AIR POLLUTION: ECONOMIC ANALYSIS

Main Report

Ann Ballinger
Tanzir Chowdhury
Chris Sherrington
George Cole

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Prepared by Ann Ballinger, Tanzir Chowdhury and George Cole

Approved by

……………………………………………….

Chris Sherrington

Eunomia Research & Consulting Ltd
37 Queen Square
Bristol
BS1 4QS

United Kingdom

Tel: +44 (0)117 9172250
Fax: +44 (0)8717 142942

Web: www.eunomia.co.uk

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Executive Summary

E.1.1 Approach Taken in the Study

The aim of this report is to assess the cost-effectiveness of a range of local authority interventions to reduce traffic related air pollution. It accompanies the report on the review of evidence on the effectiveness and cost-effectiveness of these interventions. Certain interventions were identified as effective in the evidence review report produced by NICE, based on information available in high quality published and unpublished sources. An economic model was developed to synthesise the data on costs and effectiveness from different sources for estimating the net cost-effectiveness of the interventions from a UK local authority perspective. This report presents the findings of the modelling exercise.

Cost-effectiveness is modelled using the following two approaches:

- Cost Benefit Analysis (CBA) – where the cost-effectiveness is measured using the metric Net present value (NPV) of discounted sum of costs and benefits, and the cost-benefit ratio; and
- Cost Utility Analysis (CUA) – where the cost-effectiveness is measured using the metric Cost per Quality Adjusted Life Years (QALYs) gained.

The main inputs to the model are:

- Changes in pollution concentration from the intervention – collected from the source literature on effectiveness of different interventions;
- Modelled population size – determined from the source literature (where available) or modelled using information from other sources, such as population databases;
- Data on wider benefits of implementing the intervention – gathered from a range of published and unpublished academic and non-academic research papers; and
- Financial costs of undertaking the intervention – collected from wide variety of sources including UK local authority reports.

The calculation stage of the model can be divided into two streams:

- Estimation of total financial costs of undertaking the intervention; and
- Estimation of benefits from reduced air pollution as a result of the intervention.

The financial costs were modelled as the sum of initial capital costs (apportioned annually over the life of the intervention) and on-going annual operating costs. The benefits were estimated using a damage cost approach, which is a logical step-by-step approach to build the estimates of damages for each pollutant through different health endpoints (mortality, morbidity, etc.). Various sources, such as the Committee on the

Medical Effects of Air Pollutants (COMEAP) research reports,[1,2] the Defra damage cost detailed methodology document,[3] and other published research papers[4,5] were consulted for gathering the data needed for estimating health damages from exposure to different pollutants. For monetising the estimated health benefits, the Interdepartmental Group on Costs and Benefits (IGCB) has recommended a set of values to be used; these were incorporated into the model.[6]

When estimating the net present value (NPV) of health benefits and financial costs over multiple years, a discount rate of 3.5% was used, as recommended in the NICE manual.[7] Moreover, future benefits were uplifted by 2% per annum as recommended in the supplementary Green Book guidance on valuing air quality, to account for the increase in people's willingness to pay for health over time with economic growth.[8]

To estimate the costs per Quality Adjusted Life Year (QALY) gained from an intervention, the unadjusted years of life lost (YLL) from deaths attributable to air pollution were adjusted for quality of life, using the number of deaths data from a study on estimation of the NICE cost-effectiveness threshold.[9]

The original scope of the NICE guidance on local authority interventions to reduce traffic related air pollution focuses on 12 review topics in four broad areas:[10]

- Environmental change and development planning;
- Traffic management and enforcement, and financial incentives and disincentives;

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[1] COMEAP (2009). Long-Term Exposure to Air Pollution: Effect on Mortality. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/304667/COMEAP_long_term_exposure_to_air_pollution.pdf

[2] COMEAP (2015), Interim statement on quantifying the association of long-term average concentrations of nitrogen dioxide and mortality. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/485373/COMEAP_NO2_Mortality_Interim_Statement.pdf

[3] AEA Technology (2006), Damage Costs for Air Pollution, Final report to Defra, Issue 4.

[4] Atkinson RW, Kang S, Anderson HR, Mills IC, Walton HA (2014). Epidemiological time series studies of $PM_{2.5}$ and daily mortality and hospital admissions: a systematic review and meta-analysis. Thorax 2014; 69: 660-665.

[5] Mills, IC, et al. (2015). Quantitative systematic review of the associations between short-term exposure to nitrogen dioxide and mortality and hospital admissions. BMJ Open 5(5).

[6] AEA Technology (2006), Damage Costs for Air Pollution, Final report to Defra, Issue 4.

[7] https://www.nice.org.uk/media/default/about/what-we-do/our-programmes/developing-nice-guidelines-the-manual.pdf

[8] HMT (2013), Valuing impacts on air quality: Supplementary Green Book guidance, May 2013. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/197893/pu1500-air-quality-greenbook-supp2013.pdf

[9] Karl Claxton, et al. (2015), Methods for the estimation of the National Institute for Health and Care Excellence cost-effectiveness threshold, Health technology assessment: Volume 19, Issue 14.

[10] https://www.nice.org.uk/guidance/GID-PHG92/documents/air-pollution-outdoor-air-quality-and-health-final-scope2

- Travel Planning and other initiatives providing information, advice, education and skill development; and
- Advice and warnings for the public and people at particular risk.

The review of evidence on effectiveness and cost-effectiveness of these interventions under component 1 of the guidance development process shortlisted 45 studies identified by a systematic search of relevant databases and call for evidence from registered stakeholders. To complement the search process in Component 1, Eunomia and UWE has undertaken another systematic search on effectiveness and financial costs of different interventions.

E.1.2 Results

Based on the availability of evidence on effectiveness and quality of identified evidence as well as from discussion with the NICE public health advisory committee on effectiveness of different interventions, 9 interventions in 5 review topics were selected for modelling cost-effectiveness. Furthermore, out of these 9 interventions, a study on dust suppressants was excluded because of the uncertainty in reported results. The summary of the modelled cost-effectiveness results are presented in Table E1-1.

Table E1-1: Case Study Results

	Indicative financial costs in first year	Total indicative benefits in first year	Indicative case study cost benefit ratio	Indicative Cost per QALY gained	Case study verdict	Applicability to typical UK local authority
Off road cycle paths	£61,100	£853,236	14	£5,075	Cost effective	Optimistic scenario modelled[1]
Bypass construction	£266,250	£2,620,276	10	£6,971	Cost effectiveness uncertain due to data quality issues	Highly dependent on local circumstances
Motorway barriers	£240,985	£626,883	3	£25,199	Cost effectiveness uncertain due to data quality issues	Optimistic scenario modelled[1]
Street washing and sweeping	£25,825	£3,849,845	149	£441	Cost effective	Optimistic scenario modelled[1]
One off road closures	Unknown	£39,020	N/A	N/A	Cost effectiveness uncertain due to data quality issues	Does not reflect typical closure scenario

	Indicative financial costs in first year	Total indicative benefits in first year	Indicative case study cost benefit ratio	Indicative Cost per QALY gained	Case study verdict	Applicability to typical UK local authority
Low emission zones	£598,157	£15,939,949	27	£2,465	Long term cost effectiveness uncertain	Some dependency on local circumstances
Speed restrictions	£37,500	£1,905,673	51	£1,293	Cost effective	Optimistic scenario modelled[1]
Vehicle idling (at schools)	£19,000	£830,908	44	£1,572	Cost effective	Optimistic scenario modelled[1]

Notes:

1. Where this comment has been included, this is a reflection of the original case study data being based on a relatively optimistic set of circumstances, e.g. in terms of numbers of cyclists who might be affected by the intervention, or the intervention being undertaken in an area of high population density, etc. Where this is the case, the benefits seen here are therefore likely to be higher than those that might be found in a more typical scenario.

The analysis reveals that the benefits are much higher than the costs for some of the interventions. This suggests that despite the considerable uncertainties inherent within the modelling, some interventions look to be cost effective in reducing the health impacts of pollution from road traffic, particularly under certain circumstances:

- **Off road cycle paths** – in urban areas where the specific paths are likely to be widely used by the cyclist population;
- **Street washing and sweeping** – in urban areas with a relatively high population density when there is low rainfall; and
- **Motorway speed restrictions** – where the road passes through areas of relatively high population density.

However, for the other interventions there is less certainty regarding their effectiveness:

- **Bypass construction** – cost-effectiveness uncertain due to the lack of data on financial cost as well as benefits are highly dependent on local factors;
- **Motorway barriers** – cost-effectiveness uncertain as the data on the local pollution impacts is incomplete, especially for the impact of increasing pollution levels downstream from where the measurements were taken;
- **Road closures** – cost-effectiveness uncertain due to the lack of data on the costs of implementing road closures, as well as the uncertainties relating to the health impacts of a one-off closure of all roads in a city for a day;

- **Low Emission Zones (LEZ)** – cost-effectiveness uncertain, especially for future LEZs, due to the lack of data on effectiveness for the size and distribution of the current vehicle fleets;
- **Vehicle idling** – cost-effective in the US context for areas with large number of school busses, but likely to have relatively limited applicability to the UK.

It is further noted that a detailed consideration of some of the wider benefits was not possible for some of the above measures. A full consideration of these benefits may make some of the above interventions more likely to be cost-effective.

Finally, further research on the dispersion of the pollution in the local area in relation to the affected population is needed to improve the robustness of results for each of the interventions considered in this study.

Contents

List of Tables, Figures and Boxes

1.0 Introduction

1.1 Purpose of this report

The aim of this report is to assess the cost-effectiveness of a range of local authority interventions to reduce traffic related air pollution. It accompanies the report on the review of evidence on the effectiveness and cost-effectiveness of these interventions.[11] Certain interventions were identified as effective in the evidence review report based on information available in high quality published and unpublished sources. This report mainly focuses on these identified interventions and evaluates the cost-effectiveness of these interventions based on economic modelling.

1.2 Background

Road transport is one of the major anthropogenic sources of outdoor air pollution. According to a technical report of the European Topic Centre on Air Pollution and Climate Change Mitigation, road traffic frequently accounts for more than 64% of air pollution at urban monitoring sites.[12] Air pollutants related road transport primarily consists of particulate matter (PM_{10} and $PM_{2.5}$) and oxides of nitrogen (NO_X). Road transport roughly accounts for 31% of NO_X, 18% of PM_{10} and 19.5% of $PM_{2.5}$ emissions in the UK.[13]

Currently, local authorities in the UK are required to review and assess air quality against the objectives set out in the national Air Quality Strategy every 3 years. Where the measured pollution levels exceed the limits set out in the national strategy, the local authority must declare an air quality management area and develop an action plan to tackle the problems. Most local air quality management areas have been in response to emissions associated with road transport and actions tend to focus on road-transport-related activity.

The National Institute for Health and Care Excellence (NICE) has received a referral from the Department of Health in England to produce guidance on reducing the effects of outdoor air quality on health, focusing on how local authorities can reduce exposure to air pollution from road traffic. The guidance development process comprises of two main components:

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[11] Reference to NICE Component 1 report

[12] European Topic Centre on Air Pollution and Climate Change Mitigation (2013), *Road traffic's contribution to air quality in European cities,* ETC/ACM Technical Paper 2012/14, http://acm.eionet.europa.eu/reports/docs/ETCACM_TP_2012_14_traffic_contribution_city_aq.pdf

[13] Defra (2015), Emissions of air pollutants in the UK, 1970 to 2014.

1) A review of evidence on effectiveness and cost-effectiveness of various interventions to reduce exposure to pollution from road traffic; and
2) An economic analysis these of these interventions to assess their cost-effectiveness.

Component 1 was undertaken by the internal guidelines technical team of the Public Health and Social Care Centre (PHSCC) within NICE. Eunomia Research & Consulting in collaboration with University of West England (UWE) has been commissioned to develop the economic model of cost-effectiveness under Component 2. This report presents the findings of the modelling exercise.

1.3 Cost effectiveness evidence around interventions

The literature search on cost-effectiveness of different interventions undertaken as a part of the evidence review identified five cost-effectiveness studies on two of the interventions considered in the original scope of the study. Three of these studies, on alternative fuel technologies for public transport were conducted in the US. The other two were on economic benefits and costs of congestion charging schemes in Stockholm, Sweden and Milan, Italy.

Critical review of the identified studies revealed that the reported cost-effectiveness results have limited applicability in the context of a local authority in the UK, mainly due to the various geographical, social, cultural and economic differences. Moreover, evidence on cost-effectiveness of other interventions included in the study could not be identified.

In the absence of sufficient cost-effectiveness evidence for the interventions considered in the evidence review, it is necessary to develop an economic model to assess the cost-effectiveness of local authority interventions to reduce traffic related air pollution in the UK.

1.4 Structure of the report

The rest of the report is structured as follows:

- **Section 2.0** describes the structure of the cost-effectiveness model, the general assumptions behind the model, and various limitations of modelling;
- **Section 3.0** discusses how the interventions were selected for modelling, and approaches to model each of the selected interventions;
- **Section 4.0** presents the cost-effectiveness results for each of the selected interventions, discusses the sensitivity analyses undertaken for the interventions that seems cost-effective, and summarises the main findings; and
- **Section 5.0** concludes the report with directions for further research.

2.0 Modelling Cost-Effectiveness

2.1 Model Structure

The aim of the model is to estimate the cost-effectiveness of different interventions to reduce traffic related air pollution that can be undertaken by the local authorities in the UK. In most cases, the impacts of an intervention are compared to a baseline of the intervention not taking place. Cost-effectiveness - here taken to mean the cost of achieving a given reduction in pollution - is modelled using the following two approaches:

- **Cost Benefit Analysis (CBA)** – where the cost-effectiveness is measured using the metric *Net present value (NPV) of discounted sum of costs and benefits,* and the *cost-benefit ratio*; and
- **Cost Utility Analysis (CUA)** – where the cost-effectiveness is measured using the metric *Cost per Quality Adjusted Life Years (QALYs) gained*.

Under the cost-benefit analysis, NPV of benefits and costs are estimated for short-term (1 year), medium-term (5 years) and long-term (30 years) using the recommended discount rate (3.5%) for evaluating how benefits and costs change over time.

Cost-utility analysis was undertaken for the first year only. On the cost side, annualised costs of the intervention (including both investment and ongoing costs, typically annualised over each year of the intervention) were included and then divided by the QALYs to determine the cost per QALY. The results provide an indication of whether the cost per QALY was within - or exceeded - the NICE threshold for cost effectiveness of £20,000 per QALY using CUA. Accordingly, given the annualised nature of the costs and the existence of a social rate of time preference, if we were to discount both the cost and the QALYs, the cost per QALY would effectively be constant. Therefore, if both cost and QALY are discounted at the same rate, the figure is the same as that presented for the year one results.

The main inputs to the model are:

- Changes in pollution concentration from the intervention;
- Modelled population size;
- Data on wider benefits of implementing the intervention; and
- Financial costs of undertaking the intervention.

The first set of inputs were collected from the source literature on effectiveness of different interventions. Where available, the modelled population sizes for each intervention were also determined from the source literature. In other cases, where the population size was not available from the source literature, it is modelled to reflect the approximate population size associated with the intervention in the source. This was done using information from other sources, such as, national population databases for country of intervention. For the data on wider benefits, a range of published and grey literature (unpublished academic research papers and non-academic research reports) sources were consulted. Finally, the data on financial costs for each intervention was collected from various sources, including the source literature and UK local authorities that have undertaken (or are planning to undertake) similar interventions.

The above approach meant that the results from the different interventions relate to a range of local authorities in respect of the size of population. Although it was considered to be desirable to be able to compare different interventions in terms of their effect on a local authority of the same size, the scaling of these interventions was felt to add an additional layer of uncertainty, as it was not clear to what extent the effect of the intervention could be scaled up in each case.[14] Population data is, however, reported in the final results tables such that general comparisons can be made in terms of the size of the local authority population that is considered to be affected in each case.

The calculation stage of the model can be divided into two streams:

- Estimation of total financial costs of undertaking the intervention; and
- Estimation of benefits from reduced air pollution as a result of the intervention.

The details of financial cost modelling are discussed in Section 2.2. The general approach to estimating the benefits is illustrated in Figure 2-1 below, and the various stages involved are discussed in detail in Sections 2.3 to Section 2.6.

There are a number of uncertainties involved in developing a general model on effectiveness of various local authority interventions to reduce traffic related air pollution. To account for some of these uncertainties, various sensitivity analyses were undertaken to evaluate how key modelling assumptions affect the model results. The sensitivity analyses are detailed in Section 2.7, and various limitations of the model are discussed in Section 2.8.

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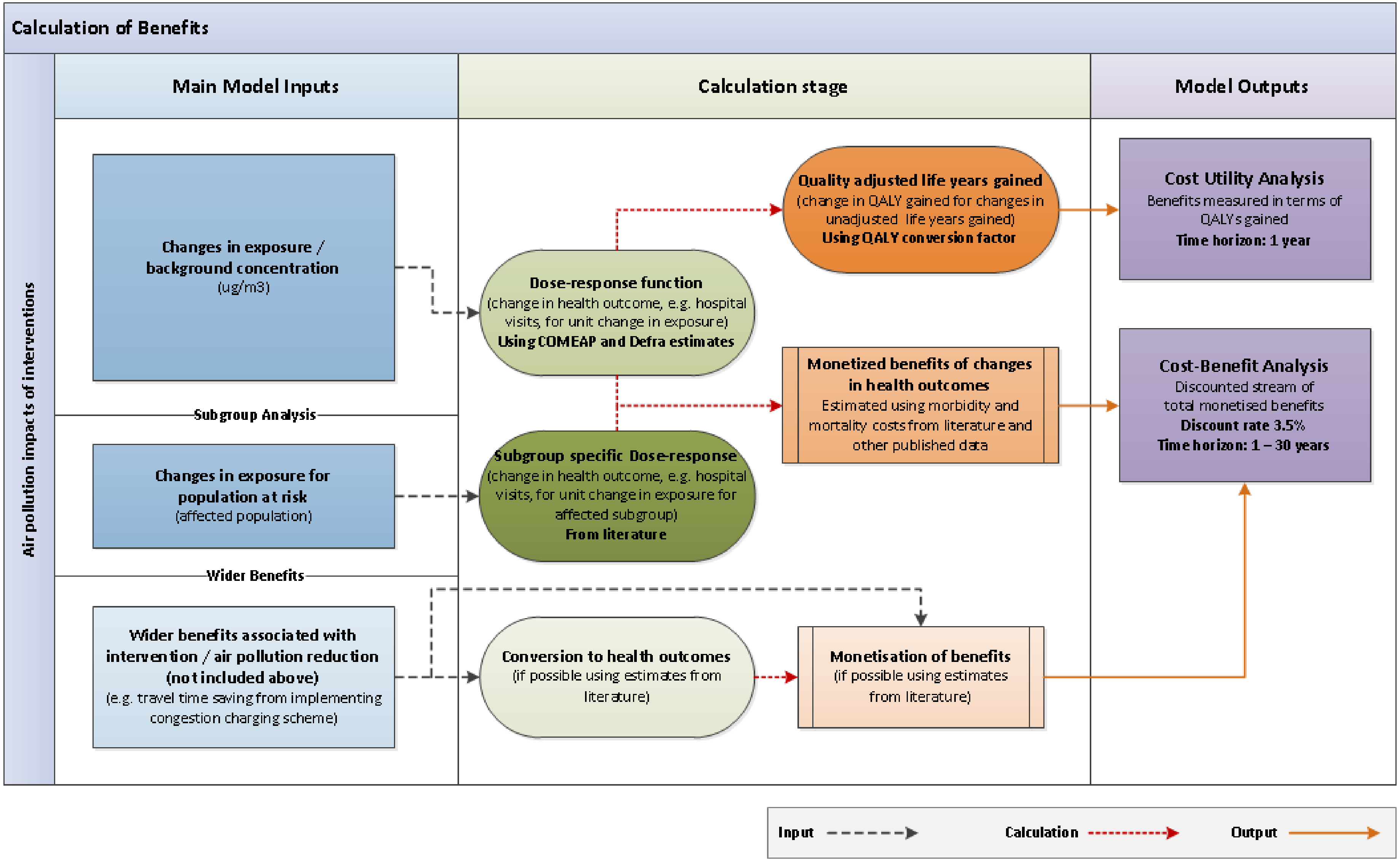
[14] For example, in the case of cycle paths, it was not clear how many additional cycle paths of a specific length might be needed for an authority with a larger population size

Figure 2-1: Modelling benefits



2.2 Modelling of Financial Costs

To estimate the cost-effectiveness of a local authority intervention to reduce traffic related air pollution, the financial cost of implementing the intervention needs to be modelled. Financial costs of an intervention can be broadly categorised into:

- Capital costs; and
- Operating costs.

While operating costs are usually on-going for the life of the intervention, capital costs are typically incurred upfront. However, it is more practical to spread the capital cost over a number of years through various financing options, especially for large ones.

In the model, operating costs are modelled to be incurred every year. On the other hand, capital costs for different interventions are apportioned over various lengths of time according to the type of cost.[15] For example, the cost of vehicles for street sweeping and washing is spread over 7 years (average life of the vehicle), cost of speed cameras is spread over 10 years (average lifetime of speed cameras), etc.

When calculating the net present value (NPV) of financial costs associated with an intervention, costs incurred in future years are discounted with a discount rate of 3.5%, as recommended in the NICE manual.[16]

2.3 Modelling of Health Impacts in Cost Benefit Analysis

To estimate the health impacts of air pollution reduction in the cost-benefit analysis (CBA), it is necessary to quantify a series of different effects to understand the overall impact of reduced concentration of pollutants on the population. For this, the model uses a damage cost approach, which is a logical step-by-step approach to build the estimates of damages for each pollutant through different health endpoints (e.g. mortality, morbidity, etc.). The damage cost of a pollutant for a particular health endpoint is calculated using the following general relationships:

Impact = Pollution x Population at risk x Dose-response function

Damage cost = Impact x Unit value of impact

Here, pollution is usually expressed in terms of change in concentration. 'Population at risk' relates to the exposed population in the modelled domain. The Dose-response function for a health endpoint measures the risk of occurrence of the endpoint for a unit change in pollution. The valuation in the final stage is generally done using the concept of 'willingness to pay' (WTP) for avoiding that endpoint.

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[15] Cost of financing was assumed to be zero for simplicity.

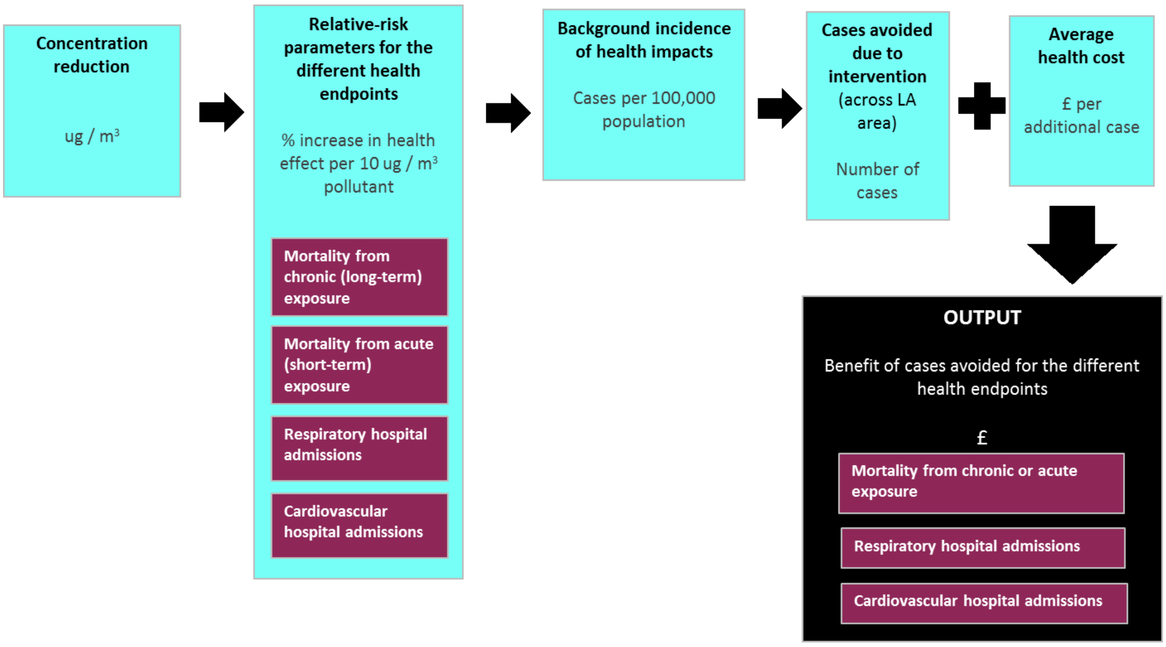
[16] https://www.nice.org.uk/media/default/about/what-we-do/our-programmes/developing-nice-guidelines-the-manual.pdf

The basic approach to estimating the effects of a pollutant for any particular health endpoint using a dose-response function involves the following steps:

1) Measurement of change in concentration for the pollutant;
2) This is combined with a relative-risk coefficient (percentage change in risk for a unit change in pollution) to derive the resulting change in frequency of occurrence for the endpoint;
3) This is linked to the background incidence rates of the endpoint (new cases per year per unit population) to calculate the resulting additional cases per year per unit population
4) This is multiplied by the population size to arrive at the total number of additional cases per year for the target population; and
5) This is multiplied by the value of the endpoint to estimate the monetary value of the additional cases per year.

An example of the above process is illustrated in Figure 2-2.

Figure 2-2: Steps involved in estimation of damage costs



Concentration reduction

ug / m³

Relative-risk parameters for the different health endpoints

% increase in health effect per 10 ug / m³ pollutant

Mortality from chronic (long-term) exposure

Mortality from acute (short-term) exposure

Respiratory hospital admissions

Cardiovascular hospital admissions

Background incidence of health impacts

Cases per 100,000 population

Cases avoided due to intervention (across LA area)

Number of cases

Average health cost

£ per additional case

OUTPUT

Benefit of cases avoided for the different health endpoints

£

Mortality from chronic or acute exposure

Respiratory hospital admissions

Cardiovascular hospital admissions

Note: Additional health effects of SO2, ozone and VOCs were not included due to lack of data on these pollutants in the source literature.

The following sections describe the underlying assumptions in detail for each of these steps in damage cost estimation.

2.3.1 Measured Changes in Pollution

For each intervention modelled, the measured changes in pollution levels have been captured from source literature on the effectiveness of the intervention. In most cases the changes in pollution concentration were expressed in µg/m^3. However, in some cases, the changes in NO_2 concentration were expressed in parts per billion (ppb). These were converted to μg/m^3 using a conversion factor of 1.9125 μg/m^3 per ppb, as recommended by the European Commission.[17]

2.3.2 Modelling Population at Risk

The damage costs of air pollution vary significantly according to a range of parameters including:

- Local and regional meteorology; and
- Population size, density and geographical spread.

Accordingly, for modelling the population at risk in the damage cost approach, pollution dispersion modelling is required using the information on population size and density, and meteorological conditions, such as wind speed, wind direction, etc. As such information was not typically provided in the source literature on effectiveness of interventions, bespoke scaling factors have been used in modelling the affected population for each intervention. These scaling factors were developed based on population size, magnitude of the intervention, and any other relevant information present in the source literature. More information on the development of the scaling factors for each intervention is provided in Section 3.2.

2.3.3 Health Endpoints Modelled

To model the health impacts for changes in air quality, two types of health outcomes were considered. These are:

- **Short-term (acute) pollution effects:** mortality or deaths brought forward, and respiratory and cardiovascular hospital admissions from acute (short-term) exposure to air pollution; and
- **Long-term (chronic) effects:** mortality or changes in life expectancy from chronic (long-term) exposure to air pollution.

Data on the relative-risk coefficient and background incidence rate for a pollutant are needed to quantify the effects of changes in concentration of that pollutant on the above outcomes. The pollutants to include in the model were selected based on availability of the evidence in the source literature on effectiveness. Impacts were measured in terms of changes in concentration of $PM_{2.5}$ and/or NO_2 in all source literature reviewed. Thus both these pollutants have been included in the model. Moreover, chronic and acute effects of PM_{10} have also been included in the model, as some of the source literature estimated the impacts of PM_{10} instead of $PM_{2.5}$. The health

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[17] Ricardo-AEA (2014), Conversion Factors Between ppb and μg m-3 and ppm and mgm-3. https://uk-air.defra.gov.uk/assets/documents/reports/cat06/0502160851_Conversion_Factors_Between_ppb_and.pdf

effects of SO_2, ozone and VOCs were not included due to lack of data on these pollutants in the source literature.

2.3.3.1 Data Sources for Relative-risk Coefficients and Background Rates

Values recommended by the Committee on the Medical Effects of Air Pollutants (COMEAP) were used for the relative-risk coefficients for mortality from chronic exposure to $PM_{2.5}$ and NO_2.[18,19] On the other hand, relative risk coefficients for the World Health Organisation's EUR-A region was used for modelling the acute effects of these pollutants, as COMEAP does not provide specific figures for the UK.[20] These values were collected from two recent meta-analysis studies on short term health effects of $PM_{2.5}$ and NO_2.[21,22]

For modelling the acute morbidity effects of PM_{10}, relative risk coefficients provided in the detailed methodology document for Defra air pollution damage costs were applied.[23] For the mortality from acute and chronic exposure to PM_{10}, the coefficients for $PM_{2.5}$ have been scaled to 50%. In considering the impacts for this air pollutant, the epidemiological studies upon which these coefficients have been developed account within the analysis for the impacts on the population of other risk factors likely to cause increased incidence of cardio-vascular conditions, such as smoking and occupational exposure.[24]

The background incidence rate for mortality from chronic exposure has been calculated as the number of incidences per 100,000 people using the population and mortality data from the 2011 population census (latest available) for the UK. The background rates for respiratory and cardiovascular hospital episodes were constructed using the hospital admissions data for England as a proxy for the UK. The background rate for mortality

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[18] COMEAP (2009). Long-Term Exposure to Air Pollution: Effect on Mortality. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/304667/COMEAP_long_term_exposure_to_air_pollution.pdf

[19] COMEAP (2015), Interim statement on quantifying the association of long-term average concentrations of nitrogen dioxide and mortality. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/485373/COMEAP_NO2_Mortality_Interim_Statement.pdf

[20] Countries included in the WHO EUR-A region is defined at: http://www.who.int/choice/demography/euro_region/en/

[21] Atkinson RW, Kang S, Anderson HR, Mills IC, Walton HA (2014). Epidemiological time series studies of $PM_{2.5}$ and daily mortality and hospital admissions: a systematic review and meta-analysis. Thorax 2014; 69: 660-665.

[22] Mills, IC, et al. (2015). Quantitative systematic review of the associations between short-term exposure to nitrogen dioxide and mortality and hospital admissions. BMJ Open 5(5).

[23] AEA Technology (2006), Damage Costs for Air Pollution, Final report to Defra, Issue 4.

[24] Pope CA, Burnett RT, Thun MJ, et al (2002) Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution, JAMA, 287:1132-1141

from acute exposure was selected from the air pollution damage costs methodology used by Defra.[25]

Additionally, the following assumptions have been made to avoid the risk of possible double counting when estimating the total effects on health:

- Mortality from acute exposure has been excluded from calculation of benefits when the mortality from chronic exposure is included; and
- Relative-risk coefficients for mortality from chronic exposure to NO_2 have been reduced by 30% according to COMEAP recommendations to account for the possible overlap with PM when both PM and NO_2 are included.[26]

Table 2-1 provides the full list of relative-risk coefficients and background incidence rates used in the model.

The diseases included in respiratory hospital admissions (RHA) are, chronic obstructive pulmonary disease (COPD), lower respiratory infections (e.g. bronchitis, pneumonia, bronchiolitis, tuberculosis, etc.), asthma, and acute upper respiratory infections (e.g. flu, tonsillitis, sinusitis, laryngitis, etc.). Cardiovascular hospital admissions (CHA), on the other hand includes, cardiac diseases, Ischaemic Heart Disease (IHD), stroke, heart failure, dysrhythmias, etc. The mortality relative-risk coefficients and background rates are based on all causes of mortality.

Table 2-1: Relative-risk parameters and associated background incidence for different health endpoints

Health Endpoint	Relative-risk parameter with 95% CI in parenthesis (% change in health effect per 10 µg/m³ pollutant)	Background Incidence rate (number of cases per 100,000 population)
$PM_{2.5}$ mortality from chronic exposure	6% (1% to 12%)	1,382
$PM_{2.5}$ mortality from acute exposure	1.23% (0.45% to 2.01%)	990
$PM_{2.5}$ respiratory hospital admissions	1.9% (−0.18% to 4.02%)	1,379
$PM_{2.5}$ cardiovascular hospital admissions	0.91% (0.17% to 1.66%)	953
PM_{10} mortality from chronic exposure [1]	3% (0.5% to 6%)	1,382
PM_{10} mortality from acute exposure	0.75% (0.62% to 0.86%)	990

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[25] AEA Technology (2006), Damage Costs for Air Pollution, Final report to Defra, Issue 4.

[26] COMEAP (2015), Interim statement on quantifying the association of long-term average concentrations of nitrogen dioxide and mortality.

Health Endpoint	Relative-risk parameter with 95% CI in parenthesis (% change in health effect per 10 µg/m^3 pollutant)	Background Incidence rate (number of cases per 100,000 population)
PM_{10} respiratory hospital admissions	0.8% (0.48% to 1.12%)	1,379
PM_{10} cardiovascular hospital admissions	0.8% (0.6% to 0.9%)	953
NO_2 mortality from chronic exposure	2.5% (1% to 4%)	1,382
NO_2 mortality from chronic exposure (when PM is also valued)[2]	1.75% (0.7% to 2.8%)	1,382
NO_2 mortality from acute exposure	0.9% (0.45% to 1.35%)	990
NO_2 respiratory hospital admissions	0.52% (0.09% to 0.95%)	1,379
NO_2 cardiovascular hospital admissions	0.42% (0.23% to 0.62%)	953

Notes:

1. *As per COMEAP recommendation, relative Risk parameter of PM_{10} is assumed to be 50% of relative risk parameter for $PM_{2.5}$*
2. *As per COMEAP recommendation, relative risk parameter of NO_2 is reduced by 30% to account for the overlap between $PM_{2.5}$ and NO_2 when both are included*

A number of health endpoints have not been included in the model due to lack of data. These include:

- Infant mortality from chronic exposure;
- Asthmatic symptoms in asthmatic children;
- Bronchitis in children;
- Restricted activity days from acute exposure (excluding hospital admission days);
- Mortality and morbidity from acute exposure to SO_2;
- Mortality and morbidity from acute exposure to ozone (formed indirectly from VOCs and NO_2); and
- Additional effects on morbidity from chronic (long-term) exposure.

2.3.4 Modelling Impacts for Vulnerable Population Subgroups

This is only considered for the CBA results, as there is no separate mortality risk parameter for the vulnerable population in the case of the CUA.

To model the effect of air pollution on vulnerable population subgroups, additional health endpoints have been included for children (aged 19 and below) and the elderly (aged 65 and above) based on the definitions of relative risk-coefficients in the literature. The relative risk-parameters for these vulnerable population groups were selected from meta-analysis studies on short term health effects of $PM_{2.5}$ and NO_2.[27, 28] The background rates for respiratory and cardiovascular hospital episodes for these groups were constructed using the hospital admissions data for England as a proxy for the UK. These are presented in Table 2-2.

Table 2-2: Included health endpoints for the vulnerable population subgroups

Health Endpoint	Relative-risk parameter with 95% CI in parenthesis (% change in health effect per 10 µg/m^3 pollutant)	Background Incidence rate (number of cases per 100,000 population)
$PM_{2.5}$ RHA for ages below 20	0.32% (-1.18% to 1.84%)	1,049
$PM_{2.5}$ RHA for ages 65+	0.99% (-0.90% to 2.92%)	4,333
$PM_{2.5}$ CHA for ages 65+	1.91% (0.92% to 2.91%)	3,536
NO_2 RHA for ages below 20	0.18% (-0.12% to 0.48%)	1,049
NO_2 RHA for ages 65+	0.17% (-0.43% to 0.78%)	4,333
NO_2 CHA for ages 65+	1.02% (0.08% to 1.97%)	3,536

Notes:

1. *RHA: Respiratory Hospital Admissions*
2. *CHA: Cardiovascular Hospital Admissions*

Due to a lack of estimates for relative risk parameters for mortality from acute and chronic exposure in the vulnerable population subgroup, mortality effects of air pollution could not be modelled from these subgroups.

Effects of air pollution reduction on the vulnerable population groups are included in the sensitivity analysis.

2.3.5 Monetisation of Health Impacts

For monetising the health impacts of air pollution, the Interdepartmental Group on Costs and Benefits (IGCB) has recommended a set of values to be used.[29] These values along with the associated methodological notes are reported in Table 2-3.

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[27] Atkinson RW, Kang S, Anderson HR, Mills IC, Walton HA (2014). Epidemiological time series studies of $PM_{2.5}$ and daily mortality and hospital admissions: a systematic review and meta-analysis. Thorax 2014; 69: 660-665.

[28] Mills, IC, et al. (2015). Quantitative systematic review of the associations between short-term exposure to nitrogen dioxide and mortality and hospital admissions. BMJ Open 5(5).

[29] AEA Technology (2006), Damage Costs for Air Pollution, Final report to Defra, Issue 4.

Table 2-3: IGCB-recommended Values for Valuing Different Health Effects

Health Effect	Form of measurement to which the valuations will apply	Valuation (2004 prices)	
		Central Value	Sensitivity
Mortality from acute exposure	Number of years of life lost due to air pollution (life years) - assuming 2-6 months loss of life expectancy for every death brought forward. Life-expectancy losses assumed to be in poor health.	£15,000	10% and 15% of life years valued at 29,000 instead of £15,000 (to account for avoidance of sudden cardiac deaths in those in apparently good health)
Mortality from chronic exposure	Number of years of life lost due to air pollution (life years) - Life-expectancy losses assumed to be in normal health.	£29,000	£21,700 - £36,200 (sensitivity around the 95% confidence intervals)
Respiratory hospital admissions (RHA)	Case of a hospital admission - of average duration 8 days.	£1,900 - £9,100*	£1,900- £9,600
Cardiovascular hospital admissions (CHA)	Case of a hospital admission - of average duration 9 days.	£2,000 - £9,200*	£2,000 - £9,800

* *Central values for the respiratory and cardiovascular hospital admissions were provided as range in the IGCB recommendations.*

For hospital admissions, the estimates include resource costs (e.g. NHS costs) and dis-utility from illness. For valuing mortality from acute and chronic exposure, the concept of value of a life year (VOLY) is used.[30]

For monetising the morbidity effects of air pollution, the central value of RHA and CHA (mid-point of the recommended range) were multiplied by the reduction in hospital episodes for the affected population due to the intervention.

For estimating the mortality from acute and chronic exposure, it is necessary to convert the number of '*attributable deaths*' related to air pollution into the number of life years lost.[31] For mortality from acute exposure, the guidance from IGCB has been to assume that between 2 and 6 months of life is lost, on average. Thus, a loss of 4 months per death brought forward was used as a central value in the model. For mortality from

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[30] HMT (2013), Valuing impacts on air quality: Supplementary Green Book guidance, May 2013. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/197893/pu1500-air-quality-greenbook-supp2013.pdf

[31] COMEAP (2009). Long-Term Exposure to Air Pollution: Effect on Mortality. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/304667/COMEAP_long_term_exposure_to_air_pollution.pdf

chronic exposure, the COMEAP recommendation of 12 life years lost per attributable death was used to convert attributable deaths to years of life lost.[32]

For estimating the health benefits in the model, the central values recommended by IGCB for each health effect have been converted to current year (2016-17) prices using the GDP deflator and money GDP data from the Office of National Statistics (ONS).[33] These are presented in Table 2-4.

Table 2-4: Monetary Values of Different Health Effects used in the Model

Health Effect	Central value in 2004 prices	Central value to use in model (2016/17 prices)
Mortality from acute exposure (per year of life lost)	£15,000	£22,078
Mortality from chronic exposure (per year of life lost)	£29,000	£38,610
RHA (per episode)	£5,500*	£8,095
CHA (per episode)	£5,600*	£8,242

* *These are the midpoints of the range for central values for the respiratory and cardiovascular hospital admissions, respectively, provided in the IGCB recommendations.*

2.3.6 Discounting and Uplifting

When estimating the net present value (NPV) of health benefits over multiple years, a discount rate of 3.5% was applied, as recommended in the NICE manual.[34] However, alongside the discounting, future benefits also needed to be uplifted to account for the increase in people's willingness to pay for health over time with economic growth. The supplementary Green Book guidance on valuing air quality impacts recommends that in air pollution appraisal, the health values in future years need to be uplifted by 2% per annum.[35] Thus, alongside discounting the future benefits by 3.5%, they were also uplifted by 2%.

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[32] COMEAP (2012), Statement on estimating the mortality burden of particulate air pollution at the local level.

[33] Office of National Statistics (2016), All data related to Quarterly National Accounts: Quarter 1 (Jan to Mar) 2016. Accessed from: https://www.ons.gov.uk/economy/grossdomesticproductgdp/bulletins/quarterlynationalaccounts/quarter1jantomar2016/relateddata

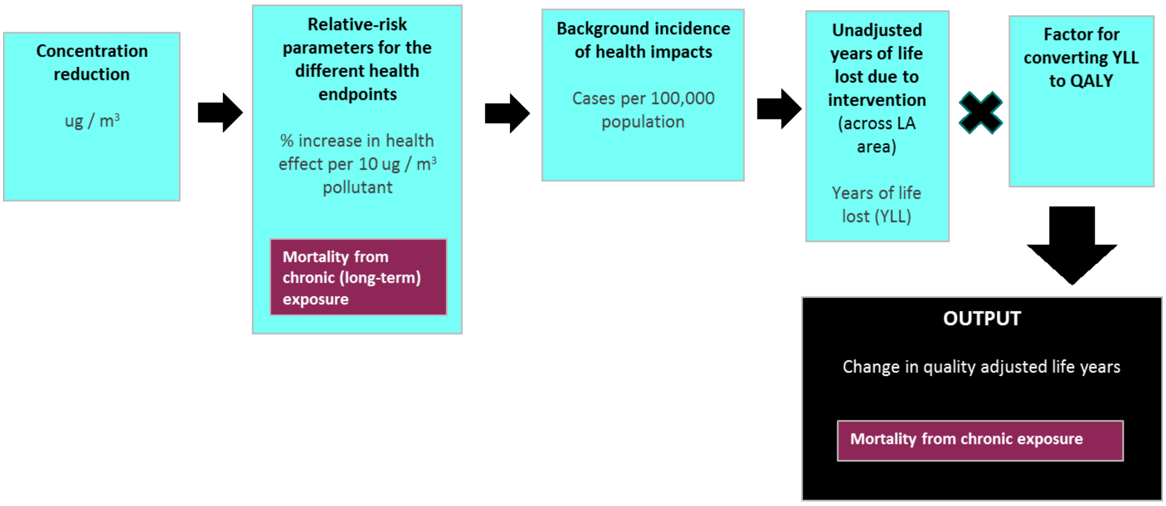
[34] https://www.nice.org.uk/media/default/about/what-we-do/our-programmes/developing-nice-guidelines-the-manual.pdf

[35] HMT (2013), Valuing impacts on air quality: Supplementary Green Book guidance, May 2013. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/197893/pu1500-air-quality-greenbook-supp2013.pdf

2.4 Cost Utility Analysis

To estimate the costs per Quality Adjusted Life Year (QALY) gained from an intervention, the unadjusted years of life lost (YLL) from attributable deaths estimated under the cost-benefit analysis needs to be adjusted for quality of life. Estimates of YLL adjusted for quality of life associated with observed deaths from different diseases are reported in a study on the estimation of the NICE cost-effectiveness threshold.[36] Using these estimated quality adjusted and unadjusted YLL for different diseases, an unadjusted YLL to QALY conversion factor of 0.65 has been constructed for the model.[37] Thus multiplying the years of life gained from an intervention by the QALY conversion factor will provide the QALYs gained from the intervention. For example, given the relative risk coefficient of 6% and the background incidence rate of 1,382 cases per 100,000 people for mortality from chronic exposure to $PM_{2.5}$, a reduction of $PM_{2.5}$ concentration by 1 µg/m^3 will lead to 10 quality unadjusted life years gained, which is equivalent to 6.5 QALYs gained. The process for estimating changes in QALY due to pollution reduction is depicted in Figure 2-3.

Figure 2-3: Modelling steps for estimating change in QALY



It should be noted that the cost effectiveness assessment between the CUA and CBA will be different mainly due to the following reasons:

- Life years lost in CUA is adjusted for quality of life, while life lost in CBA is an unadjusted figure; and
- CUA only includes mortality effects of air pollution, while CBA additionally includes morbidity effects and wider benefits.[38] Thus the cost-effectiveness

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[36] Karl Claxton, et al. (2015), Methods for the estimation of the National Institute for Health and Care Excellence cost-effectiveness threshold, Health technology assessment: Volume 19, Issue 14.

[37] The QALY conversion factor is estimated as the ratio of quality adjusted and unadjusted YLL aggregated over all diseases reported in Table 19 of Karl Claxton, et al. (2015).

[38] Based on the available data, changes in QALY were calculated based only on mortality effects, and hence these exclude morbidity effects.

measured under CUA will improve if these additional morbidity effects are included.

2.5 Modelling of Wider Benefits

The approach used to identify potential wider benefits of local authority interventions to reduce air pollution was to undertake an exercise that attempted to map the interventions to the potential consequences on residents, economic sectors, and wildlife. The aim was to trace through the potential impacts of interventions to reduce air pollution as a means to highlight where potential benefits may arise, and to highlight what information might be needed in order to estimate those benefits.

The key potential wider impacts identified were:

- Increased physical activities from changes in active travel behaviour;
- Community engagement;
- Mental health benefits;
- Accidents and injuries;
- Noise pollution;
- Visual disamenity;
- Urban heat island effect;
- Drainage and flood risk;
- Traffic congestion and travel time saving;
- Reduction of fuel cost;
- Damage to crops;
- Material damages;
- Climate change; and
- Ecosystem effects from acidification, eutrophication and ozone exposure;
- Impacts on biodiversity.

It is difficult to quantify most of the above wider impacts, mainly because of the following two reasons:

- Lack of method or data for quantification of some these impacts; and
- Difficulty in applying these impacts in the context of the interventions considered, even if the method for quantification and the data are available.

However, some of these wider benefits have been quantified for different interventions, which are detailed in Section 3.2.

2.6 Time Horizons

The time horizon for the estimated monetised benefits and cost can be varied in the model to calculate the net present value (NPV) of benefits and costs for a period of 1 year to 30 years. For all of the analysed interventions, CUA and CBA results were presented for the first year of the intervention. Additionally for the CBA, NPV of benefits and financial costs, as well as the Benefit-Cost Ratio (BCR) were also estimated for 5 years and 30 years to reflect the medium- and long-term effects. Long-term effects were not estimated for the CUA, as the health benefits are not measured in monetary terms.

2.7 Sensitivity Analysis

Because of the various uncertainties attached to modelling the impacts of different local authority interventions, sensitivity analysis has been undertaken to detect the changes in cost-effectiveness of an intervention for changes in different underlying assumptions. In particular, the following sensitivity analyses were considered:

- **Effectiveness of intervention** – by changing the effectiveness scaling parameter in the model;
- **Cost of intervention** – by estimating the cost-effectiveness for lower and upper limits of intervention costs;
- **Vulnerable population subgroups** – by varying the fraction of children (aged below 20) and elderly people (aged 65+) within the affected population;
- **Discount rates** – by changing the base discount rate for costs and benefits from 3.5% to 1.5%, 2% and 5%;
- **Uplift factor** – by removing the uplift factor for valuing future benefits; and
- **Population density** – by changing the density of the affected population with the intervention area.

Because of a lack of information on the population density in the source literature, the sensitivity analysis for changing population density could not be undertaken.

2.8 Limitations

The main challenges faced when developing a model on the cost effectiveness for a typical UK local authority interventions to reduce traffic related air pollution are:

- **Absence of pollution dispersion modelling:** The effects of air pollution are highly dependent on local meteorological conditions, such as wind speed and direction, precipitation, rainfall, etc., and local population characteristics. So proper pollution dispersion modelling is required to estimate effectiveness of an intervention to reduce air pollution in a specific area, which is not possible to develop for a typical UK local authority.
- **Validity of the results from source literature:** The estimated effectiveness of the interventions in the source literature might be biased in many cases, as pollution dispersion may not have been properly accounted for when measuring the resulting change in pollution.
- **Applicability of the results from source literature to an average UK local authority:** As the effects of air pollution depends on various local factors, it is very difficult to generalise the effectiveness reported in specific studies to an average local authority in the UK. Most of interventions in the source literature were implemented in other countries in the world, thus they might have limited applicability to the UK. Even for studies conducted in the UK, the measured effectiveness of the intervention might not be always applicable

for a general case, as this would depend on various local conditions of the area of the original intervention.

- **Calculation of life years lost:** This relates to the universal application of an average loss of life per attributable death of 12 years for a general case, regardless of the underlying mortality rate, population age-structure and socio-economic status of the local area.

Some of the other limitations of the model are listed below:

- A limited number of health endpoints were used to measure health benefits as some of the endpoints have not been measured in the source literature on effectiveness. These are listed in Section 2.3.3.
- In most cases the source literature did not contain information on population densities, thus it was not possible to estimate how the effectiveness might vary with changing population densities.
- Many of the wider benefits associated with the interventions could not be estimated because of the difficulty in quantifying these benefits, especially in the context of the interventions considered.

3.0 Modelling the Specific Interventions

This section covers the data sources and approaches used for each intervention

3.1 Developing the Short List of Interventions

The development of NICE guidance on local authority interventions to reduce traffic related air pollution focuses on 12 review topics in four broad areas:

- Environmental change and development planning;
- Traffic management and enforcement, and financial incentives and disincentives;
- Travel Planning and other initiatives providing information, advice, education and skill development; and
- Advice and warnings for the public and people at particular risk.

The full list of the review topics along with interventions considered within each topic from the final scope of the guidance development process are listed in Table 3-1.

Table 3-1: Full list of interventions

Review Topic	Interventions
1. Planning development control	Transport related planning, land allocation and development control decisions including • Building or land use • Siting of developments • Layout of developments

Review Topic	Interventions
	- Design of developments and connection to local community
2. Public transport routes and services	Developing public transport routes and services - Implementation of or changes to bus or public transport lanes - Implementation of or changes to public transport services (including cost) - Public transport quality improvements - Use of standards in commissioning public transport services - Provision of information about existing services - Action to integrate public transport services with other low emission modes such as walking or cycling
3. Low emission transportation	- Implementation of or changes to cycle routes or pedestrianised areas - Implementation of or changes to fuelling services for low emission vehicles - Use of low emission public sector vehicle fleets - options for siting of routes (e.g. low traffic vs normal traffic; avoiding inclines; siting and timing of traffic signals)
4. Absorption, adsorption & impingement deposition	- Use of natural and artificial barriers (such as trees and foliage) - Use of surface treatments (such as titanium oxides) - Use of dust suppressants, such as calcium magnesium acetate
5. Traffic management systems & signal coordination	- Road signs, traffic signals and road markings - Lane control - Traffic calming measures - Speed management zones - Vehicle bans or restrictions - Elements of routes (e.g. positioning of traffic lights) - Roadside emission testing
6. Zoning interventions	- Congestion charging - cordons or zones - distance-based charging - speed management zones - keep clear zones - time-based charging - toll road charging
7. Parking restrictions	- Restricted parking zones (including low emission vehicles, car clubs and electric vehicle recharging points) - parking charges - waiting and loading restrictions
8. Vehicle idling restrictions and charges	- Waiting restrictions - loading restrictions - enforcement of existing restrictions

Review Topic	Interventions
9. Settings-based travel planning interventions	• Car sharing schemes • car parking • improved facilities to encourage cycling or other non-motorised travel • cycle-to-work schemes • policies relating to business travel, including using public transport rather than driving, or incentives for businesses to promote cycling at work • management of vehicle movements related to business activities • interest-free season ticket loans • signage and cycle parking • lighting and planting
10. Personalised travel planning interventions	• Personalised travel planning to provide individuals with information, education, incentives and motivation to support low emission travel choices
11. Driver information	Information, education and training on: • Fuel • vehicles (including zero-emission vehicles) • route choice • driving styles including ○ the need to avoid heavy acceleration ○ minimise braking and excessive speed ○ switching off when stationery
12. Advice and warnings for public and people at particular risk	Provision of: • air pollution forecasts and real time data • air pollution early warning alerts via text or emails • air pollution early warning or monitoring information via web- or app-based geographical systems • support for route choices

The review of evidence on effectiveness and cost-effectiveness of these interventions under component 1 of the guidance development process shortlisted 45 studies identified by a systematic search of relevant databases and call for evidence from registered stakeholders.

To complement the search process in Component 1, Eunomia and UWE has undertaken another systematic search on effectiveness and financial costs of different interventions. The search strategies were developed in collaboration with the NICE Information Services team. The following databases were searched using database specific search queries to identify the most relevant literature sources:

- GreenFILE;
- EconLit;
- Business Source Premier;
- SocIndex;

- Web of science;
- Planex;
- NICE Evidence database;
- Social Policy and Practice;
- Transport Research International Documentation (TRID);

However, the complimentary search process undertaken by Eunomia and UWE mostly identified published evidence on effectiveness of different interventions that were already included in the evidence review undertaken in Component 1 of the study.

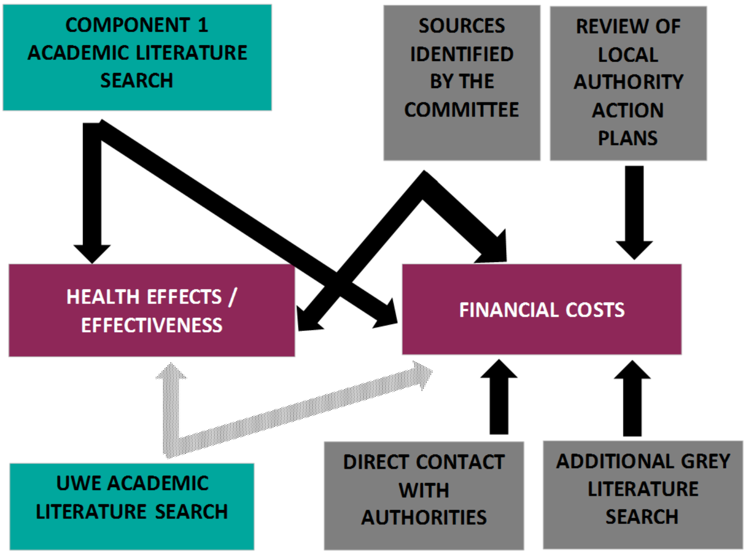
In addition to the database search, Local Air Quality Management (LAQM) reports were reviewed for information on financial costs of undertaking different interventions in the context of local authorities in the UK. Where required, local authorities were contacted directly for further details on financial costs.

Finally, additional grey literature on effectiveness and financial costs of interventions were reviewed from a range of sources, including:

- Defra;
- Sustrans;
- Living Streets;
- Streets Alive;
- Forest Research;
- Playing Out;
- WHO;
- World Bank;
- REVIHAAP;
- HRAPIE;
- Public health outcomes framework; and
- ECO Stars.

The search process undertaken by Eunomia and UWE is illustrated in Figure 3-1.

Figure 3-1: Eunomia/UWE search process



Further detail on the academic searches undertaken is provided in Appendix A.1.0.

For selecting the case studies to be used in the cost-effectiveness modelling, studies included in the evidence review undertaken by NICE as part of Component 1 with a quality rating of '-' or above were shortlisted. The selection was narrowed down further based on the reported measure of effectiveness (i.e. studies which captured a significant change pollution purely as a result of the intervention considered). Based on the quality of identified case studies as well as from discussion with the NICE public health advisory committee on effectiveness of different interventions, 9 interventions in 5 review topics were finally selected for modelling cost-effectiveness. These are listed in Table 3-2. One of the nine selected studies (on the impact of road dust suppressants on PM levels in urban areas) have been excluded from the final model, as the evidence of effectiveness was not robust enough in the opinion of the authors.

Table 3-2: Interventions included in modelling cost-effectiveness

Review Topic	Modelling decision	Included intervention(s)
3. Low emission transportation	Included	Comparison of NO_2 levels between on road and off road cycle routes
	Included	Bypass construction
4. Absorption, adsorption & impingement deposition	Included	Impact of roadside noise barriers on pollution concentrations near freeways
	Excluded	Impact of road dust suppressants on PM levels in urban areas
	Included	Urban PM pollution benefit induced by street cleaning activities
5. Traffic management systems & signal coordination	Included	Benefits of road closures
6. Zoning interventions	Included	Implementation of low emission zones
	Included	Implementing speed restrictions
11. Driver information	Included	Anti-idling campaigns taking place at urban schools

3.2 Approach Taken to Modelling Each Intervention

3.2.1 Off Road Cycle Paths

3.2.1.1 Modelling Effectiveness

The effectiveness of this intervention was modelled using data from Bean et al.[39] The study used diffusion tubes to model the exposure of cyclists to NO_2 using the off-road cycle routes in the city in comparison to the on-road cycle routes. The research was carried out in York over a number of months in 2008/9. Since longer journey times were used for the off-road routes, the authors calculated a time weighted average concentration and exposure for each route. These values were used in the model, taking the average across the two months. The data from the study is shown in Table 3-3.

Table 3-3: Pollution Data Comparisons in York – On-road vs Off-road Paths

Average time-weighted concentration of NO_2 (ppb)	On-road	Off-road	Concentration difference	Average concentration difference
August	14.7	9.5	5.2	5.8
September	16.2	9.8	6.4	

A calculation of the effectiveness in terms of health impacts requires the pollution reduction figure to be applied to a likely estimate of the population affected by the change. The NO_2 reduction figures were applied to the number of cyclists likely to make significant use of the off road routes that are developed, which will be a proportion of the total number of cyclists, which is in turn a proportion of the total population. Across the country the average probability of becoming a cyclist and making a journey by bike at least once per week across the population is 5%.[40] However, other data indicates that York has a higher than average proportion of cyclists. It is estimated that 15% of the adults in York undertake on an average three journeys a week.

For this intervention, the results are calculated on the basis of impacts of the number of the cyclists in York, and so these proportions are applied to the population of York, here assumed to be circa 200,000. The more paths developed, the more likely it is that cyclists will be able to use them. Against this, some cyclists do not use the paths even where they could do so, but continue to cycle along the same route. The affected population is therefore estimated to be 2% of York's total population.

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[39] Bean T, Carslaw N, Ashmore M, Gillah A and Parkinson C (2011) How does exposure to nitrogen dioxide compare between on-road and off-road cycle routes? Journal of Environmental Monitoring, 13, pp1039

[40] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/510268/national-propensity-to-cycle-full-report.pdf

In this case, the pollution data given in the study relates to a reduction in pollution relative to the background level of pollution experienced by the cyclists. These people will potentially be exposed to the background level of pollution during the periods when they are not cycling. There is potentially a need to consider further scaling the benefits to account for the points in the day where the cyclists are still exposed to the background level of pollution in York, but are not on the cycle paths.

Journey times within the York study on the off-road paths took around 25 minutes. This suggests that – assuming the cyclists undertake a journey there and back – their exposure time during cycling will be 50 minutes. It is assumed that the cyclists will only be exposed to the background pollution levels whilst they are outdoors.[41] Data elsewhere indicates that the median length of time spent outdoors by the UK population is 1 hour during the weekdays, although this rises to 1.4 during weekends. This suggests that the time spent cycling will account for much of the exposure that cyclists will have to the background levels of pollution.[42]

In considering the wider benefits that may arise from the development of separate cycle tracks, evidence was reviewed in respect of the potential of such tracks to bring about a reduction in road accidents. Reviews of the evidence available elsewhere (considering the situation in both the UK and beyond) suggest that the provision of dedicated separate cycle tracks does not reduce the risk of accident, but rather these reviews indicate that this risk is increased.[43] Although cyclists are safer where these tracks do not interface with junctions, where this is the case, the risk of accident is higher than for cyclists riding on the roads. Due to lack of quantitative evidence on decreased or increased risk of accidents from using off-road cycle paths, this has been excluded from the estimation of net benefits.

There may be an increased take-up of cycling as a result of the construction of the paths. Where this occurs, there may be additional health benefits occurring as a result of the increase in population of cyclists; an estimate of these benefits is included in the model. Bean et al cite the aim in Hackney of increasing cycling by 400% through construction of cycling routes. However, the potential increase in the number of cyclists that may occur as a result of developing specific paths is likely to be influenced by the existing path network: the relatively high proportion of cyclists in York itself may also be an indication of the increased take up as a result of the development of the cycle routes. We have therefore assumed a more modest increase in the number of cyclists of 10% (double of

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[41] Diffey BL (2011) An Overview Analysis of the Time People Spend Outdoors, Br J Dermatol, 16(4), pp848-54

[42] The sensitivity analysis undertaken in Section 4.9.1 considers the impacts associated with reducing the overall effectiveness of the intervention

[43] See for example, http://www.cycling-embassy.org.uk/wiki/cycle-paths-are-unsafe http://www.cyclecraft.co.uk/digest/research.html and http://www.bikexprt.com/research/pasanen/helsinki.htm

the national average). Health benefits are taken from a study undertaken for Cycling England in 2007 which estimated that the total health benefits on an annual basis per cyclist were valued at £160 (note this is a net figure, taking account of increased risk of injury from accidents).[44]

It is assumed that benefits from this intervention would continue indefinitely over the lifetime of the cycle path(s).

A summary of key assumptions is provided in Table 3-4.

Table 3-4: Assumptions – Effectiveness of Off-Road Cycle Paths

	Central Assumption	Source	Notes
Pollution change	11.09 µg/m^3 NO_2	Bean et al (2011)	Time weighted averages over a number of sites. Original data converted from ppb to µg/m^3.
Population affected	2% of population (in York, with a population of c. 200,000)	Cycling UK	Cycle UK data indicates that 15% of York's population cycles at least 3 times a week. Impact scaled as not all of these cyclists will use the three off-road paths considered in the study on a regular basis.
Time considerations	Continued benefits through life of path		Life of the off-road cycle path was assumed to be 20 years for calculation of benefits and costs.
Additional benefits modelled	Health benefits from cycling increase: £64 k p.a.	SQW	Health benefits from additional cycling: 10% increase in cyclists (applied to above population of cyclists figure), with a benefit of £160 per cyclist per year estimated by SQW.[45]

3.2.1.2 Modelling Costs

The fixed costs of cycle path construction vary considerably depending on how and where the path is built. Data from Sustrans provides the following examples:[46]

- Where there are no complicated legal issues, and where the path can be built by volunteers, the cost per km of track is estimated at £35,000;

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[44] SQW Ltd (2009) Valuing the Benefits of Cycling: A Report to Cycling England
[45] SQW Ltd (2009) Valuing the Benefits of Cycling: A Report to Cycling England
[46] Sustrans (u.d.) Costs and Sources of Funding, available from http://www.sustrans.org.uk/sites/default/files/images/files/migrated-pdfs/17%20costs%5B1%5D(1).pdf

- Costs rise to around £94,000 per km of track for paths developed from disused railway lines;
- Costs are higher still where construction is not undertaken by volunteers and where bridge repairs are required – in this instance, the cost rises to over £163,000 per km.

Sustrans indicates typical costs to be £94,000 per mile of track, which is close to a separate estimate of £100,000 per mile provided by the Cycling Embassy of Great Britain.[47]

These fixed costs would ideally be applied to the total length of path network in York. The journeys indicated in the study covered around 13 miles of track. This is unlikely to be the full extent of the off-road cycle network in York as a whole, or even the full length of the three paths considered in the study. Maps of the cycle route network in York indicate that some of these routes are long, although it is not possible to clearly determine the total length of the off-road track across the city. Equally, however, pollution reduction impacts are likely to be most significant in the city centre routes, and may not be applicable to the whole of the network.

The central estimate of fixed costs is calculated by multiplying the typical cost of the path per mile by Sustrans of £94,000 by the total length of track considered in the study – a length of 13 miles. This gives a total cost of £1.2 million to be annualised over 20 years.

There is a lack of information as to the on-going costs associated with maintaining the paths. However, the project team received verbal confirmation from Sustrans that such costs are usually relatively small in comparison to the fixed costs, as the path network is typically maintained by volunteers.

Box 3-1: Modelled Cost

Modelled annualised cost: £61,100

3.2.2 Bypass Construction

3.2.2.1 Modelling Effectiveness

This intervention considered the impact of the construction of a bypass on pollution levels in a small town in North Wales.[48] Pollution levels were measured on a series of sites in and around the main high street before and after the bypass was constructed. Pollution levels (of $PM_{2.5}$ and PM_{10} only) were measured using aerosol filters. The

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[47] See http://www.cycling-embassy.org.uk/sites/cycling-embassy.org.uk/files/documents/ltn208.pdf

[48] Burr M, Karani G, Davies B, Holmes B and Williams K (2004) Effects on Respiratory Health of a Reduction in Air Pollution from Vehicle Exhaust Emissions, Occup Environ Med, 61, pp212-218

benefits are modelled based on the $PM_{2.5}$ data only. The authors did not appear to have adjusted the figures for local meteorological conditions. No measurements were provided with respect to pollution impacts on the bypass itself, and no information was provided on this in respect of the population potentially affected.

The town was not named in the study but authors confirmed the population of the town was 23,000. Given the size of the town it was considered that the majority of the population would be impacted. Benefits were assumed to last for the lifetime of the bypass (assumed to be 40 years).

Table 3-5: Assumptions – Effectiveness of Bypass Construction

	Central Assumption	Source	Notes
Pollution change	3.4 $\mu g/m^3$ $PM_{2.5}$	Burr et al (2004)	Average pollution reduction figures over a number of sites (including congested and uncongested streets). No meteorological adjustments made. No NO_2 measurements undertaken.
Population affected	75% of 23,000	Developed from Burr et al (2004)	It is assumed that benefits can be applied to the majority of the population in this case given the size of the town, and the centrality of the sites where pollution was monitored.
Time considerations	Continued benefits through life of bypass		Life of the bypass was assumed to be 40 years for calculation of benefits and costs.
Additional benefits modelled	Noise, accidents & congestion: £45k per km (3 km of congested road assumed)	Developed from University of Sheffield (2012) & Burr et al (2014)	Costs per vehicle km of the three impacts taken from DfT tables published in the economic model on Active Travel (Sheffield University). Applied to vehicle count data in Burr et al.

Wider benefits will be highly location specific. For some bypasses, significant job creation potential has been estimated; for the Kingkerswell Bypass, for example, the employment creation potential was estimated at £9 for every £1 spent on constructing the road. It is not clear that such benefits could be applied to this case, which involves the construction of a bypass around a relatively small town. As such, these benefits have been excluded from the analysis.

A Swiss study indicated that the avoidance of noise-related sleep disturbance for one year resulted in monetised benefits of between 1,500 and 9,000 Swiss Francs (CHF) per person year.[49] This includes effects on property prices as well as related health impacts. The extent to which these benefits might be seen following this intervention is unclear.

A review of the literature on the potential for bypass construction to bring about a reduction in road accidents suggested that on average (across over 90 studies undertaken globally) the construction of a bypass was associated with a 25% reduction in the number of road accidents with casualties.[50]

Data on both these externalities as well as congestion is provided in the previous economic model developed by the University of Sheffield and published by NICE on active travel.[51] The study reproduces data from the Department of Transport which gives the following assumptions in respect of these external costs, to be applied at the margin to changes in the numbers of vehicles using the road:

- Noise – 0.1 pence per vehicle km;
- Congestion – 13.1 pence per vehicle km;
- Accidents – 1.5 pence per vehicle km.

From this it can be seen that the congestion related impacts dominate the external costs. It is noted that the figures used in the University of Sheffield study relate to cars, whereas the vehicle counts relate to heavy goods vehicles. Vehicle counts may, however, be overestimated for the HGVs, as the average count data comes from sampling carried out during the day. In addition, the length of the congested area is not known. As such, these costs are speculative providing an indication of the order of magnitude of the impacts.

The size of the population affected within the town provides a broad indication as to the size of the bypass. Based on this, monetised wider benefits have been estimated based on 3 km of congested street.

3.2.2.2 Modelling Costs

Cost estimates for constructing a bypass are highly site dependent. Fixed costs associated with the construction of the Lyminster North Bypass in West Sussex, for example, were estimated to be £9.3 million[52], whereas those associated with the Kingkerswell Bypass in North Devon were £136 million[53].

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[49] Swiss Agency for the Environment, Forests and Landscape SAEFL (2003) Monetisation of the health impact due to traffic noise

[50] Elias W, Hakkert S, Plaut P and Shiftan Y (2006)

[51] University of Sheffield (2012) Walking and Cycling: local measures to promote walking and cycling as forms of travel or recreation, Economic Modelling report for NICE

[52] Cost estimate provided in https://www.westsussex.gov.uk/roads-and-travel/roadworks-and-projects/road-projects/lyminster-bypass/

[53] See http://www.devon.gov.uk/sdlr-ers-benefit-analysis-june-2010.pdf

It was difficult to estimate the costs associated with this particular example, as no information was provided in the study as to the location of the bypass in question. However, the size of the town suggests that the bypass is relatively small, indicating that cost estimates towards the lower end of the spectrum presented above would be more likely to be appropriate.

Data from Imperial College London indicated that the average cost per km for a dual carriageway bypass was £4.54 million (at 2003 prices) for a four lane bypass with a capacity of 1,700 vehicles per hour.[54] Costs for a single lane bypass were estimated at £2.13 million per km. For a 5 km single carriage bypass, this equates to a total cost of £10.65 million, to be annualised over 40 years.

Box 3-2: Modelled Cost

Modelled annualised cost: £266,250

3.2.3 Motorway Barriers

3.2.3.1 Modelling Effectiveness

The evidence base for this intervention comes from a study that considers the construction of two brick freeway barriers in Southern California (the freeways in question were the I-710 and the I-5).[55] The researchers considered pollution levels including particulate measurements and the dispersion of NO_2. Measurements were taken at a range of sites in the immediate vicinity of freeways both with and without the brick barriers. The authors considered particulate pollution but did not look at this in terms of concentration such that population exposure figure could be calculated.

Without the barrier, pollution levels are reduced back down to background levels at a distance between 150 – 200 m from the roadside. With the barrier, there is a reduction in pollution in the area around 80 – 100 m from the freeway, followed by a surge in pollution – within this zone further away from the freeway, pollution levels are higher than would be the case at the same distance from the freeway where there is no barrier. Background pollution levels are only again reached 250 – 400 m from the freeway with the barrier. Information on the reduction in NO_2 pollution concentration within the low pollution zone is clearly stated, but the measured pollution changes are less well quantified outside this zone. The two barriers also resulted in different impacts. As a

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[54] http://www.rudi.net/files/iir_main.pdf

[55] Ning Z, Hudda N, Daher N, Kam, W, Herner J, Kozawa K, Mara S and Sioutas C (2010) Impact of Roadside Noise Barriers on Particle Size Distributions and Pollutant Concentrations Near Freeways, Atmospheric Environment, 44, pp3118-3127

conservative estimate, the lower of the two impacts was used in the study given the uncertainties surrounding the local pollution levels.

No information is provided within the study on population distribution or density, so it is difficult to know the size of the population affected. The study indicates that one of the noise barriers is located in a residential district in Bell Gardens, California. Another source indicates that the barrier on the Freeway I-710 is approximately 700 m to 1 km in length.[56] US Census Data indicates that the total population for the city is 42,072 and that the area has a relatively high population density of 6,595 people per sq. km.[57] When the population density is combined with the length data, and the data from the Burr study on the low pollution zone, this suggests that the size of population directly benefiting from the low pollution zone is 1,319 people, calculated based on the average population density figure above, or 3% of the city's population. This calculation is based on a low pollution zone that spreads 100 m on each side of the freeway.

However, as was indicated above it is important to note that there is a rebound effect such that the pollution increases again in the area from 100 m to 250 m and beyond (up to 400 m), and the study confirms that in part of this zone, pollution levels are higher than in the case where there was no barrier. The study does not provide sufficient detail with which this impact can be modelled, but it is clear that the benefit from the low pollution zone would be offset by this impact, such that the net impact is likely be lower than that modelled here. Any benefits are assumed to last for the lifetime of the barriers (assuming some ongoing maintenance occurs), which is here assumed to be 10 years.

Assumptions are summarised in Table 3-6. Noise related benefits have not been estimated here as it was not clear how the data in Section 3.2.2.1 could be applied to this intervention.

Table 3-6: Assumptions – Effectiveness of Motorway Barriers

	Central Assumption	Source	Notes

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[56] US Department of Transport, see https://www.fhwa.dot.gov/environment/noise/noise_barriers/inventory/summary/stable710.cfm

[57] The population density is slightly higher than that of London

Pollution change	28 µg/m^3 NO_2	Ning et al (2010)	Benefit taken from the low pollution zone; is the lowest benefit across the two sites converted from ppb to concentration. Does not include rebound effect on population just beyond the low pollution zone; this could not be directly calculated from the study.
Population affected	3% of 42,072 (for one barrier)	US Census US Dept. Transport	Barrier of 1 km in length, affected population based on a population density of 6,595 people per sq. km. Affected population taken also to include the non-residents.
Time considerations	Lifetime of barrier		Life of the barrier was assumed to be 10 years for calculation of benefits and costs.
Additional benefits modelled	None		

3.2.3.2 Modelling Costs

Data from the US Department of Transport suggests that the average cost across the two barriers considered in the study by Ning et al is £2,409,849.[58] This is then annualised over 10 years to get to the annual cost figure.

Box 3-3: Modelled Cost

Modelled annualised cost: £240,985

3.2.4 Street Washing and Sweeping

3.2.4.1 Modelling Effectiveness

This intervention considered the impact of regular mechanised street washing activity on a street – Carrer Valencia – in Barcelona.[59] Impacts were measured using quartz fibres to consider the PM pollution impact, sites up and downwind from the road. Impacts were

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[58] US Department of Transport, see https://www.fhwa.dot.gov/environment/noise/noise_barriers/inventory/summary/stable710.cfm

[59] Amato F, Querol X, Alastuey A, Pandolif M, Moreno T, Gracia J and Rodriguez P (2009) Evaluating Urban PM_{10} pollution benefit induced by street cleaning activities, Atmospheric Environment, 43, pp4472-4480

adjusted for meteorological activity by measuring the background pollution levels in a further three sites. The intervention only considered the impact of the activity on particulate pollution, i.e., $PM_{2.5}$ and PM_{10} (NO_2 not being targeted).

Since the data is from Spain, meteorological impacts may be somewhat different from those in some parts of the UK with respect of rainfall and temperature. However, parts of the east of the country have a similar rainfall pattern to that of Barcelona, that of less than 700 mm per year.[60]

The area cleaned measured 500 m by 19 m. The street flows through one of the busiest zones in the city, L'Eixample. This zone has a population density of up to 33,000 inhabitants per km^2, although the average across the city is around 15,000 inhabitants per km^2.[61] It is both a commercial and a residential area, and as such the impacts on population would ideally consider both those working in and travelling through the area as well as those who are resident. The reduction in pollution impacts is measured across two sites that are 1.2 km apart. The downwind site is 900 metres away from upwind site located within the centre of the zone that was cleaned, and registered lower pollution levels than the site that was within the cleaning zone after the street cleaning has taken place. From this it can be seen that impacts of the street cleaning activity extended some distance beyond the zone of cleaning. It is assumed that 40,000 people would be affected by this activity: the figure aiming to take into account both the approximate area affected by the cleaning activity and the resident population within it, as well as the additional non-resident population.

Benefits last for the duration of time over which cleaning activity continues to occur.

Assumptions are summarised in

Table 3-7.

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[60] See http://www.metoffice.gov.uk/climate/uk/regional-climates/ee and http://www.barcelona.climatemps.com/precipitation.php

[61] Population density data is available from http://geographyfieldwork.com/PopDensity.htm

Table 3-7: Assumptions – Effectiveness of Street Washing

	Central Assumption	Source	Notes
Pollution change	4.5 µg/m^3 PM$_{2.5}$	Amato et al (2009)	Pollution impacts measured across two sites approx. 1 km apart. Measurements adjusted to account for meteorological conditions by measuring background levels of pollution at other sites.
Population affected	40,000	Derived from Amato et al (2009) and population density	Highest residential population density in the area is c. 33,000, but affected population will also include non-residents. Measurement sites indicate that impacts could occur over 1 km.
Time considerations	Benefit continued whilst cleaning continues		
Additional benefits modelled	None		

3.2.4.2 Modelling Costs

The capital cost of vehicle purchase is estimated at £115,000.[62] The capital cost is annualised over seven years, as this is the time period over which local authority street cleaning contracts typically operate.

Operational costs are calculated on the basis of a daily cleaning regime using one vehicle for two hours at a time, based on information provided in the research by Amato et al. The costs are calculated on the basis of fuel used by the vehicle, together with the salary costs of the operative. The former is calculated assuming a fuel efficiency of 6.5 litres per

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[62] Data from a Swedish supplier cross referenced with internal data obtained directly from Surrey County Council on street cleaning costs

hour based on manufacturer’s data. Annual salary costs of £21,000 are assumed, scaled to account for the hours spent on sweeping activities (assuming the employee works a 7.5 hour day with 2 hours sweeping activity assumed).

Box 3-4: Modelled Cost

Modelled annualised cost: £25,825

3.2.5 Road Closures

3.2.5.1 Modelling Effectiveness

This intervention considered the impact on pollution from traffic over one week of the closure of all roads in Boston, United States, on one day for the National Democratic Convention in 2004.[63] Pollution impacts were measured at a range of sites across the whole city. Both $PM_{2.5}$ and NO_2 measurements were taken. The $PM_{2.5}$ measurements were taken using a DustTrak Model 8520, a laser photometer fitted with an impactor to exclude larger particles, whilst the NO_2 measurements were taken using a Yanagisawa passive filter badges. Measurements were adjusted for background meteorological conditions.

Since the measurements were taken across the whole city, it is assumed that the affects were city wide and that the whole population would benefit. However, the closure was short lived. Impacts were measured on weekly pollution levels. The overall impact was therefore scaled to 2% of the population (assumed to be 645,000 according to census data) – one week being roughly equivalent to 2% of a year.

Given that the intervention in this case was short-term (one day), only the acute health impacts have been valued in the model; impacts for mortality from chronic exposure have been excluded.

Since this is a one off short term change, no impacts are seen past the first year in this case. Particularly given the short term nature of the change, it is difficult to model the wider benefits.

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[63] Levy J, Baxter L and Clougherty J (2006) The air quality impacts of road closures associated with the 2004 Democratic National Convention in Boston, Environmental Health, a Global Access Science Source, 5, 16

Assumptions are summarised in

Table 3-8.

Table 3-8: Assumptions – Effectiveness of One-off Street Closures

	Central Assumption	Source	Notes
Pollution change	6.5 ug / m^3 $PM_{2.5}$ 3.8 ug / m^3 NO_2	Levy et al (2006)	Measurements taken on weekly pollution levels on sites across the city, adjusted for prevailing meteorological conditions. Acute impacts only considered.
Population affected	2% of 645,000	US Census	Impacts based on the population of Boston. Scaling here aims to reduce impacts in line with the short term nature of the intervention (lasting for at least 1 week of the year).
Time considerations	One off – impacts for first year only		
Additional benefits modelled	None		

3.2.5.2 Modelling Costs

No cost data was available for the road closures taking place during the National Democratic Convention. Costs are available for one off road closures on various local authority websites; this data suggests that the costs associated with these closures ranges from £750 to £1700 per road. It is not clear how these costs might be applied to a city-wide closure event.

Box 3-5: Modelled Cost

Modelled annualised cost: Not modelled

3.2.6 Low Emission Zones

3.2.6.1 Modelling Effectiveness – the Amsterdam Case Study

This intervention considered the impact of the introduction of the low emission zone in Amsterdam (LEZA), which applied restrictions such that heavy goods vehicles meeting only the Euro 0, I and II standard were excluded from entering the low emission zone from 2009.[64] Impacts on the levels of PM_{10} and NO_2 were measured from two sites within the LEZA using quartz filters and chemiluminescence monitors for each type of pollutant respectively. Measurements were taken prior to the introduction of the LEZA and soon after the enforcement activity associated with the restrictions had begun. Crude measurements were adjusted for meteorological conditions. No measurements were taken on pollutant levels in the area surrounding the LEZA.

The study did not indicate the population affected by the reduction in pollutant levels. Data elsewhere indicates that the population living within the LEZA is 250,000, and this has been used as the affected population when estimating the benefits.[65] Impacts may vary within the zone itself, and may also be extended beyond the borders of the LEZA, although analysis undertaken elsewhere of the impacts of other low emission zones also indicates that there may be an increase in pollution in the surrounding areas as a result of the displacement of traffic that would otherwise be travelling within the zone.[66] Sensitivity analysis is used to determine the impacts of changing the population affected by the intervention; in this case, the population affected by the intervention is halved, to account for the potential impact of traffic re-distribution.

Although benefits associated with introducing traffic restrictions of this type will continue in subsequent years beyond the initial introduction, the impact will tail off in subsequent years if restrictions remain limited to the vehicle classes considered within the study, as fleet renewal reduces the number of vehicles of these standards that

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[64] Panteliadis P, Strak M, Hoek G, Weijers E, van der Zee S and Dijkema M (2014) Implementation of a low emission zone and evaluation of effects on air quality by long-term monitoring, Atmospheric Environment, 86, pp113-119

[65] Keuken, M., Joners, S., Zandveld, P., Voogt, M., Elshout van den, S., (2012) Elemental carbon as an indicator for evaluating the impact of traffic measures on air quality and health, Atmospheric Environment 61, pp1-8

[66] AEA (2016) Evidence Review on effectiveness of transport measures at reducing nitrogen dioxide, report and appendices for Defra

continue to be in use. These impacts were not considered within the study data, and so assumptions would need to be made in respect of modelling the extent to which benefits might continue over time, where the impacts are considered for one specific definition of the low emissions zone. Equally, however, the benefits would be continued to some extent if the zone definition is continually updated to reflect the changes in vehicle fleet.

There may be potential benefits in respect of reduced fuel consumption, accidents and noise but these were excluded from the modelling as it was not clear how to estimate the scale of the benefits on the basis of the existing estimates of these monetised impacts.

Assumptions are summarised in Table 3-9.

Table 3-9: Assumptions – Effectiveness of Low Emission Zone (Amsterdam)

	Central Assumption	Source	Notes
Pollution change	1.54 µg/m^3 PM_{10} 2.47 µg/m^3 NO_2	Panteliadis et al (2014)	Measurements taken within the LEZA adjusted for wind direction and wind speed. Benefit for mortality from chronic exposure to PM_{10} scaled by 50% to account for $PM_{2.5}$ impacts, and by 30% to account for overlap between $PM_{2.5}$ and NO_2 impacts.
Population affected	250,000 Reduced by 50% in sensitivity analysis	Keuken et al (2012)	Based on the population of the entire LEZA, not taking into account any impacts associated with the re-distribution of traffic into the surrounding areas (which might increase pollution there). This equates to c. 20% of the greater urban population (source: World Population Review).
Time considerations	Some ongoing benefit (variable depending on design of LEZ)		
Additional benefits modelled	None		

3.2.6.2 Modelling Costs – the Amsterdam Case Study

No cost data was available for the Amsterdam case study. However, data is available for the costs of the London Low Emission Zone; this data is presented in Table 3-10.[67] In this case, both fixed costs and operating costs are provided, as well as estimates of revenues from the fines (the latter only being provided for the London LEZ). Average costs are presented in the table, the cost data being applied to the case study of Amsterdam (estimated to be 1.1 million) by multiplying the average cost by the total population of the greater urban area.

The costs will continue on an annual basis whilst the restrictions are in operation. The effectiveness data indicates the benefits may be reduced due to vehicle fleet renewal reducing the numbers of the more polluting vehicles. However, once the LEZ is up and running, benefits could also be extended to subsequent years by changing the classes of vehicles affected by the restriction(s), although it is important to note that such restrictions may result in a change in effectiveness.

Table 3-10: Annual Cost Data – London Low Emission Zone

Cost type	Annual costs
Fixed costs	£8,000,000 (range £6-10 million)
Operating Costs	£6,000,000 (range £5-7 million)
Revenue from Fines	-£2,500,000 (range £1-4 million)
Notes **Costs scaled by population (source World Population Review)**	

Box 3-6: Modelled Cost

Modelled annualised cost: £598,157

3.2.6.3 Ultra Low Emission Zone Case Study

The Amsterdam LEZ involved restricting HGVs of class 0, I and II starting from 2009. However, numbers of these vehicles are likely to have been reduced significantly in recent years as a result of fleet renewal. This will result in a reduction in benefits

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[67] Harrow Council (2004), Air Quality Action Plan – May 2004. Available from: http://aqma.defra.gov.uk/action-plans/HarrowC%20AQAP%202004.pdf

associated with the policy. For benefits to continue, restrictions need to be modified to encourage the uptake of cleaner vehicles.

Transport for London will introduce an Ultra Low Emission Zone (ULEZ) in London from September 2020. Following introduction of the restrictions associated with this zone, the following vehicles need to pay a charge when entering the ULEZ (which is intended to cover the same area as the existing congestion charge zone):

- Euro VI HGVs and non-TFL buses and coaches;
- Euro 4 petrol engine and Euro 6 diesel engine LGVs;
- Euro 3 motorcycles and power two-wheelers.

It is intended that TFL double decker buses meet the Euro VI hybrid standard, whilst single decker buses should be zero emission at source. The proposal also requires all newly licensed taxis to be zero emissions capable from 2018.

The introduction of the ULEZ has been subject to an impact assessment undertaken by Jacobs.[68] This assessment indicated health benefits of £101 million for 2020, resulting from the reduction in NOx, PM_{10} and $PM_{2.5}$. However, benefits are expected to decline to £32 million by 2025.

Benefits are attributed to the following:

- A reduction in NO_2 for sensitive receptors (residential properties, care homes, health facilities and schools) relating to reduction pollution from cars, buses and taxis;
- A minor reduction in impacts relating to PM_{10} and $PM_{2.5}$.

It is expected that benefits will arise across the city from a greater use of lower emissions vehicles. It is not clear whether impacts associated with the diversion of traffic – whereby vehicles avoid travelling in the congestion zone, thus increasing pollution impacts in surrounding areas – have been considered in the calculation of the net benefit figures set out above. However, the impact assessment does indicate that the above benefit figures do not include consideration of wider benefits, such as those relating to active travel and noise.

3.2.7 Speed Restrictions

3.2.7.1 Modelling Effectiveness

The case study considered in order to model the potential impacts of speed restrictions looked at the impact of introducing a speed restriction on a stretch of motorway located

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[68] Jacobs (2014) Ultra Low Emission Zone Integrated Impact Assessment, available from https://consultations.tfl.gov.uk/environment/ultra-low-emission-zone/user_uploads/ulez-iia-report_final.pdf

within an urban area in Amsterdam.[69] The speed limit introduced reduced the top speed down to 80 k.p.h. from 100 k.p.h.. The researchers measured the change in PM_{10} emissions in the year following the introducing of the limit, with the change in concentration being measured using a tapered element oscillating microbalance. NOx levels were measured but the data indicated no substantial reduction in impacts and as such these impacts were not considered in the modelling. Two monitoring stations were used to obtain the results, with data on background levels of pollution being obtained from other stations elsewhere in the local monitoring network. The pollution figures were adjusted to account for long range pollution and meteorological factors.

The study confirmed that 40,500 people live in the area within the immediate vicinity of the road and would therefore be likely impacted by the introduction of the speed limit; effects on the population beyond this point were not considered. The impacts on those using the road were also not considered. Once the intervention has been introduced, benefits would be expected to continue whilst the speed limit was enforced.

There may be potential benefits in respect of reduced fuel consumption, accidents and noise but these were excluded from the modelling as it was not clear how to estimate the scale of the benefits on the basis of the existing estimates of these monetised impacts.

Table 3-11: Assumptions - Effectiveness of Speed Restrictions

	Central Assumption	Source	Notes
Pollution change	2.2 µg/m^3 PM_{10}	Dikjema et al (2008)	Average measurements from two sites, adjusted for meteorological conditions and long range pollution effects. Benefit for PM_{10} scaled by 50% to account for $PM_{2.5}$ impacts.
Population affected	40,500	Dikjema et al (2008)	Population living in the immediate vicinity of the road as indicated in the study is 40,500.
Time considerations	Benefits continue whilst restrictions are enforced		
Additional benefits modelled	None		

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[69] Dijkema M, van der Zee S, Brunekreef B and van Strien R (2008) Air quality effects of an urban highway speed limit reduction, Atmospheric Environment, 42, pp9098-9105

3.2.7.2 Modelling Costs

The study indicated that drivers are informed of this speed limit by many road signs. The study indicates that no additional devices causing traffic interruptions, such as speed control traffic signals, are used; the authors of the research further state that the speed limit is “automatically adhered to through monitoring of vehicle specific trajectory driving speed and stringent fines”. It is not clear what is meant in respect of the speed monitoring in practice, or what the costs of the enforcement activity in this specific case might be.

Many parts of the road network in the UK are already covered by speed cameras but coverage is far from being complete across the country. The cost of implementation for this intervention will therefore depend on whether cameras are already in place and operational. The fixed costs of covering a 12 km stretch of the M1 with speed cameras were estimated by AEA in 2005 to range from £700,000 to £4.8 million, depending on the type of camera installed.[70] Costs associated with installing cameras have reduced since that time, although the cost remains variable depending on the type of camera and the location where it is to be installed. Data from one manufacturer confirms that the cost of an individual camera vary from £20,000 in an urban area – appropriate for the intervention modelled here – to £40,000 where the camera is installed in a rural location.[71] Increasingly, average speed cameras are being installed in place of the fixed cameras that identify the speed of a motorist at a specific point; the costs of installing this type of camera have fallen from £1.5 million per mile in the early 2000s to £100,000 per mile in 2016.[72]

The above study by AEA suggested that operating costs for maintaining the camera network were zero. However, the fixed camera itself only takes the photograph of the vehicle. Additional enforcement activity – involving salary costs of enforcement officers, for example - is therefore required to follow through on the evidence provided by the camera. In addition, there is the energy requirement of the camera. Thus whilst the on-going costs may not be substantial, they are unlikely to be zero.

The analysis by Dijkema et al confirmed that the speed restriction in Amsterdam covered a stretch of road that was 6 km in length. The fixed cost of camera installation – where this is required - is therefore estimated at being £375,000 for this stretch of road, based on the cost of installing the average speed cameras in 2016. This cost is apportioned over ten years.

Box 3-7: Modelled Cost

Modelled annualised cost: £37,500

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[70] AEA (2005) Technical and Non-technical Options to Reduce Emissions of Air Pollutants from Road Transport, Final Report to Defra

[71] Cost data available from http://www.speedcamerasuk.com/gatso.htm

[72] See http://www.speedcamerasuk.com/specs.htm

3.2.8 Vehicle Idling

3.2.8.1 Modelling Effectiveness

In the case study used to model the effectiveness of this intervention, the researchers considered the impacts associated with a reduction in vehicle idling outside four schools in Cinncinati, to establish the potential effectiveness of the Cincinnati Anti Idling Campaign.[73] The research in this case focussed on the reduction in idling associated with school buses – this being of particular significance in this area as a significant proportion of pupils are transported to school using these buses. The average number of busses per arrival/departure at these schools are provided in Table 3-12.

Four sets of measurements were taken, in each case both pre- and post- the start of the campaign, using Harvard impactor filters. Measurements were compared to background pollution levels in each case. No adjustments were made for meteorological conditions. A significant reduction in PM_{10} pollution was only seen in the case where the school was served by a large number of buses.

Table 3-12: Average Number of Busses at Different Schools

School	**A**	**B**	**C**	**D**
Average number of busses	5	39	11	9

Although the research only measured impacts for four schools, the campaign was aimed at tackling bus idling at all schools in the city.[74] In addition to the effects on pupils attending the schools by bus, there will also be localised impacts for the population living close to these schools. In the central case, results are calculated assuming 2% of the population of Cincinnati is affected: this proportion being based on 10% of the population being of school age, and assuming benefits were only applicable to a proportion of those educational establishments having the highest number of buses. Sensitivity analysis considered a decrease in the effectiveness, with 0.5% of population affected.

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[73] Ryan,P, Reponen T, Simmons M, Yermakov M, Sharkey K, Garland-Porter Eghbalnia and Grinshpun S (2013) The impact of an anti idling campaign on the outdoor air quality at four urban schools, Environ. Sci. Processes Impacts, 15, 230

[74] See http://www.cps-k12.org/families-students/student-safety/anti-Idling

Benefits are expected to continue beyond the initial educational activity aimed at reducing idling, although campaigns may need to be renewed to achieve such a result, in order to ensure that new drivers become involved in the campaign.

Wider benefits modelled in respect of this intervention are the cost savings as a result of reduced diesel consumption and the associated climate change benefits. A study undertaken in New York identified fuel savings of 157 gallons per year for heavy goods vehicles from a reduction in idling, which was used as the basis for estimating the cost savings to drivers / fleet operators.[75]

Assumptions are summarised in Table 3-13.

Table 3-13: Assumptions – Effectiveness of Vehicle Idling

	Central Assumption	Source	Notes
Pollution change	3.12 µg/m^3 PM_{10} (only applicable to schools with a large number of buses)	Ryan et al (2013)	Benefit from the best performing school (some schools saw no improvement). No adjustment for meteorological conditions. Benefit for PM_{10} scaled by 50% to account for $PM_{2.5}$ impacts.
Population affected	2% of 297,500 (sensitivity analysis uses 0.5%)	US Census Data	Based on proportion of school age children, assuming that impacts only applicable to 25% of schools in the city (those with a large number of buses)
Time considerations	Benefits continue (provided campaign is sustained)		
Additional benefits modelled	Cost savings: £36,658 Climate change: £540	Environmental Defense Fund (2009)	Calculations based on fuel savings of 157 gallons per year from Environmental Defense Fund, applied to number of vehicles in Ryan et al

3.2.8.2 Modelling Costs

No cost data appears to be available in respect of the running of the Cincinnati Anti Idling campaign. Ryan et al confirm that the campaign consisted of four components including research and development, campaign activities, online training videos, and implementation of the EPA Tools for Schools. Other activities included the erection of

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[75] Environmental Defense Fund (2009) The Health, Environmental and Economic Impacts of Engine Idling in New York City

signage, a monitoring programme on the buses, and the provision of information to parents. The scale of these activities suggests there will be some financial costs associated with commencing this programme across the whole authority, and sustaining it over a period of time such that benefits can be expected to be continued.

Elsewhere a list (published by the EPA) of various programmes aimed at community outreach and promotional activities confirmed that grants of $25,000 were available to fund such activities, including another campaign in Cincinnati to educate residents about air pollution.[76] In the absence of any other information on the likely cost of this programme, the figure of $25,000 (or £19,000) has been used as an estimate of the start-up costs of the intervention.

Elsewhere Oxford has previously considered the costs of adopting statutory powers to request drivers to switch off vehicle engines. Costs of signing and adopting powers-drafting traffic orders were estimated as being £10-20,000, not including enforcement costs. These powers would not be required in respect of running a voluntary campaign, and so they have not been included here.

Box 3-8: Modelled Cost

Modelled annualised cost: £19,000 (in the first year only)

4.0 Results

This section presents the results of the cost-effectiveness analysis for the interventions discussed in Section 3.2. Both CBA and CUA results are presented for each of the interventions, except for the road closures, as the financial costs could not be modelled in this case study.[77] There are a number of points to note regarding the presentation of the results under the different analyses, as follows:

- For the CBA, annual impacts of an intervention are presented as the monetised benefits, financial costs, and benefit-cost ratio (BCR) in the first year. For the impacts over a longer time horizon, the net present value (NPV) of benefits over costs over 10 years is also reported.
- As explained in Section 2.1, CUA was undertaken for the first year only, and both gains in QALY and the cost per QALYs gained in the first year are

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[76] See https://yosemite.epa.gov/opa/admpress.nsf/d0cf6618525a9efb85257359003fb69d/6010c547583cbee08525779e0069f902!OpenDocument

[77] For the road closure intervention a cost-threshold for undertaking the intervention is reported, which indicates the maximum cost for the intervention to be cos-effective.

reported for most of the interventions, (an exception was the intervention looking at road closures: this was a temporary measure and hence the long-term mortality effects - needed for estimating QALY gains - were excluded).

- Within the CBA framework, an intervention is considered as cost-effective if the net present value of undertaking the intervention is positive or the benefit-cost ratio is above one. For the CUA, on the other hand, the NICE threshold for cost-effectiveness of an intervention is £20,000 per QALY gained.[78] Finally, a case study verdict on the cost-effectiveness is reported for each intervention, which reflects the view of the authors taking into account the quality of the analysis in each case study.

The economic perspective for all of the interventions considered is the public sector, focusing in particular on the local authorities, as they will bear the cost of implementing the interventions.

4.1 Off Road Cycle Paths

Intervention costs and benefits calculated assuming a number of paths are developed. Development of one individual path would cost less but may also be less effective, as less of the population is likely to be targeted.

The results calculated by the economic model are summarised in Table 4-1.

Specific data quality issues for the effectiveness modelling include the following:

- Diffusion tubes are an indicative monitoring technique, with an error margin for individual measurements of +/- 25%, so there is some uncertainty in respect of the size of the change directly arising from the measurement technique used
- No exposure to PM was considered.
- Impacts will depend on the background level of pollution; a more polluted city might see higher benefits, but equally the benefits will be lower in an area with less traffic.
- Results are highly dependent on the number of routes developed. The up-take of the paths by cyclists will determine the population affected; this will depend on the location of the route(s) that are developed.

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[78] https://www.nice.org.uk/media/default/about/what-we-do/our-programmes/developing-nice-guidelines-the-manual.pdf

Table 4-1: Results Summary – Off Road Cycle Paths

Case study results		Monetised benefits	Financial Costs
CBA	Annual impacts	£789,236	£61,100
	Impacts over time	Continue over the life of the path	Fixed costs annualised over 20 years
	Wider impacts (annual)	Additional monetised benefits of £64,000 resulting from increased take up of cycling	
	Case study data quality considerations	Difficult to assess affected population - this needs to be scaled on the proportion of cyclists using the specific paths in question but this is not known.	Difficult to calculate costs as the length of cycle paths is not known; costs likely to be underestimated in consequence. No data on on-going operational costs but these are expected to be small.
	Benefit-Cost Ratio	14 in the first year	
	NPV over 10 years	£7,470,943	
CUA	QALY gained	12 QALYs	
	Cost per QALY	£5,075	
	Case study verdict	**Cost effective**	
Wider applicability of case study results			

- York has a very high proportion of regular cyclists compared to the national average. Impacts will be lower in areas with a lower cyclist population, although there may also be an increase in cycling resulting from building the paths. However the latter will not affect the monetised benefits from the intervention, which compares the reduction in exposure to pollution for pre-existing cyclists who would otherwise be cycling on the road.
- Impact depends on the level of pollution where paths are situated. Less effective in areas with lower background pollution levels.
- Location of the path also determines its cost as does the method of construction.
- Impact will depend on the take-up of pathways by cyclists. The extent to which paths are likely to be used on a regular basis is not known; more research is required to determine this generally, but local factors will be an important determinant. If the paths are not well located and therefore not well used, benefits will be less.

4.2 Bypass Construction

The results calculated by the economic model are summarised in Table 4-2.

Table 4-2: Results Summary – Bypass Construction

Case study results		**Monetised benefits**	**Financial Costs**
CBA	Annual impacts	£2,507,601	£266,250
	Impacts over time	Continue throughout the life of the bypass	Fixed costs annualised over 40 years
	Wider impacts (annual)	Additional monetised benefit of £112,675 (congestion, accident and noise reduction)	
	Case study data quality considerations	No data on the proportion of affected population or the size of the affected local road network. The latter could be used to estimate some of the wider benefits, as could more detail on the location of the bypass. No information on pollution levels close to the bypass and the population potentially affected by this.	No data on the length of bypass with which to estimate costs, or whether this is a single or dual carriageway. As such fixed costs are highly uncertain. No data on operating costs available.
	Benefit-Cost Ratio	10 in the first year	
	NPV over 10 years	£22,266,485	
CUA	QALY gained	38 QALYs	

	Cost per QALY	£6,971
	Case study verdict	**Cost effective under these assumptions but considerable uncertainty due to lack of data on costs and affected population**
Wider applicability of case study results		
• Local factors are likely to be very important in determining the cost effectiveness of this intervention: ○ In some cases there may be significant wider economic benefits from reducing congestion and improving economic outcomes. These benefits will not be applicable to all cases. ○ Net impacts will be dependent on where the bypass is located as there will be pollution impacts associated with the bypass itself. Net impacts therefore will also depend on the distribution of population in the local area. ○ Benefits may be much higher where the bypass diverts traffic from a densely populated area.		

4.3 Motorway Barriers

The results calculated by the economic model are summarised in Table 4-3.

Table 4-3: Results Summary – Motorway Barriers

Case study results		**Monetised benefits**	**Financial Costs**
CBA	Annual impacts	£626,883	£240,985
	Impacts over time	Continue through the lifetime of the barriers	Fixed costs annualised over 10 years
	Wider impacts (annual)	Not calculated. There may be wider benefits from noise reduction but the scale of these benefits could not be determined.	Not calculated
	Case study data quality considerations	Net benefits are difficult to determine based on the study data. There is a low pollution zone immediately beyond the barrier but an increase in pollution further beyond this. Data on the latter is not clearly provided in the study. Also concentration differentials varied considerably across the two study sites.	Typical fixed costs for the type of barriers in question provided by US Dept. of Transport so data quality is reasonable in this respect. No on-going cost data available, although such costs are not expected to be significant.
	Benefit-Cost Ratio	3 in the first year	
	NPV over 10 years	£3,801,074	

CUA	QALY gained	10 QALYs
	Cost per QALY	£25,199
	Case study verdict	**Cost effectiveness uncertain due to quality of data on effectiveness**
Wider applicability of case study results		

- Population density for the local area is relatively high, it being slightly higher than that of Portsmouth which is the area with the highest population density outside of London. Benefits will be much lower in areas with less people living close to the motorway.
- Case study relates to brick barriers. Benefits may be different for some types of natural barrier.
- Case study data suggests intervention may be cost effective in some cases depending on the distribution of local population in relation to the dispersal of pollution but this could only be determined by undertaking specific local studies.

4.4 Street Washing and Sweeping

The results calculated by the economic model are summarised in Table 4-4.

Table 4-4: Results Summary - Street Washing and Sweeping

Case study results		**Monetised benefits**	**Financial Costs**
CBA	Annual impacts	£3,849,845	£25,825
	Impacts over time	Continue as long as regular street cleaning activity takes place	Annualised over seven years
	Wider impacts (annual)	None calculated	None calculated
	Case study data quality considerations	Difficult to calculate affected population, which should include non-residents who are regular visitors - this is difficult to determine. Local population density also varies considerably.	Data on fixed costs is of reasonable quality. High level estimate of on-going costs is provided.
	Benefit-Cost Ratio	149 in the first year	
	NPV over 10 years	£35,897,450	
CUA	QALY gained	59 QALYs	
	Cost per QALY	£441	
	Case study verdict	**Cost effective**	
Wider applicability of case study results			

- The study takes place in a very densely populated zone of Barcelona, in an area of the city that is close to the centre. In this zone, population densities are approximately twice that of the most densely populated areas of London, which has the highest population density in the UK. Benefits will be much lower in areas with a lower population density and/or in areas outside the city centre.
- Barcelona has relatively low annual rainfall levels. Benefits will be lower in areas with higher rainfall which is the case in many areas of the UK. However some areas such as East Anglia have rainfall levels similar to that in Barcelona so there is some applicability to the UK situation.

4.5 Road Closures

The results calculated by the economic model are summarised in Table 4-5.

Table 4-5: Results Summary – Road Closure

Case study results		Monetised benefits	Financial Costs
CBA	Annual impacts	£39,020	UK costs per road closure c. £1,250
	Impacts over time	Short term - benefits in year one only	Costs in year one only
	Wider impacts (annual)	None calculated.	None calculated. Wider financial impacts difficult to determine but could be substantial.
	Case study data quality considerations	It is difficult to model what the short term benefits might be; to account for this only acute impacts are considered.	Financial costs are highly uncertain. Cost estimates available for single road closures in the UK but it is not clear how these could be applied to the closure of all roads in a city.
	Benefit-Cost Ratio	Not calculated (due to lack of relevant US cost data)	
	NPV over 10 years	Not calculated (temporary intervention with short-term benefits only)	
CUA	QALY gained	Unknown (lack of data on long term health impacts which is needed to calculate QALYs gained)	
	Cost per QALY		
	Cost Threshold	£39,020 per year	
	Case study verdict	**Cost effectiveness uncertain due to lack of data on costs and difficulty in modelling short term impacts**	
Wider applicability of case study results			

- The case study considers the benefit of a temporary closure of all roads in a particular city. Impacts relating to the longer term closures of a smaller number of roads are likely to be different. Short term closures may result in journeys not be made during the closure period, whereas for longer term closures there is likely to be greater re-distribution of traffic, lowering the pollution reduction benefit.
- Wider impacts – such as economic effects from the closures - are likely to vary considerably depending on local factors.
- Boston is a relatively large city; impacts on a smaller city with a lower population will be commensurately reduced.

4.6 Low Emissions Zones

The results calculated by the economic model are summarised in Table 4-6.

Table 4-6: Results Summary – Low Emission Zones

Case study results		Monetised benefits	Financial Costs
CBA	Annual impacts	£15,939,949	£598,157
	Impacts over time	Continued benefits likely to vary depending on how the scheme is updated over time to reflect changing vehicle emissions standards	Annualised over 20 years
	Wider impacts (annual)	None calculated	None calculated
	Case study data quality considerations	All measurements are taken from within the LEZ. The study does not consider the potential effects from the re-distribution of traffic occurring as a result of the LEZ, as no measurements outside of the LEZ were taken. Difficult to ascertain the population affected by the intervention.	The cost data is from the London LEZ although it has been scaled to Amsterdam (by population). Extent to which this is applicable is unclear.
	Benefit-Cost Ratio	27 in the first year	
	NPV over 10 years	£144,246,878	
CUA	QALY gained	243 QALYs	

	Cost per QALY	£2,465
	Case study verdict	**Cost effective during initial years; on-ongoing benefits are more uncertain and dependent on scheme updates**
Wider applicability of case study results		
• This case study considers the introduction of restrictions applied to the most polluting HGVs. Levels of these vehicles have decreased and LEZs introduced in the future need to be designed to take into account the changes in vehicle emissions standards. Benefits will be different depending on the design of the scheme. Future schemes based on Euro 6 vehicles may have greater benefits than those seen here, but there is no data on effectiveness available yet in this respect, only projected changes in pollution levels. • The study did not take into account pollution increases in other areas of the city occurring as a result of traffic re-distribution impacts. The extent of these impacts – and the consequential impact on the net results – will be dependent on local factors, including the size of the LEZ and availability of alternative routes, as well as the population density in the areas where the re-distributed traffic is diverted to.		

4.7 Speed Restrictions

The results calculated by the economic model are summarised in Table 4-7.

Table 4-7: Results Summary – Speed Restrictions

Case study results		**Monetised benefits**	**Financial Costs**
CBA	Annual impacts	£1,905,673	£37,500
	Impacts over time	Continue whilst enforcement activity continues	Fixed costs annualised over 10 years
	Wider impacts (annual)	None calculated. Potential benefits in terms of accident reduction and noise reduction.	None calculated. Potential increase in congestion costs.
	Case study data quality considerations	Estimate of affected population is provided in the study	Enforcement activities are not clearly described in the paper. Costs will vary depending on whether additional speed cameras are required; this appears not to have been the case in this instance. Data on on-going enforcement costs is not available; these costs may not be substantial but are not zero.
	Benefit-Cost Ratio	51 in the first year	
	NPV over 10 years	£17,823,237	

CUA	QALY gained	29 QALYs
	Cost per QALY	£1,293
	Case study verdict	**Cost effective**

Wider applicability of case study results

- The case study considers the impact of reducing speed on a stretch of dual carriageway. Benefits will be different for different types of speed restriction e.g. where 20 mph speed limits are placed on local residential roads
- The road in question is located in a relatively densely populated part of the city (population density here being equivalent to that of some of the most densely populated areas of the UK); benefits will be reduced in areas with a lower population density
- Costs will vary depending on the existing enforcement infrastructure already in place in the stretch of road where the limit is introduced
- Ongoing benefits are likely to be dependent upon effective enforcement of the limit

4.8 Vehicle Idling

The results calculated by the economic model are summarised in Table 4-8.

Table 4-8: Results Summary – Vehicle Idling

Case study results		**Monetised benefits**	**Financial Costs**
CBA	Annual impacts	£793,710	£19,000 (costs in year 1 only)
	Impacts over time	Sustained whilst campaign activity continues, and possibly beyond	On-going costs difficult to determine (see below)
	Wider impacts (annual)	Benefits of reduced fuel consumption (including climate change) £37,198	
	Case study data quality considerations	Little or no benefit was seen in three out of four schools. Max benefit was used to model benefits. Difficult to model affected population. No adjustment for meteorological conditions.	Cost of the campaign are highly uncertain, particularly in respect of the activity required to sustain the behaviour change benefit over time.
	Benefit-Cost Ratio	44 in the first year	
	NPV over 10 years	£7,768,606	
CUA	QALY gained	12 QALYs	
	Cost per QALY	£1,572	

Case study verdict	**Likely to be cost effective only for schools using a large number of buses**
Wider applicability of case study results	
- Buses are less widely used to transport pupils in much of the UK than is the case in the US so this intervention may not have much applicability to the UK context - Not clear how these potential benefits might be extrapolated to other anti-idling campaigns	

4.9 Sensitivity Analysis

Sensitivities are explored in the results for different interventions for which changing the model parameter values could alter the conclusion about the cost-effectiveness of the intervention. This analysis also reveals the point at which the intervention is no longer cost-effective and the effect of different conditions such as considering different subgroups of population. Additionally, sensitivities related to the affected population and other assumptions used to model the effectiveness of the intervention are also analysed for interventions which are likely to be cost-effective for the UK.[79]

Here, an intervention is considered as cost-effective if the net present value of undertaking the intervention is positive or the benefit-cost ratio is above one. The present value of benefits and costs are calculated for future years and values are discounted to account for the time preference for money. Willingness to pay is assumed to rise in line with economic growth and so the value of benefits is uplifted by 2% per annum, as recommended in the supplementary Green Book guidance on valuing air quality impacts. Annual values are summed over a given timescale to calculate the net present value of benefits and costs.

4.9.1 Off Road Cycle Paths

The annual impacts in terms of monetised benefits and financial costs are presented in Table 4-9. The monetised benefits are made up of £789,236 value of health impacts and £64,000 value of wider benefits. These values create a benefit-cost ratio of 14. The intervention would therefore have to be 1/14th as effective or be 14 times as expensive before it stops being cost-effective. In the central case, the intervention was considered to affect 4,000 people who are assumed to regularly use the cycle paths. Following this logic, the intervention would cease to be effective if less than 285 people used the paths in question regularly, assuming the financial costs stay as they are. These results suggest that there would still be a benefit even if the amount of time spent outdoors by the

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[79] Although the street washing and sweeping is likely to be cost-effective in the UK, sensitivity analysis for the intervention has not been reported as the cost-effectiveness very robust, i.e., the outcomes are unaffected even for large changes in parameter values.

cyclists was much greater than one hour; which would suggest that the benefits might need to be scaled down to account for the additional background exposure.

Table 4-9: Cost-Benefit Analysis - Off Road Cycle Paths (Central)

	Monetised benefits	Financial Costs	Benefit-cost ratio	NPV over 10 years	Cost per QALY
Annual impacts	£853,236	£61,100	14	£7,470,943	£5,075

The air pollution health benefits arise from a reduced exposure to NO_2. In the analysis above the impacts are calculated for mortality from chronic exposure, RHA and CHA endpoints. The impact for RHA can be calculated for specific age groups: ages 0 – 19 and ages over 65, as shown in Table 4-10. It is assumed that the entire affected population is comprised of the age group specified, i.e. 2% of a population of 200,000 are either all ages, ages 0 – 19, or ages over 65. However, it should be noted that the dose-response parameters for the mortality from chronic exposure to $PM_{2.5}$ and NO_2 (which accounts for more than 95% of the monetised health benefits) were not available for these age subgroups separately, and hence the cost-effectiveness estimates of the intervention for the vulnerable age groups is uncertain.

Table 4-10: RHA Impact for Different Age Groups - Off Road Cycle Paths

	Annual cases avoided by intervention	Monetised benefit
All ages	0.32	£2,576
Ages 0 – 19	0.08	£678
Ages over 65	0.33	£2,646

The net present value of benefits and costs is shown in Table 4-12. Results are shown for different discount rates and different timescales over which values are calculated. The intervention becomes significantly more cost-effective when analysed over a 30 year timescale. This is because the costs have been annualised over 20 years resulting in zero annual costs modelled after year 20.

4.9.2 Speed Restrictions

The annual impacts in terms of monetised benefits and financial costs are presented in Table 4-11. These values create a benefit-cost ratio of 51. The intervention would therefore have to be 1/51 as effective or be 51 times as expensive before it stops being cost-effective. In the central case, the intervention was considered to affect 40,500 assumed to live within the vicinity of the highway. Following this logic, the intervention would cease to be cost effective if less than 795 people lived close to the highway where the intervention takes place, assuming the financial costs stay as they are.

Table 4-11: Cost-Benefit Analysis – Speed Restrictions (Central)

	Monetised benefits	Financial Costs	Benefit-cost ratio	NPV over 10 years	Cost per QALY
Annual impacts	£1,905,673	£37,500	51	£17,823,237	£1,293

The air pollution health benefits arise from a reduced exposure to PM_{10}. There is insufficient data to calculate the impact of PM_{10} on different age groups.

The net present value of benefits and costs is shown in Table 4-13. Results are shown for different discount rates and different timescales over which values are calculated. The intervention becomes significantly more cost-effective when analysed over a 30 year timescale. This is because the costs have been annualised over 10 years resulting in zero annual costs modelled after year 10.

Table 4-12: Net Present Value of Benefits and Costs - Off Road Cycle Paths

Discount rate for benefits and costs	Impacts in year zero		Impacts over 5 years		Impacts over 10 years		Impacts over 30 years	
	Monetised benefits	Financial costs	Monetised benefits	Financial costs	Monetised benefits	Financial costs	Monetised benefits	Financial costs
1%	£853,236	£61,100	£4,351,500	£299,510	£8,922,729	£584,484	£29,635,416	£1,113,609
2%	£853,236	£61,100	£4,266,181	£293,752	£8,532,362	£559,813	£25,597,085	£1,019,054
3.5%	£853,236	£61,100	£4,144,303	£285,525	£7,996,873	£525,930	£20,879,472	£898,771
5%	£853,236	£61,100	£4,029,265	£277,758	£7,514,887	£495,388	£17,347,326	£799,513
3.5% (without uplift factor)	£853,236	£61,100	£3,987,240	£285,525	£7,344,389	£525,930	£16,242,005	£898,771

Table 4-13: Net Present Value of Benefits and Costs – Speed Restrictions

Discount rate for benefits and costs	Impacts in year zero		Impacts over 5 years		Impacts over 10 years		Impacts over 30 years	
	Monetised benefits	Financial costs	Monetised benefits	Financial costs	Monetised benefits	Financial costs	Monetised benefits	Financial costs
1%	£1,905,673	£37,500	£9,718,924	£183,824	£19,928,605	£358,726	£66,189,669	£358,726
2%	£1,905,673	£37,500	£9,528,366	£180,290	£19,056,732	£343,584	£57,170,197	£343,584
3.5%	£1,905,673	£37,500	£9,256,155	£175,240	£17,860,737	£322,788	£46,633,572	£322,788
5%	£1,905,673	£37,500	£8,999,224	£170,473	£16,784,238	£304,043	£38,744,647	£304,043
3.5% (without uplift factor)	£1,905,673	£37,500	£8,905,362	£175,240	£16,403,438	£322,788	£36,275,952	£322,788

4.9.3 Bypass Construction

The annual impacts in terms of monetised benefits and financial costs are presented in Table 4-14. These values create a benefit-cost ratio of 10. The intervention would therefore have to be 1/10th as effective or be 10 times as expensive before it stops being cost-effective. In the central case, the intervention was considered a 5 km single carriage bypass. Depending on the size of the town and the surrounding road network, a longer stretch of bypass may be required. The benefit-cost ratio shows the intervention would cease to be cost-effective due to increased financial costs if a single bypass of 50 km or more was required to achieve the same level of benefits, assuming that the benefits continue to affect the same number of people.

Table 4-14: Cost-Benefit Analysis – Bypass Construction (Central)

	Monetised benefits	Financial Costs	Benefit-cost ratio	NPV over 10 years	Cost per QALY
Annual impacts	£2,620,276	£266,250	10	£22,266,485	£6,971

Table 4-15 presents the monetised benefits and financial costs of the intervention using the central values of the relative risk coefficients, along with the lower and upper bound of the 95% confidence interval. For the lower bound of the relative risk coefficients, the intervention is no longer cost-effective under CUA, as the cost per QALY of £41,824 exceeds the NICE cost-effectiveness threshold of £20,000 per QALY gained. However, under CBA the intervention still seems to be cost-effective albeit with a lower benefit-cost ratio of 2.

Table 4-15: Sensitivity Analysis with 95% Confidence Interval for the Relative-risk Coefficients – Bypass Construction

	Monetised benefits	Financial Costs	Benefit-cost ratio	NPV over 10 years	Cost per QALY
Central estimate	£2,620,276	£266,250	10	£22,266,485	£6,971
Lower bound	£527,441	£266,250	2	£2,651,595	£41,824
Upper bound	£5,128,580	£266,250	19	£45,775,323	£3,485

It is also possible to develop other scenarios where the cost effectiveness is less certain. For example, cost effectiveness is less clear cut in the case where a 10 km dual carriage bypass was required, and where only 30% of the population (or 6,900 people) would benefit from the reduction in pollution. In this situation, wider benefits would become more decisive in determining the outcome.

4.9.4 Low Emissions Zones

In the central case, the intervention was considered for a population of 250,000. However, discussion with committee members confirmed that the LEZ may cause pollution to increase in the surrounding area due to the displacement of the traffic no longer travelling within the zone. In Table 4-16 the population affected by the intervention is halved to account for the potential impact of traffic re-distribution.

Table 4-16: Sensitivity Analysis of Population Affected – Low Emissions Zones

Population affected	Monetised benefits	Financial Costs	Benefit-cost ratio	NPV over 10 years	Cost per QALY
250,000	£15,939,949	£598,157	27	£144,246,878	£2,465
125,000	£7,969,975	£598,157	13	£69,549,067	£4,930

4.9.5 Vehicle Idling

In the central case, the health impacts intervention is assumed to affect 2% of the population of Cincinnati, based on 10% of the population being of school age and that benefits only apply to a proportion of educational establishments (as PM_{10} reduction was only seen was in the case where the school was served by a large number of buses). Due to the uncertainty in these assumptions the results are also calculated for 0.5% of the population, shown in Table 4-17.

Table 4-17: Sensitivity Analysis of Population Affected – Vehicle Idling

Population affected	Monetised benefits	Financial Costs	Benefit-cost ratio	NPV over 10 years	Cost per QALY
5,950	£830,908	£19,000	44	£7,768,606	£1,572
1,488	£235,626	£19,000	12	£2,189,378	£6,286

In the central case, assuming 2% of the population is affected by the health impact of the intervention, these values create a benefit-cost ratio of 44. The intervention would therefore have to be 1/44 as effective or be 44 times as expensive before it stops being cost-effective. This means that in order for the intervention to cease being cost-effective the affected population would have to be less than 113 people, assuming the same costs apply. In the case study this equates to 0.04% of the population.

4.10 Summary of Results

A summary of the results is presented in Table 4-18. The table includes a summary of the case study verdict and the applicability to the results of the case study analysis to the general case in the UK. In respect of the latter, it can be seen that a number of the interventions have been modelled using an optimistic scenario in the central case when compared to the UK situation – with many of these assumptions being derived directly from the case studies (such as the population density of the affected area). Where this is the case, in the opinion of the authors the benefits estimated here can be seen as representative of the upper end of benefits that could be observed in the general case for UK authorities.

There are a significant number of uncertainties and limitations which make the results highly uncertain for all interventions. Overarching limitations in respect of all modelled interventions are set out in Section 2.8. A key limitation is that there was no data on the dispersal of pollution in relation to population for any of the case studies modelled. In the absence of this data, the affected population was estimated, based, for the most part, on population density data for the case study area. This introduces a significant amount of uncertainty to the results. It is further important to note that even if this data were known for the case studies, there is still likely to be difficulty in confirming the results with certainty in the general case.

Table 4-18: Case Study Results Comparisons

	Indicative financial costs in first year	Total indicative benefits in first year	Indicative case study cost benefit ratio	Indicative Cost per QALY gained	Population Size of intervention area	Population assumed affected	Case study verdict	Applicability to general case
Off road cycle paths	£61,100	£853,236	14	£5,075	200,000	4,000	Cost effective	Optimistic scenario modelled
Bypass construction	£266,250	£2,620,276	10	£6,971	23,000	17,250	Cost effectiveness uncertain due to data quality issues	Highly dependent on local circumstances
Motorway barriers	£240,985	£626,883	3	£25,199	42,072	1,262	Cost effectiveness uncertain due to data quality issues	Optimistic scenario modelled
Street washing and sweeping	£25,825	£3,849,845	149	£441	40,000	40,000	Cost effective	Optimistic scenario modelled
One off road closures	Unknown	£39,020	N/A	N/A	645,000	12,900[1]	Cost effectiveness uncertain due to data quality issues	Does not reflect typical closure scenario
Low emission zones	£598,157	£15,939,949	27	£2,465	250,000[2]	250,000	Long term cost effectiveness uncertain	Some dependency on local circumstances
Speed restrictions	£37,500	£1,905,673	51	£1,293	40,500	40,500	Cost effective	Optimistic scenario modelled
Vehicle idling	£19,000	£830,908	44	£1,572	297,500	5,950	Cost effective	Optimistic scenario modelled

Notes:

1. *Total population scaled to 2% to reflect impacts lasting for a week only.*
2. *This is the population within the low emission zone, whereas costs are scaled to the total population of Amsterdam (1.1 million)*

However, the benefits are much higher than the costs for some of the interventions, suggesting that despite the considerable uncertainties inherent within the modelling, some interventions look to be cost effective in reducing the health impacts of pollution from road traffic, particularly under certain circumstances:

- Construction of off-road cycle paths particularly in urban areas where the specific paths are likely to be widely used by the cyclist population;
- Regular street sweeping and cleaning in urban areas with a relatively high population density when there is low rainfall, such as areas in the east of the country;
- Restricting the speed on a highway where the road passes through areas of relatively high population density.

In the case of the cycle path interventions, the case study did not consider PM reductions, whilst the speed restrictions intervention did not measure NO_2 impacts. As such both sets of results may understate the total benefit.

There is less certainty regarding the effectiveness of the other interventions. In particular:

- A lack of data on financial cost has meant that the cost effectiveness of bypass construction is uncertain. Our results indicate the bypass is cost effective at reducing pollution assuming it is effective in diverting a significant quantity of traffic away from the more densely populated urban areas affecting a significant proportion of the population without requiring a significant length of road to be built. It is also expected to be cost effective where the impacts relating to the wider benefits are significant - such as economic benefits. However benefits are highly dependent on local factors and it is therefore difficult to model the general case for this type of intervention.
- It is not clear whether the construction of brick motorway barriers is cost effective at reducing road pollution, as the data on the local pollution impacts is incomplete. As such, results shown in Section 4.3 do not account for the impact of increasing pollution levels downstream from where the measurements were taken, resulting in a potentially significant overestimation of the benefits.
- The lack of data on the costs of implementing road closures, and uncertainties relating to the health impacts of a one-off closure of all roads in a city for a day mean that it is not possible to determine whether this measure is cost effective. Such a situation is relatively unusual. The benefits (or otherwise) of one-off closures would not provide an indicative of the likely benefit of more frequent road closures occurring over a smaller area.
- The data suggests that the introduction of a low emission zone tackling the more polluting HGVs was cost effective in Amsterdam in 2009. However, since numbers of these vehicles will now be significantly reduced, this does not provide an indication of the likely effectiveness of a future LEZ, such as one encouraging an early shift to Euro 6 vehicles. In addition, the Amsterdam

case study did not consider the potential impacts associated with traffic diversion which may result in increased pollution levels outside the LEZ. Data from Transport for London indicates that the introduction of the ULEZ is expected to result in a significant benefit of £101 million in the initial year of introduction, but this estimate is based on modelled impacts rather than actual effectiveness data. This indicates that benefits can continue through an update of the requirements of the zone. However, in this case impacts are also expected to reduce significantly over time, such that the long term impacts (e.g. over 10 years) are uncertain. It is also not clear whether impacts associated with traffic diversion were considered within the benefits estimate for the ULEZ.

- US data suggests campaigns tackling school bus idling look to be cost effective in areas where a large number of school buses is used. This is likely to have relatively limited applicability to the UK. The data does suggest, however, that an effective anti-idling campaign – applied to a wider number of vehicles other than school buses – may be cost effective at reducing pollution from road traffic. Further work is needed to determine the costs of undertaking such an intervention including the on-going costs associated with maintaining the requisite behaviour change over time.

It is further noted that a consideration of some of the wider benefits was not possible for some of the above measures; a full consideration of these may make a cost effectiveness verdict more likely.

5.0 Further Work

The robustness of results for each of the interventions considered in this study would be improved by further case studies which show the dispersion of the pollution in the local area in relation to the affected population. This type of analysis is ultimately required to determine with certainty the cost effectiveness of specific interventions to tackle air pollution within a specific area, as this is the only way that the impact of variables such as local meteorology can be ascertained. It is further noted that the majority of case studies are modelled using data from outside of the UK.

For those case studies considered within this study, additional data is particularly required on the following, in order to allow for a full assessment of cost effectiveness to be undertaken:

- Financial costs of constructing the bypass in question, as well as the wider benefits such as those relating to economic benefits;
- Data on financial costs for vehicle idling campaign including on-going costs required to maintain behaviour change;
- Data on the financial impacts of road closures including economic impacts on the local population as well as costs to the authority;

- Ongoing data on the effectiveness of LEZs, taking into account the traffic diversion impacts;
- Ongoing data on the financial costs of operating the LEZ;
- The dispersion of pollution in respect of the construction of motorway barriers, so that the downwind increase in pollution can be more effectively accounted for.

APPENDICES

A.1.0 Academic Search Strategy

The following sections indicate the search strategies used to search each of the databases.

A.1.1 Glossary for Search Terms

AB	Abstract
TI	Title

A.1.2 GreenFILE (via EBSCO)

Ran the following search as TI and AB separately. 0 results returned for TI and 12 returned for AB Limited to peer reviewed articles, published in English between 1996 and 2016.

> ((budget* OR CBA OR CCA OR Cost* OR CUA OR economic OR Expenditure OR financ* OR fund* OR Investment OR “net benefit” OR Value) AND (“air pollut*” OR “air toxics” OR “black carbon” OR “car emission*” OR “Carbon Dioxide” OR “Carbon monoxide” OR CO2 OR “diesel emission*” OR “diesel fuel” OR “diesel fume*” OR “elemental carbon” OR “fine particle*” OR “nitrogen dioxide*” OR “nitrogen oxide*” OR NO2 OR nox OR ozone OR particulate* OR “petrol emission*” OR “petrol fuel” OR “petrol fume*” OR “PM emission*” OR PM2* OR PM5 OR PM10 OR Smog OR SO2 OR “Sulphur dioxide” OR “ultrafine particle*” OR “Vehicle Emission*” OR “vehicle exhaust*” OR “vehicle fume*” OR "air particl*") AND (bus OR buses OR car OR cars OR HDV OR "heavy duty vehicle*" OR HGV OR "heavy goods vehicle*" OR LGV OR "light goods vehicle*" OR LDV OR "light duty vehicle*" OR lorry OR lorries OR "motor vehicle*" OR motorbike* OR motorcycle* OR taxi OR taxis OR fleet OR van OR vans OR automobile* OR truck OR road* OR highway* OR motorway* OR "rush hour" OR rush-hour OR street* OR "tail back*" OR tail-back* OR tailback* OR traffic OR congestion OR transport* OR "trunk route*" OR idling OR "vehicle parc" OR pedestrian* OR cyclist* OR driver* OR driving OR commute*) AND (Asthma OR birth OR “Blood pressure” OR BMI OR “Body mass index” OR Cancer OR Cardiovascular OR cerebrovascular OR “Chronic Obstructive Pulmonary Disease” OR “congenital anomalies” OR COPD OR CVD OR DALY OR Death* OR Diabet* OR “Disability Adjusted Life Years “ OR Disease OR Elderly OR epidemiology OR exposure OR “GP attendance” OR Health OR “health outcome” OR health* OR “heart attack” OR “Heart disease” OR “Heat vulnerability” OR “Hospital admission*” OR “Inhalation Exposure” OR ischaemic OR “lung function” OR Morbidity OR mortality OR myocardial OR “oxidative

stress” OR “premature death*” OR QALY OR “Quality Adjusted Life Years” OR respiratory OR Stroke OR vascular OR Vulnerable OR years of life lost)) AND ("air flow" OR "air quality" OR AQAP OR AQO OR AQMA OR "clean air" OR “street canyon*” OR canyon street*” OR “green space*” OR "health impact assessment*" OR “environment* impact assessment*” OR "heat island*" OR zone* OR infrastructure OR “land allocat*” OR “land use*” OR neighbourhood* OR neighbourhood* OR "open space*" OR pavement* OR kerb* OR roadside OR walkway* OR surface* OR turbulence OR wind OR "pollution reduction*" OR exceedance* OR exceedence* OR "limit value*" or "target value*") AND (city OR cities OR town* OR urban OR building* OR environment*) N2 (plan* OR develop* OR design* OR infrastructure)

A.1.3 EconLit (via EBSCO)

Ran the following search as TI and AB separately. 0 results returned for TI and 0 returned for AB Limited to peer reviewed articles, published in English between 1996 and 2016.

> ((budget* OR CBA OR CCA OR Cost* OR CUA OR economic OR Expenditure OR financ* OR fund* OR Investment OR “net benefit” OR Value) AND (“air pollut*” OR “air toxics” OR “black carbon” OR “car emission*” OR “Carbon Dioxide” OR “Carbon monoxide” OR CO2 OR “diesel emission*” OR “diesel fuel” OR “diesel fume*” OR “elemental carbon” OR “fine particle*” OR “nitrogen dioxide*” OR “nitrogen oxide*” OR NO2 OR nox OR ozone OR particulate* OR “petrol emission*” OR “petrol fuel” OR “petrol fume*” OR “PM emission*” OR PM2* OR PM5 OR PM10 OR Smog OR SO2 OR “Sulphur dioxide” OR “ultrafine particle*” OR “Vehicle Emission*” OR “vehicle exhaust*” OR “vehicle fume*” OR "air particl*") AND (bus OR buses OR car OR cars OR HDV OR "heavy duty vehicle*" OR HGV OR "heavy goods vehicle*" OR LGV OR "light goods vehicle*" OR LDV OR "light duty vehicle*" OR lorry OR lorries OR "motor vehicle*" OR motorbike* OR motorcycle* OR taxi OR taxis OR fleet OR van OR vans OR automobile* OR truck OR road* OR highway* OR motorway* OR "rush hour" OR rush-hour OR street* OR "tail back*" OR tail-back* OR tailback* OR traffic OR congestion OR transport* OR "trunk route*" OR idling OR "vehicle parc" OR pedestrian* OR cyclist* OR driver* OR driving OR commute*) AND (Asthma OR birth OR “Blood pressure” OR BMI OR “Body mass index” OR Cancer OR Cardiovascular OR cerebrovascular OR “Chronic Obstructive Pulmonary Disease” OR “congenital anomalies” OR COPD OR CVD OR DALY OR Death* OR Diabet* OR “Disability Adjusted Life Years “ OR Disease OR Elderly OR epidemiology OR exposure OR “GP attendance” OR Health OR “health outcome” OR health* OR “heart attack” OR “Heart disease” OR “Heat vulnerability” OR “Hospital admission*” OR “Inhalation Exposure” OR ischaemic OR “lung function” OR Morbidity OR mortality OR myocardial OR “oxidative stress” OR “premature death*” OR QALY OR “Quality Adjusted Life Years” OR respiratory OR Stroke OR vascular OR Vulnerable OR years of life lost)) AND ("air flow" OR "air quality" OR AQAP OR AQO OR AQMA OR "clean air" OR “street canyon*” OR canyon street*” OR “green space*” OR "health impact

assessment*" OR “environment* impact assessment*” OR "heat island*" OR zone* OR infrastructure OR “land allocat*” OR “land use*” OR neighbourhood* OR neighbourhood* OR "open space*" OR pavement* OR kerb* OR roadside OR walkway* OR surface* OR turbulence OR wind OR "pollution reduction*" OR exceedance* OR exceedence* OR "limit value*" or "target value*") AND (city OR cities OR town* OR urban OR building* OR environment*) N2 (plan* OR develop* OR design* OR infrastructure)

A.1.4 Business Source Premier (Via EBSCO)

Ran the following search as TI and AB separately. 0 results returned for TI and 3 returned for AB Limited to peer reviewed articles, published in English between 1996 and 2016.

((budget* OR CBA OR CCA OR Cost* OR CUA OR economic OR Expenditure OR financ* OR fund* OR Investment OR “net benefit” OR Value) AND (“air pollut*” OR “air toxics” OR “black carbon” OR “car emission*” OR “Carbon Dioxide” OR “Carbon monoxide” OR CO2 OR “diesel emission*” OR “diesel fuel” OR “diesel fume*” OR “elemental carbon” OR “fine particle*” OR “nitrogen dioxide*” OR “nitrogen oxide*” OR NO2 OR nox OR ozone OR particulate* OR “petrol emission*” OR “petrol fuel” OR “petrol fume*” OR “PM emission*” OR PM2* OR PM5 OR PM10 OR Smog OR SO2 OR “Sulphur dioxide” OR “ultrafine particle*” OR “Vehicle Emission*” OR “vehicle exhaust*” OR “vehicle fume*” OR "air particl*") AND (bus OR buses OR car OR cars OR HDV OR "heavy duty vehicle*" OR HGV OR "heavy goods vehicle*" OR LGV OR "light goods vehicle*" OR LDV OR "light duty vehicle*" OR lorry OR lorries OR "motor vehicle*" OR motorbike* OR motorcycle* OR taxi OR taxis OR fleet OR van OR vans OR automobile* OR truck OR road* OR highway* OR motorway* OR "rush hour" OR rush-hour OR street* OR "tail back*" OR tail-back* OR tailback* OR traffic OR congestion OR transport* OR "trunk route*" OR idling OR "vehicle parc" OR pedestrian* OR cyclist* OR driver* OR driving OR commute*) AND (Asthma OR birth OR “Blood pressure” OR BMI OR “Body mass index” OR Cancer OR Cardiovascular OR cerebrovascular OR “Chronic Obstructive Pulmonary Disease” OR “congenital anomalies” OR COPD OR CVD OR DALY OR Death* OR Diabet* OR “Disability Adjusted Life Years “ OR Disease OR Elderly OR epidemiology OR exposure OR “GP attendance” OR Health OR “health outcome” OR health* OR “heart attack” OR “Heart disease” OR “Heat vulnerability” OR “Hospital admission*” OR “Inhalation Exposure” OR ischaemic OR “lung function” OR Morbidity OR mortality OR myocardial OR “oxidative stress” OR “premature death*” OR QALY OR “Quality Adjusted Life Years” OR respiratory OR Stroke OR vascular OR Vulnerable OR years of life lost)) AND ("air flow" OR "air quality" OR AQAP OR AQO OR AQMA OR "clean air" OR “street canyon*” OR canyon street*” OR “green space*” OR "health impact assessment*" OR “environment* impact assessment*” OR "heat island*" OR zone* OR infrastructure OR “land allocat*” OR “land use*” OR neighbourhood* OR neighbourhood* OR "open space*" OR pavement* OR kerb* OR roadside OR walkway* OR surface* OR turbulence OR wind OR "pollution reduction*" OR exceedance* OR exceedence* OR "limit value*" or "target value*") AND (city OR cities OR town* OR urban OR building* OR environment*) N2 (plan* OR develop* OR design* OR infrastructure)

A.1.5 SocIndex (Via EBSCO)

Ran the following search as TI and AB separately. 0 results returned for TI and 1 returned for AB Limited to peer reviewed articles, published in English between 1996 and 2016.

> ((budget* OR CBA OR CCA OR Cost* OR CUA OR economic OR Expenditure OR financ* OR fund* OR Investment OR “net benefit” OR Value) AND (“air pollut*” OR “air toxics” OR “black carbon” OR “car emission*” OR “Carbon Dioxide” OR “Carbon monoxide” OR CO2 OR “diesel emission*” OR “diesel fuel” OR “diesel fume*” OR “elemental carbon” OR “fine particle*” OR “nitrogen dioxide*” OR “nitrogen oxide*” OR NO2 OR nox OR ozone OR particulate* OR “petrol emission*” OR “petrol fuel” OR “petrol fume*” OR “PM emission*” OR PM2* OR PM5 OR PM10 OR Smog OR SO2 OR “Sulphur dioxide” OR “ultrafine particle*” OR “Vehicle Emission*” OR “vehicle exhaust*” OR “vehicle fume*” OR "air particl*") AND (bus OR buses OR car OR cars OR HDV OR "heavy duty vehicle*" OR HGV OR "heavy goods vehicle*" OR LGV OR "light goods vehicle*" OR LDV OR "light duty vehicle*" OR lorry OR lorries OR "motor vehicle*" OR motorbike* OR motorcycle* OR taxi OR taxis OR fleet OR van OR vans OR automobile* OR truck OR road* OR highway* OR motorway* OR "rush hour" OR rush-hour OR street* OR "tail back*" OR tail-back* OR tailback* OR traffic OR congestion OR transport* OR "trunk route*" OR idling OR "vehicle parc" OR pedestrian* OR cyclist* OR driver* OR driving OR commute*) AND (Asthma OR birth OR “Blood pressure” OR BMI OR “Body mass index” OR Cancer OR Cardiovascular OR cerebrovascular OR “Chronic Obstructive Pulmonary Disease” OR “congenital anomalies” OR COPD OR CVD OR DALY OR Death* OR Diabet* OR “Disability Adjusted Life Years “ OR Disease OR Elderly OR epidemiology OR exposure OR “GP attendance” OR Health OR “health outcome” OR health* OR “heart attack” OR “Heart disease” OR “Heat vulnerability” OR “Hospital admission*” OR “Inhalation Exposure” OR ischaemic OR “lung function” OR Morbidity OR mortality OR myocardial OR “oxidative stress” OR “premature death*” OR QALY OR “Quality Adjusted Life Years” OR respiratory OR Stroke OR vascular OR Vulnerable OR years of life lost)) AND ("air flow" OR "air quality" OR AQAP OR AQO OR AQMA OR "clean air" OR “street canyon*” OR canyon street*” OR “green space*” OR "health impact assessment*" OR “environment* impact assessment*” OR "heat island*" OR zone* OR infrastructure OR “land allocat*” OR “land use*” OR neighbourhood* OR neighbourhood* OR "open space*" OR pavement* OR kerb* OR roadside OR walkway* OR surface* OR turbulence OR wind OR "pollution reduction*" OR exceedance* OR exceedence* OR "limit value*" or "target value*") AND (city OR cities OR town* OR urban OR building* OR environment*) N2 (plan* OR develop* OR design* OR infrastructure)

A.1.6 Web of Science

Ran the following search as TI and AB separately. 0 results returned for TI and 1,779 returned for AB Limited to peer reviewed articles, published in English between 1996 and 2016.

> ((budget* OR CBA OR CCA OR Cost* OR CUA OR economic OR Expenditure OR financ* OR fund* OR Investment OR “net benefit” OR Value) AND (“air pollut*” OR “air toxics” OR “black carbon” OR “car emission*” OR “Carbon Dioxide” OR “Carbon monoxide” OR CO2 OR “diesel emission*” OR “diesel fuel” OR “diesel fume*” OR “elemental carbon” OR “fine particle*” OR “nitrogen dioxide*” OR “nitrogen oxide*” OR NO2 OR nox OR ozone OR particulate* OR “petrol emission*” OR “petrol fuel” OR “petrol fume*” OR “PM emission*” OR PM2* OR PM5 OR PM10 OR Smog OR SO2 OR “Sulphur dioxide” OR “ultrafine particle*” OR “Vehicle Emission*” OR “vehicle exhaust*” OR “vehicle fume*” OR "air particl*") AND (bus OR buses OR car OR cars OR HDV OR "heavy duty vehicle*" OR HGV OR "heavy goods vehicle*" OR LGV OR "light goods vehicle*" OR LDV OR "light duty vehicle*" OR lorry OR lorries OR "motor vehicle*" OR motorbike* OR motorcycle* OR taxi OR taxis OR fleet OR van OR vans OR automobile* OR truck OR road* OR highway* OR motorway* OR "rush hour" OR rush-hour OR street* OR "tail back*" OR tail-back* OR tailback* OR traffic OR congestion OR transport* OR "trunk route*" OR idling OR "vehicle parc" OR pedestrian* OR cyclist* OR driver* OR driving OR commute*) AND (Asthma OR birth OR “Blood pressure” OR BMI OR “Body mass index” OR Cancer OR Cardiovascular OR cerebrovascular OR “Chronic Obstructive Pulmonary Disease” OR “congenital anomalies” OR COPD OR CVD OR DALY OR Death* OR Diabet* OR “Disability Adjusted Life Years “ OR Disease OR Elderly OR epidemiology OR exposure OR “GP attendance” OR Health OR “health outcome” OR health* OR “heart attack” OR “Heart disease” OR “Heat vulnerability” OR “Hospital admission*” OR “Inhalation Exposure” OR ischaemic OR “lung function” OR Morbidity OR mortality OR myocardial OR “oxidative stress” OR “premature death*” OR QALY OR “Quality Adjusted Life Years” OR respiratory OR Stroke OR vascular OR Vulnerable OR “years of life lost”)) AND ("air flow" OR "air quality" OR AQAP OR AQO OR AQMA OR "clean air" OR “street canyon*” OR “canyon street*” OR “green space*” OR "health impact assessment*" OR “environment* impact assessment*” OR "heat island*" OR zone* OR infrastructure OR “land allocat*” OR “land use*” OR neighbourhood* OR neighbourhood* OR "open space*" OR pavement* OR kerb* OR roadside OR walkway* OR surface* OR turbulence OR wind OR "pollution reduction*" OR exceedance* OR exceedence* OR "limit value*" or "target value*") AND (city OR cities OR town* OR urban OR building* OR environment*) NEAR (plan* OR develop* OR design* OR infrastructure)

A.1.7 Planex

Ran the following search as TI and AB separately. 0 results found.

(Costs OR Economics OR Budgets) AND ((Air Pollution OR Air Pollutants OR Inhalation Exposure OR Particulate Matter OR Nitrogen Oxides OR Nitrogen Dioxide OR Vehicle Emissions) AND (Motor Vehicles OR Automobiles OR Transportation) AND (City Planning OR Environment Design OR Urban Renewal))

A.1.8 NICE Evidence database

Ran the following search and 437 results found.

(Costs OR Economics OR Budgets) AND ((Air Pollution OR Air Pollutants OR Inhalation Exposure OR Particulate Matter OR Nitrogen Oxides OR Nitrogen Dioxide OR Vehicle Emissions) AND (Motor Vehicles OR Automobiles OR Transportation) AND (City Planning OR Environment Design OR Urban Renewal))

A.1.9 Social Policy and Practice (via Ovid)

Ran the following search and 0 results found.

(Costs OR Economics OR Budgets) AND ((Air Pollution OR Air Pollutants OR Inhalation Exposure OR Particulate Matter OR Nitrogen Oxides OR Nitrogen Dioxide OR Vehicle Emissions) AND (Motor Vehicles OR Automobiles OR Transportation) AND (City Planning OR Environment Design OR Urban Renewal))

A.1.10 TRID

Ran the following search and 365 results found.

(Costs OR Economics OR Budgets) AND ((Air Pollution OR Air Pollutants OR Inhalation Exposure OR Particulate Matter OR Nitrogen Oxides OR Nitrogen Dioxide OR Vehicle Emissions) AND (Motor Vehicles OR Automobiles OR Transportation) AND (City Planning OR Environment Design OR Urban Renewal))

A.2.0 Model Quality Assurance

Key quality assurance steps taken during the development of the model are indicated in Table A2-1.

Table A2-1: Key Model Quality Assurance Steps

Model Quality Assurance Point	Date	Description
Overarching assumptions review	20/06/16	Technical sign-off stage for key overarching model assumptions (health effects, economic assumptions etc.)
Generic calculation structure review	27/06/16	Sign off of generic grids for calculating air pollution impacts and cost calculations. Calculations checked for technical soundness and calculation logic.
Key scenario assumptions review	11/07/16	Cross check of key assumptions from literature used to model scenarios.
First complete draft results QA	18/07/16	Output checking and cross checking of key calculations.
Detailed calculations cross check	20/08/16	Check of all model calculations in Excel tool to ensure calculation logic is sound.
Final cross check	21/10/16	Cross checking model assumptions and results against outputs in Final Report following final amendments.