m^3$ annual average $PM_{2.5}$.

d. Estimating the mortality burden attributable to current concentrations of air pollutants

21. We do not think it appropriate to try to estimate the mortality burden attributable to current concentrations of NO_2 alone. In numerical terms, the same coefficient could be applied to impact or burden calculations. However, several Members felt that there were differences in terms of how the results are used. Burden estimates may include estimation of effects at low concentrations (typically, impact estimates do not) where there is a lack of certainty whether NO_2 increases mortality and/or over the shape of the concentration-response relationship. Impact calculations typically involve comparisons across policies. The uncertainties may not affect the relative comparisons whereas burden has a more absolute status. Burden calculations may be publicised in the media without the associated uncertainties. Finally, the main interest is in the overall burden associated with air pollution as a whole, as a general impetus for action, rather than the effects of particular pollutants.

22. Some Members do not think it appropriate to try to calculate an overall burden of the mortality associated with the air pollution mixture. Others are of the view that an attempt can be made based on associations with NO_2 and $PM_{2.5}$, and using information from two-pollutant models. This could be presented as a range of central estimates, but methods to represent the full statistical uncertainty are unlikely to be available.

Provision of these recommendations to Defra

23. Summaries of these draft recommendations were provided to Defra officials following the COMEAP meeting held on 24 February 2017. It was noted that they were subject to confirmation by the Committee, and that a number of caveats would need to be borne in mind when any calculations were undertaken.

Next steps

24. These recommendations remain draft until they are formally signed off by Members during finalisation of our report. We are currently working to develop a version of the report which will present the recommendations agreed by the majority of Members. It will also reflect the full range of contrasting views held across the Committee.

We hope these draft recommendations are useful for your revised cost-benefit analyses of measures to reduce NO_2 concentrations.

Yours sincerely

Professor Frank Kelly, COMEAP Chair

Professor Roy Harrison, COMEAP NO_2 Working Group Chair

Dr Heather Walton, COMEAP's subgroup on Quantification of Air Pollution Risks Chair

CC: Mr Jesse Norman MP, Parliamentary Under Secretary of State for Roads, Local Transport and Devolution

Annex B - UK climatic data, topography and population

B.1 The UK climate

The UK lies in the latitude of predominately westerly winds where depressions and their associated bands of cloud and rain ('fronts') move eastwards or north-eastwards across the North Atlantic, bringing with them unsettled and windy weather particularly in winter. Between the depressions there are often small mobile anticyclones that bring fair weather. It is the sequence of depressions and anticyclones that is responsible for the UK's changeable weather.

The western and northern parts of the UK tend to lie close to the normal path of the Atlantic depressions. Consequently, in those parts of the UK winters tend to be mild and stormy while the summers, when the depression track is further north and the depressions less deep, are mostly cool and windy. The mountains in these regions have the effect of producing a marked increase in rainfall. The lowlands of England have a climate similar to that in continental Europe: drier with a wider range of temperatures than in the north and west. However, the winters are not as severe as those on the continent. Overall, the south of the UK is usually warmer than the north, and the west is wetter than the east. The more extreme weather tends to occur in mountainous regions where it is often cloudy, wet and windy.[84]

Detailed UK climatic data is available on the Met Office website.[85]

B.2 Topography and population distribution

The highest point in England is 978 metres above sea level in the upland Lake District in the North West. The population is concentrated in lowland urban areas, particularly in London and the South East, the Midlands, and the North East and North West.

The mountainous regions of north and west-Scotland include the highest point 1344 metres above sea level. The population is concentrated in the lowland central belt between the cities of Glasgow and Edinburgh.

[84] National Meteorological Library and Archive Fact sheet 4 — Climate of the British Isles <www.metoffice.gov.uk/learning/library/publications/factsheets>

[85] The Met Office <www.metoffice.gov.uk/>

The mountainous regions of mid and north-Wales include the highest point 1085 metres above sea level. The population is concentrated in the lowland South which includes Cardiff and Swansea.

The highest point in Northern Ireland is 850 metres above sea level on the south-east coast. The population is concentrated around the city of Belfast on the east coast.

Detailed UK population density data is available from the Office of National Statistics.[86]

[86] Office of National Statistics <www.neighbourhood.statistics.gov.uk/HTMLDocs/dvc134_c/index.html>

Annex C – Reporting zone NO_2 concentrations

The air quality modelling from the PCM model estimates the average annual NO_2 concentration for over 9,000 road links in the UK. The links with the highest average annual concentration in each reporting zone are then used to determine which zones are in compliance with annual NO_2 concentration limits. Compliance is therefore determined on a zone-by-zone basis.

Table **C.1** shows the estimated reporting zone-level baseline projections from 2017-2030 assuming no further action is taken. This allows for a comparison to be made between the highest average annual concentration in each reporting zone and the expected improvement in concentrations as a result of the measures modelled in this report.

Table C.1 Estimated projections of annual average concentration of NO_2 ($\mu g/m^3$) on the road link with the highest estimate in each reporting zone

Zone name	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Greater London Urban Area	**97**	**84**	**76**	**66**	**61**	**56**	**53**	**49**	**47**	**45**	**42**	40	38	37
West Midlands Urban Area	**58**	**56**	**53**	**51**	**48**	**45**	**43**	**41**	39	37	35	34	33	32
Greater Manchester Urban Area	**53**	**50**	**48**	**45**	**42**	40	38	36	34	32	31	30	29	28
West Yorkshire Urban Area	**58**	**55**	**52**	**49**	**46**	**44**	**41**	39	37	36	34	33	31	30
Tyneside	**54**	**52**	**49**	**46**	**43**	40	38	36	34	32	31	29	28	27
Liverpool Urban Area	**46**	**44**	**42**	40	38	36	34	32	30	29	28	26	26	25
Sheffield Urban Area	**53**	**51**	**49**	**46**	**44**	**41**	39	37	36	34	33	31	30	29
Nottingham Urban Area	**57**	**54**	**52**	**49**	**46**	**43**	**41**	39	37	35	33	32	31	30
Bristol Urban Area	**52**	**49**	**47**	**45**	**42**	40	38	36	34	33	31	30	29	28
Brighton/Worthing/Littlehampton	36	35	33	32	30	29	27	26	25	24	23	22	21	20
Leicester Urban Area	**45**	**44**	**42**	40	38	36	35	33	32	31	30	29	28	28
Portsmouth Urban Area	**51**	**49**	**47**	**44**	**42**	39	37	35	34	32	31	29	28	27
Teesside Urban Area	**62**	**59**	**56**	**52**	**49**	**45**	**43**	40	38	36	35	33	32	31
The Potteries	**53**	**50**	**47**	**44**	**41**	39	37	35	33	31	30	29	28	27
Bournemouth Urban Area	**46**	**45**	**43**	**41**	39	37	35	33	31	30	28	27	26	25
Reading/Wokingham Urban Area	**44**	**43**	**41**	39	37	35	34	32	31	30	29	28	27	26
Coventry/Bedworth	**51**	**49**	**47**	**45**	**42**	40	38	36	34	33	31	30	29	28
Kingston upon Hull	**50**	**47**	**44**	**42**	39	37	35	33	32	30	29	28	27	26
Southampton Urban Area	**58**	**55**	**52**	**49**	**46**	**44**	**41**	40	38	37	36	35	34	33
Birkenhead Urban Area	**44**	**42**	40	38	36	34	32	31	29	28	27	26	25	24
Southend Urban Area	**52**	**49**	**47**	**45**	**42**	40	38	36	34	32	31	29	28	27
Blackpool Urban Area	32	31	29	28	26	25	23	22	21	20	19	18	17	16
Preston Urban Area	35	34	33	31	29	27	26	25	23	22	21	20	19	19
Glasgow Urban Area	**63**	**59**	**55**	**51**	**47**	**44**	**41**	39	37	35	33	32	31	30
Edinburgh Urban Area	**46**	**44**	**42**	40	37	35	33	31	30	28	27	26	24	24
Cardiff Urban Area	**50**	**48**	**46**	**43**	**41**	38	36	34	32	31	29	28	27	26
Swansea Urban Area	**45**	**43**	**41**	39	37	35	33	31	29	28	26	25	24	23

Belfast Metropolitan Urban Area	**51**	**48**	**46**	**43**	**41**	38	37	35	33	32	31	30	29	28
Eastern	**54**	**51**	**49**	**46**	**43**	40	38	36	34	33	31	30	28	27
South West	**50**	**48**	**45**	**43**	40	37	35	33	32	30	28	27	26	25
South East	**54**	**51**	**49**	**46**	**44**	**41**	39	37	35	33	32	30	29	28
East Midlands	**57**	**55**	**52**	**49**	**46**	**44**	**41**	39	37	35	34	32	31	30
North West & Merseyside	**59**	**55**	**52**	**49**	**45**	**42**	40	38	36	34	33	31	30	29
Yorkshire & Humberside	**53**	**51**	**48**	**46**	**43**	40	38	36	34	33	31	30	29	28
West Midlands	**54**	**51**	**48**	**46**	**43**	**41**	39	37	35	34	33	32	31	30
North East	**54**	**52**	**49**	**46**	**43**	40	38	36	34	32	30	29	28	27
Central Scotland	**46**	**44**	**42**	40	37	35	33	31	30	28	27	26	24	24
North East Scotland	**46**	**44**	**42**	40	38	36	34	33	32	31	30	29	29	28
Highland	31	30	28	26	25	23	22	20	19	18	17	16	15	15
Scottish Borders	26	25	24	22	21	19	18	17	16	15	14	14	13	13
South Wales	**65**	**62**	**59**	**56**	**53**	**50**	**47**	**44**	**42**	40	38	36	35	33
North Wales	**50**	**48**	**46**	**43**	40	38	36	34	32	30	29	27	26	25
Northern Ireland	36	33	31	30	28	26	25	24	23	22	21	20	19	18

Note: Results in bold indicate concentrations that are above average annual NO_2 limits

Annex D - Distribution of effects across the population

D.1 Introduction

Building on the draft Plan technical report evidence on the distributional impacts of NO_2 has been drawn from peer-reviewed papers, Defra-commissioned research and reviews by authoritative bodies.

In-house geographical analysis has been used to better understand the patterns of NO_2 concentrations and populations in the places with the biggest air quality challenge: the towns and cities modelled as CAZs in the CAZ scenario. The latest 2015 NO_2 concentration data produced by the PCM was mapped to residential postcodes and compared against small area data from statistics on income and deprivation published by the Office for National Statistics (ONS).

Finally, in line with the public sector equality duty, analysis has been undertaken to understand how the costs of the scenario fall across the population. This has been conducted on a range of data covering travel behaviours, vehicle use and ownership (for example from the National Travel Survey), as well as ONS data on income and expenditure and industry data on vehicle sales. Beneficiaries of mitigations and how they might compare to the affected groups has also been considered.

D.2 The distribution of health effects of air quality, and plans to improve it, across the population

In England, associations between socio-economic status (SES) and environmental pollution have been found to be stronger for ambient air pollution measurements than for other pollutants such as radon and waste.[87] [88] Over half (57 per cent) of the people living in the most polluted areas for NO_2 have been found to be in the bottom three deprivation

[87] Briggs, D et al. ‘Environmental inequity in England: Small area associations between socio-economic status and environmental pollution’, *Social Science & Medicine* 2008; 67: 1612-1629

[88] Differing patterns for differing pollutants have also been found in other countries. See for instance Vrijheid, M et al. ‘Socioeconomic status and exposure to multiple environmental pollutants during pregnancy: evidence for environmental inequity?’ *Journal of Epidemiology and Community Health* 2012; 66: 106-113

deciles[89] [90] and neighbourhoods in the most deprived quintiles have been found to experience, on average, an additional 7.9µg/m^3 of NO_2 compared to the least deprived quintile.[91] However, the association is non-linear. More specifically it has been found to be U-shaped, with people of high and low SES being exposed to higher concentrations of NO_2 than those in the middle of the distribution.[92] This broadly reflects the population living in urban centres where levels of air pollution are highest.[93] Indeed, whether a neighbourhood is urban or not has been found to be one of the strongest determinants of environmental inequality in exposure to air pollution.[94]

Higher concentrations of NO_2 have been found in ethnically diverse neighbourhoods (those with a non-white population greater than 20 per cent), even after adjusting for urbanisation and SES. Conversely, the same study found that areas of high neighbourhood air pollution have lower percentages of adults aged 65+ and children after adjusting for urbanisation, deprivation and ethnicity[95] (although this is disputed[96]).

In Wales (which, along with the North of England, Scotland and Northern Ireland has lower average levels of air pollution) a marked U-shaped distribution of NO_2 concentrations has been found, with average rates highest in the 'most' deprived areas[97] and the next highest

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[89] Based on the income domain from the Index of Multiple Deprivation, 2004. Deprivation deciles are arrived at by taking all areas included in the index and dividing these into ten equal groups so that 10% most deprived are in decile one, the next 10% are in decile two and so forth.

[90] AEA Technology plc, '*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>

[91] The earliest studies referenced here date from 2004. NO_2 emissions have fallen significantly since then. However, given that transport remains the key source of NO_2 emissions and that there have not been wholesale changes in population patterns, it is likely that the overall pattern of spatial distribution remains similar.

[92] Briggs, D et al., 'Environmental inequity in England: Small area associations between socio-economic status and environmental pollution', *Social Science & Medicine* 2008; 67: 1612-1629

[93] See Section **2.1** and Department for Environment, Food and Rural Affairs, '*Air Pollution in the UK 2015*' 2015 <https://uk-air.defra.gov.uk/library/annualreport/viewonline?year=2015_issue_1&jump=tp>

[94] D. Fecht et al., 'Associations between air pollution and socioeconomic characteristics, ethnicity and age profile of neighbourhoods in England and the Netherlands', *Environmental Pollution* 2015; 198: 201-210 <http://dx.doi.org/10.1016/j.envpol.2014.12.014>

[95] Ibid.

[96] See references in Brunt et al. (2016)

[97] Measured using data from the income element of the Welsh Index of Multiple Deprivation (WIMD)

in the 'least' deprived.[98] [99] This reflects higher concentrations of NO_2 in south-east urban areas (which include some of the least deprived areas of Wales) as well as in areas of heavy industry. A recent study on air pollution, deprivation and health in Wales concluded that:

> *'interactions between air pollution and deprivation modified and strengthened associations with all-cause respiratory disease mortality, especially in* [the] *'most' deprived areas where Wales' most-vulnerable* [sic] *people live'.*[100]

The Joint Air Quality Unit's (JAQU) in-house analysis confirms that the areas of towns and cities covered by the modelled CAZs in England[101] have a larger proportion of the comparatively deprived[102] population than the population outside CAZs (Figure **D.1**).

[98] Brunt et al. 'Air pollution, deprivation and health: understanding relationships to add value to local air quality management policy and practice in Wales, UK' *Journal of Public Health* (2016)

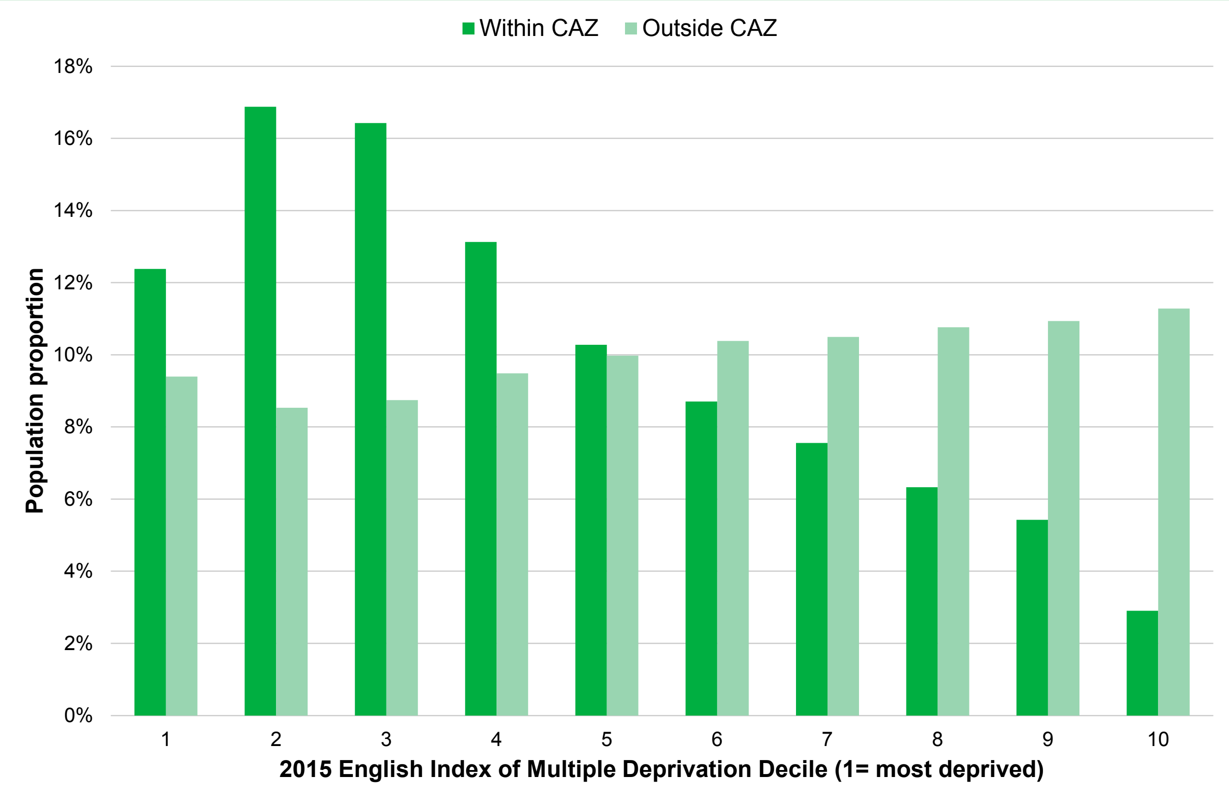
[99] Please note that this is based on newer information than that reported in AEA's 2006 research,

[100] Brunt et al. (2016). Ibid.

[101] The analysis has been restricted to the proposed CAZs in England because of the small number of modelled CAZs in each of Scotland, Wales and Northern Ireland. The units of measurement are not comparable across the devolved administrations so each nation needs to be looked at individually.

[102] The population is described as 'comparatively deprived' because the analysis undertaken uses the index of multiple deprivation. This is a measure of relative deprivation which ranks every small area in England from the most to the least deprived based on information from seven different areas (income, employment, education, health, crime, housing and the living environment).

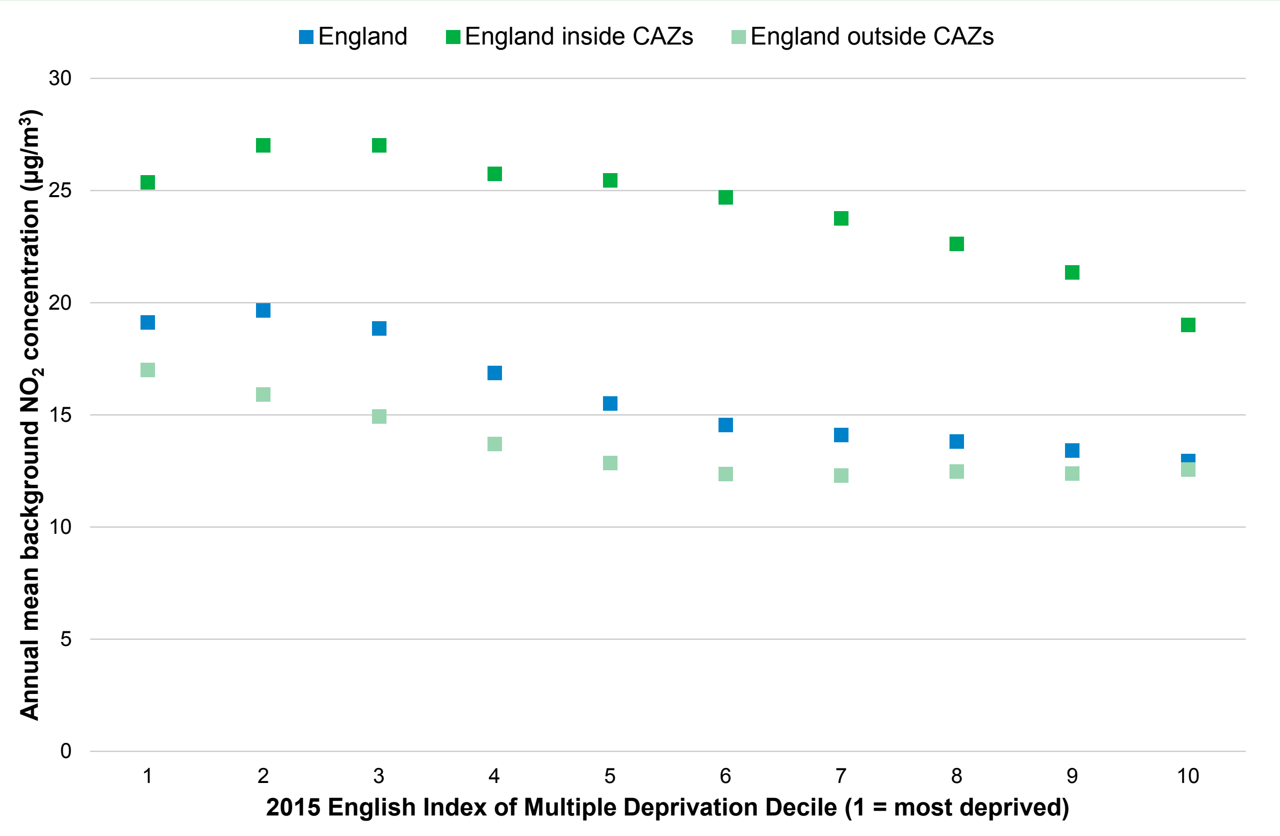
Figure D.1: Relative deprivation of population living within and outside the modelled English CAZs[I]



[I] The deprivation decile is calculated at Lower-layer Super Output Area (LSOA, 2011) level.

The relationship between deprivation and air quality in England is also confirmed by the analysis, particularly for NO_2: air quality tends to be poorest in areas of high deprivation, both within and outside the modelled CAZs (Figure **D.2**). The introduction of CAZs therefore has the potential to improve air quality for some of the most deprived areas of the UK and for some of those that risk the greatest exposure.

Figure D.2: Annual mean NO_2 concentration (2015) by multiple deprivation decile, England 2015 (overall and inside and outside proposed CAZs)[l]



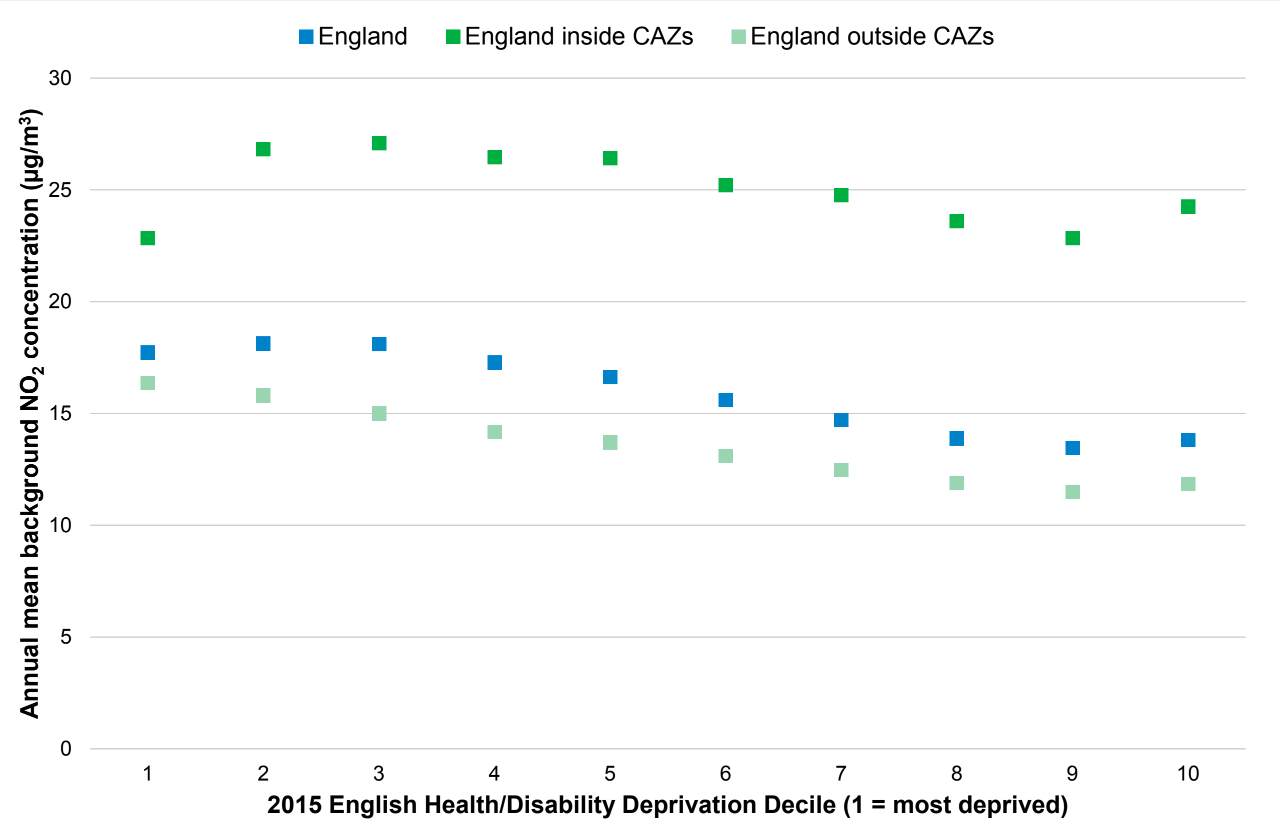
[l] The deprivation decile is calculated at Lower-layer Super Output Area (LSOA, 2011) level.

Income distributions at small area level are not produced in the UK. This prevents analysis of income levels within and outside of CAZs. However, the number of people who experience deprivation related to income is published at small area level.[103] Using this measure, a greater proportion of the population residing within CAZs in England are found to be income-deprived than those outside (aligning with the general findings on deprivation). Specifically, 29 per cent of the potential CAZ population in England is found to reside in the 20 per cent most income-deprived areas. Within CAZs, those areas with relatively high income deprivation are also found to have slightly higher NO_2 concentrations.

Analysis by health and disability deprivation deciles (Figure **D.3**) shows a tendency of those resident in more health-deprived areas of England to experience greater levels of NO_2 exposure (around 56 per cent of the CAZ population are in the 50 per cent most health and disability deprived areas in England).

[103] This primarily relates to the number of people who are in families that receive working benefits and/or tax credits; or those whose income falls below 60 per cent of the median income.

Figure D.3: Annual mean NO_2 concentration (2015) by health and disability deprivation decile, England 2015 (overall and inside and outside proposed CAZs)[I]



[I] The deprivation decile is calculated at Lower-layer Super Output Area (LSOA, 2011) level.

JAQU's analysis, like many of the other studies referenced, uses ambient concentrations of outdoor air pollution where people live as a proxy for their exposure. This is overly simplistic since not all those living in a particular geographic area, however small, have the same level of NO_2 exposure. As discussed by Havard et al.[104] and others,[105] average concentrations do not reflect uneven distributions within small areas (for example, high concentrations along roads drop off steeply). Neither does exposure based on residence take into account time-activity patterns which vary substantially at the individual-level: Some will spend long periods working in areas with different ambient concentrations to where they live, for example. It also fails to take into account indoor air quality (including air quality in cars and public transport systems), a significant source of exposure given that

[104] Harvard S, Deguen S, Zmirou-Navier D, Schillinger C, Bard D, 'Traffic-related air pollution and socioeconomic status, a spatial autocorrelation study to assess environmental equity on a small-area scale', *Epidemiology* 2009; 20: 223-230

[105] See for example Fecht D et al. (ibid) and Forastiere, F et al., Socioeconomic Status, Particulate Air Pollution, and Daily Mortality: Differential Exposure or Differential Susceptibility. *American Journal of Industrial Medicine,* 2007; 50: 208-216

people across the developed world spend the majority of their time indoors (in the US, around 87 per cent in buildings and 6 per cent in an enclosed vehicle).[106] In a recent review of evidence on the health aspects of air pollution, ambient air, indoor sources (particularly unvented gas appliances) and commuting were all found to be important for population exposure to NO_2. The contribution to overall NO_2 exposure originating from ambient air was placed at between 40 and 90 per cent (depending on individual circumstances).[107] This is an ongoing area of academic interest which will be central to refining understanding of the risks associated with poor air quality.

Separately, higher underlying mortality and morbidity rates in certain groups may make it more likely they will be detrimentally affected by poor air quality.[108] Susceptibilities have been linked to a range of factors including exposure, stress, diet, smoking, drinking, access to healthcare and underlying health conditions.[109] There is also evidence of specific vulnerabilities to exposure at certain points during the life-course. Studies have reported statistically significant associations between long-term exposure to NO_2 and lung function in children as well as respiratory infections in early childhood for example.[110] [111] [112]

Research commissioned by Defra in 2006[113] looking at the projected change in distribution of NO_2 concentrations by deprivation decile based on the implementation of planned

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[106] See for example Klepeis et al., 'The national Human Activity Survey (NHAPS): a resource for assessing exposure to environmental pollutants', *Journal of Exposure Analysis and Environmental Epidemiology,* 2001 May-Jun; 11(3): 231-52 <www.ncbi.nlm.nih.gov/pubmed/11477521>

[107] World Health Organization '*Review of evidence on health aspects of air pollution – REVIHAAP project: final technical report*' (2013) <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>

[108] See for example O'Neill M.S et al., 'Health, wealth, and air pollution: advancing theory and methods', *Environmental Health Perspectives*, 2003; 111 (16): 1861-1870

[109] For further references, see Forastiere, F et al., 'Socioeconomic Status, Particulate Air Pollution, and Daily Mortality: Differential Exposure or Differential Susceptibility', *American Journal of Industrial Medicine,* 2007; 50: 208-216.

[110] World Health Organization (2013) – Ibid.

[111] ESCAPE, European Study of Cohorts for Air Pollution Effects (2014), quoted in COMEAP (2015) 'Nitrogen dioxide: health effects of exposure'.

[112] Royal College of Physicians, '*Every breath we take: the lifelong impact of air pollution*', 2016 <www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution>

[113] AEA Technology plc, '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>

policies at the time showed that while policies could reduce the scale of exposure, inequalities were expected to persist.

Nevertheless, the evidence base described in this section suggests that actions aimed at reducing the highest concentrations of NO_2 have the potential to narrow the gap and disproportionately benefit more deprived and ethnically diverse groups by reducing the extent of inequalities.

D.3 The distribution of the financial effects of Plan across the population

The measure in the Plan that could have the greatest distributional impact is the implementation of CAZs; more specifically the implementation of Class D CAZs as set out in the CAZ Framework, which, if used, would impose charges on the owners of cars (Section **3.1.2**).

D.3.1 Class A, B and C CAZs – costs to businesses

The average costs of upgrading non-compliant commercial vehicles, as modelled in the Fleet Adjustment Model (FAM), are shown in Figure **D.4**. These assume upgrades within fuel class to the cheapest available alternative (generally Euro 6 vehicles in the case of LGVs). Based on GPS trip data, it is expected that around 40 per cent of all the LGVs entering a Class C or D CAZ at least once a week, in 2021, will be non-compliant.

Generally, it is assumed that businesses will attempt to redistribute their vehicle fleet before considering upgrading vehicles or paying any charges. This could be by transferring a compliant vehicle operating outside the CAZ network with a non-compliant one driving within the network. Alternatively it could be achieved by individual businesses electing to focus on serving certain areas, with a non-compliant vehicle owning business swapping their custom within the CAZ area for that outside the network.

In the event that a business is unable to redistribute their fleet, the costs of upgrading fleet vehicles (through retrofit or replacement) or paying charges may be passed on to customers. Where this is the case, it would have minimal impact on businesses themselves.[114] Given the uncertainty around this, the modelling was undertaken on the basis that businesses would not need to pass costs on. As part of a feasibility study and using tailored local data, local authorities will investigate this in more depth.

It is acknowledged that in some instances recovering the investment needed to upgrade commercial vehicles or the cost of charges can be more difficult. This may be the case for vehicles owned by public and charitable bodies, such as schools and community groups

[114] The London congestion charge was found to typically account for around five per cent of transport-related costs for businesses within the zone (see reference below).

who own minibuses and vans. It may also be the case that for certain small businesses, for example, those for which transport costs represent a particularly significant proportion of expenditure (like delivery companies).[115]

D.3.2 Class A, B and C CAZs – costs to individuals

As discussed in the technical report accompanying the draft Plan, distributional impacts of these CAZs at an individual level may include:

- Small impacts on consumers as organisations pass on the costs of retrofitting, upgrading commercial vehicles or paying charges
- Small to medium impacts on bus users, subject to how bus operators deal with the costs of retrofitting, upgrading or redistributing their buses or paying charges
- Small impacts on taxi and private hire users, subject to how operators deal with the costs of upgrading or redistributing to compliant vehicles
- A range of impacts on individuals who own minibuses, vans, and light commercial vehicles (around four per cent of the population of Great Britain[116]). Many of these vehicles are used for commercial purposes, in which case it is expected that costs will be passed onto customers (subject to the caveats made above). However, some of these vehicles may be exclusively for private use.[117] In this case, options for switching to compliant vehicles will be more limited than for individuals affected by Class D CAZs, as the stock of older, compliant vehicles is more limited. (Only a small number of older petrol vans are available so van owners wanting to switch may need to choose a newer Euro 6 diesel). This is reflected in the 'mean sale and purchase prices by vehicle type' shown in Table **D.4**.

D.3.3 Class D CAZs – costs to businesses

It is assumed that the main impact of class D CAZs on businesses will be from any changes in turnover due to variations created in customers' purchasing behaviour. In modelling the response to the presence of CAZs, it has been anticipated that a certain

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[115] The smallest businesses tend to operate on small margins. See for example <www.statista.com/statistics/291299/average-profit-of-smes-in-the-uk-by-enterprise-size/> (based on BDRC Continental's SME Finance Monitor, which surveys 4,500 UK SMEs each quarter).

[116] Source: Wealth and Assets Survey (July 2012 to June 2014), Office for National Statistics. Percentage of households owning vans, by total household net equivalised income decile varies from three per cent in households in the first, lowest, income decile to six per cent in the eighth income decile.

[117] Examples of vehicles classified as 'light commercial vehicles or vans' include 4x4 utility vehicles and double-cab pick-ups as well as dual-purpose SUVs such as the Land Rover Discovery Commercial series. Motorised caravans, horseboxes and minibuses will also be included under the restrictions.

proportion of journeys will be cancelled (Table **3.3**), which may particularly impact businesses just inside CAZ boundaries (particularly those whose customers usually reach them by private vehicle). This said, three years after the introduction of the London congestion charging scheme, TfL found that no significant consequences on business activity were identifiable. In particular, they noted “no evidence that congestion charging disproportionately affected any particular size of business in the charging zone.” TfL also concluded that the impacts of charging on the boundary area were largely neutral with “a general absence of adverse traffic, congestion, economic and environmental effects attributable to charging.” An independent review agreed with the assessment that (with a £5 charge) charging had a broadly neutral impact on the business economy of central London.[118]

D.3.4 Class D CAZs – costs to individuals

The main financial impacts of the modelled CAZ scenario on individuals are expected to be on those living in or needing to enter Class D CAZs on a regular basis, using private vehicles affected by restrictions. This includes people who use their private vehicles for work but might not be able to pass on additional costs to their employer or customers, such as those working for public and third sector organisations.

It is estimated that around 5 million people live in the areas modelled as class D CAZs in this report – or approximately 2 million households. A significant proportion of these are in London.[119] In 2021 (the year it is assumed all CAZs would be implemented by), it is estimated that in total 2.3 million non-compliant cars and 1.0 million non-compliant vans would be affected by CAZs (Class C and D for vans, Class D for cars). Not all of these would enter CAZs repeatedly, with roughly half of the affected cars estimated to enter once a week or more. Section **F.2** contains further detail.

As demonstrated in the draft Plan technical report, although a smaller proportion of those in lower income groups stand to be affected by Class D CAZ restrictions because of lower levels of vehicle ownership among these groups, the impact on those who are affected is likely to be greater than for those on higher incomes. This is particularly true of those in the lowest income groups who own the oldest (pre Euro 4) petrol and diesel cars or pre Euro 6 diesel vans. These are the people who will necessarily incur additional up-front expenditure if they wish to acquire a compliant vehicle because they will not have the option of ‘trading down’. Owners of newer non-compliant (diesel) vehicles will have the choice of upgrading to a newer petrol or diesel or switching to either an equivalent or an older petrol vehicle (trading down). They therefore have a greater range of options available to them for minimising initial expenditure.

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[118] Ibid.

[119] Figures estimated by mapping population data from the 2011 census and mid-2015 updates onto the areas modelled as Class D CAZs (and relevant travel to work zones as appropriate). 3.6 million people or 1.5 million households live in the modelled Class D London CAZ.

The latest costs for trading to the cheapest available vehicle *within fuel type*, as modelled by the FAM and reflecting capital costs only - not total welfare costs, are shown in Table **D.4**.

Table D.4: Mean sale and purchase prices by vehicle type for 2020 (£2017 prices)

	Cars	LGVs	Buses	Minibuses/ coaches
Average sell value	3,100	3,500	10,800	6,700
Average buy value	5,000	10,000	44,700	28,000
Difference	-1,900	-6,500	-34,000	-21,300

Although, in general terms, those on lower incomes with 'non-compliant' vehicles are most at risk of being adversely affected by vehicle charging, they may also benefit more than others from investments in alternatives (for example improved public transport) if these enable them to avoid running a vehicle. This is particularly relevant to those in the lowest income quintiles for whom the fixed costs of running a car would represent a significant proportion of consumption expenditure (see Table 7.4 in the draft Plan[120]).

Specific personal circumstances, however, are likely to have a strong influence on the degree to which measures impact individuals. Factors include:

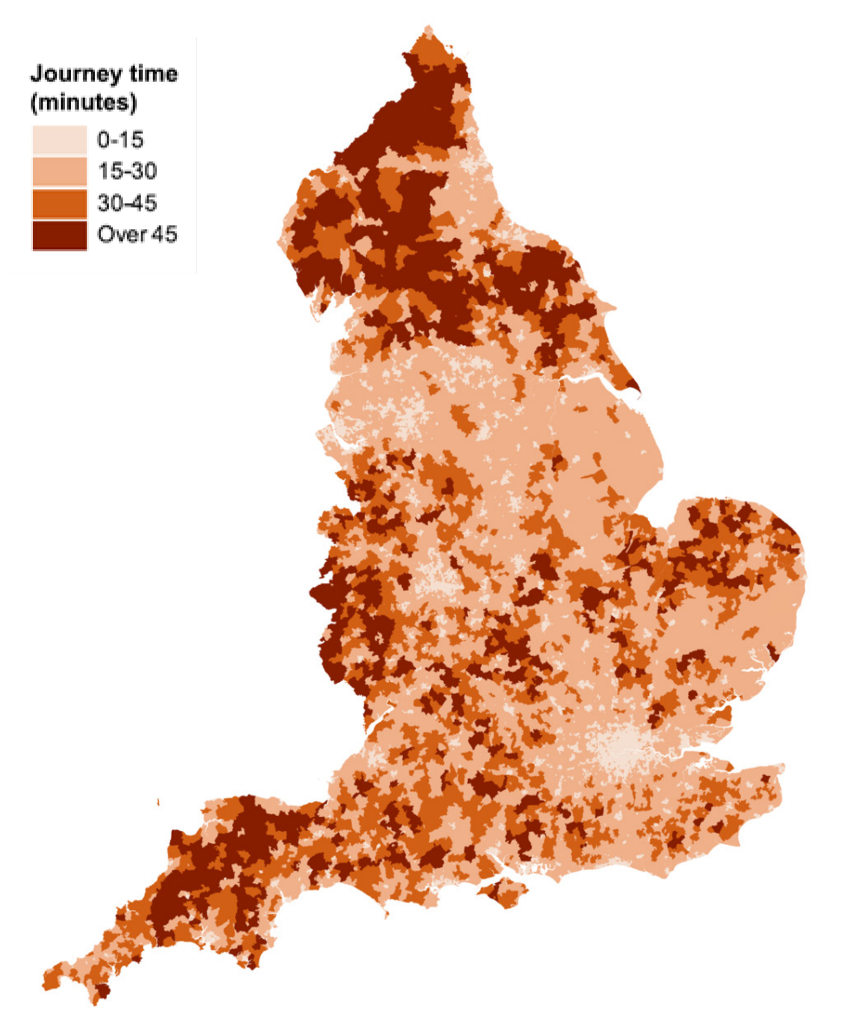
- the alternative forms of transport available to (and convenient for) the individual: other vehicles owned, accessibility of public transport, presence of park and ride schemes, bicycle ownership, presence of bike hire and car club schemes, availability of taxis and/or mini-cabs, etc.
- the degree of individual reliance on the 'non-compliant' vehicle: people and goods needing to be transported, distances travelled, number of stops needing to be made, times at which journeys are taken, vehicle adaptations present, time pressure, etc.
- how often travel into a class D CAZ is required
- the impact of any potential mitigation measures put in place locally and nationally

As with the other elements affecting individual circumstances, there are significant variations in the public transport available at an individual and local level. This has a

[120] p. 135 of Department for the Environment, Food and Rural Affairs, '*Draft UK Air Quality Plan for tackling nitrogen dioxide – Technical Report*', 2017 <www.gov.uk/government/consultations/improving-air-quality-reducing-nitrogen-dioxide-in-our-towns-and-cities>

significant effect on journey times as demonstrated by Figure **D.5**, which shows the time taken to access key local services by walking or using public transport.

Figure D.5: Average minimum travel time for eight key local services by public transport or walking



Note: The eight key services are: medium sized employment centres, primary schools, secondary schools, further education colleges, GPs, hospitals, food stores and town centres. Source: DfT Journey Time Statistics (2014) <www.gov.uk/government/uploads/system/uploads/attachment_data/file/485222/jts-access-2014.pdf>

As a result of these individual circumstances, finding viable alternatives to travelling into a CAZ by car (and paying the relevant charge) will be challenging for certain people.

D.3.5 Class D CAZs – mitigations

Local, regional, and national measures have the potential to help mitigate the impact of charging CAZs on individuals and businesses, including:

- Minimising the number of people affected by charging (for example by reducing the need for class D CAZs or reducing the areas that they cover)

- Providing CAZ charge discounts on the charging level for specific affected groups (such as those described in the 'Cost to individuals' section, above);

- Enhancing the alternatives available to those who currently drive private vehicles into CAZs, thereby limiting the need to do so. For example:

    - investment in public transport networks (like increasing the number or frequency of bus routes or their hours of operation)

    - improving the safety or desirability of alternatives (like improving roads to benefit pedestrians or cyclists, encouraging car sharing schemes or improving workplace facilities for cyclists)

    - expanding the reach of the current public transport network by enabling switching onto another modes (enabling individuals to use routes that would not otherwise take them close enough to their start or finish point with cycle hire schemes or other initiatives such as smart ticketing)

- Encouraging drivers of non-compliant vehicles to switch to cleaner alternatives (for example by providing infrastructure improvements like electric charging points)

- Minimising the cost of alternatives for certain groups (for example by creating concessionary public transport schemes or providing 'credits' for alternatives like car clubs, taxis and minicabs and bike hire)

- Exempting some of those who are least able to change their behaviour from the charge[121]

We will not know the degree to which local plans will impact residents and individuals until local authorities come forward with their plans. In the meantime, the government will work with local authorities and others to consider how to help minimise the impact of such measures on local businesses, residents and those travelling into towns and cities to work where such action is necessary; and will issue a further consultation in autumn to aid development and assessment of options. The measures considered in that consultation will include options to support motorists: in particular private car drivers on lower incomes, or those who may have to switch to a cleaner vehicle. Options considered could include retrofitting, subsidised car club membership, exemptions and discounts from any restrictions, permit schemes for vans or concessionary bus travel.

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[121] Provision has been made in the CAZ framework for Local Authorities to make exemptions for specific vehicles (for example historic and specialist vehicles, emergency services vehicles and vehicles within the disabled passenger vehicle tax class). Under the framework, Local Authorities are also invited to consider whether to discount or exempt community transport vehicles; provide discounts to residents living within the zone; and to consider ways in which the cost of any charge could be reduced for groups they identify as facing particular challenges.

A targeted scrappage scheme will also be considered in this consultation focussing on certain groups of drivers who most need support (such as those on lower incomes or those living in the immediate vicinity of a Clean Air Zone) and providing an incentive to switch to a cleaner vehicle.

Following the consultation on the draft Plan, it is clear that a number of issues remain with such mitigation options and in particular with scrappage schemes – analysis of previous schemes has shown poor value for the taxpayer and that they are open to a degree of fraud. We welcome views from stakeholders in the forthcoming consultation on whether it is possible to overcome these issues, alongside any wider options that should be considered. All proposals considered for government support would need to demonstrate that support can be targeted to those who need it most and that any scheme could be delivered effectively with minimal risk of fraud or abuse. Proposals considered would also need to demonstrate that they offer clear value for taxpayer's money. Finally, given all measures will be funded by relevant taxes on new diesel cars alongside existing departmental budgets, proposals put forward would need to be fair to the taxpayers who would fund any measures.

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Annex E – Fleet Adjustment Model

E.1 Summary

The Fleet Adjustment Model quantifies as far as possible the societal costs and benefits associated with changes in UK vehicle fleet. Fleet changes may be triggered by a number of different policies. In this case, the model has been used to assess the impact of an expanded network of charging CAZs to inform preparation of the Plan.

The Fleet Adjustment modelling approach follows a number of sequential stages as outlined in Figure **E.1** below. The other sections of this annex elaborate on the assumptions and approach of the modelling.

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, HGVs, LGVs and cars)) in each year modelled;
- The number of vehicle kilometres driven by each type of vehicle and their location in each year.

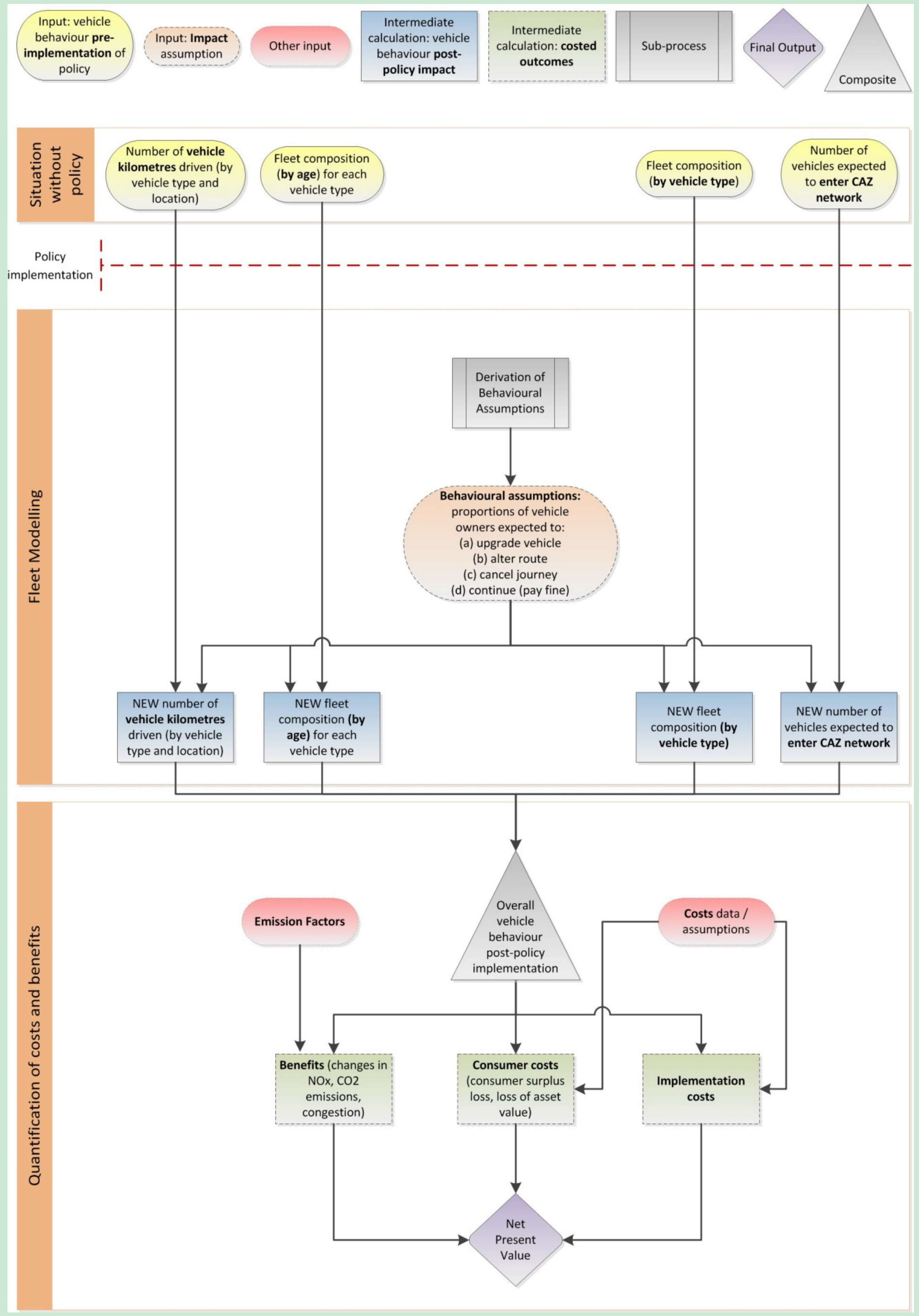
More information on the definition of the baseline is set out in Section **E.2**.

The second stage of the model introduces measures that 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 the 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 non-compliant vehicles spend driving in different locations. The detailed assumptions are set out in Section **E.3**.

The third stage then quantifies and values the main societal impacts of the changes in fleet composition 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 and CO_2 pollution. The methodology and assumptions are set out in Section **E.4**.

Finally, all the impacts are discounted and the total costs are subtracted from the total benefits to provide a net present value (NPV), in 2015 prices. Full details of this step are contained in Section **E.5**.

Figure E.1 Flow diagram of the assessment of costs and benefits in the FAM



E.2 Model design

The primary application of the Fleet Adjustment Model is to assess the societal impact of changes in the UK's fleet of road-vehicles. This model has predominantly been used to assess four types of charging CAZ as set out below. These zones levy a charge on the most polluting vehicles entering the areas to encourage behavioural changes that will improve air quality. The four types of zone are:

- 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, cars, motorcycles and mopeds

The Fleet Adjustment Model calculates the monetised social impact of measures over a period of years. For the purpose of the proposed CAZ measure, this period is 2020-2030 as 2020 represents the earliest date by which zones may be implemented. In reality 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.

E.2.1 Model design principles

The assessment has been made in line with best practice as set out in the HM Treasury Green Book[122]. This is supported by the following Green Book supplementary guidance:

- Valuing impacts on air quality: Defra Supplementary Green Book Guidance (2013)[123] and updated guidance on valuing oxides of nitrogen
- Web-based Transport Analysis Guidance: WebTAG (2014)[124]
- Valuation of energy use and greenhouse gas emissions guidance (2017)[125]

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[122] HM Treasury, '*The Green Book: appraisal and evaluation in central government*', <www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent>

[123] HM Treasury, '*Valuing impacts on air quality: Supplementary Green Book guidance*', <www.gov.uk/government/uploads/system/uploads/attachment_data/file/197893/pu1500-air-quality-greenbook-supp2013.pdf>

[124] Department for Transport, Transport analysis guidance: WebTAG, <www.gov.uk/transport-analysis-guidance-webtag>

The Fleet Adjustment Model works alongside the Pollution Climate Mapping (PCM) model. The models use consistent input sources where applicable, for example the National Atmospheric Emissions Inventory (NAEI) projections data on fleet compositions by Euro standard and kilometres travelled by each vehicle type.

E.3 Establishing the baseline

Fleet size projections, fleet composition data, and vehicle usage data provide the baseline scenario against which any modelled changes are compared.

Fleet size projections for cars and light goods vehicles were calculated using data produced by DfT using the Fleet Fuel Efficiency Model. This is an improvement on the methodology used in the consultation version of the FAM in which historic values were projected forward. For heavy goods vehicles, the NAEI's road transport model was modified to arrive at a projection for the number of vehicles. Finally bus projections were obtained by applying a five-year rolling average to historic values, utilising the same approach as in consultation. 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

E.3.1 Inputs

The inputs described within Boxes **E.2** and **E.4** as well as Table **E.3** are used when quantifying the impacts of policy implementation. Box **E.2** describes the inputs defined as vehicle characteristics within the model.

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[125] Department for Business, Energy and Industrial Strategy, '*Valuation of energy use and greenhouse gas*', 2017 <www.gov.uk/government/uploads/system/uploads/attachment_data/file/615374/1._Valuation_of_energy_use_and_greenhouse_gas_emissions_for_appraisal_2016.pdf>

Box E.2 Vehicle characteristics used within the Fleet Adjustment Model
Average vehicle age Euro standards relate to vehicle age, for example a diesel van registered from 2006-2009 is of a Euro 4 standard. The years in which each standard was sold are averaged to give the vehicle age.
Vehicle depreciation rates Depreciation rates are attributed to each vehicle type over a ten-year period. They were estimated based upon the depreciation rates of the most popular 10 cars sold in the UK in 2014. Van depreciation rates were estimated from published data on resale values. After ten years the rate of depreciation is assumed to remain constant for all vehicle types. Table **E.3** shows the assumed depreciation rates, given as the proportion of value lost per year.
Vehicle annual distance travelled Vehicle annual distance data are sourced from the National Atmospheric Emissions Inventory (NAEI)[126]. The NAEI provides average annual distance travelled by vehicle type. This distance changes year on year throughout the period of the policy.
Average length of vehicle ownership Length of vehicle ownership data, broken down by vehicle type, sourced from the RAC.[127]

Table E.3 Vehicle depreciation rates

Year	Cars	Other vehicle types
1	0.37	0.35
2	0.18	0.18
3+	0.16	0.18

Box **E.4** describes the inputs that are defined as local authority characteristics within the model.

[126] National Atmospheric Emissions Inventory < http://naei.beis.gov.uk/>

[127] Royal Automobile Club Foundation for Motoring, '*Car ownership in Great Britain*' (2008) <www.racfoundation.org/assets/rac_foundation/content/downloadables/car%20ownership%20in%20great%20britain%20-%20leibling%20-%20171008%20-%20report.pdf>

Box E.4 Local authority characteristics used within the Fleet Adjustment Model

Zone perimeters and population (local authority characteristics)

For modelling purposes, the perimeters of each CAZ were defined to include all roads within local authority control that were projected to exceed a certain concentration of NO_2. The approach to mapping an illustrative boundary of a CAZ is detailed in Annex **F**.

Zone area, surrounding built up area and trip length distribution

The comparative area covered by the CAZs and the built-up area that surrounds them is combined with trip-length distribution (from the DfT National Traffic Survey) to estimate the impact of CAZs on those people residing just outside the zones.

Fraction of vkms spent within the zones

The fraction of vkms travelled within the network varies by vehicle type. The vkms, for cars, spent within each Local authority was obtained from DfT[128] and then scaled by the ratio of CAZ to LA area. For the remaining vehicle classes, the value used in consultation (obtained from Ricardo Energy & Environment) for each class was adjusted using the difference.

Unique vehicle entries

Vehicle-entries into zones in England & Wales by vehicle type are provided by Trafficmaster, sourced from DfT GPS Journey information. The number of vehicles entering CAZs in Scotland and Northern Ireland was assumed to be equal to the number entering an English (or Welsh) city of an equivalent size. Vehicles which enter more than one zone, are only counted once to mitigate double counting (a driver will only need to upgrade a vehicle once). The aim of this is to calculate unique vehicle-entries into each zone. CAZs in Scotland and Northern Ireland are treated as exceptions: vehicles entering these areas are considered to all be unique. These CAZs are geographically isolated relative to the other areas within the network, so this assumption is used to estimate the additional fleet entering these locations. Unique vehicle-entries are then calculated over the assessment period.

The Trafficmaster sample of vehicles, a subset of the national fleet, then is scaled up to give an estimation of the number of vehicles, nationally, entering the network of CAZs. The number of trips into the London Low Emission Zone area, both nationally and within the sample, is compared and a scaling factor is obtained. The fleet in the Trafficmaster sample entering the remainder of the network is then converted to be representative of the national fleet using this factor. Over the assessment period, the fleet of vehicles that enter the zones is assumed to exhibit change similar to that of the national fleet and the vehicle entries are altered accordingly.

Days in network

The Trafficmaster dataset also enables the average number of days spent in the zones

[128] Department for Transport (2017), *Traffic by local authority*, Table TRA8905 [data file]. Available from <www.gov.uk/government/statistical-data-sets/tra89-traffic-by-local-authority>

for each vehicle-type to be calculated. This is used to estimate costs that are based on the number of days a vehicle would enter the zone in each year.

Box **E.5** outlines all inputs that are not defined under vehicle characteristics or local authority characteristics but which are used to calculate impacts within the model.

Box E.5 Additional inputs used within the Fleet Adjustment Model

Fuel costs

Petrol and diesel fuel costs are annual average values. Fuel costs up to 2016 are observed, whereas values from 2017 onwards are projections based on the central fossil fuel price scenario published in October 2014 by the former Department of Energy and Climate Change (DECC). These are used to estimate the fuel efficiency savings when using the 'financial cost' approach (for more details see Section **E.4**)

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 **E.4**)

Air quality damage costs

NO_X and PM damage costs (£/tonne) are used in the FAM, 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 zones, the damage cost pertaining to the relevant class of city is used (so for London, the 'London, inner' cost is used) whereas for outside-zone emissions, the transport average is used. Damage costs are assumed to remain constant in real terms and are therefore not adjusted for inflation. However, the calculation applies a 'health uplift' of 2% per annum to account for higher willingness to pay for healthcare.

Greenhouse gas abatement costs

Vehicle emissions are not included in the European Trading Scheme (ETS). To calculate the impact of a change in CO_2 emissions the calculation uses an average CO_2 non-traded central carbon price for the assessment period (£71.6/tonne in 2015 prices), published by DECC in October 2014.

Fleet emission factors

Emission factors are split by each vehicle type and emission standard for carbon dioxide (CO_2) and particulate matter (PM) as shown in Table **E.6**. 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 5 as implemented in the National Atmospheric Emissions Inventory.

The CO_2 emission factors are provided by DfT for cars and vans and from a TRL report for the other vehicle categories. CO_2 is the only greenhouse gas (GHG) that is produced by vehicles considered within BEIS guidance.[129] As a result, no equivalent tonnes of CO_2 can accounted for.

Table E.6 Vehicle emission factors

Emission factors	Petrol cars	Diesel cars	Petrol LGVs	Diesel LGVs	RHGVs	AHGVs	Buses	Coaches
PM (g/km)								
Euro 3	0.0012	0.0270	0.0012	0.0217	0.0321	0.0428	0.0316	0.0461
Euro 4	0.0013	0.0021	0.0013	0.0010	0.0360	0.0488	0.0350	0.0534
Euro 5	0.0015	0.0014	0.0013	0.0010	0.0032	0.0044	0.0032	0.0048
Euro 6	0.0012	0.0270	0.0012	0.0217	0.0321	0.0428	0.0316	0.0461
CO_2 (g/km)								
Euro 3	197.75	184.00	223.78	247.78	602.42	962.71	663.10	663.10
Euro 4	192.10	190.79	218.10	246.45	587.78	921.99	662.74	662.74
Euro 5	172.54	171.28	229.70	244.67	587.78	921.99	662.74	662.74
Euro 6	140.96	149.36	173.07	218.73	587.78	921.99	662.74	662.74

Note: the NOx vehicle emission changes are taken directly from the PCM model but equivalent figures for PM and CO_2 are not included in the PCM model.

E.4 Modelling changes in the fleet

This section sets out how changes in the fleet have been modelled to reflect measures taken. Assumed behavioural responses of vehicle owners are applied to model the resulting change in fleet. Changes in total annual distance travelled by each vehicle type

[129] Department for Business, Energy and Industrial Strategy, '*Valuation of energy use and greenhouse gas*', 2017 <www.gov.uk/government/uploads/system/uploads/attachment_data/file/615374/1._Valuation_of_energy_use_and_greenhouse_gas_emissions_for_appraisal_2016.pdf>

and vehicle kilometres travelled within and outside the zone are then estimated. More details on the behavioural assumptions are given below.

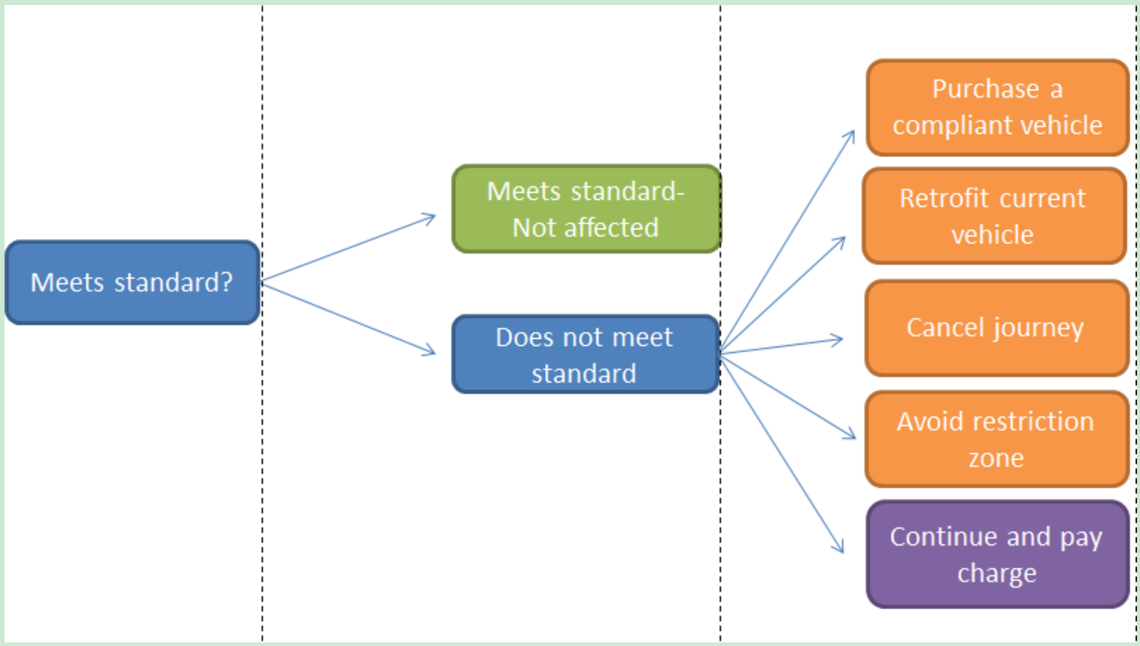
E.4.1 Behavioural response of owners with vehicles subject to charge

The consumers (households/businesses) who own vehicles subject to the charge are assumed to have the following choices within the model (Figure **E.7**):

- **Replace current vehicle with a vehicle exempt from the charge**: this will enable the new vehicle's owner to continue to drive in restricted areas without charge.
- **Cancel journeys**: some owners will choose to cancel trips into the zone where restrictions apply. (This includes consolidation of deliveries etc. into fewer journeys.)
- **Avoid restriction zones**: some owners may divert their journeys around the zone.
- **Pay a charge for entering the zone**: some drivers will choose to pay a charge for entering restricted zones instead of one of the actions listed above. This may be the most cost-effective option for drivers that enter these zones infrequently.
- **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.
- **Change mode**: Some users may be able to alter their mode of transport away from vehicles. For example they may choose to take the bus or train to work, transport goods by train as opposed to via HGV or walk to the shops. Because of the inherent local variation between the transport networks of different local authorities we have been unable to model this behaviour uniquely and instead have used the same method as the 'avoid' behavioural response.

It is also possible that vehicle owners will choose to retrofit their vehicles in order to make them compliant with the CAZ standards. However, this has not been modelled due to a lack of strong evidence. It is likely that vehicle owners will only choose to retrofit if the cost of doing so is lower than the cost of upgrading their vehicle. Therefore, it has been conservatively assumed that all who choose to upgrade their current vehicle will replace rather than retrofit.

Figure E.7 Decision tree for road transport users



The behavioural response choices apply to vehicles that are subject to the charge. They are based upon a survey that was carried out by Transport for London when considering implementing the Ultra-Low Emissions Zone.

This survey, though detailed, did not contain information on some vehicle classes (buses, for instance, did not have a behavioural response as they are under direct control of Transport for London). For this minority of vehicle classes we consulted with experts on transport modelling to arrive at our expected behavioural responses for these vehicles to the CAZ charge. These behavioural responses are taken to be representative of the reactions of the drivers into each of the CAZs, therefore potential local variations are not taken into account. It was also recognised that the characteristics and responses of individuals outside of London was likely to be different to other areas.

In reality the responses of drivers will vary based upon the local characteristics of each CAZ. There are thus large and considerable uncertainties surrounding these behavioural responses which, in turn, may have a significant impact on the costs or benefits. As a result, it is anticipated that, should a CAZ be required, a Local Authority would assess the effect of the charge level on the behavioural response as part of their impact assessment.

The assumed proportions of non-compliant vehicle owners who respond according to the different options available are summarised in Table **E.8**.

Table E.8 Proportions of non-compliant vehicle owners which choose certain behavioural responses					
Response	**Cars**	**LGVs**	**HGVs**	**Buses**	**Coaches**
Upgrade	22%	25%	44%	62%	41%
Cancel	16%	12%	14%	38%	26%
Change mode	23%	4%	0%	0%	0%
Avoid	23%	17%	14%	0%	0%
Pay	16%	42%	28%	0%	33%

It is also assumed an additional 25% of those vehicles that are upgraded will be scrapped, which translates to about 5% of the total fleet. It is anticipated that the charge is estimated to lead to 16% of unique cars choosing to continue to enter the zone and so to pay the charge.

It has been assumed that any journey undertaken by businesses will not be cancelled, since if a trip was profitable beforehand then it will still be profitable for a business with a compliant vehicle to undertake it instead. Therefore the cancel category for all vehicles classes, with the exception of cars, can be thought of as representing redeploy or redistribute. So, for instance, 26% of the non-compliant coaches entering the network of CAZs will be redeployed to unaffected cities with newer, compliant, coaches taking their place.

E.5 Quantifying the impacts

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

- **Loss of consumer welfare/ financial cost of upgrading:** Consumers who upgrade their vehicle as a result of traffic restrictions will incur a cost by doing so. The model calculates this via two alternative methods.
- **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 correspond to a loss of asset-value as their value was greater than zero in the baseline.
- **Cost of cancelling trips or avoiding the zone:** Consumers who cancel trips or avoid the zone will incur a loss of welfare as a result.
- **Traffic Flow:** As a result of some car drivers choosing to cancel their journeys there are fewer vehicles on the road. This reduction has wide range of both positive and negative impacts which are valued by DfT, with congestion improvements being the largest impact. The impact of having fewer vehicles on the road in terms of lower congestion is therefore valued.

- **Infrastructure implementation and running cost:** Costs are incurred by local authorities in setting up the infrastructure of CAZs and running them.
- **Emission change impacts:** A change in emissions will change the health and environmental impacts on society.

These impacts are assessed consistently with the baseline modelling. The detailed inputs to the model are set out in Section **E.2** with headings corresponding to those in the calculation flow-charts within Section **E.4**.

E.5.1 Cost of upgrading

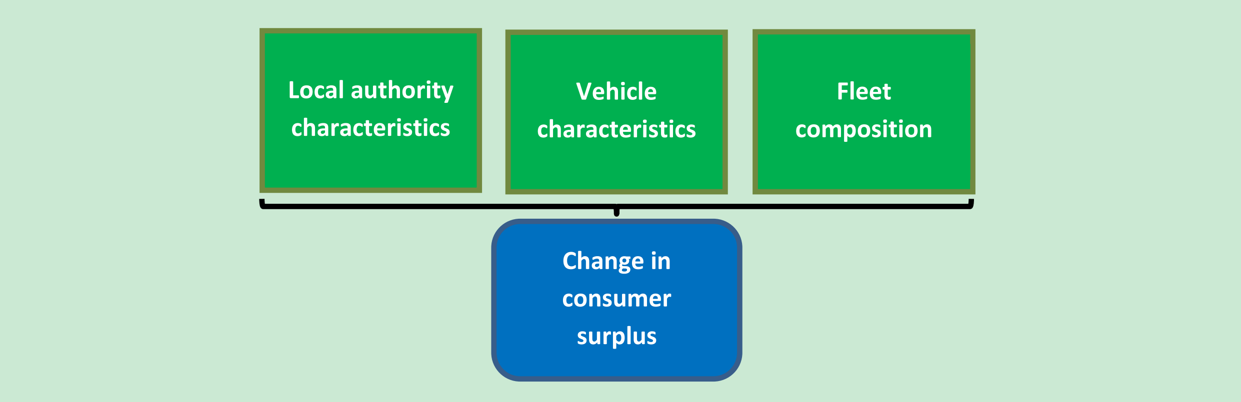
The different vehicle response functions are explained in Section **E.3**. The response with the most significant impact on societal welfare is those consumers that choose to upgrade to a vehicle exempt from the charge, which leads to their old vehicle being either scrapped or sold on.

There are two alternative ways in which the analysis has looked to estimate the societal cost of upgrading to a charge-exempt vehicle: the ‘consumer surplus’ approach and the ‘financial cost’ approach. For the central cost-benefit analysis the ‘consumer surplus’ approach was used. The ‘financial cost’ approach however provides useful insights particularly when considering the distribution of costs.

E.5.2 Consumer surplus approach

Figure **E.9** demonstrates the inputs that feed into the consumer surplus calculation (see Boxes **E.2** and **E.4** as well as Table **E.3** for a full list of inputs).

Figure E.9 Inputs to consumer welfare loss calculation



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

- 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).

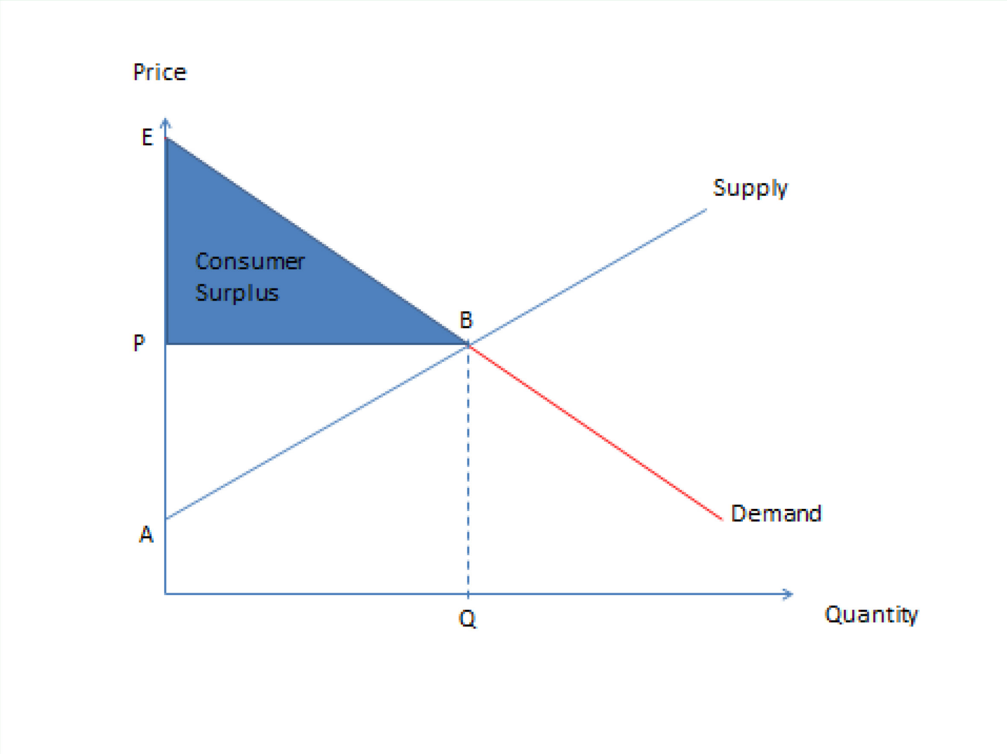
- The market price is the minimum price at which owners would value their vehicle. This is assumed on the basis that they would otherwise sell their vehicle in the baseline.

- 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.

The loss of surplus from selling old vehicles is calculated based on these assumptions (See Box **E.10** for an economic explanation of consumer surplus).

Box E.10: Consumer surplus – economic explanation
The value a consumer puts on a vehicle above 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 with 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 E.11 Simplified illustration of consumer surplus



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. It is assumed that the effort required to purchase a new vehicle remains the same, regardless of whether or not a new measure is implemented.

It should be noted that there will be a shift in demand from vehicles subject to a charge to exempt vehicles. This will 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. However, it is not possible to forecast this change in the market price and this impact is therefore not assessed. The degree to which this will affect the results will depend upon the percentage of the UK fleet that is affected by the traffic restrictions; this impact is expected to be relatively small.

Additionally, it is assumed in the model that no corresponding non-monetised benefits are accrued via retrofitting. Therefore, the cost of a retrofit 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 welfare approach to valuation is taken.

Note that 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 welfare calculation.

E.5.3 Financial cost approach

Vehicle owners that upgrade will incur monetary costs from purchasing a newer (and therefore more expensive) vehicle. Therefore, the costs and benefits valued in the 'financial cost' 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

If a vehicle is scrapped, the cost of the cheapest compliant 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), incurring the corresponding cost.

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.

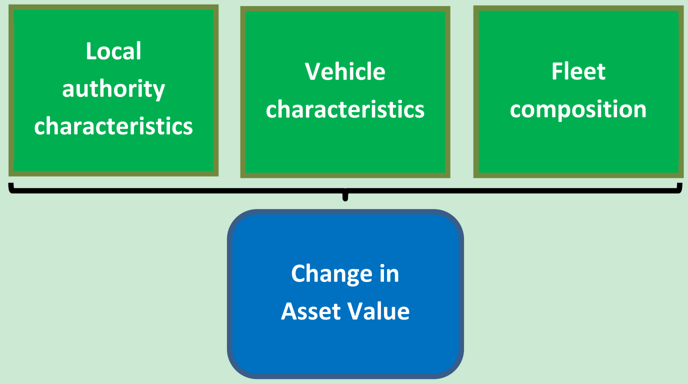
This approach does not estimate the additional impact on owners who operate outside the CAZs. These owners will be able to purchase vehicles that do not meet zone standards at a lower price, and sell vehicles that do for a higher price to those drivers who do enter such zones.

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 CAZs, and any fuel efficiency savings incurred by vehicle owners from upgrading vehicles will be implicitly captured in the consumer welfare calculation. However, for the UK 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 compliant vehicles. This translates into a resource saving from reduced expenditure on fuel.

E.5.4 Change in asset cost

Figure **E.12** demonstrates the specific inputs that are used as part of the change in asset cost calculation. A detailed breakdown of this calculation is laid out in the paragraphs below.

Figure E.12 Flow of inputs to change in asset value

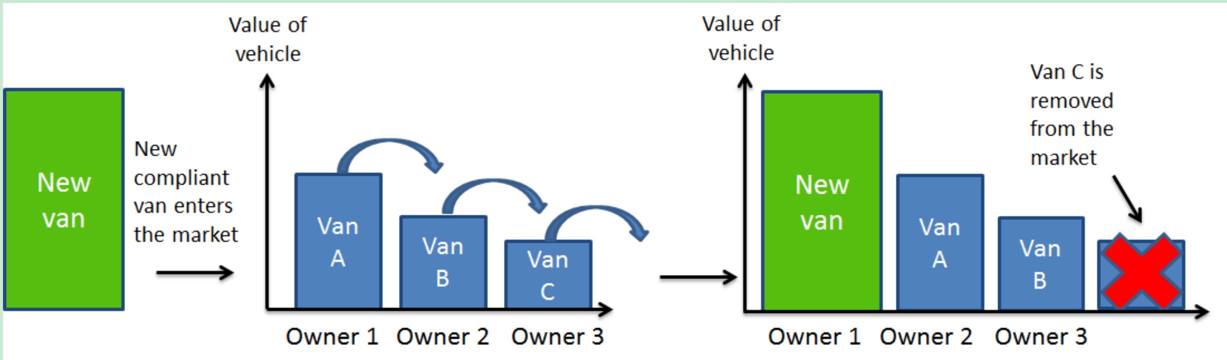


A proportion of the upgrading vehicle owners will buy a new vehicle, assumed to be 25%, with the remainder selling their current vehicle to a buyer largely unaffected by the access restriction and purchasing a second-hand exempt one. Assuming that the market for vehicles operates efficiently, given that the total fleet in operation will not increase, it follows that the same number of the oldest, most polluting vehicles will exit the market and be scrapped. This is because demand for such vehicles has fallen to zero, resulting in deterioration in value for these vehicles.

The entrance of new vehicles to the market and subsequent knock-on effects on the rest of the vehicles in the market is demonstrated in Figure **E.13**. 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.

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 for this vehicle type would fall, and therefore there is an additional cost to society.

Figure E.13 Fleet turnover process



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 the CAZs.

The residual value of the vehicles scrapped prior to the introduction of the CAZs has been calculated based on the age of vehicle and depreciation rates over time. For example, a vehicle that has 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 CAZs.

E.5.5 Cost of cancelling trips or avoiding zones

Non-compliant vehicle owners are assumed to cancel their trip or avoid the zones only if the cost of doing so is equal to or less than the cost of entering the zone. Since these incurred costs will range on a continuous scale from zero to the value of the fine for entering the zone, the assumption is that the average cost is equal to half of the fine value. Therefore, the overall cost of cancelling trips and avoiding the zones is equal to the total number of trips where this behaviour is expected multiplied by half the fine value.

E.5.6 Change in infrastructure costs

CAZs that are included in the network will incur costs in both set-up and enforcement of vehicle emission standards. Such costs could include the following:

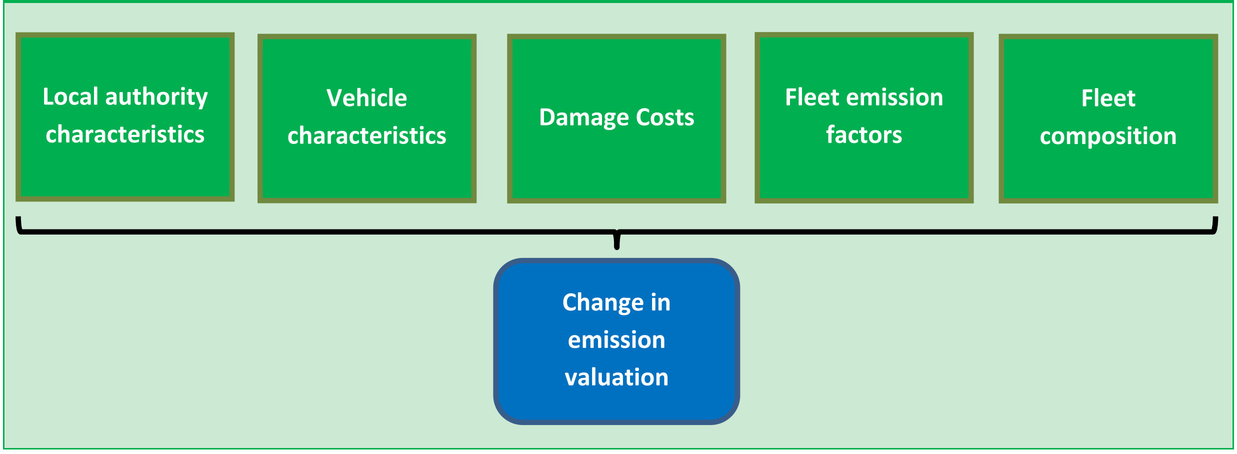
- General infrastructure and implementation costs (e.g. signage, monitoring compliance)
- Automatic Number Plate Recognition system (e.g. ANPR camera and installation costs, running costs, IT equipment) however, other systems may be more appropriate for the area in question
- Ongoing communication, enforcement, and staff costs

These costs will vary significantly based upon the local variation within each CAZ. The method used to value these costs draws upon evidence available from similar schemes and scales their impacts accordingly.

E.5.7 Emission change impacts

Figure **E.15** highlights the specific inputs that are used to calculate the emission changes as a result of CAZ implementation. The full process is detailed below.

Figure E.15 Inputs to emissions change



The tonnage of NO_X emission reductions inside zones is provided from the PCM model runs for each of the years modelled, so from 2020 to 2030. Reductions will decrease with time as the fleet naturally upgrades to cleaner vehicles exempt from the charge.

A change in NO_x emissions is expected outside the zones. Vehicles subject to the charge will be sold outside the zone when drivers upgrade to vehicles exempt from the charge. This will lead to a switch from lower NO_x emitting petrol vehicles to higher polluting diesel vehicles; however this would still be an upgrade from a slightly older vehicle. Therefore there is a reduction in net emissions outside the zone because the benefits of the newer, hence cleaner, fleet outweigh the impacts of an increase in higher polluting diesel vehicles.

For those vehicles scrapped (and replaced by a new vehicle) as a result of the traffic restriction 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, are multiplied by the remainder of each scrapped vehicles expected lifetime within the assessment period. This provides the expected emissions that are no longer produced on the roads by scrapped vehicles, as a result of the traffic restrictions. These are then compared with the quantity of emissions that will be produced by the new vehicles that the scrapped ones are being replaced with. The difference between the two gives the total emissions savings resulting from scrapped vehicles.

The CAZs do not generally cover the entire built-up area for the city or town they are placed in. These built-up areas would have the same damage costs as the zone, which is higher than the national average used for outside zones. We would expect vehicles entering the zone to also travel through a built-up area on the journey and therefore there are additional benefits outside the zone to be realised from the behavioural changes. To estimate these additional benefits the NO_x emissions savings from upgrading for each zone are uplifted by a factor based on the ratio of the zone to built-up area modified by trip length distribution. This uplift factor is also applied to the congestion benefit for those CAZs which are anticipated to impact private car drivers.

The PCM does not provide estimates of CO_2 changes. CO_2 emission factors for different vehicle types and Euro standards are obtained from the Transport Research Laboratory. There will be a reduction in CO_2 emissions as the fleet upgrades to newer, more fuel-efficient vehicles and a proportion of the fleet is scrapped. 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 possible to calculate the fuel cost savings using projections of diesel and petrol prices from DECC.[130]

E.6 Calculating Net Present Value

For ongoing benefits, an appraisal period stretching from 2020 to 2030 (when the policy is assumed to be fully implemented) is used. For analysis purposes, costs incurred with implementation and upgrading are upfront costs and are assumed to be incurred in 2020 or 2021, dependent on the expected implementation date of the local authority's CAZ. Fuel, NO_X, and carbon impacts associated with local measures are incurred over the full appraisal period.

As outlined previously, total benefits include emission damage cost reduction, traffic flow improvements and fuel savings, while total costs include asset loss, consumer welfare loss and infrastructure costs. Residual values of infrastructure at the end of the appraisal period have not been considered but are not expected to be significant.

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 2017 prices.

[130] Department for Energy and Climate Change, Fossil fuel price projections: 2014, <www.gov.uk/government/publications/fossil-fuel-price-projections-2014>.

Annex F – Clean Air Zone modelling details

Unlike greenhouse gases, the risk from NO_2 is focused in particular places: it is the build-up of pollution in a particular area that increases the concentration in the air and the associated risks. So intervention needs to be targeted to problem areas, where specific roads with air pollution problems have been identified, mostly in cities and towns. The effort to reduce NO_2 also need to be targeted on the sources that make the biggest contribution to the problem: road vehicles contribute about 80% of NO_2 pollution at the roadside and growth in the number of diesel cars has exacerbated this problem.

Given the local nature of the problem, local action is needed to achieve improvements in air quality. As the UK improves air quality nationally, air quality hotspots are going to become even more localised and the importance of action at a local level will increase. Local knowledge is vital to finding solutions for air quality problems that are suited to local areas and the communities and businesses affected. A leading role for local authorities is therefore essential.

But it is also recognised that there is a need for strong national leadership. Central government will set a clear national framework for the steps that local authorities need to take. It will provide direct financial support to enable local authorities to develop and implement their plans, and pursue national measures to reinforce their efforts. And those local plans will be required to be developed and implemented at pace so that air quality limits are achieved within the shortest possible time.

The areas with the greatest problem, with exceedances to project beyond the next three to four years will be required to develop local plans to tackle those exceedances. Other areas will also be expected to take steps now to reduce emissions if there are measures they could take to being forward the point where they meet legal limits.

These authorities face varying challenges, and the solutions will not all be the same. In particular, in some cases the problem is a single road that passes through, or around, a town centre. In others it is urban traffic that is causing the problem. Each authority will be required to undertake local assessments to consider the best option to achieve the statutory NO_2 limit values within the shortest possible time. The UK government will expect other bodies, including upper tier local authorities and Highways England to work with these local authorities, where appropriate. We will require local authorities to set out initial plans eight months from now, by the end of March 2018. These will be followed by final plans by the end of December 2018. To assist local authorities in meeting these timescales, they can immediately draw on an Implementation Fund, as well as central government expertise.

It is for local authorities to develop innovative local plans that will achieve statutory NO_2 limit values within the shortest possible time. For modelling purposes, CAZs that include charging have been identified as the measure that can be modelled nationally which will achieve statutory NO_2 limit values in towns and cities in the shortest possible time. This annex describes some of the detailed assumptions that it has been necessary to make to conduct this modelling. Given the potential impacts on individuals and businesses, when considering between equally effective alternatives to deliver compliance, the UK government believes that if a local authority can identify measures other than charging zones that are at least as effective at reducing NO_2, and are at the same or lower cost, those measures should be preferred as long as the local authority can demonstrate that this will deliver compliance as quickly as a charging CAZ.

F.1 Mapping illustrative CAZs for modelling

Illustrative CAZ boundaries were needed to model the air quality and economic impacts of CAZs in the Plan. The boundaries were defined based on maps of roads in urban centres with estimated NO_2 concentrations for the year a CAZ is assumed to be possible to implement (Table **F.1**). Several key principles for drawing illustrative CAZ boundaries were defined to act as a guide to ensure a consistent and transparent approach to producing each boundary.

In reality, where local authorities opt to introduce a CAZ, the final boundaries will be decided at a local level after detailed local feasibility studies and consultations. It is therefore important to recognise that the boundaries used for modelling are illustrative by comparison, but following the guidelines below ensures they are as practical and consistent as possible. All of the following guidelines were read subject to the fundamental requirement that a CAZ must deliver compliance in the shortest possible time.

F.1.1 Mapping Principles

Overarching principles:

- Strategic road network (SRN) links, which are controlled by Highways England, will not be modelled as CAZs (unless these happen to be within a pre-determined CAZ area).
- Single roads and exceedances where the traffic is ‘through traffic” (i.e. not immediately heading towards a city centre) will not be modelled as a CAZ.
- An exceedance along a bridge with no alternative route will not be modelled as a CAZ.
- Keep the CAZ area as small as possible while still being practical.
- The boundary should be a sensible shape/solution (no sudden changes of direction etc.).

Where to set the boundary:

- A natural boundary (e.g. a river).
- A ring road where possible; or

- If no ring-road then A-roads, where suitable or larger B roads (smaller and residential roads should be avoided (as far as possible) as the boundary)

Alternative routes:

- Alternative routes around the CAZ must be considered. CAZs are likely to cause some vehicles to divert their journeys to avoid the zone. Therefore, CAZ boundaries need to consider the likely impact of the CAZ on the compliance status of roads close to the CAZ which are likely to experience an increase in traffic due to these diverted journeys.

- The NO2 concentration and size of any alternative routes (links) must be considered.

CAZ groupings:

- If a large number of exceedances are in close proximity then this should form a natural CAZ area.

- If there are small clusters of exceedances over a larger area (metropolitan area) then several smaller distinct CAZs may be appropriate (rather than one large CAZ).

- The size of a CAZ should be proportionate. If the inclusion of one extra exceedance would significantly increase the size of the CAZ then a distinct separate CAZ for that one exceedance may be more appropriate.

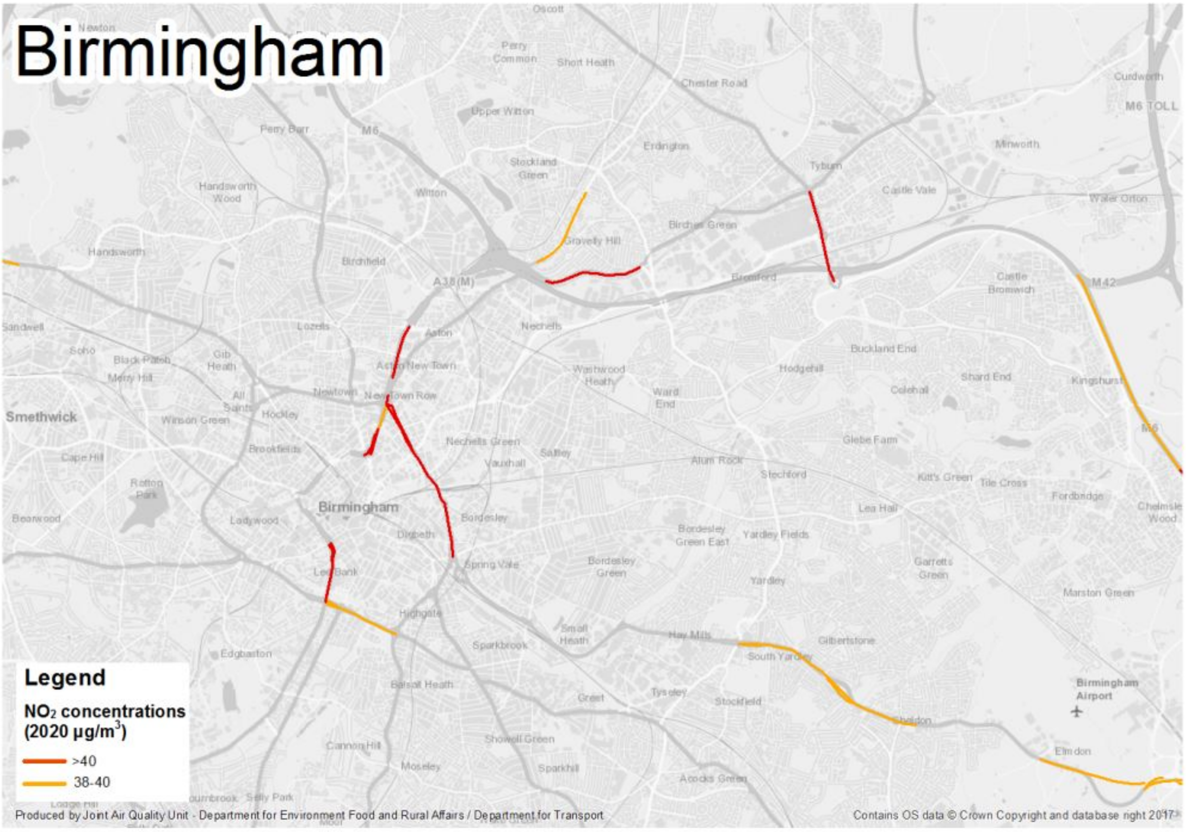
- Exceedances that go across multiple LA boundaries can form a single CAZ.

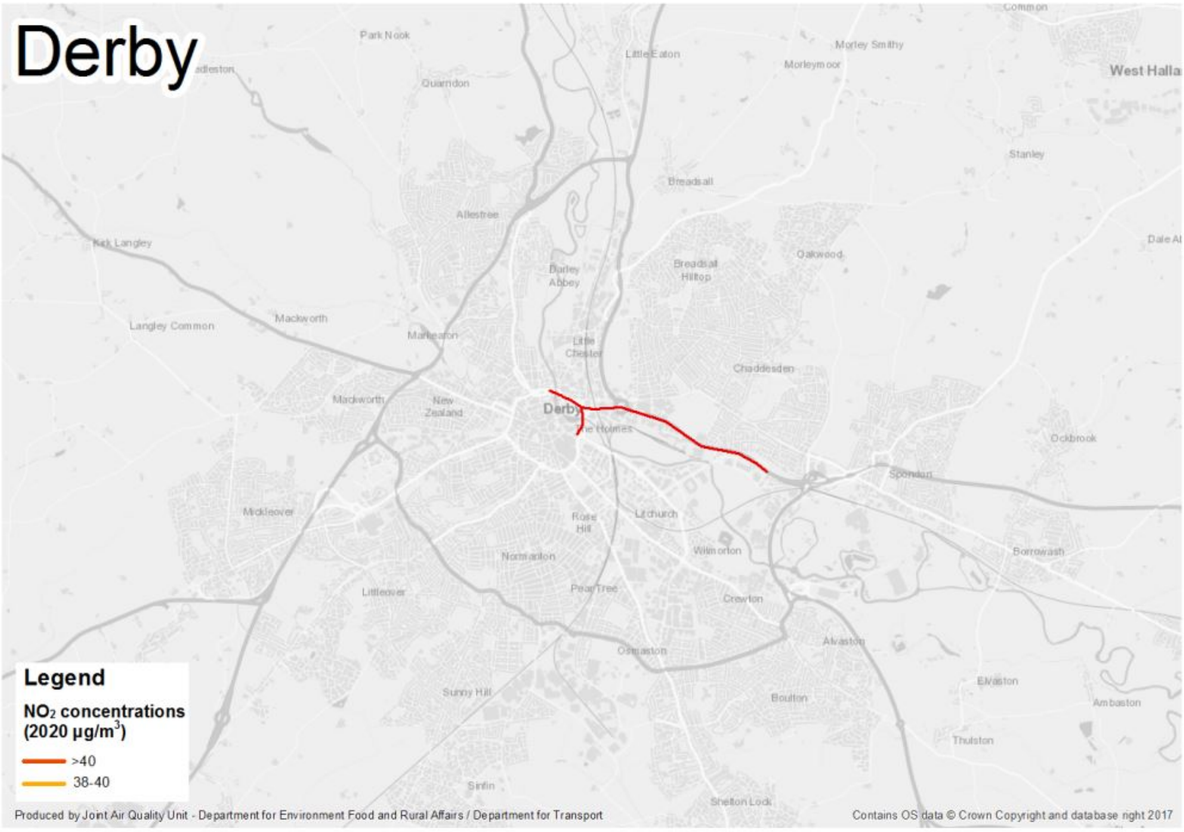
CAZ class:

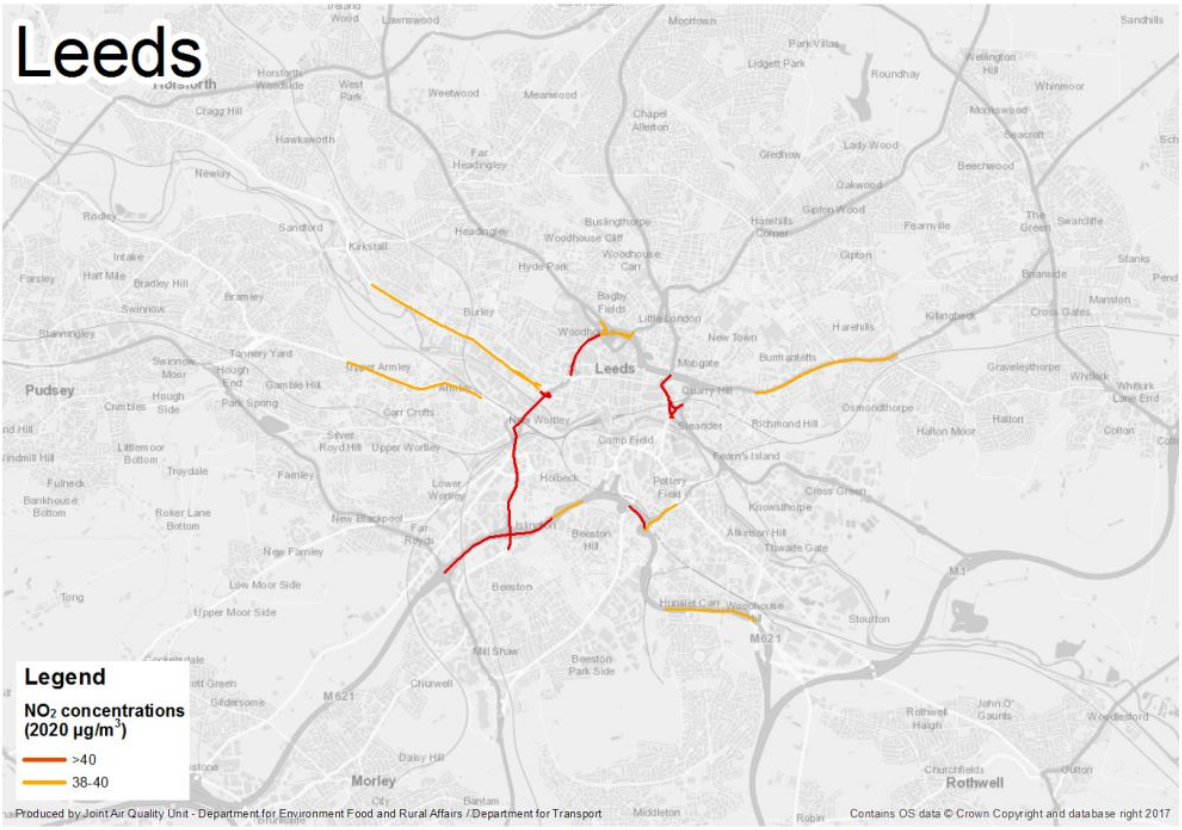
- The class of CAZ that is modelled is determined by modelling the effects of all classes of CAZ for each area to find the lowest category of CAZ that is needed to bring about compliance in the shortest possible time. This is not necessarily the class of CAZ that will be implemented in practice since local authorities may identify alternative interventions that are able to bring about compliance just as quickly.

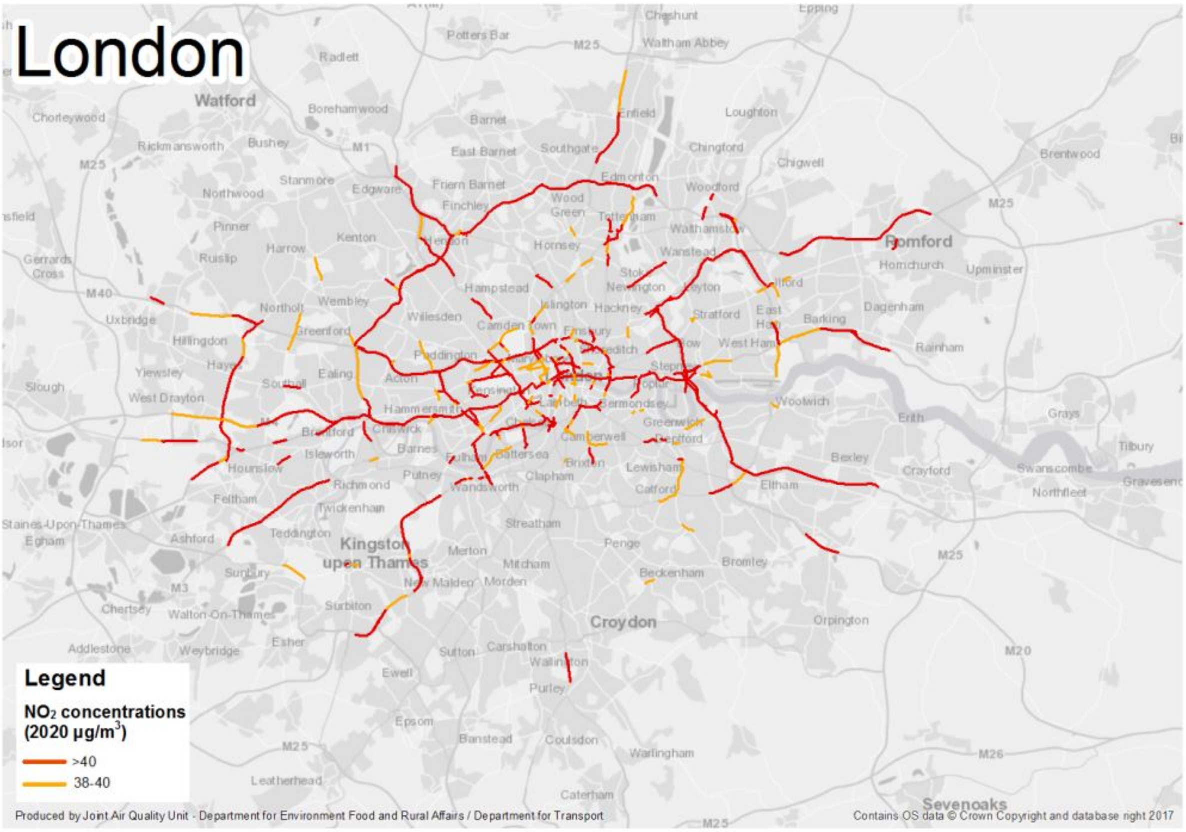
While the principles were developed in order to ensure a consistent approach was taken, the process of applying these principles is still subjective and requires judgement. Therefore, many decisions are not clear-cut.

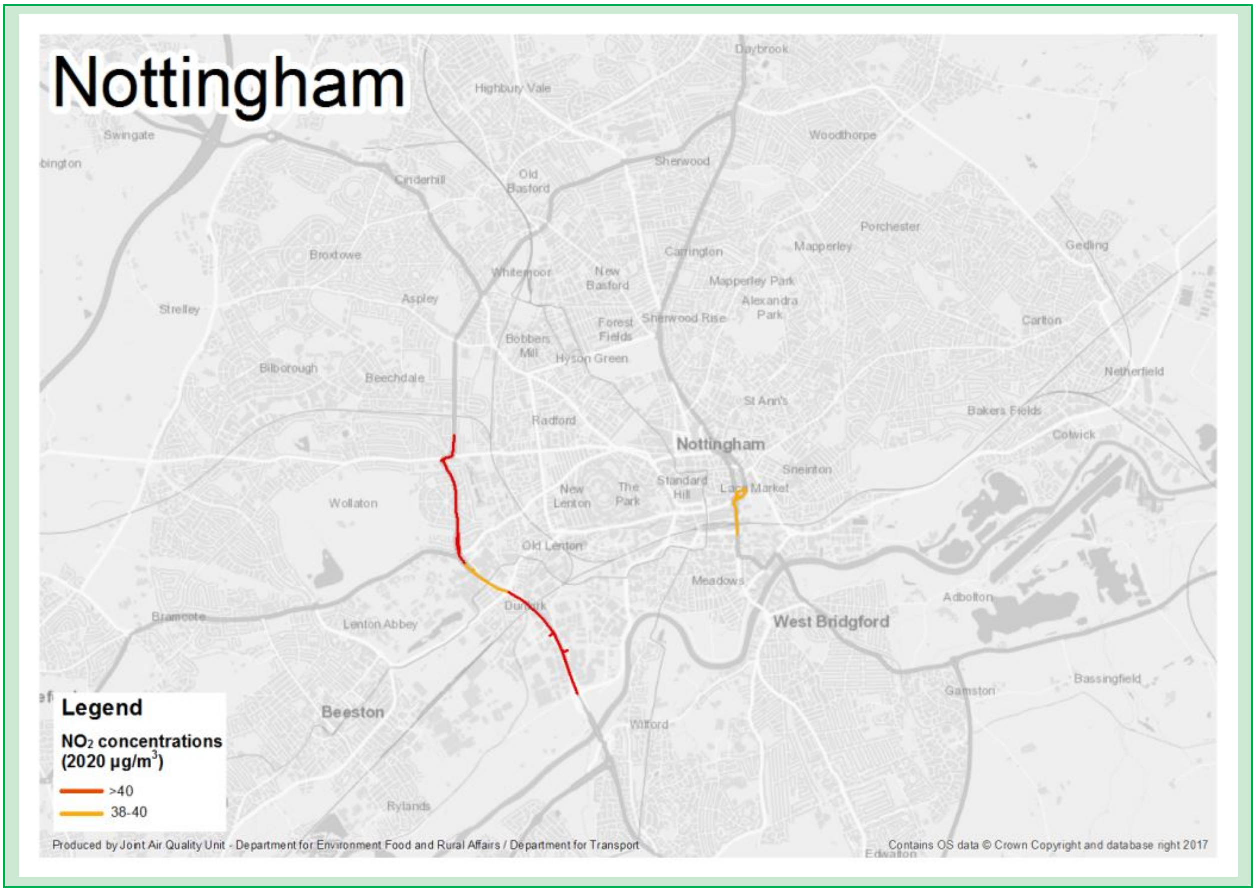
Figure F.1: Maps of urban centres with estimated roadside NO_2 concentration projections (μg/m^3) for 2020 or 2021 (see individual map legends for details)






Leeds
Legend
NO2 concentrations (2020 µg/m3)
>40
38-40
Produced by Joint Air Quality Unit - Department for Environment Food and Rural Affairs / Department for Transport
Contains OS data © Crown Copyright and database right 2017


London
Legend
NO2 concentrations (2020 µg/m3)
>40
38-40
Produced by Joint Air Quality Unit - Department for Environment Food and Rural Affairs / Department for Transport
Contains OS data © Crown Copyright and database right 2017


Nottingham
Legend
NO2 concentrations (2020 µg/m3)
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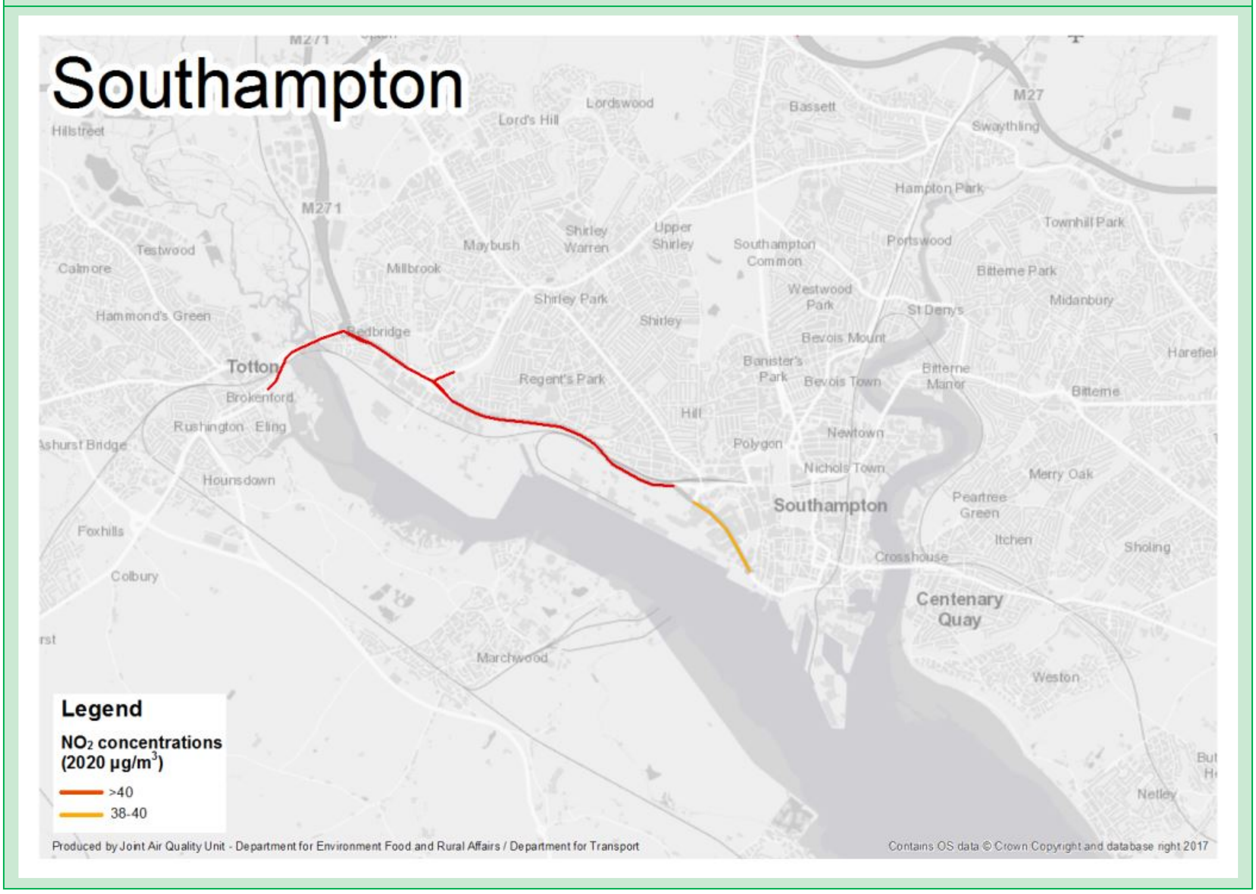
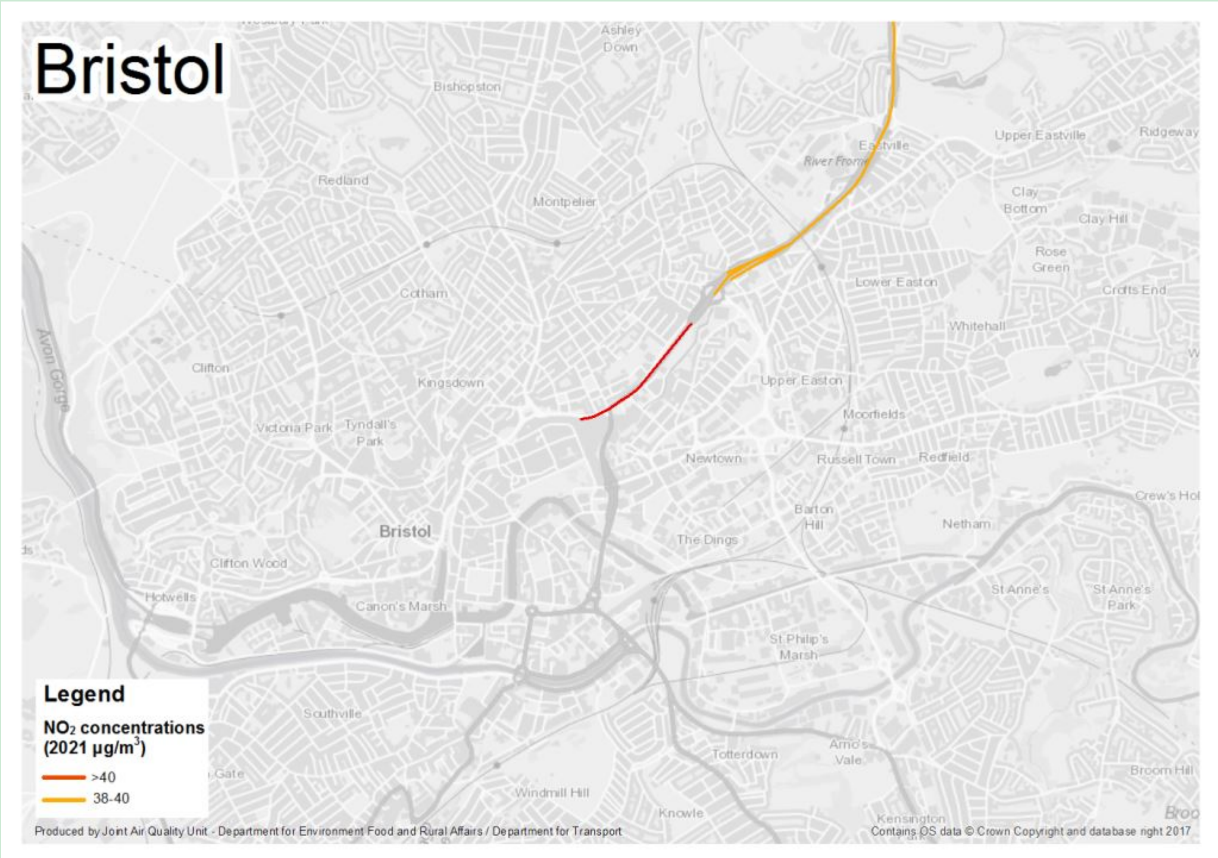
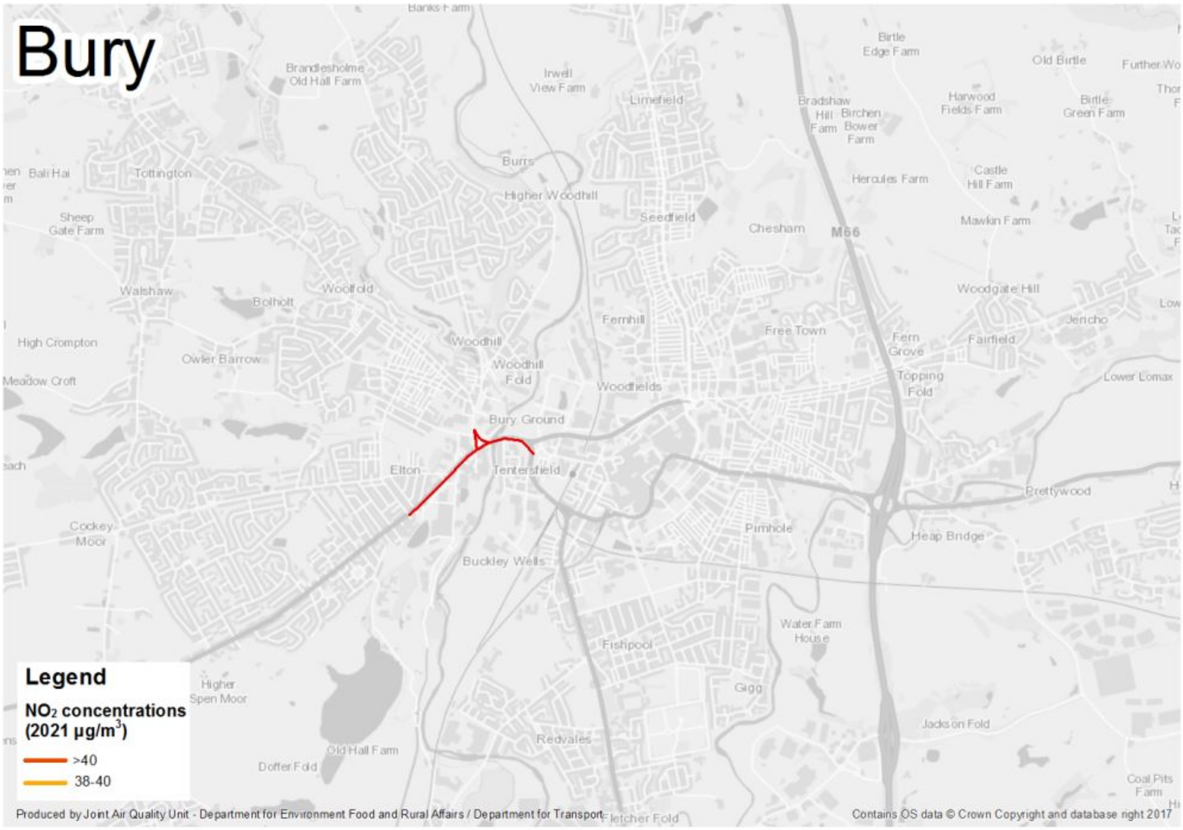
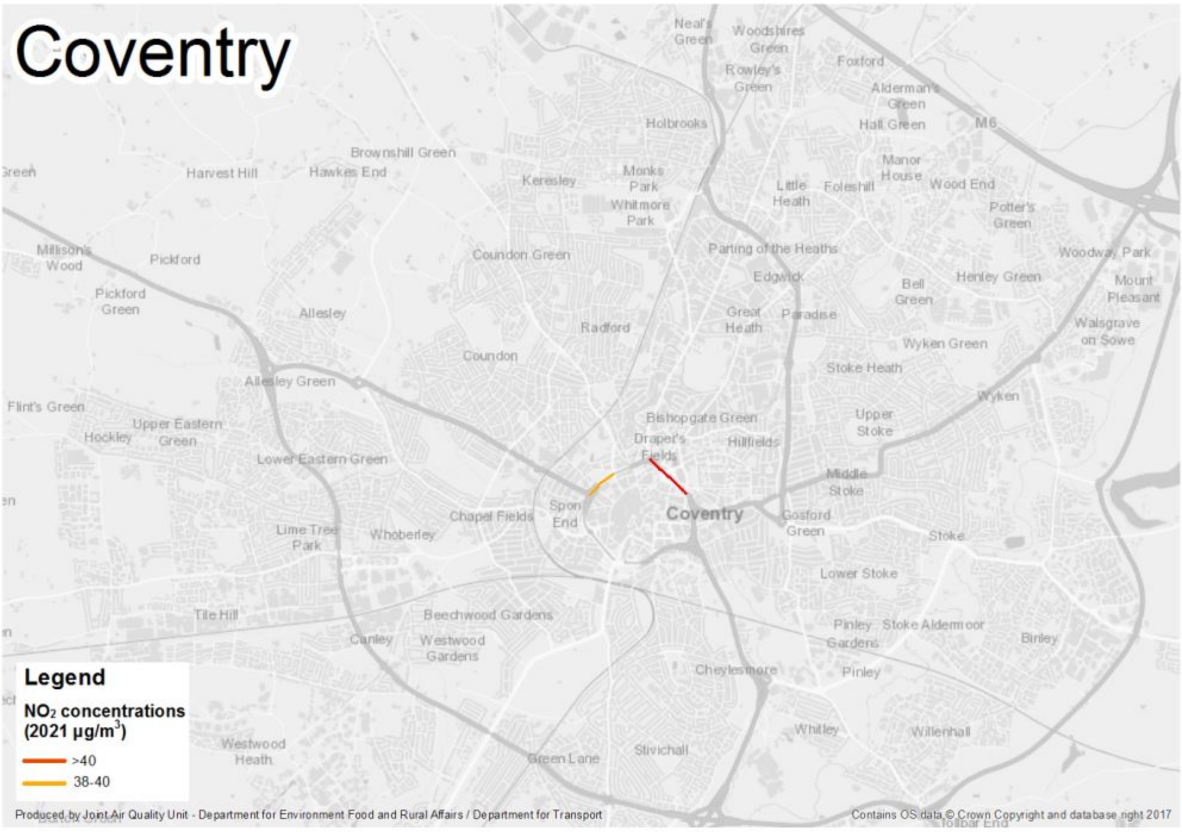
38-40
Produced by Joint Air Quality Unit - Department for Environment Food and Rural Affairs / Department for Transport
Contains OS data © Crown Copyright and database right 2017


Southampton
Legend
NO2 concentrations (2020 µg/m3)
>40
38-40
Produced by Joint Air Quality Unit - Department for Environment Food and Rural Affairs / Department for Transport
Contains OS data © Crown Copyright and database right 2017


Bolton
Legend
NO2 concentrations (2021 µg/m3)
>40
38-40
Produced by Joint Air Quality Unit - Department for Environment Food and Rural Affairs / Department for Transport
Contains OS data © Crown Copyright and database right 2017


Bristol
Legend
NO2 concentrations (2021 µg/m3)
>40
38-40
Produced by Joint Air Quality Unit - Department for Environment Food and Rural Affairs / Department for Transport
Contains OS data © Crown Copyright and database right 2017


Bury
Legend
NO2 concentrations (2021 µg/m3)
>40
38-40
Produced by Joint Air Quality Unit - Department for Environment Food and Rural Affairs / Department for Transport
Contains OS data © Crown Copyright and database right 2017


Coventry
Legend
NO2 concentrations (2021 µg/m3)
>40
38-40
Produced by Joint Air Quality Unit - Department for Environment Food and Rural Affairs / Department for Transport
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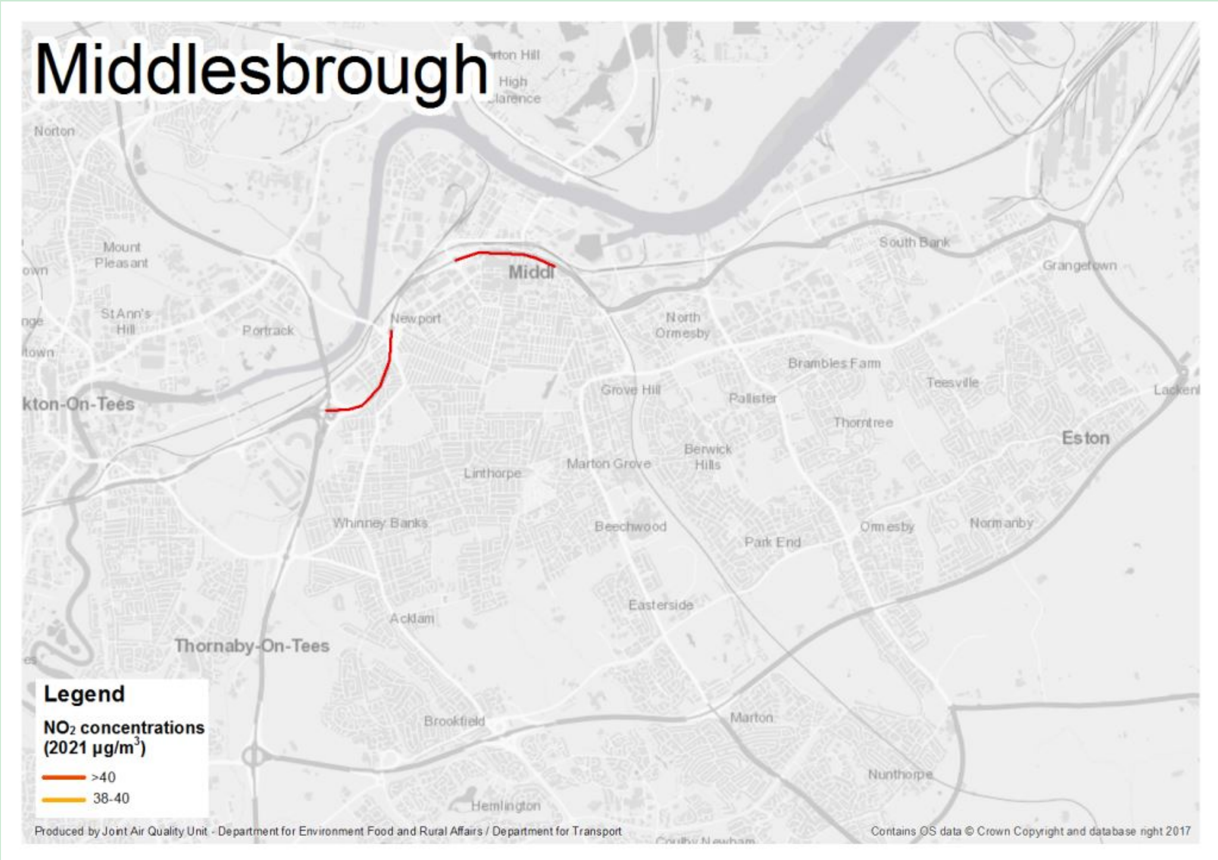
Manchester
Legend
NO2 concentrations (2021 µg/m3)
>40
38-40
Middleton
Chadderton
Oldham
Whitefield
Walkden
Prestwich
Mossley
Rendlebury
Failsworth
Worsley
Swinton
Salford
Eccles
M602
Manchester
Ashton-Under-Lyne
Stalybridge
Droylsden
Dukinfield
Denton
M67
Hyde
Urmston
Stretford
M60
Sale
Gatley
Stockport
Romiley
Marple
Altrincham
Hale
Cheadle
Cheadle Hulme
Hazel Grove
Produced by Joint Air Quality Unit - Department for Environment Food and Rural Affairs / Department for Transport
Contains OS data © Crown Copyright and database right 2017


Middlesbrough
Legend
NO2 concentrations (2021 µg/m3)
>40
38-40
Norton
Mount Pleasant
St Ann's Hill
Portrack
Newport
South Bank
Grangetown
North Ormesby
Brambles Farm
Teesville
Grove Hill
Pallister
Thorntree
Eston
Linthorpe
Marton Grove
Berwick Hills
Whinney Banks
Beechwood
Park End
Ormesby
Normanby
Easterside
Acklam
Thornaby-On-Tees
Brookfield
Marton
Nunthorpe
Hemlington
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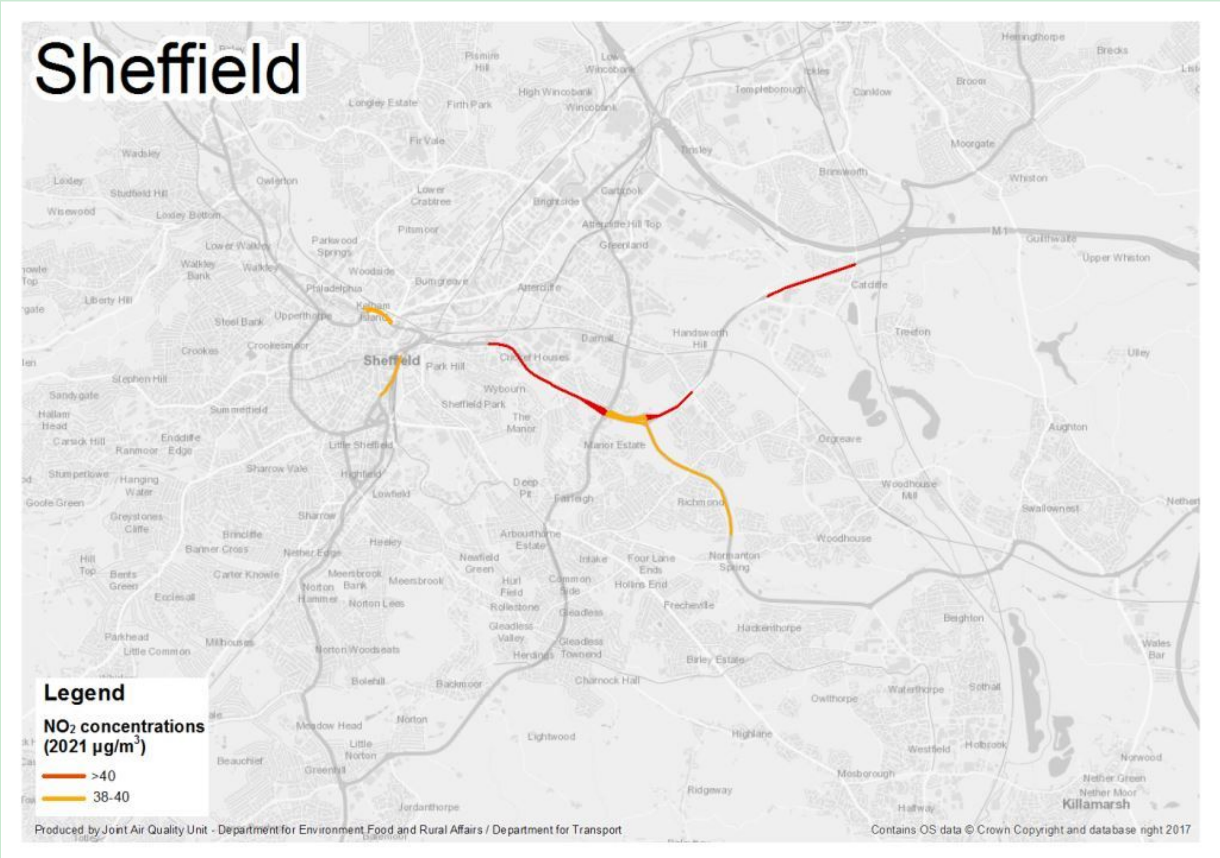
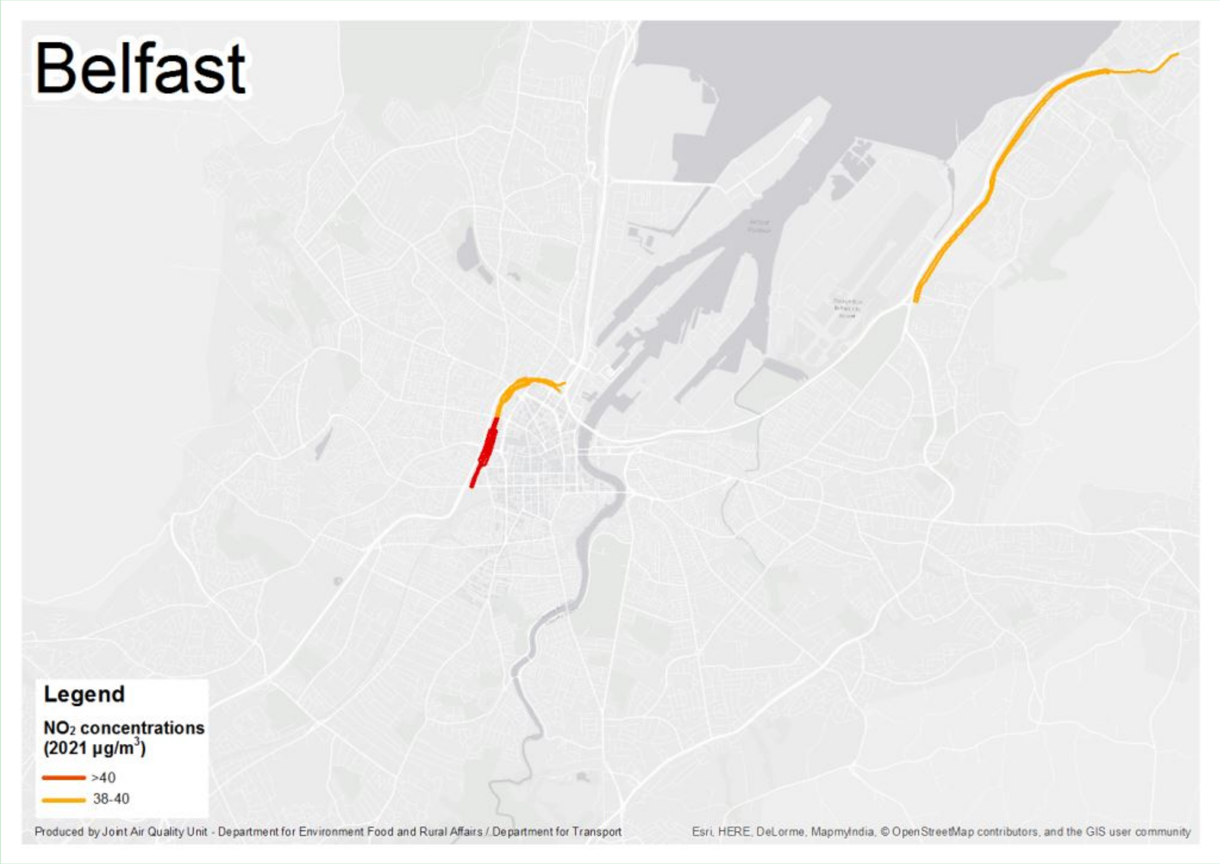
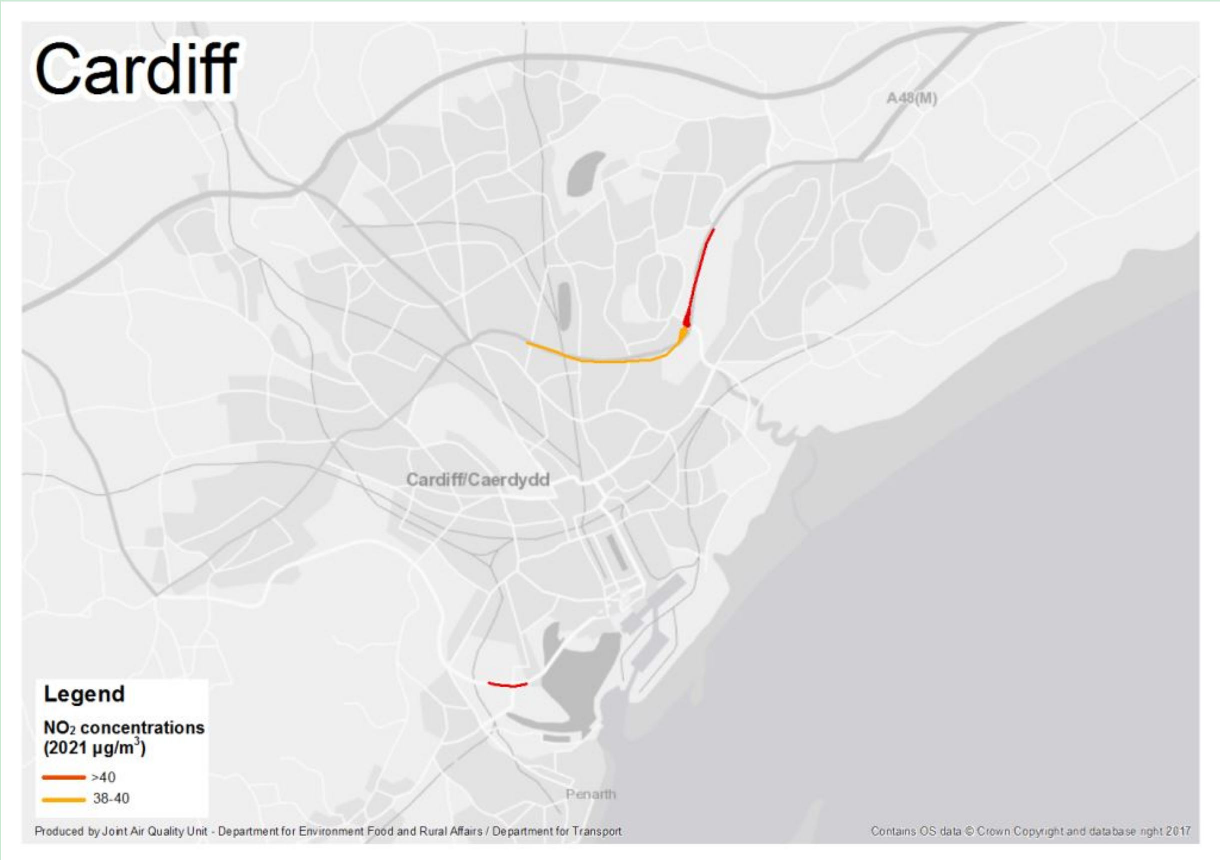
Newcastle and Gateshead
Ponteland
Newcastle International Airport
Whitley Bay
Tynemouth
Longbenton
Wallsend
Newcastle upon Tyne
A167(M)
Jarrow
Hebburn
Blaydon
Gateshead
Whickham
Legend
NO2 concentrations (2021 µg/m3)
>40
38-40
Produced by Joint Air Quality Unit - Department for Environment Food and Rural Affairs / Department for Transport
Contains OS data © Crown Copyright and database right 2017



Sheffield
Sheffield
M1
Catcliffe
Treeton
Handsworth Hill
Darnall
Killamarsh
Legend
NO2 concentrations (2021 µg/m3)
>40
38-40
Produced by Joint Air Quality Unit - Department for Environment Food and Rural Affairs / Department for Transport
Contains OS data © Crown Copyright and database right 2017


Belfast
Legend
NO2 concentrations (2021 µg/m3)
>40
38-40
Produced by Joint Air Quality Unit - Department for Environment Food and Rural Affairs / Department for Transport
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community


Cardiff
A48(M)
Cardiff/Caerdydd
Penarth
Legend
NO2 concentrations (2021 µg/m3)
>40
38-40
Produced by Joint Air Quality Unit - Department for Environment Food and Rural Affairs / Department for Transport
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F.2 Estimated number of cars and vans affected by charging CAZs

Estimates of the potential number of cars and vans regularly entering CAZs have been produced by forecasting the number of vehicles owned nationally, identifying the proportion that would be non-compliant, and then estimating the proportion that is likely to enter a CAZ area, based on historic data.

The forecast fleet of cars and vans in 2020 is based on data produced by DfT using the Fleet Fuel Efficiency Model. The UK car fleet is estimated to be 31.7m in 2020 and 32.3m in 2021, while the van fleet is estimated to be 3.9m in 2020 and 4.0m in 2021.

The proportion of non-compliant vehicles uses estimates of the split of the vehicle stock by Euro standard at a national level used as inputs in the PCM. Because information on Euro standards is not collected these are estimated using DfT statistics on vehicle ages and information on the introduction dates of Euro standards. The age mix of the fleet is projected forwards to understand the mix of vehicles by Euro standard in future years. In total it is estimated that 8.0m cars and 2.4m vans could be non-compliant in 2020 (the earliest year that CAZs are expected to be introduced).

Estimates of the number of vehicles entering CAZs are then made using GPS data.

- GPS data tracks vehicles and can be used to identify the numbers that enter different local authorities. The data is provided by Trafficmaster. The data captures the movements of approximately 90,000 cars and 75,000 vans in 2015.

- The number of vehicles in the dataset that enter the modelled Class C CAZ areas (for vans) and Class D CAZ areas (for cars and vans) was based on the assumed boundaries produced as outlined in Section **F.1**. In reality the final CAZ boundaries and classes will be decided at a local level after detailed local feasibility studies and consultations.

- Because the Trafficmaster data captures only a sample of vehicles (and some for less than the 12 month period), estimates were scaled up to provide an estimate of the total number affected.

Finally, GPS data is also used to track the number of times that cars and vans enter the assumed CAZ boundaries. This was used to estimate the proportion of that might enter the assumed CAZ areas at least once a year.

There is significant uncertainty regarding the number of cars that will be impacted, due to uncertainty around the number of CAZs, their boundaries, and the number that will cover cars. Furthermore, there is also uncertainty in the methodology as it relies on GPS data, which covers only a sample of newer vehicles and may not accurately reflect vehicles on a national basis. It also does not take account of local differences in the age of vehicles, or travel patterns. Finally, these calculations only estimate the number of non-compliant cars that might be expected to enter the areas where a CAZ may be implemented and do not take account of the behaviour change that would result from CAZ charging.

To reflect this uncertainty a significant range is placed around these estimates, from -50 per cent to +100 per cent in the estimates of cars that enter the CAZs. The results of this assessment, covering the modelled Class C CAZ areas (for vans) and the modelled Class D CAZ areas (for cars and vans), are presented in Table **F.3**.

Table F.3 Non-compliant cars and vans that enter CAZs (millions)						
CAZs assumed to be introduced by 2020	**Cars**			**Vans**		
	Low	**Central**	**High**	**Low**	**Central**	**High**
At least once per year	1.1	2.3	4.6	0.4	0.8	1.5
> 11 times per year	1.0	2.0	3.9	0.4	0.7	1.5
> 51 times per year	0.6	1.2	2.4	0.3	0.6	1.1
CAZs assumed to be introduced by 2021	**Cars**			**Vans**		
	Low	**Central**	**High**	**Low**	**Central**	**High**
At least once per year	1.1	2.3	4.6	0.5	1.0	2.0
> 11 times per year	1.1	2.0	3.9	0.5	1.0	2.0
> 51 times per year	0.6	1.2	2.4	0.4	0.7	1.5

F.3 Exceedances that fall outside of illustrative modelled CAZ boundaries

Some road links that exceed the 40μg/m^3 concentration limit for NO_2 do not fall within these illustrative boundaries and, therefore, are not necessarily resolved in this modelled scenario (though it's important to note that CAZs will have a beneficial impact on road links outside of the boundary due to accelerated fleet turnover). These exceedances would require separate and additional action, if possible. See Section **3.1.3** for more details on the modelling of these road links.

Table **F.4** lists the road links that fall outside of the illustrative modelled CAZ boundaries but which are still required to undertake feasibility studies to improve local air quality.

Table F.4: Estimated NO_2 concentrations ($\mu g/m^3$) in 2021 on road links that fall outside of the illustrative modelled CAZ boundaries but which are still required to undertake feasibility studies							
Reporting Zone(s)	**Length (m)**	**Road name**	**LA name**	**Road ownership** [I]	**Baseline**	**CAZ scenario**	**CAZs + additional actions**
5, 36	1,526	A1	Gateshead Metropolitan Borough Council	HE	41	38	38
36	381	A1	Gateshead Metropolitan Borough Council	HE	41	38	38
5	1,637	A1	Gateshead Metropolitan Borough Council	HE	41	38	38
5, 36	1,289	A1	Newcastle City Council	HE	43	40	38
29	337	A127	Basildon District Council	LA	42	40	40
29	2,308	A127	Basildon District Council	LA	43	40	38
21	2,004	A127	Rochford District Council	LA	42	40	40
12	2,939	A27	Fareham Borough Council	LA	40	38	38
12, 31	1,677	A27	Havant Borough Council	HE	42	39	39
31	1,263	A331	Guildford Borough Council	LA	42	40	40
31	2,048	A331	Rushmoor Borough Council	LA	43	41	38
31	696	A331	Surrey Heath District Council	LA	41	39	39
31	1,544	A331	Surrey Heath District Council	LA	41	38	38
31	689	A331	Surrey Heath District Council	LA	40	38	38
31	678	A331	Rushmoor Borough Council	LA	40	38	38
31	297	A331	Surrey Heath District Council	LA	40	38	38
30	1,675	A4	Bath & North East Somerset Council	LA	40	37	37
41	1,277	A472	Caerphilly County Borough Council	LA	53	50	46

42	2,146	A494	Flintshire County Council	WG	40	38	38
14	612	A50	Stoke-on-Trent City Council	HE	40	38	38
14	2,465	A500	Newcastle-under-Lyme Borough Council	HE	41	38	38
14	1,107	A500	Stoke-on-Trent City Council	HE	41	39	39
35	1,008	A500	Stoke-on-Trent City Council	HE	41	38	38
35	472	A500	Stoke-on-Trent City Council	HE	42	40	40
35	130	A500	Stoke-on-Trent City Council	HE	40	38	38
33	497	A533	Halton Borough Council [II]	LA	45	43	40
24	3,858	A8	North Lanarkshire Council	SG	42	39	39
24	1,154	A8	North Lanarkshire Council	SG	47	44	41
24	2,726	A8	North Lanarkshire Council	SG	44	41	38
19, 31	1,887	M27	Test Valley Borough Council	HE	41	38	38
19, 32	344	M27	Test Valley Borough Council	HE	44	41	38
31	1,552	M27	Test Valley Borough Council	HE	41	39	39
1	2,441	M4	Hounslow, London Borough of	HE	46	46	43
3	684	M56	Manchester City Council	HE	40	38	38
3, 33	2,580	M60	Manchester City Council	HE	40	38	38
3, 33	1,664	M60	Tameside Metropolitan Borough Council	HE	42	39	39

[I] HE = Highways England, LA = Local Authority, WG = Welsh Government, SG = Scottish Government

[II] Halton Borough Council is forecast to have persistent exceedances. However these are expected to be addressed by the Mersey Gateway Bridge, which is due to open in Autumn 2017.

Annex G – Policy assessment details

To model the air quality impacts of the indicative package of measures, a series of scenarios were run using the SL-PCM. These modelled the effects of the measures as set out in Section **3.1**. In order to build up a full set of NO_2 concentration results for the whole of the UK, the results from each scenario were applied to the roads they would affect and in the order they will start to have impacts. The resulting mosaic of measures was combined together to provide the overall assessment. The full list of scenarios modelled is as follows:

- **Adjusted baseline scenario:** a modelling construct created to remove the ULEZ impacts from the SL-PCM baseline in order to enable the impacts of this policy to be assessed. Modelled for 2018 to 2030 for the whole of the UK.
- **GBS-T scenario:** modelled for 2018 and 2019 for the UK outside of London. After this point, the impacts of this policy were included in the CAZ scenarios.
- **Class A CAZ scenario:** modelled from 2021 to 2030 in the UK outside of London.
- **Class B CAZ scenario:** modelled from 2021 to 2030 in the UK outside of London.
- **Class C CAZ scenario:** modelled from 2021 to 2030 in the UK outside of London.
- **Class D CAZ scenario:** modelled from 2020 to 2030 in the UK outside of London.
- **ULEZ expansion scenario:** modelled from 2021 to 2030 in inner and outer London. Inner London modelled as implementing a class D CAZ, outer London modelled as implementing a class B CAZ
- **Wider impacts of the CAZ network scenario:** modelled from 2020 to 2030 in the UK outside of London.
- **Measures for exceedances not suitable for a CAZ scenario:** modelled from 2021 to 2023 in outer London and from 2021 to 2025 in the UK outside of London.
- **ZEZ scenario:** modelled from 2025 to 2030 in central London. The impacts from this scenario were only included in additional actions scenario results.

The SL-PCM allows policies to be assessed in four distinct areas (central London, inner London, outer London and the rest of the UK) and in the years 2018-2030. However, modelling scenarios for multiple years and multiple areas is very resource intensive. Therefore, only those areas and years that were needed for each scenario were actually modelled.

Table **G.1** summarises which scenarios were applied to which roads in each year.

Table G.1: Summary of the scenario results used for different modelled roads to create the final assessment results.	
Area	**Scenarios applied**
Modelled roads assumed to be within Class A CAZ boundaries based on indicative CAZ boundaries drawn	GBS-T scenario results taken until 2020. Class A CAZ scenario results applied from 2021 onwards. GBS-T scenario results taken until 2020. Class A CAZ scenario results applied from 2021 onwards. The CAZ scenario results were compared against the results from the wider impacts of the CAZ network and the lower concentration out of the two was taken.
Modelled roads assumed to be within Class B CAZ boundaries based on indicative CAZ boundaries drawn	GBS-T scenario results taken until 2020. Class B CAZ scenario results applied from 2021 onwards. The CAZ scenario results were compared against the results from the wider impacts of the CAZ network and the lower concentration out of the two was taken.
Modelled roads assumed to be within Class C CAZ boundaries based on indicative CAZ boundaries drawn	GBS-T scenario results taken until 2020. Class C CAZ scenario results applied from 2021 onwards.
Modelled roads assumed to be within Class D CAZ boundaries based on indicative CAZ boundaries drawn	GBS-T scenario results were taken until 2019 for first wave of CAZ cities and until 2020 for other CAZ areas. Class D CAZ scenario results were taken from 2020/21 onwards.
Modelled roads in central London	SL-PCM baseline includes the effects of a ULEZ in central London from 2020 so the SL-PCM baseline scenario results were taken for these roads. For the additional actions results the ZEZ scenario results were applied from 2025 onwards.
Modelled road in inner London	SL-PCM baseline results taken until 2021. ULEZ expansion scenario results applied from 2021 onwards.
Modelled roads in outer London except for motorways	SL-PCM baseline results taken until 2021. ULEZ expansion scenario results applied from 2021 onwards. Motorways in outer London were treated in the same way as roads outside of the indicative CAZ boundaries because they were not considered to be suitable to be included in a CAZ.
Modelled roads outside of indicative CAZ boundaries and motorways in outer London	GBS-T scenario results taken until 2020. Results from wider impacts of CAZ network scenario applied from 2021 onwards. For roads that were still in exceedance following the wider impacts of the CAZ network, an alternative scenario was modelled to reflect the uncertainty in the evidence base around the measures that might be applied to these exceedances. The results of this alternative scenario are only included in the additional actions results.

Annex H – Evidence of potential effectiveness of measures to tackle exceedances not suitable for a CAZ

Evidence of the potential effectiveness of measures to tackle exceedances not suitable for a CAZ is limited. No one measure is likely to be applicable in all situations and there is high uncertainty of the effectiveness of these measures. The available evidence, and plans to improve it, is set in this annex.

H.1 Traffic management

Vehicle testing typically finds that drive cycles with lower average speeds produce lower NO_x emissions. This is subject to significant uncertainty and many confounding variables, including typical driving dynamics, the extent of acceleration, weather conditions, and others. However, overall, there is reasonable cause to expect this intervention to reduce emissions in some areas.

Some empirical evidence also supports this claim. Eight published studies that evaluated the impact of traffic management on air pollution[131] were reviewed. Taking into account the studies that estimated the overall reduction in NO_x emissions, the average impact across these studies was a 10.9 per cent reduction.

[131] Baldasano et al., 'Air pollution impacts of speed limitation measures in large cities: The need for improving traffic data in a metropolitan area', *Atmospheric Environment*, Vol. 44, 25 (2010), pp.2997-3006; Olde Kalter et al., '*Reducing speed limits on highways: Dutch experiences and impact on air pollution, noise-level, traffic safety and traffic flow*', 2005; Dijkema et al. (2008) 'Air quality effects of an urban highway speed limit reduction', *Atmospheric Environment*, Vol. 40, 40 (2008), pp.9098-9105; Stoelhorst et al., '*Summary results of Dutch field trials with dynamic speed limits (dynamax)*', 2011; Keller et al. 'The impact of reducing the maximum speed limit on motorways in Switzerland to 80 km h^{-1} on emissions and peak ozone', *Environmental Modelling & Software*, Vol. 23, 3 (2008), pp.322-332; Bel and Rosell, 'Effects of the 80 km/h and variable speed limits on air pollution in the metropolitan area of Barcelona', *Transportation Research Part D: Transport and Environment*, Vol. 23 (2013), pp.90-97; Bel et al., 'The environmental effects of changing speed limits: A quantile regression approach', *Transportation Research Part D: Transport and Environment*, Vol. 36 (2015), pp.76-85; Keuken et al., 'Reduced NO_x and PM_{10} emissions on urban motorways in The Netherlands by 80 km/h speed management', *Science of the Total Environment*, Vol. 408, 12 (2010), pp.2517-2526.

H.2 Signage and rerouting

Evidence was reviewed for the 2015 Air Quality Plan and two relevant studies were found.[132]

- A study on dynamic re-routing and traveller information in Copenhagen, Denmark, suggested that more travellers followed the alternative route (at least 12 per cent of the time) as the displayed travel time between the original and alternate route increased. Uptake could be higher if problems with display systems were resolved.
- In the Netherlands, re-routing information is displayed through full matrix dynamic message sign 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 25-33 per cent. In normal conditions, it was found that 8-10 per cent of drivers were reacting to the information.

H.3 Changes to driver behaviour

Fuel-efficient driving techniques ('eco-driving') can improve fuel economy by as much as 15 per cent immediately after a single lesson with the same level of reduction in CO_2.[133] A report by the RAC Foundation reviewed the evidence on fuel savings from eco-driving based on a range of studies.[134]

However, these savings in fuel do not necessarily correspond to reductions in NO_x emissions in a simple way. Published evidence on the impact of fuel-efficient driving on NO_x emissions is limited. Recent work on a small number of vehicles conducted to establish whether there are driving techniques that deliver both NO_x and CO_2 emissions reductions suggest that this may be dependent on the fuel, model and emissions standard of the vehicle. Work will continue in order to determine if there are particular aspects of driver behaviour that will have a universal (or near universal) shared benefit to both fuel efficiency and air quality. There remains potential for a carefully designed and targeted

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[132] Department for Environment, Food and Rural Affairs, '*Improving air quality in the UK: Technical Report*', 2015 <www.gov.uk/government/uploads/system/uploads/attachment_data/file/492901/aq-plan-2015-technical-report.pdf>

[133] Section 2.4.4 of Department for Environment, Food and Rural Affairs, '*Evidence review on effectiveness of transport measures in reducing nitrogen dioxide*', 2016 <https://uk-air.defra.gov.uk/assets/documents/reports/cat05/1605120947_AQ0959_appendix_1-evidence_review_on_air_quality_effects_of_transport_measures.pdf>

[134] RAC, '*Easy on the gas – the effectiveness of eco-driving*', 2012 <www.racfoundation.org/assets/rac_foundation/content/downloadables/easy_on_the_gas-wengraf-aug2012.pdf>

efficient driving scheme to reduce NO_x emissions. With the current state of knowledge, the abatement potential is uncertain.

H.4 Improving the evidence base

Steps are being taken across government to develop the evidence base over the next six to 12 months. In respect of traffic speed management this work includes:

- Ongoing investigation into driving behaviours under different driving conditions, for example free flow and congestion, peak time versus day time driving and the influence of SMART motorway. This work is being delivered jointly by Highways England and DfT, working with Transport Systems Catapult and emission modelling experts TNO in the Netherlands. This study will help to identify if there are opportunities to help manage traffic and driving behaviours to support reduction in vehicle emissions.

- Air quality monitoring has been deployed alongside the M1 as part of the SMART motorway scheme. Monitoring data is currently being collected and will allow for a comparison between periods of 60mph speed limits and no speed controls. This will help to evaluate the real world performance of this intervention.

- Highways England has also recently commissioned emissions testing for a range of diesel cars and vans (Euro 4 to 6). Whilst the purpose of the emissions testing is to evaluate the impact of gas to liquid diesel versus conventional diesel, the outcomes of the testing can be used to help provide an insight into NO_x emissions for different speeds and engine loads. This work is scheduled to run over the summer and report early in Autumn 2017.

Annex I – Uncertainty panel summaries

I.1 Air quality modelling uncertainty panel

A panel was convened on 19th June 2017 to discuss uncertainties related to air quality modelling for the final NO_2 plan. In attendance were Professor Paul Monks (University of Leicester), Professor David Carslaw (University of York) and Professor Ricardo Martinez-Botas (Imperial College London), referred to collectively herein as 'the panel'. The meeting was chaired by Professor Ian Boyd (Defra's Chief Scientific Advisor) in the presence of officials.

First, the panel discussed the use of measured versus modelled NO_2 concentration data as an indicator of the level of uncertainty in the modelling. Initially using ±30 per cent (used in model verification plots for following standards set out in the Air Quality Directive) as the bounds of the error distribution was discussed. There was agreement that although this was a reasonable estimate, it would be better to perform a statistical analysis (based on prediction intervals) on the model verification data. This would provide a more rigorous estimate of the overarching uncertainty in the SL-PCM model.

Emission factors were identified by all members of the panel as the key source of uncertainty in the model. Estimates of 50 per cent and 60 per cent for one standard deviation were proposed. There was agreement that the conformity factors used in the model were accurate. It was agreed that, although systematic issues with emission factors would be largely dealt with in the calibration of the model, future projections based on emission factors carried a large degree of uncertainty. Professor Martinez-Botas indicated that data which he had collected on behalf of DfT would provide a useful source to estimate uncertainty in emission factors for cars. The panel agreed that HGV and bus emission factors carried greater uncertainty than those for cars and suggested a TfL dataset on heavy vehicle emission factors. The panel proposed that traffic composition, while linked to emission factors, was of secondary importance and could be viewed as modulating the uncertainty in the emission factors.

Professor Carslaw proposed that dispersion modelling was the next most significant area of uncertainty. The panel broadly agreed with this, although Professor Monks felt that traffic composition was of comparable importance. In particular, the fact that the model categorised roads simply as motorway or non-motorway was discussed. There was agreement that the failure of the model to take into account the 'canyon effect' propagated much uncertainty. Professor Monks felt that the model's use of average meteorological data from one site compounded the uncertainty caused by the dispersion modelling. However, Professor Carslaw and Professor Martinez-Botas argued that this was a fair assumption based on the fact that the model outputted annual average NO_2 concentrations only. The panel agreed that meteorology was of secondary importance (with respect to uncertainty) to dispersion modelling.

The panel identified atmospheric chemistry as a further source of uncertainty in the model. There was agreement that NO_x-NO_2 conversion via the empirical Jenkin equation was fairly robust but that primary NO_2 emissions were a significant source of uncertainty. Professor Carslaw proposed that ambient measurements indicated that current primary NO_2 fractions constituted an overestimate and agreed to share data to this effect. The panel agreed that a sensitivity study should be performed around primary NO_2, using a range derived from Professor Carslaw's data.

Finally, the panel agreed that there were no other significant areas of uncertainty. An official asked the panel whether they felt that the relationship between speed and emission was an area of concern. The panel agreed that it was not and reiterated their belief that emission factors were the greatest source of uncertainty.

I.2 Cost-benefit uncertainty panel

A panel was convened on 22nd June 2017 to discuss uncertainties related to cost-benefit analysis for the final NO_2 plan. In attendance were Dr Heather Walton (King's College London), Dr Risa Morimoto (The School of Oriental and African Studies), Professor Sir David Spiegelhalter (University of Cambridge), Dr Jacopo Torriti (University of Reading) and John Henderson (Department of Health), referred to collectively herein as 'the panel'. The meeting was chaired by John Curnow (Defra's Chief Economist) in the presence of officials and Professor Ian Boyd (Defra's Chief Scientific Advisor).

Mr Curnow and Professor Boyd set the scene, explaining that the purpose of the meeting was to further develop an understanding of uncertainty around the analysis for the NO_2 plan. It followed an air quality modelling panel held on 19th June, at which empirical estimates were agreed for a range of identified uncertainties. Professor Boyd explained that the aim of the meeting was to take the outputs from the earlier panel and replicate that work for uncertainties around health, behavioural responses, and cost-benefit analysis.

The discussion initially focussed on the most appropriate approach to presenting the overall uncertainty in the analysis. It was agreed that, while a probabilistic approach would be highly desirable, the current evidence did not support a Monte Carlo method and would not be practicable in the available time. At this stage, it would be more appropriate to base the overall range on the element of the analysis that had the greatest impact on uncertainty, as determined by modelling a range of sensitivity scenarios.

The panel agreed it was likely that the biggest driver of uncertainty in the NO_2 plan was the link between NO_2 and health, specifically on mortality. This is calculated as the expected number of life-years lost. New advice from the Committee on the Medical Effects of Air Pollutants (COMEAP) indicated a much lower impact of NO_2 on mortality than had previously been suggested. It also indicated that there were new uncertainty ranges around this link. Some of the factors driving this were discussed. It was important to note, however, that the debate and evidence is still evolving and that the evidence provided by COMEAP was not the final recommendation. The reason for the change from previous international recommendations on this link was discussed, noting that the World Health

Organization (WHO) uses a significantly higher hazard ratio. However, the WHO recognised this as more uncertain than some other pollutant health outcomes.

There was a discussion about the regulatory framework and the fact that legislative requirements were effectively pushing for action on a single pollutant (NO_2). Professor Boyd questioned whether this level of disaggregation was supported by the evidence. Dr Walton responded that there was more confidence in the effects of the mixture but that COMEAP had not been requested to address the impacts of general pollution, given the specific policy context of the NO_2 plan. However, it was recognised that given the correlation between the pollutants, a general reduction would be more reflective of the strongest aspects of the evidence.

The panel agreed that morbidity impacts were important. They noted that, currently, there is only a COMEAP recommendation available from 1998 for NO_2 and respiratory hospital admissions (for use in sensitivity analysis only). It was reflected that this was potentially a significant gap as morbidity impacts might affect more people than mortality. Dr Walton outlined extant concentration-response function recommendations of COMEAP and the WHO on hospital admissions and from the WHO on bronchitic symptoms in asthmatic children. It was also pointed out that there are human volunteer studies of NO_2 and airway hypersensitivity in asthmatics. These were not population studies so could be used to understand causality but not the total population effect. Dr Walton also suggested that asthma is the best respiratory disease to focus on in terms of available evidence on effects of NO_2. Mr Henderson suggested that respiratory diseases such as chronic bronchitis, which have a greater impact on quality of life, should also be considered.

On valuation, mortality impacts are valued in a way that is consistent with best practice (Green Book Guidance). Mr Henderson outlined this approach and its consistency with DfT studies, which value preventing a fatality at around £2 million. Mr Henderson agreed to provide further information on ranges associated with valuation.

An official sought views on the uncertainties around exposure modelling. They noted that the exposure modelling is based on concentrations outside the individuals' place of residence rather than actual daily exposure. It was suggested that this was the best available approach to assess exposure within the timeframe. Dr Walton explained that concentration at place of residence acted as a proxy for personal exposure. Provided that the spatial pattern of pollution and the way people moved around a city was similar in the location of the original study and relevant UK locations, this was probably a reasonable approximation for now. She suggested that while it would not be possible to provide data for personal exposure at present (this was difficult to do for large numbers of subjects), there was information estimating sensitivities using air pollution modelling at different spatial scales in London.

It was agreed that, in the longer term, improvements in the assessment of the link between concentration and exposure was fundamental to both better understanding the health impacts and designing policies. However, within the timeframe for publication this would not be possible.[135]

Mr Curnow summarised the above discussion as follows:

- On mortality, the best approach was to use the advice of COMEAP and the associated ranges.
- On morbidity, though the effect cannot be estimated quantitatively at present, Defra's air quality plan should provide a qualitative description stating that the morbidity impacts are significant but that it cannot be sure whether they are more or less than the mortality effects. With reference to the IPCC grid, the panel agreed that it was 'medium agreement, medium evidence'.
- On valuation, to use the existing values but check for the ranges available.

An official raised the issue of behavioural modelling. The only study that had been conducted on this used Transport for London data (so focussed on London) which anticipated the introduction of CAZs. It was recognised that this is a robust study for its intended use (in London) but using the research to infer reactions in other areas was challenging. Using the IPCC grid, the panel agreed that the analysis from the London study should be assessed as 'medium agreement, limited evidence', given that it applies to just one region.

There was some discussion around the welfare costs to drivers upgrading their vehicles to less polluting models. Mr Henderson suggested that it was a personal choice and would reflect a series of benefits that arise. An official indicated that a treatment that might provide a sensitivity would be not to count costs where drivers upgrade their vehicle. Mr Curnow suggested that this treatment be discussed with DfT.

It was suggested that, in addition to congestion relief, a number of other benefits arise from encouraging fewer car journeys (for example health benefits from cycling). Mr Henderson offered to pass on advice on this derived from an earlier discussion with DfT, from which it might be feasible to extrapolate further. It was agreed that an IPCC assessment of societal benefits would not possible, given their potential breadth.

Mr Curnow invited the panellists to give their thoughts on the overall challenge. Dr Morimoto suggested that the standard government social discount rate of 3.5 per cent had been used in this study. However, other discount rates (i.e. a range of appropriate discount rates) could be used to examine the sensitivity of the results and related uncertainty

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[135] Although not discussed in the meeting research has subsequently been identified which suggests that movement patterns could have a major impact on exposure. One example in research for NERC found that a person who worked from home had around half the exposure to NO_2 of a commuter to a major city. NERC Centre for Ecology & Hydrology, *'Integration of modelling and personal exposure monitoring of air pollution',* 2014 <www.gla.ac.uk/media/media_363829_en.pdf>

surrounding the overall findings. Mr Henderson queried whether the residual value of infrastructure (including charging points for electric cars) needed to be reflected. There was a general discussion of the fact that the cost-benefit analysis results might differ if an appraisal period longer than ten years had been used. An official agreed that this is an uncertainty that in principle could be addressed. However, this was unlikely to have a major impact on the results. Dr Walton suggested that the uncertainties around the costs of the policies should be considered in a similar way to the discussions of modelling and health benefit uncertainties. She also suggested a discussion of the uncertainties introduced by the use of damage costs rather than the full impact analysis pathway that would usually be used when there was more time.

Mr Curnow summed up the meeting by stating that, at present, the focus of work was to identify the major uncertainties around air quality impacts and develop ranges for them. The area of greatest uncertainty was expected to be around the mortality estimates. The overarching uncertainty discussed by the air quality modelling panel should be used to bound the overall cost-benefit analysis uncertainty. This was an evolving policy area and it would be helpful for the panel to reconvene in the future.

Annex J – Impact of updated health advice on results published in the draft Plan technical report

Recent changes to monetary valuation estimates have the effect of reducing the quantified value for money of charging CAZs. The health benefits associated with all measures would be affected in a similar way, meaning that the changes do not diminish the rationale for implementing CAZs.

Table **J.1** reproduces the results of the policy assessments from the consultation technical report, with all calculations kept the same with the exception of using the updated damage costs (explained in Section **2.2.1**). This demonstrates the downward revision to the health benefits of all policies. As no other changes have been made to the analysis these results are not directly comparable to the results presented in Section **3**; they are purely to demonstrate how the results for the draft Plan would have varied had the revised advice on the mortality impacts of NO_2 been available.

Table J.1: Table 10.1 from the draft Plan technical report, showing the impact of revised advice on health benefits of the policies assessed at that stage.

		Air quality impact[I]		Timing to impact[II]	Category of impact (£m)[III]			
		First year of impact	Total 10 year NO_x reduction		Health	Government	Public	Greenhouse gases
CAZ	**Clean Air Zone[IV]** Expansion from 5 plus London to a further 21	8.6µg/m^3 in 2020	24kt	1-3yrs	£3,600m £620m	-£600m	-£1,900m	£19m
Supporting Measures	**Retrofit** Retrofitting of buses, HGVs and black taxis between now and 2020	0.09µg/m^3 in 2019	10kt	1-3yrs	£440m £60m	-£170m	Negligible	Negligible
Supporting Measures	**Scrappage** National scheme promoting a transfer from older conventional cars and vans to electric	0.008µg/m^3 in 2020	0.4kt	1-3yrs	£10m £1.4m	-£110m	£70m	£10m
Supporting Measures	**Ultra Low Emission Vehicles** Providing additional support to purchasers of electric vehicles	0.008µg/m^3 in 2017	2kt	<1yr	£50m £7.8m	-£290m	£170m	£50m

		Air quality impact[I]		Timing to impact[II]	Category of impact (£m)[III]			
		First year of impact	Total 10 year NO_x reduction		Health	Government	Public	Greenhouse gases
National Measures	**Speed Limits**[V] Reduce motorway speed limits to 60mph where there is poor air quality	Up to 2.5μg/m^3 in 2021 [IV]	Up to 0.05kt	>3yrs	Up to £1m Less than £0.5m	-£25m	Up to -£8m	Up to £0.5m
National Measures	**Government Buying Standards** 30% of all new central government diesel cars are petrol from 2018	0.0005μg/m^3 in 2018	0.083kt	<1yr	£2.0m Less than £0.5m	-£1.7m	Negligible	-£0.23m
National Measures	**Vehicle Labelling** AQ emissions information on new car labels	0.004 μg/m^3 in 2018	0.73kt	<1yr	£18m £2.8m	Negligible	Not quantified	-£5.3m
National Measures	**Influencing Driving Style** Training and telematics for 100,000 car and van drivers by 2020	0.012 μg/m^3 in 2019	0.34kt	1-3yrs	£8.80m £1.4m	-£14m	Not quantified	£17m

I Air quality impacts are expressed in two ways. The first year of impact is the reduction in average NO_2 concentrations, in the first year where air quality impacts are expected to arise as a result of the implementation of the option, relative to the baseline projection for the option in the particular year specified. The total 10 year NO_x reduction is the total reduction in NO_x emissions resulting from this policy option over its ten-year appraisal period relative to the baseline projection for the option over the same ten-year appraisal period.

II Indicative timings are provided for all options as either <1, 1-3 or >3 years.

III All monetised values are ten year Net Present Values

IV Clean Air Zones are expected to be implemented in non-compliant areas in 2020. This represents the average reduction in the maximum concentration for these areas in 2020.

V Speed limit impacts are shown just for the <1% of motorway projected to be in exceedance in 2021. These impacts cannot be extrapolated to other roads. All impacts related to air quality are expressed as 'up to *x*' because there is uncertainty over the modelling approach in relation to vehicle speed. Highways England's approach (Box 6.3) would not give a reduction in NO_2 concentrations or congestion following speed limit reduction. The air quality impact of this measure is calculated on the assumption that traffic on failing motorway links is travelling at the same speed as the national average (for the type of motorway). It is possible that failing motorway links tend to be busier and more heavily congested, and that average speeds on them are lower. In this case, a change in the speed limit may have little impact on air quality - because cars are already travelling at speeds below the limit. Work is ongoing to improve our understanding of speeds on these links.