# Air Quality Benefits of Active Travel

Final Report for Sustrans

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**Report for Andy Cope, Sustrans**

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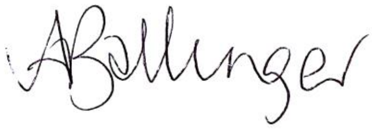
Approved by



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# Executive Summary

Sustrans is increasingly aware of the need to articulate the contribution, or the potential contribution, of their delivery activity in terms of reducing air pollution or improving air quality. Sustrans therefore commissioned Eunomia to construct a model that will enable the quantification of the potential contribution of walking and cycling in the context of air quality. The work to date focuses on infrastructure schemes, i.e. cycling and walking routes. The funding for this study came from Transport Scotland - Eunomia and Sustrans therefore would like to gratefully acknowledge the contribution of Transport Scotland.

## E.1.1 Scheme-Based Model

### E.1.1.1 Methodology

Eunomia has developed two models that considers the potential air pollution impacts of some of Sustrans activities. The first approach is the scheme-based model, which takes data on specific Sustrans schemes such as Connect2 and Community Links for specific areas, with the aim of estimating air pollution impacts for these schemes. The model developed here therefore uses a bottom-up approach to estimating the air pollution impacts of the changing travel behaviour, with the air pollution impacts modelled based on numbers of individuals changing their travel behaviour.

The model estimates two kinds of air pollution benefits from shifting to active travel. These are:

1) **Reducing Car Journeys:** This relates to the air quality benefits to the local population due to reduced emissions from car journeys replaced by active travel
2) **Route Users Personal Exposure:** This relates to the air quality benefit (or dis-benefit) to an individual due to change in pollution exposure from shifting to active travel. This key component of the model has not been considered the modelling work published by government in this field to date, although it is considered in the academic literature on the subject.

### E.1.1.2 Results

Impacts from the schemes varied from -£1,740 in Leeds (representing a dis-benefit) to £104,820 in Glasgow. The performance of the scheme is influenced significantly by the number of scheme participants. Other influential factors include:

- The proportion of scheme that is traffic-free;
- The proportion of essential journeys undertaken by bus in the counterfactual scenario (bus journeys taking longer than car journeys, thereby exposing people to more pollution);
- The location of the scheme – in particular, the population density of the surrounding area.

Outputs from the scheme-based model were adapted and used to derive initial estimates of the impact of achieving targets included in the recently published national strategies for investment in active travel, as follows:

1. If England's Cycling and Walking Investment Strategy (CWIS) target to double cycling is achieved this would result in £288 million in air pollution benefits per year (extrapolating benefits from the Dover case study);
2. If the CWIS target to increase walking to 300 stages per person per year is achieved, this would result in £279 million in air pollution benefits per year;
3. If the target of 10% of all journeys set out in Scotland's Cycling Action Plan (CAPS) were achieved this would mean £364 million in air pollution benefits per year (extrapolating benefits from the Glasgow case study).

### E.1.2 Area-Wide Model

The top-down area-wide model considers the potential benefits of a more substantial intervention across a whole city, based on the methodology previously developed by Eunomia for the National Institute of Health and Care Excellence (NICE). This models the health impacts based on changes in atmospheric pollution levels arising as a result of sustained campaign activity on active transport. The advantage of this approach is that it allows for a relatively high-level consideration of the potential results of a more substantial intervention affecting larger numbers of people.[1]

The modelling assumes a city-wide intervention is successful in making a long-term reduction in 10% of the vehicles that are assumed to cause the normal drop in school-related travel, equivalent to a net reduction in $NO_2$ of 0.5% occurring as a result of the intervention. This was applied to the city of Southampton, which has a population of circa 249,000 people.

Initial results developed using the above approach suggest that health benefits in the order of £477k per year would be seen. It is further noted that the above analysis considers reductions in $NO_2$ – additional benefits would also be seen if $PM_{2.5}$ impacts were considered. These results therefore suggest that if sustained campaign activity can bring about a long term reduction in car usage across a whole area, it has the potential to bring about a substantial health benefit from a reduction in air pollution – provided suitable infrastructure is in place locally to support the shift to greater levels of active travel.

### E.1.3 Implications

Although the air quality impact values of many of the individual schemes are relatively modest, there are clear signals that the potential value of air quality benefits are very significant. These can be realised by adjusting the design and implementation of routes (e.g. to avoid high exposure areas), by increasing the impact of the schemes (e.g. numbers of users, and by increasing the extent of modal shift. Furthermore it is important to consider that air pollution is only a small part of the overall benefit value of such schemes. In this respect, it is

[1] Further information on the technical details behind the modelling work is set out in Eunomia / UWE (2017) Air Pollution: Economic Analysis, Final Report for NICE, April 2017

important to note that the above results reflect the benefits that would be obtained from one year only. Furthermore, benefits from the CWIS and CAPS are likely to continue for longer than those of other interventions aimed primarily at tackling tailpipe emissions - such as the Clean Air Zones (CAZ) proposed by Government - as the reduction in the number of cars on the road from the CWIS and the CAPS will bring about continued benefits in terms of the reduction in PM emissions occurring due to a reduction in car tyre wear and related impacts.

The modelling work has demonstrated which factors drive higher benefit values in respect of individual schemes. These include increasing scheme user numbers, targeting regular travellers, focussing in on more densely populated urban areas, whilst reducing rates of exposure to air pollution of scheme users through the use of off-road routes. These factors are explored in the modelling work both through "what-if" analysis. Alongside this, outputs from the area-wide model latter in particular suggests that the potential benefits from a more substantial intervention are very considerable. Wider benefits could be brought about with more complete networks, denser networks, behaviour change accompaniment, measures to reduce exposures, better targeting of specific user groups. Such measures could bring about a reduction in the impacts of air pollution in the local area, as well as representing more effective delivery of measures to support walking and cycling.

To bring about this level of change, delivery of the above measures needs to happen as part of a large scale, integrated package of intervention/delivery, potentially in tandem with effective traffic-restraint measures. In this way, the two types of interventions could be mutually supportive, as cycling and walking is an important part of the local mobility solution when motorised mobility is necessarily constrained.

### E.1.4 Limitations and Further Work

Key variables concerning the exposure of cyclists and walkers - such as the regularity of journeys undertaken by users of the active travel schemes – are currently based on modelling assumptions. More detailed information on the travel behaviour of scheme users would improve the quality of the outputs. Other areas for improvement include the availability of pollution monitoring data, and uncertainty in the calculation of inhalation rates in different locations and travel environments.

Taking into account the above limitations as well as the prevailing policy environment, the next steps in terms of the research are therefore expected to include:

- Consideration of how the model may need to develop if it were to support the production of local authority clean air plans;
- The integration of more detailed modal change data;
- Consideration of integrating this type of intervention with traffic restraint measures, and linking of the corresponding modelling outcomes; and
- Better linking of atmospheric emissions data with travel data.

# Contents

# 1.0 Introduction

## 1.1 Background to the study

Sustrans aims to make smarter travel choices possible, desirable and inevitable. Sustrans is a leading UK charity enabling people to travel by foot, bike or public transport for more of the journeys they make every day. Sustrans works with families, communities, policy-makers and partner organisations so that people are able to choose healthier, cleaner and cheaper journeys, with better places and spaces to move through and live in.

Sustrans' delivery work focuses on increasing active travel. In that sense it is reasonable to infer that most of Sustrans' delivery aims to impact on air quality. However, the extent of the contribution that Sustrans' delivery activity makes in terms of reducing air pollution or improving air quality is uncertain. Sustrans therefore commissioned Eunomia to construct a model that will enable the quantification of the potential contribution of walking and cycling in the context of air quality. A key component of this work is the consideration of the changes in scheme users' exposure to pollution occurring as a result of the switch to active travel, which is currently not considered in much of the modelling work published by government in this field to date.

For Sustrans, reporting on the impact of their work in terms of air quality is an aspiration in the context of advocacy and making-the-case for continued and expanded delivery in the sort of programmes that they deliver. However, it is also an exercise in understanding how to refine delivery to build greater effect, and in being able to acknowledge where there are gaps in evidence of scheme effectiveness in respect of air quality in some areas.

The work has a much wider application too. Sustrans is one among many organisations delivering interventions that support walking and cycling. We hope that this model will have application across the sector. This report is published against the backdrop of the UK Government's attempts to establish a national air quality strategy, and the development of, for example, Clean Air Zones and the CleanAir Fund in England.

The funding for this study came from Transport Scotland. Eunomia and Sustrans would like to gratefully acknowledge the contribution of Transport Scotland.

Key outputs from this study are the following:

- Analysis of the air pollution impacts of 19 Sustrans schemes operating across England and Scotland;
- An estimate of the potential air pollution benefits associated with undertaking a wide-scale intervention across a city;
- An estimate of the potential air pollution benefits associated with England's Cycling and Walking Investment Strategy (CWIS) and the Cycling Action Plan for Scotland (CAPS).

## 1.2 Modelling the Air Pollution Impacts of Sustrans Activities

Eunomia has developed two models that considers the potential air pollution impacts of some of Sustrans activities. These have taken two different approaches to estimate the air quality benefits of its work.

The first approach is the **scheme-based model**, which takes data on specific Sustrans schemes such as Connect2 and Community Links for specific areas, with the aim of estimating air pollution impacts for these schemes. The Connect2 projects focussed on overcoming physical barriers to cycling and walking, whilst the Community Links programme provides grant funding for the creation of cycle network infrastructure; as such, both types of schemes are oriented around improving the physical infrastructure. The model developed here therefore uses a bottom-up approach to estimating the air pollution impacts of the changing travel behaviour, with the air pollution impacts modelled based on numbers of individuals changing their travel behaviour. The methodology for this is discussed in Section 2.0.

Initial results from selected schemes are set out in Section 3.0. The scheme-based model has also been used to develop an initial estimate of the potential impacts of England's Cycling and Walking Investment Strategy, and the corresponding strategy for Scotland.

A top-down **area-wide model** then considers the potential benefits of a more substantial intervention across a whole city, based on the methodology previously developed by Eunomia for the National Institute of Health and Care Excellence (NICE). This models the health impacts based on changes in atmospheric pollution levels arising as a result of sustained campaign activity on active transport, and is discussed in Section 4.0.

The work undertaken as part of this study should be seen as the first stage in quantifying these impacts in detail. Limitations of the modelling undertaken to date are set out in Section 5.2.

## 1.3 Interface between Eunomia Models and Other Analyses

This commission was undertaken in order to isolate the value of air quality impacts, and to develop mechanisms for filling 'gaps' in the current approaches to estimating and valuing impacts of poor air quality. Part of the process of developing this model therefore involved a review of what other tools produce in terms of air quality output data. Webtag is the Department for Transport's preferred transport scheme evaluation tool, and STAG (Scottish Transport Appraisal Guidance) and Weltag (Welsh Transport Appraisal Guidance) are used in those respective nations. Although there is a degree of overlap between the model developed in this study and these tools, the main way that new model differs from these versions of transport appraisal guidance is in the way it incorporates the impact of a scheme on route user pollution exposure levels. As was noted in Section 1.1, this element has, to date, not been included in other analyses undertaken by government, although it has been considered elsewhere in the academic literature, as will be discussed further in Section 2.3. The World Health Organisation HEAT (Health Economic Assessment Tool) is also considered, and although plans are afoot to develop a specific air quality module for HEAT, the two models do not directly overlap.

Webtag calculates a Marginal External Cost (MEC) value of a travel scheme. This value relates to the additional cost of adding a car km to the road (or the benefit of removing a car km from the road), and relates to the health and environmental impacts of atmospheric emissions of all pollutants from motorised vehicles ($CO_2$, CO, $SO_2$, $NO_x$, $PM_{10}$, Hydrocarbons, Benzene, 1,3-butadiene). Both the scheme-based model developed by Eunomia and Webtag calculate the impacts on the local population/area; however the former focuses on the Health impacts associated with $NO_x$ and $PM_{10}$, whereas the MEC method attempts to incorporate Heath and Non-health (local environment) impacts for the larger group of pollutants identified above. A similar calculation methodology is used in terms of estimating the health benefits in both models, but Eunomia's model uses more recent data (the core datasets updated in 2015 and 2017, in comparison to the use of data from 2001 and 2011 in Webtag).

The estimation of health benefits in HEAT does not directly consider air pollution benefits. However, estimates of the overall benefits to health derived from the physical activity of cycling and walking will be influenced by the amount of pollution that active travellers were exposed to. This, in turn, is captured in the epidemiological evidence used to develop the health benefits estimates in HEAT. As such, there is an overlap between the two tools in this respect. This is discussed further in Section 5.2.

# 2.0 Methodology for Scheme-based Model

## 2.1 Introduction

Eunomia has developed a model that considers the potential air pollution impacts of some of Sustrans' schemes. This section discusses the methodology behind the modelling work.

The model estimates two kinds of air pollution benefits from shifting to active travel. These are:

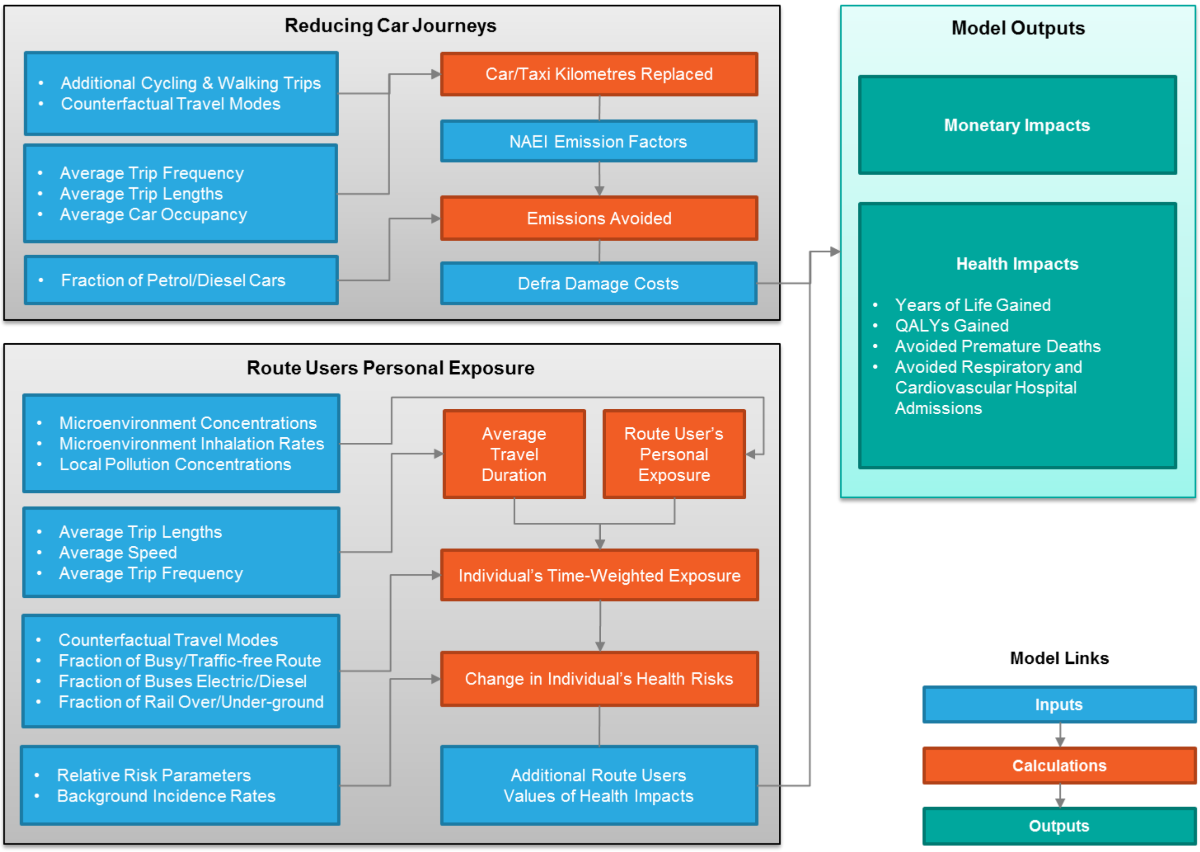
3) **Reducing Car Journeys:** This relates to the air quality benefits to the local population due to reduced emissions from car journeys replaced by active travel
4) **Route Users Personal Exposure:** This relates to the air quality benefit (or dis-benefit) to an individual due to change in pollution exposure from shifting to active travel.

Figure 1 illustrates the main steps involved in the calculation of the abovementioned benefits. The approach used can be summarised as follows:

- Data from Sustrans is used to consider switches in active travel occurring at a local level, supplemented by data from the UK's National Travel survey;
- Key technical assumptions in respect of calculating the route user's personal exposure are largely derived from the peer reviewed academic literature;
- The health benefits arising from changes in pollution (as a result of either a reduction in car journeys, or changes to route users' personal exposure) are estimated in line with the UK government's methodology for assessing these impacts.

Detailed assumptions, data sources, and various other technical aspects behind these calculation steps are discussed in the following sections.

## Figure 1: Modelling of Health Impacts of Air Pollution




*Source: Eunomia*

## 2.2 Reducing Car Journeys

Air pollution benefits occurring from a reduction in car journeys as result of the shift to active travel are estimated using the following steps:

1) Estimate the total car kilometres avoided in a year, which is derived from the total individual shifts to active travel from car;
2) Multiply the outputs from point 1 with road transport emission factors to derive the total avoided emissions over a year; and
3) Multiply that with the appropriate Defra air pollution damage costs per tonne of emission for health and monetary benefits to derive the total health and monetary impacts for a year.

These steps are explained in more detail in the subsequent sections.

### 2.2.1 Car Kilometres Avoided

Sustrans estimates the car kilometres avoided by shifts to active travel associated with each individual scheme in the Connect2 and the Linking Communities projects, using the National Travel Survey (NTS) data on average number of trips and trip lengths. However, these estimates vary significantly over different schemes and some of these seemed inconsistent with some of the other Sustrans data. So we have estimated the total annual car kilometres avoided following the approach set out below:

- The number of additional route users (adults and children) cycling and walking is taken from Sustrans' scheme usage data;

- The counterfactual (alternative) travel mode that could have been used instead of using active travel mode on the route is taken from the Route User Intercept Survey (RUIS);
- The purpose of the journey is also taken from RUIS;
- The average car occupancy for different journey purpose has been taken from the NTS ; and
- In the absence of any firm data, we have developed assumptions regarding the average number of trips for each of the different types of journey.

Table 1 presents the data used in the model on average car occupancy by journey purpose from NTS.

### Table 1: Average Car Occupancy by Purpose

| Journey Purpose | Average Car Occupancy |
|---|---|
| **Commuting** | 1.2 |
| **Education + Escort** | 2.0 |
| **Other (non-regular trips)** | 1.6 |

*Source: DfT NTS*

Assumptions regarding the frequency of trips for each type of journey are presented in Table 2. For regular trips made for commuting and education purposes, it was assumed that 2 trips will be made in a day. It was assumed there were a total of 3 commuting days per week (reduced to account for part-time employment and home-working), whilst there are assumed to be a total of 4.5 travel days per week, each with 2 trips, for education (and escort) to account for the absences from school. We also assumed one non regular trip made per day for other purposes, but assume only a quarter of them are on the scheme route.

### Table 2: Trip Frequency for each Journey Purpose

| Purpose | Weeks | Trips/Day | Days/Week | Trips per Year |
|---|---|---|---|---|
| **Commuting** | 46 | 2.00 | 3 | 276 |
| **Education + Escort** | 39 | 2.00 | 4.5 | 351 |
| **Other (non-regular trips)** | 52 | 0.25 | 7 | 91 |

*Source: Eunomia*

## 2.2.2 Emission Factors

Emission factors for cars, which consider emissions of different pollutants per vehicle kilometre travelled, are reported by the National Atmospheric Emissions Inventory (NAEI).[2] The emission factors used in the model are reported in Table 3.

[2] http://naei.defra.gov.uk/data/ef-transport

**Table 3: Pollution Emission Factors**

| | $PM_{10}$ | | NOx | |
|---|---|---|---|---|
| | **Petrol** | **Diesel** | **Petrol** | **Diesel** |
| **Exhaust Emissions factor (g/km)** | 0.001 | 0.016 | 0.118 | 0.635 |
| **Brake/Tyre/Road Emissions factor (g/km)** | 0.022 | 0.022 | | |

*Source: NAEI*

The model assumes approximately half of the fleet is petrol and half diesel, based on the national average fleet distribution by fuel types. However, this is a scheme level assumption, and thus can be adjusted for each scheme separately if more information becomes available on the proportion of vehicles of each fuel type for a particular area.

### 2.2.3 Damage Costs

Damage costs for $PM_{10}$ and NOx measure the annual health and non-health impacts from these pollutants in monetary terms, for a tonne of emission of each pollutant arising from road transport. These data are standard assumptions used in cost benefit analysis by government, and have been developed by Defra over many years.[3] They are intended to be used in relatively high level policy appraisals, where an initial estimate of the environmental impacts of pollution is deemed appropriate, and where the output from the appraisal is likely to be an estimated reduction in the tonnage of a given pollutant.[4]

National data sets on the overall health impacts of air pollution are used to consider pollution from different sources, such that the impacts can be apportioned per tonne of pollutant. Different costs exist for pollution from traffic and other industrial sources – the traffic estimates being higher as the pollution is emitted closer to the ground, and as such, it is deemed to have a more significant effect upon the population. The underlying approach to calculation of the health impacts is largely the same as that set out in Section 2.3.3 and Section 2.3.4.

The damage costs used in the model for $PM_{10}$ and NOx are reported in Table 4 and Table 5, respectively, with values given for different types of locations (these values being influenced by the density of population in different areas).

[3] https://www.gov.uk/guidance/air-quality-economic-analysis
[4] This is distinct from analyses that focus on a reduction in the concentration of pollutant in the atmosphere, measured typically in terms of mg pollutant per $m^3$

### Table 4: $PM_{10}$ Damage Costs for Transport by Location

| Location Type | Damage cost per tonne of pollutant per year, 2015 prices | | |
|---|---|---|---|
| | Central Estimate | Low Central Range | High Central Range |
| **Transport average** | £58,125 | £45,510 | £66,052 |
| **Transport central London** | £265,637 | £207,981 | £301,859 |
| **Transport inner London** | £273,193 | £213,898 | £310,447 |
| **Transport outer London** | £178,447 | £139,717 | £202,781 |
| **Transport inner conurbation** | £141,248 | £110,590 | £160,507 |
| **Transport outer conurbation** | £87,770 | £68,722 | £99,739 |
| **Transport urban big** | £104,627 | £81,918 | £118,895 |
| **Transport urban large** | £84,283 | £65,989 | £95,776 |
| **Transport urban medium** | £66,264 | £51,881 | £75,300 |
| **Transport urban small** | £41,850 | £32,768 | £47,557 |
| **Rural** | £18,020 | £14,108 | £20,476 |

*Source: Defra*

### Table 5: NOx Damage Costs for Transport by Location if $PM_{10}$ is also valued

| Location Type | Damage cost per tonne of pollutant per year, 2015 prices | | |
|---|---|---|---|
| | Central Estimate | Low Central Range | High Central Range |
| **Transport average** | £21,044 | £8,417 | £33,670 |
| **Transport central London** | £96,171 | £38,468 | £153,874 |
| **Transport inner London** | £98,907 | £39,563 | £158,251 |
| **Transport outer London** | £64,605 | £25,842 | £103,368 |
| **Transport inner conurbation** | £51,137 | £20,455 | £81,820 |
| **Transport outer conurbation** | £31,776 | £12,710 | £50,842 |
| **Transport urban big** | £37,879 | £15,152 | £60,607 |
| **Transport urban large** | £30,514 | £12,206 | £48,822 |
| **Transport urban medium**[1] | £28,788 | £11,515 | £46,061 |
| **Transport urban small**[1] | £18,182 | £7,273 | £29,091 |

| Location Type | Damage cost per tonne of pollutant per year, 2015 prices | | |
|---|---|---|---|
| | Central Estimate | Low Central Range | High Central Range |
| Rural[1] | £7,829 | £3,131 | £12,526 |

*Notes:*
1. *These damage costs were not reported for NOx if PM is also valued, so NOx damage cost when PM is not valued were used instead.*

*Source: Defra*

The data behind the damage costs can also be used to derive other quantified health impacts instead of the monetised impacts, including:

- Chronic mortality effects: the numbers of life years lost (over 100 years) per tonne of pollutant; and
- Morbidity effects – number of respiratory and cardiovascular hospital admissions avoided per year per tonne of pollutant.

This allows for several alternative metrics by which to measure the health impacts from air pollution apart from the damage cost data which express the output in monetary terms. The above data were included in Defra's 2011 report on damage cost methodology, and are presented in Table 6.[5] The data is used to derive alternative outputs from the modelling work, in terms of number of premature deaths avoided and avoided hospital emissions. This is discussed further in Section 3.1.3.

### Table 6: Supplementary Data on $PM_{10}$ Health Impacts

| Location Type | Health impacts per tonne of pollutant per year | | |
|---|---|---|---|
| | Years of Life Lost (cases over 100-year period) | Respiratory hospital admissions (cases per annum) | Cardiovascular hospital admissions (cases per annum) |
| Transport average | 2.059 | 0.017 | 0.017 |
| Transport central London | 10.226 | 0.079 | 0.080 |
| Transport inner London | 10.517 | 0.082 | 0.082 |
| Transport outer London | 6.870 | 0.053 | 0.053 |
| Transport inner conurbation | 5.438 | 0.042 | 0.042 |
| Transport outer conurbation | 3.379 | 0.026 | 0.026 |
| Transport urban big | 4.028 | 0.031 | 0.031 |
| Transport urban large | 3.245 | 0.025 | 0.025 |

[5] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/182391/air-quality-damage-cost-methodology-110211.pdf

| Location Type | Health impacts per tonne of pollutant per year | | |
|---|---|---|---|
| | Years of Life Lost (cases over 100-year period) | Respiratory hospital admissions (cases per annum) | Cardiovascular hospital admissions (cases per annum) |
| **Transport urban medium** | 2.551 | 0.020 | 0.020 |
| **Transport urban small** | 1.611 | 0.013 | 0.013 |
| **Rural** | 0.694 | 0.005 | 0.005 |

*Source: Defra*

Defra updated the damage costs for NOx in 2015, but the health impacts of avoided NOx emissions presented in Table 6 were not updated in line with the new NOx damage cost values. The health impacts of avoided emissions are therefore extrapolated from the health impact data for PM, to give the revised outputs for NOx presented in Table 7.

### Table 7: NOx Health Impacts

| Location Type | Health impacts per tonne of pollutant per year | | |
|---|---|---|---|
| | Years of Life Lost (cases over 100-year period) | Respiratory hospital admissions (cases per annum) | Cardiovascular hospital admissions (cases per annum) |
| **Transport average** | 0.745 | 0.006 | 0.006 |
| **Transport central London** | 3.702 | 0.029 | 0.029 |
| **Transport inner London** | 3.808 | 0.030 | 0.030 |
| **Transport outer London** | 2.487 | 0.019 | 0.019 |
| **Transport inner conurbation** | 1.969 | 0.015 | 0.015 |
| **Transport outer conurbation** | 1.223 | 0.009 | 0.009 |
| **Transport urban big** | 1.458 | 0.011 | 0.011 |
| **Transport urban large** | 1.175 | 0.009 | 0.009 |
| **Transport urban medium** | 1.108 | 0.009 | 0.009 |
| **Transport urban small** | 0.700 | 0.006 | 0.006 |
| **Rural** | 0.302 | 0.002 | 0.002 |

*Source: Eunomia*

It should be noted that Defra does not report damage costs for $PM_{2.5}$, which is more harmful than $PM_{10}$. Therefore, the model underestimates the benefits from reducing car journeys. Benefits modelling for route users' personal exposure, on the other hand, is based on exposure to $PM_{2.5}$ (see Section 2.3.3), and therefore does not suffer from this issue.

## 2.3 Route Users Personal Exposure

The individuals who shift to active travel will also experience a change in their exposure to pollution, as they will be exposed to a different microenvironment. In the context of this project, the term microenvironment is assumed to mean well-defined surroundings (e.g. travelling in a car) resulting in a similar exposure of individuals to air pollution, taking into account the variation in people's breathing patterns resulting from changing levels of activity.

So, for example, travellers who were previously exposed to pollution whilst sitting on a bus may now be exposed to a different amount of pollution whilst, for example, walking a different route. For walkers, the amount of atmospheric pollution they are exposed to will differ if the route they take is away from the road; their journey duration will also change. Each of these factors affects the total amount of pollution exposure.

Benefits (or dis-benefits) from changes in route users' personal exposure - occurring as a result of shifting to active travel mode - are estimated using the following steps, which are summarised in the list below:

1) The personal exposure of a route user to different pollutants under different travel modes is estimated, taking into account the pollution concentration and inhaled dosage of pollutants for each travel mode;
2) Using the above parameters in point 1, we derive an estimate of the time-weighted average daily personal exposure for individual travellers under the different travel modes, based on average daily travel journey times for these different modes;
3) To derive the change in health risk that is attributable to a change in travel mode (and therefore pollution exposure), we apply what are known as *relative risk parameters*, which express the different health risks arising from the changes in personal exposure to pollution, occurring as a result of the switch to cycling and walking from the counterfactual travel modes;[6] and
4) The output is then multiplied by the number of additional route users cycling and walking to calculate the annual health impacts, which are then monetised so that the outputs can be expressed financial terms.

These steps are explained in more detail in the sections that follow.

### 2.3.1 Personal Exposure under Different Travel Modes

Personal exposure to pollution under different travel modes depends on the following three factors:

1) The concentration of pollutants in the microenvironment associated with each mode of travel – all other things being equal, the literature suggests pollution exposure to bus travellers differs significantly from that of car passengers, for example. This, however, is also influenced by other pollution sources within each area other than those relating to road transport;
2) The individual's respiratory/inhalation rate for that travel mode – active travellers having a higher respiratory rate than those sitting on a bus or train, for example; and
3) Taken together, points 1 and 2 affect the deposition of pollution in the lungs of the individual; a pollution deposition factor is therefore derived for each travel mode.

[6] This is term described in more detail in Section 2.3.3

With reference to the first point, the starting point for understanding the exposure of travelling individuals to pollution in each microenvironment is the measured air pollution data, sourced from Defra's UK-Air website. This site provides measured pollution concentration data for each area in the UK. Different measurements are available – in some cases, both the background pollution (away from kerbside sites) and kerbside measurements are available, whereas in other areas, one or the other may not be available.

In most cases, when calculating the personal exposure in the microenvironment for different travel modes we have used the average annual mean of measured kerbside concentration of pollutants. We have used Defra's modelled background pollution levels for estimating the exposure of travellers on the off-road schemes, as these route users will not be being exposed to the same level of pollution as those travelling on the road. This value is assumed to be representative of exposure within buildings (rather than being outside). The same source is used to estimate pollution levels when individuals are not travelling. In this case, however, we use the modelled background concentration with the uplift factor for resting.[7]

To account for variation in pollution in the microenvironment associated with each mode of travel – including the change in inhalation rates through exercise - we have used data from the peer reviewed literature to create *uplift factors*. These are applied to the data on the pollutant concentration for each area. The aim is that these factors take into account the deposition of pollution in the lungs' of the travellers, as set out in the points above.

For a more detailed discussion on microenvironment concentrations and respiration rates under different travel modes, see, for example: de Nazelle et al. (2012),[8] Zuurbier et al. (2009, 2010, 2011),[9,10,11] and Int Panis et al. (2010).[12]

Table 8 presents the different relative inhalation rates and associated relative pollution concentrations for different microenvironments, together with our estimated pollution uplift factors which are used in the model.[13] The data on inhalation rates and pollution concentration were sourced from various academic literature and then scaled appropriately using expert judgement.[14] Then the concentration uplift factor for each microenvironment is

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[7] The use of time-weighting is discussed further in Section **Error! Reference source not found.**

[8] de Nazelle, A., Fruin, S., Westerdahl, D., Martinez, D., Ripoll, A., Kubesch, N., and Nieuwenhuijsen, M. (2012) A travel mode comparison of commuters' exposures to air pollutants in Barcelona, *Atmospheric Environment*, Vol.59, pp.151–159

[9] Zuurbier, M., Hoek, G., Hazel, P. van den, and Brunekreef, B. (2009) Minute ventilation of cyclists, car and bus passengers: an experimental study, *Environmental Health*, Vol.8, No.1, p.48

[10] Zuurbier, M., Hoek, G., Oldenwening, M., Lenters, V., Meliefste, K., van den Hazel, P., and Brunekreef, B. (2010) Commuters' Exposure to Particulate Matter Air Pollution Is Affected by Mode of Transport, Fuel Type, and Route, *Environmental Health Perspectives*, Vol.118, No.6, pp.783–789

[11] Zuurbier, M., Hoek, G., Oldenwening, M., Meliefste, K., van den Hazel, P., and Brunekreef, B. (2011) Respiratory Effects of Commuters' Exposure to Air Pollution in Traffic:, *Epidemiology*, Vol.22, No.2, pp.219–227

[12] Int Panis, L., de Geus, B., Vandenbulcke, G., et al. (2010) Exposure to particulate matter in traffic: A comparison of cyclists and car passengers, *Atmospheric Environment*, Vol.44, No.19, pp.2263–2270

[13] We have ignored the effects on lung deposition factor because of lack of data for different microenvironments.

[14] See, for example, de Nazelle, A., Fruin, S., Westerdahl, D., Martinez, D., Ripoll, A., Kubesch, N., and Nieuwenhuijsen, M. (2012) A travel mode comparison of commuters' exposures to air pollutants in Barcelona, *Atmospheric Environment*, Vol.59, pp.151–159,Zuurbier, M., Hoek, G., Hazel, P. van den, and Brunekreef, B. (2009) Minute ventilation of cyclists, car and bus passengers: an experimental study, *Environmental Health*, Vol.8, No.1, p.48,Zuurbier, M., Hoek, G., Oldenwening, M., Lenters, V., Meliefste, K., van den Hazel, P., and Brunekreef, B. (2010) Commuters' Exposure to Particulate Matter Air Pollution Is Affected by Mode of

derived by multiplying the relative inhalation rates with the associated pollution concentrations. It can be seen that where active travellers are concerned, different concentration uplift factors are provided for the busy and traffic-free routes – reflecting the differences in route users' exposure for the different routes.

### Table 8: Microenvironment Concentration and Inhalation Rates

| Microenvironment | Inhalation Rate (relative to rest level) | Concentration (relative to background level) | Concentration uplift factor |
|---|---|---|---|
| | | $PM_{2.5}$ | |
| **Sleep (background)** | 0.50 | 1.00 | 0.50 |
| **Rest (background)** | 1.00 | 1.00 | 1.00 |
| **Car** | 1.18 | 3.84 | 4.53 |
| **Taxi** | 1.18 | 4.19 | 4.95 |
| **Bus (Diesel)** | 1.27 | 3.48 | 4.43 |
| **Bus (Electric)** | 1.27 | 2.47 | 3.14 |
| **Rail (Overground)** | 1.27 | 6.85 | 8.71 |
| **Rail (Underground)** | 1.27 | 20.39 | 25.90 |
| **Cycling (Busy)** | 2.35 | 3.38[1] | 7.95 |
| **Cycling (Traffic-free)** | 2.35 | 1.00 | 2.35 |
| **Walk (Busy)** | 2.04 | 2.78 | 5.66 |
| **Walk (Traffic-free)** | 2.04 | 1.00 | 2.04 |
| | | NOx | |
| **Sleep (background)** | 0.50 | 1.00 | 0.50 |
| **Rest (background)** | 1.00 | 1.00 | 1.00 |
| **Car** | 1.18 | 2.31 | 2.72 |
| **Taxi** | 1.18 | 2.31 | 2.72 |
| **Bus (Diesel)** | 1.27 | 3.44 | 4.37 |
| **Bus (Electric)** | 1.27 | 2.44 | 3.10 |
| **Rail (Overground)** | 1.27 | 1.15 | 1.46 |
| **Rail (Underground)** | 1.27 | 3.43 | 4.36 |
| **Cycling (Busy)** | 2.35 | 1.91[1] | 4.49 |
| **Cycling (Traffic-free)** | 2.35 | 1.00 | 2.35 |

Transport, Fuel Type, and Route, *Environmental Health Perspectives*, Vol.118, No.6, pp.783–789,de Hartog, J.J., Boogaard, H., Nijland, H., and Hoek, G. (2010) Do the Health Benefits of Cycling Outweigh the Risks?, *Environmental Health Perspectives*, Vol.118, No.8, pp.1109–1116,Kaur, S., Nieuwenhuijsen, M., and Colvile, R. (2005) Pedestrian exposure to air pollution along a major road in Central London, UK, *Atmospheric Environment*, Vol.39, No.38, pp.7307–7320,Nyhan, M., McNabola, A., and Misstear, B. (2014) Comparison of particulate matter dose and acute heart rate variability response in cyclists, pedestrians, bus and train passengers, *Science of The Total Environment*, Vol.468–469, pp.821–831

| Microenvironment | Inhalation Rate (relative to rest level) | Concentration (relative to background level) | Concentration uplift factor |
|---|---|---|---|
| **Walk (Busy)** | 2.04 | 2.03 | 4.13 |
| **Walk (Traffic-free)** | 2.04 | 1.00 | 2.04 |

**Note:**

1. For schemes where the cycle paths on busy routes are situated on the pedestrian sidewalks instead of being on the road with the traffic, the microenvironment concentration for the cyclists will be similar to the pedestrians on the sidewalks. To account for this, the relative concentration for cycling on a busy route can be adjusted to the level of relative concentration for walking on a busy route for each scheme in the model.

*Source: Eunomia*

These pollution uplift factors are then multiplied with the local pollution concentrations to calculate the personal exposure of individuals to pollution for each microenvironment.

### 2.3.2 Time-Weighted Personal Exposure

The time spent taking each type of journey is determined by the frequency of the journey, the average trip distance and the speed of the transport. For example:

- Commuters make around 1 trip per day on average (accounting for weekends, holidays and part-time workers) and typically use the same route, whereas other (non-regular) trips are less likely to be on the same route. Due to the higher frequency of car trips for commuting compared to non-regular car trips, the time spent commuting by car each day is therefore higher on average than the time spent taking other (non-regular) journeys by car, even if these journeys have the same trip distance.
- The mode of transport also affects the travel duration. For example, walking to work often makes use of a more direct route but people walk more slowly than cars drive so the overall journey time is longer despite the distance being shorter.

In the absence of any other information, the average trip distances for cycling and walking trips are estimated based on the journey purpose, the data relating to which, in turn, are sourced from NTS. This information is presented in Table 9. Data on commuting and education / escort were directly derived from the NTS. For the non-regular trips, we used the average distanced travelled for all types of non-regular trips (e.g. recreation, shopping, visiting friends/family, etc.).

### Table 9: Average Duration of Travel based on Journey Purpose for Walking and Cycling Trips

| Journey Purpose | Average Trip Length (km) | | |
|---|---|---|---|
| | Cycling | Walking | Average of Cycling and Walking[1] |
| **Commuting** | 4.6 | 1.4 | 3.0 |
| **Education + Escort** | 2.6 | 1.0 | 1.8 |
| **Other (non-regular trips)** | 4.6 | 1.4 | 3.0 |

| **Notes:** |
| --- |
| 1. **The average trip length is used to estimate the length of journeys undertaken by the counterfactual modes, as is described further below.** |

*Source: DfT NTS 2015*

However, for the counterfactual travel modes (i.e., other than walking and cycling), the NTS data could not be used. This is because the average trip lengths for journeys undertaken using cars, buses, train, etc. in the NTS are very high, due to high number of long sub-urban and rural trips made. Many of these journeys could not be replaced by active travel. So rather than use the NTS data as a means of estimating journey length, we use the average of the cycling and walking trip lengths for each of the different purposes in Table 9, and apply a scaling factor to the weighted average trip length for each travel mode, based on the directness of routes in each case. For example, walking and cycling trips usually involve more direct (and often off-road) routes than other travel modes, whilst buses usually have the longest route. Average trip lengths based on trip purpose for counterfactual travel modes are presented in Table 10.

## Table 10: Average Duration of Travel based on Journey Purpose for Counterfactual Travel Modes

| | Average Trip Lengths for Counterfactual Mode | | | |
| --- | --- | --- | --- | --- |
| | **Travel Mode** | **Weighted Average Trip Length (km)** | **Scaling Factor** | **Average Trip Length (km) with scaling factor applied** |
| **Commute** | **Car** | 3.0 | 1.5 | 4.5 |
| | **Taxi** | 3.0 | 1.5 | 4.5 |
| | **Bus** | 3.0 | 1.8 | 5.3 |
| | **Rail** | 3.0 | 1.3 | 3.8 |
| **Education + Escort** | **Car** | 1.8 | 1.5 | 2.7 |
| | **Taxi** | 1.8 | 1.5 | 2.7 |
| | **Bus** | 1.8 | 1.8 | 3.2 |
| | **Rail** | 1.8 | 1.3 | 2.3 |
| **Other (non-regular) trips** | **Car** | 3.0 | 1.5 | 4.5 |
| | **Taxi** | 3.0 | 1.5 | 4.5 |
| | **Bus** | 3.0 | 1.8 | 5.3 |
| | **Rail** | 3.0 | 1.3 | 3.8 |

*Source: Eunomia*

To estimate the average trip duration by purpose for different modes of travel, we have developed assumptions about the average speed for each mode, during peak and non-peak hours of travel, which are presented in Table 11. The distinction of average speed between peak and off-peaks hours is important, as this allows us to account for the impact of higher traffic on the route during peak hours for commuting and education trips. However, we assume the same average speed during peak and off-peak hours for active travel mode, considering they are unlikely to be affected by the increased traffic flow during the peak periods. It should be noted that this is a scheme level assumption, and thus can be adjusted for each scheme separately if more information is available on average speed for different modes during peak and non-peak hours.

### Table 11: Average Speed Assumptions

| Mode | Speed (km/hr) | |
|---|---|---|
| | Off-Peak | Peak |
| **Car** | 20 | 15 |
| **Taxi** | 20 | 15 |
| **Bus** | 15 | 11 |
| **Rail** | 40 | 40 |
| **Cycle** | 12 | 12 |
| **Walking** | 4 | 4 |

*Source: Eunomia*

For each group of travellers (commuters, education and others), we calculate the travel duration on an average day for each counterfactual transport mode - based on trip length, average speed (during peak and off-peak hours), and the annual trip frequency by purpose (Table 2). The output of these calculations is presented in Table 12.

### Table 12: Travel Duration on Average Day by Purpose for Counterfactual Travel Modes

| Journey Purpose | Counterfactual Transport Mode | Duration (hr/day) | Duration (mins/day) |
|---|---|---|---|
| **Commute** | **Car** | 0.2268 | 14 |
| | **Taxi** | 0.2268 | 14 |
| | **Bus** | 0.3529 | 21 |
| | **Rail** | 0.0709 | 4 |
| **Education + Escort** | **Car** | 0.1731 | 10 |
| | **Taxi** | 0.1731 | 10 |
| | **Bus** | 0.2693 | 16 |
| | **Rail** | 0.0541 | 3 |

| | | | |
|---|---|---|---|
| **Other (non-regular) trips** | **Car** | 0.0561 | 3 |
| | **Taxi** | 0.0561 | 3 |
| | **Bus** | 0.0873 | 5 |
| | **Rail** | 0.0234 | 1 |

*Source: Eunomia*

Similarly, for walking and cycling trips, we calculate the travel duration on an average day for each group (commuters, education and other). However, the travel duration on an average day for walking and cycling trips is split into the time spent travelling on busy (on-road) and quiet (off-road) parts of the route, based on the route characteristics for each scheme.

Finally, we calculate for an individual traveller the time weighted exposure to pollution associated with each journey purpose and relating to each transport mode, accounting for the differences in travel duration. To do this, we calculate the exposure to an individual over 24 hours. At points in the day when individuals are not travelling, we assume they are exposed to the background concentration of pollution. During the journey period, travellers receive the personal exposure for each transport mode calculated in Section 2.3.1.

Time weighted exposure levels calculated for bus and rail travellers also incorporate the fraction of buses that are electric-powered, and the fraction of rail travel that takes place underground within the area where the scheme is located, respectively to reflect the differential in exposure within these different microenvironments as seen in the data.

### 2.3.3 Health Risks Attributable to Change in Travel Modes

The change in health risk that is attributable to a change in travel mode is calculated using relative risk parameters for different health outcomes. The relative risk parameter measures the change in health risk – measured in probabilistic terms - to an individual occurring as a result of a 10 $\mu g/m^3$ change in pollution concentration. This is considered for specific health endpoints (or outcomes), such as premature mortality, hospital admissions for cardiovascular or respiratory diseases, etc.).

The health endpoints modelled are listed below:

- **Long-term (chronic) effects:** premature mortality from chronic (long-term) exposure to air pollutants; and
- **Short-term (acute) effects:** Respiratory and cardiovascular hospital admissions from acute (short-term) exposure to air pollution.

The relative risk parameters for the above health endpoints are considered separately for $PM_{2.5}$ and $NO_2$, and are sourced from the UK Government's Committee on the Medical Effects of Air Pollutants (COMEAP) as well as other recent meta-analysis studies from the academic literature. In this respect, it is understood that the COMEAP is due to publish an update on some assumptions used in the calculation of the health impacts of air pollution. Results in this report will be revised when these updates are published. The values used in this analysis are presented in Table 13.[15,16,17,18] To interpret the values in the table, the values mean, for example, that for every 10 µg/m$^3$ increase in $PM_{2.5}$, the data indicates that the risk of premature mortality increases by 6%.

### Table 13: Relative Risk Parameters

| Health Endpoint | | Relative Risk Parameters | |
|---|---|---|---|
| | | $PM_{2.5}$ | $NO_2$ |
| **Long term effects** | Chronic or Premature Mortality | 1.06 | 1.0175 |
| **Short term effects** | Respiratory Hospital Admissions (RHA) | 1.019 | 1.0052 |
| | Cardiovascular Hospital Admissions (CHA) | 1.0091 | 1.0042 |

*Source: COMEAP, meta-analysis studies*

The relative risk parameters are applied to the calculated change in pollution exposure values for travellers switching modes, using a Log (multiplicative) scaling technique. This technique is used because the relationship between the two variables is non-linear.

Health benefits are calculated in the model by considering the number of cases of each health endpoint that are avoided through changes in the level of exposure to air pollution. This is calculated by multiplying the changed relative risk for travellers (calculated in the previous step) by the *background incidence rate*. The background incidence rate is expressed in terms of the number of cases per person for a given year; values used in the model are reported in Table 14, and are provided for each health endpoint, as follows:

- The background incidence rate for premature mortality has been calculated using the population and mortality data from the 2011 population census for the UK. A background incidence rate of 0.01382 means that 1,382 premature deaths occur every year for every 100,000 people.
- Background incidence rates for respiratory and cardiovascular hospital episodes were constructed using the hospital admissions data for England (as a proxy for the UK), for these types of diseases.

### Table 14: Background Incidence Rates

| Health Endpoint | Background Incidence Rate (cases per person per year) |
|---|---|

[15] 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
[16] 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
[17] 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.
[18] 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).

| | |
|---|---|
| **Chronic (or premature) Mortality** | 0.01382 |
| **Respiratory Hospital Admissions (RHA)** | 0.01379 |
| **Cardiovascular Hospital Admissions (CHA)** | 0.0095 |

*Source: Eunomia (calculated based on data from ONS and Public Health England)*

A more detailed discussion on estimating health risk attributable to change in pollution concentration/exposure can be found in the Public Health England report on estimating mortality burdens on particulate air pollution.[19]

### 2.3.4 Monetised and Non-monetised Impacts of Switching

The calculations set out in Section 2.3.3 result in the calculation of the benefits in terms of the number of health endpoint cases avoided for the shift in travel mode. From these benefits we can calculate the monetised and non-monetised impacts for the total number of individuals making the switch. The model considers:

- Premature deaths avoided in a year;
- Years of life gained (YOLG) from avoided premature deaths;
- Gain in Quality Adjusted Life Years (QALY) associated with life-years gained; and
- Hospital admissions avoided per year for respiratory and cardiovascular diseases.

The number of premature deaths avoided by reducing air pollution is one of the most widely used metrics for communicating public health risks. Long term exposure to air pollution increases the risk of dying from respiratory and cardiovascular diseases. This metric therefore measures the number of premature deaths avoided in a year from reduction in long-term exposure to air pollution. Usually, the number of deaths avoided is estimated for adults aged 30 years or more, mainly due to low number of deaths occurring in ages below 30.

Besides estimating the number of premature deaths avoided from reduction in air pollution, it is also useful to estimate the reduction in potential loss of life associated with the reduction in exposure to air pollution. This is expressed as the years of life gained to the population from premature deaths avoided due to the reduction in exposure to air pollution. The total years of life gained to the population from premature deaths avoided is usually estimated using complex life-table analysis. However, for calculation simplicity, COMEAP recommends using an average of 12 life-years lost per premature death from chronic exposure to air pollution, which was used in the model.[20]

Another useful metric for public health policy appraisal is gains in Quality Adjusted Life Years, which measures the state of health of a person or a group in terms of both the quality and the quantity of years lived. Thus, one QALY is equal to 1 year of life in perfect health. To estimate the gains in QALYs associated with the years of life gained from reduced exposure to air pollution, the total years of life gained is multiplied by the QALY conversion factor of 0.65, developed by Eunomia for the NICE model.[21]

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[19] Public Health England (2014) *Estimating local mortality burdens associated with particulate air pollution*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/332854/PHE_CRCE_010.pdf

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

[21] Eunomia / UWE (2017) Air Pollution: Economic Analysis, Final Report for NICE, April 2017

The above three measures of health impacts are associated with the mortality effects of long-term exposure to air pollution. The avoided hospital admissions for respiratory and cardiovascular diseases, on the other hand, capture the morbidity effects of short-term exposure to air pollution.

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.[22] Table 15 presents the IGCB recommended values (converted to 2016-17 prices using the GDP deflator data from the Office of National Statistics) used in the model to monetise the different health outcomes.

### Table 15: Monetary Values of Different Health Effects

| Health Endpoint | Monetary Value (2016-17 prices) |
|---|---:|
| **Value of Life Years (VOLY) – applied to the premature mortality endpoint** | £42,683 |
| **Respiratory Hospital Admissions (RHA)** | £8,095 |
| **Cardiovascular Hospital Admissions (CHA)** | £8,242 |

*Source: Eunomia estimates using IGCB recommended values*

To estimate the monetary impact of premature mortality using the value of life years, (VOLY), the number of premature deaths avoided was converted to total years of life gained (YOLG) to the population using the average of 12 life-years lost per premature death as per COMEAP recommendations.

## 2.4 Case Studies Included in Model

The following Connect2 case studies were selected for initial inclusion in the model:

- Glasgow
- Dumfries
- Bethnal Green
- Havering
- Norwich
- Northampton
- Birmingham
- Plymouth
- Dover
- Leeds
- Cardiff

Data was also included for the following Community Links case studies:

- River Lossie – Moray
- Adelphi Street – Glasgow
- Milton Bridge, Midlothian
- Balmaha, Loch Lomond

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

- Almondvale Park, West Lothian
- Dunoon, Argyll and Bute
- Great Glen Way, Scottish Canals

# 3.0 Results of Scheme-based Model

## 3.1 Results from Case Study Schemes

Headline results for the Connect2 schemes are shown in Table 16. Results show separately the value of impacts relating to the reduction in car journeys, and the value of impacts relating to changes in the individual's exposure to pollution through changing transport modes. In the case of the latter, a breakdown is provided in respect of the purpose of the journey – allowing for a separate consideration of the contribution of regular journeys (commuting and education) from leisure travellers, as was discussed in Section 2.2.

Table 17 shows the initial results for 7 Scottish Community Links schemes. The data for these schemes shows smaller impacts for most of these schemes than is the case for the Connect2 schemes, occurring as a result of the reduced numbers of scheme users in some cases according to the survey data. In a few cases – such as for the Leeds scheme – the number of scheme users appeared to reduce post intervention, leading to negative numbers with respect to the avoided emissions from a reduction in the number of car journeys.

The results in both tables are positive where a benefit is seen, but may be negative in some cases where the net impact is an increase in the health impacts associated with increased exposure to air pollution. For a few schemes (such as Leeds) a negative value is seen in the second column – in these cases the number of scheme users declined between survey periods.

### Table 16: Headline Results for 11 Connect2 Case Studies

| | Annual impact of emissions avoided due to reduction in car journeys | Annual impacts from route user's changed exposure to pollution | | | | Overall impact |
|---|---|---|---|---|---|---|
| | | Commuting | Education | Others | Total | |
| **Connect2 Glasgow** | £28,224 | £64,751 | £6,348 | £5,498 | £76,596 | £104,820 |
| **Connect2 Dumfries** | £9,666 | £3,128 | £0 | -£637 | £2,491 | £12,157 |
| **Connect 2 Bethnal Green** | £12,254 | £2,883 | £297 | -£622 | £2,558 | £14,811 |
| **Connect 2 Havering** | £1,033 | £56 | £92 | £29 | £177 | £1,209 |
| **Connect 2 Norwich** | £3,186 | £739 | £115 | -£234 | £619 | £3,805 |
| **Connect 2 Northampton** | £7,251 | £1,133 | £82 | £1,959 | £3,174 | £10,425 |
| **Connect 2 Birmingham** | £4,135 | £722 | £80 | £830 | £1,632 | £5,766 |
| **Connect 2 Plymouth** | £25,718 | £4,127 | £102 | -£1,418 | £2,810 | £28,528 |
| **Connect 2 Dover** | £4,871 | £9,563 | £604 | £2,206 | £12,372 | £17,243 |
| **Connect 2 Leeds** | -£866 | -£361 | -£94 | -£418 | -£874 | -£1,740 |
| **Connect 2 Cardiff** | £7,146 | -£664 | £0 | -£2,335 | -£2,999 | £4,146 |

### Table 17: Headline Results for 7 Community Links Case Studies

| | Annual impact of emissions avoided due to reduction in car journeys | Annual impacts from route user's changed exposure to pollution | | | | Overall impact |
|---|---|---|---|---|---|---|
| | | Commuting | Education | Others | Total | |
| **River Lossie - Moray** | -£295 | -£78 | £0 | -£372 | -£450 | -£745 |
| **Adelphi Street - Glasgow** | £899 | £1,054 | £165 | £1,202 | £2,421 | £3,319 |
| **Milton Bridge, Midlothian** | £265 | -£192 | -£4 | -£165 | -£360 | -£96 |
| **Balmaha, Loch Lomand** | £147 | £0 | £25 | £83 | £108 | £255 |
| **Almondvale Park, West Lothian** | £1,216 | £866 | £83 | £1,046 | £1,995 | £3,211 |
| **Dunoon, Argyll and Bute** | £2,592 | £760 | £172 | £1,211 | £2,143 | £4,735 |
| **Great Glen Way, Scottish Canals** | £0 | £0 | £0 | £0 | £0 | £0 |

The data shows that for different schemes, the impacts in respect of the exposure of active travellers to air pollution arising from their change in travel behaviour are sometimes positive, and sometimes negative. A benefit is always seen from the avoided emissions from the reduction in car journeys, but the size of this benefit also varies between the different case studies. The factors associated with the variation in these different elements are discussed separately in the sub-sections that follow, which discuss separately:

- the benefits arising from a reduction in the number of car journeys (occurring from avoided car emissions), discussed in Section 3.1.1;
- the impacts arising as a result of changes in route users' personal exposure to pollution, discussed in Section 3.1.2.

The results from the central scenario are also alternatively expressed in terms of the years of life gained, QALYs gained, premature deaths avoided, and avoided respiratory and cardiovascular hospital admissions – this is discussed further in Section 3.1.3.

### 3.1.1 Benefits from reduced numbers of car journeys

Section 2.2 confirms that a key element of the model considers the benefits arising from a reduction in car journeys, and the avoided emissions arising from this. The benefits in this case are considered for the population of the area where the scheme operates, rather than just being focused on those affecting scheme users.

Benefits arising from a reduction in the number of car journeys are directly correlated to the number of scheme users who would have journeyed by car prior to changing to active travel modes; impacts also vary depending on the number of individuals using the scheme. This is shown for each of the Connect2 schemes in Table 18, and for the Community Links schemes in Table 19. The table also presents the other key characteristics that affect a significant proportion of the variability between the case studies, as will be discussed subsequently. Section 2.2.3 further confirms there is some variation in the damage cost applied to the different locales, with pollution impacts in central London, for example, being given a higher damage cost than is the case for other conurbations. This variability arises from the size of population assumed affected by the pollution.

The combined impact can be seen by comparing several case studies and the associated characteristics:

- Glasgow and Plymouth show the highest benefits in terms of the avoided car emissions. Each has a relatively high number of scheme users who would have been using cars to undertake the journeys prior to switching to active travel;
- Northampton has the third highest benefit from a reduction in car journeys despite having far fewer scheme users than Glasgow and Plymouth, as a higher proportion of the scheme users in Northampton used cars prior to switching to active travel;
- For some areas such as Norwich and Dumfries, the overall proportion of scheme users that were formerly using cars for the different journey purposes is relatively low, and as such the total benefit from avoided car journeys is relatively low. In the case of Dumfries, the impact is further reduced by virtue of the relatively low damage cost attributed to the pollution impacts as this is a small urban area.

### Table 18: Key Characteristics of the Connect2 Case Studies

| | Additional active travel scheme users per year (after delivery of scheme) | Location type (used for determining damage cost data) | Proportion of the new route that is traffic-free (i.e. away from the highway) | Proportion of essential journeys undertaken by bus | Proportion of essential journeys undertaken by car |
|---|---|---|---|---|---|
| Connect 2 Glasgow | 3,968 | Inner conurbation | 72% | 29% | 37% |
| Connect 2 Dumfries | 2,573 | Urban small | 55% | 21% | 63% |
| Connect 2 Bethnal Green | 1,741 | Central London | 36% | 42% | 20% |
| Connect 2 Havering | 68 | Central London | 74% | 4% | 63% |
| Connect 2 Norwich | 1,116 | Urban medium | 46% | 41% | 50% |
| Connect 2 Northampton | 529 | Urban medium | 91% | 10% | 86% |
| Connect 2 Birmingham | 625 | Urban big | 80% | 22% | 66% |
| Connect 2 Plymouth | 4,003 | Urban medium | 47% | 27% | 51% |
| Connect 2 Dover | 1,716 | Urban small | 66% | 46% | 42% |
| Connect 2 Leeds | -139 | Urban large | 100% | 15% | 46% |
| Connect 2 Cardiff | 1,065 | Urban medium | 31% | 22% | 40% |

## Table 19: Key Characteristics of the Community Links Case Studies

| | Additional active travel scheme users per year (after delivery of scheme update) | Location type (used for determining damage cost data) | Proportion of the new route that is traffic-free (i.e. away from the highway) | Proportion of essential journeys undertaken by bus | Proportion of essential journeys undertaken by car |
|---|---|---|---|---|---|
| **River Lossie - Moray** | -56 | Urban Small | 100% | 33% | 52% |
| **Adelphi Street - Glasgow** | 174 | Urban Large | 100% | 31% | 23% |
| **Milton Bridge, Midlothian** | 71 | Urban Small | 30% | 32% | 32% |
| **Balmaha, Loch Lomand** | 378 | Rural | 100% | 0% | 46% |
| **Almondvale Park, West Lothian** | 262 | Urban Medium | 100% | 41% | 39% |
| **Dunoon, Argyll and Bute** | 682 | Urban Small | 100% | 21% | 37% |
| **Great Glen Way, Scottish Canals** | 77 | Rural | 87% | 0% | 0% |

### 3.1.2 Impacts from changes to route users' personal exposure

The second key element in the model concerns changes to the route user's personal exposure to pollution. In contrast to the impacts set out in Section 3.1.1, the impacts in this section consider just those relating to scheme users, rather than the population of the area within which the scheme is based.

The results show both positive and negative values. The negative values mean a dis-benefit – i.e., the scheme users are exposed to a greater amount of pollution than was the case before switching to active travel. As was the case with the avoided car emissions, these impacts are also correlated to a certain extent with the number of additional scheme users, with impacts being generally more substantial (either in positive or negative terms) for those schemes that attracted greater numbers of users. Thus values are typically smaller for the Community Links schemes, because many of them are in smaller settlements and consequently they have a smaller number of users.

Cyclists are assumed to receive a higher exposure of pollution than walkers, as the journey lengths are assumed to be longer (than is the case with the walkers) and the inhalation rate of cyclists is also assumed to be higher. The latter is reflected in the higher concentration uplift factors for cyclists presented in Table 8 derived from the literature previously presented in Section 2.3.1; the same section also confirms assumptions in respect of journey duration.

Dis-benefits arising from increased exposure to pollution following a shift to active travel are therefore more likely to be seen for cyclists than walkers. Thus those schemes with the highest numbers of walkers tend to show higher overall benefits than those with a larger number of cyclists. Results in this regard are sensitive to assumptions regarding the length of journey – if cyclists' journey times are in fact shorter than is modelled here, or car trips are longer, this would make it more likely that a benefit will arise from the personal exposure element for cyclists.

In this respect, as was discussed in Section 2.3.1, a key scheme characteristic is the proportion of the active travel route that is off-road, as this directly affects all active traveller's exposure to pollution. It will be seen from the data presented in Table 18 and Table 19 that this varies considerably between the different routes – in Glasgow, where the benefit in respect of route user's personal exposure is the greatest, a significant proportion of the route is off-road, whereas the proportion is much lower in areas like Plymouth and Cardiff - where results suggest there is a dis-benefit in terms of individuals' personal exposure to pollution.

As discussed in Section 5.2, it is important to note that to consider this properly, the model needs several data points for the local area in question, relating to the urban background pollution levels as well as the kerbside pollution data. The former is considered a better indication of exposure levels for off-road users than the latter. This information was not available for all areas - in many cases only the kerbside data was available - but the requisite data is available for Glasgow.

Our model suggests benefits arising from the personal exposure element of the model are also more likely to be seen where route users have switched from public transport to active travel, in comparison to schemes where more passengers switch from car to active travel. In particular, benefits are more consistently seen for bus passengers switching to active travel, as bus journeys are relatively long in duration in comparison to other forms of motorised transport, and the data suggests that ambient pollution levels are slightly higher than is typically seen in a car.

Conversely, personal exposure benefits tend to be lower where a larger number of route users switch from car to active travel, as journey times are shorter and ambient pollution levels are somewhat lower for car passengers than is the case for bus passengers (again, this is reflected in the lower pollution concentration uplift factor for car passengers).

It is important to note that where a reduction in car passenger is seen, there will still be an overall benefit to society associated with avoided car emissions as set out in Section 3.1.1, which considers the wider benefits to the population of the local area of a reduction in car emissions.

### 3.1.3 Non-monetised Outputs

The abovementioned monetary benefits can also be expressed in terms of direct health benefits. In particular, the health benefits considered are:

- Years of life gained per annum for the population that is over 30 years;
- QALYs gained per annum for those over 30 years;
- Premature deaths avoided per annum for people over 30 years; and
- Respiratory and cardiovascular hospital admissions avoided per annum for those over 30 years.

The background to the calculation of these benefits is set out in more detail in Section 2.3.4. Table 20 and Table 21 present the estimated health benefits for the Connect2 and Community Links case studies, respectively.

### Table 20: Non-monetised Health Benefits for 11 Connect2 Case Studies

| | Health Benefits per Annum | | | | Health Benefits over 30 years | | | |
|---|---|---|---|---|---|---|---|---|
| | Years of Life Gained | QALYs Gained | Avoided Premature Deaths | Avoided Hospital Admissions | Years of Life Gained | QALYs Gained | Avoided Premature Deaths | Avoided Hospital Admissions |
| **Connect 2 Glasgow** | 2.87 | 1.88 | 0.24 | 0.08 | 86.06 | 56.32 | 7.17 | 2.48 |
| **Connect 2 Dumfries** | 0.43 | 0.28 | 0.04 | 0.01 | 12.90 | 8.44 | 1.08 | 0.25 |
| **Connect 2 Bethnal Green** | 0.53 | 0.35 | 0.04 | 0.01 | 15.94 | 10.43 | 1.33 | 0.29 |
| **Connect 2 Havering** | 0.04 | 0.03 | 0.00 | 0.00 | 1.32 | 0.86 | 0.11 | 0.02 |
| **Connect 2 Norwich** | 0.14 | 0.09 | 0.01 | 0.00 | 4.11 | 2.69 | 0.34 | 0.07 |
| **Connect 2 Northampton** | 0.35 | 0.23 | 0.03 | 0.01 | 10.59 | 6.93 | 0.88 | 0.21 |
| **Connect 2 Birmingham** | 0.20 | 0.13 | 0.02 | 0.00 | 5.91 | 3.87 | 0.49 | 0.12 |
| **Connect 2 Plymouth** | 1.06 | 0.69 | 0.09 | 0.02 | 31.66 | 20.72 | 2.64 | 0.54 |
| **Connect 2 Dover** | 0.48 | 0.31 | 0.04 | 0.01 | 14.26 | 9.33 | 1.19 | 0.41 |
| **Connect 2 Leeds** | -0.05 | -0.04 | 0.00 | 0.00 | -1.61 | -1.05 | -0.13 | -0.04 |
| **Connect 2 Cardiff** | 0.21 | 0.13 | 0.02 | 0.00 | 6.16 | 4.03 | 0.51 | 0.05 |

### Table 21: Non-monetised Health Benefits for 7 Community Links Case Studies

| | Health Benefits per Annum | | | | Health Benefits over 30 years | | | |
|---|---|---|---|---|---|---|---|---|
| | Years of Life Gained | QALYs Gained | Avoided Premature Deaths | Avoided Hospital Admissions | Years of Life Gained | QALYs Gained | Avoided Premature Deaths | Avoided Hospital Admissions |
| **River Lossie - Moray** | -0.02 | -0.01 | 0.00 | 0.00 | -0.65 | -0.43 | -0.05 | -0.02 |
| **Adelphi Street - Glasgow** | 0.09 | 0.06 | 0.01 | 0.00 | 2.73 | 1.78 | 0.23 | 0.08 |
| **Milton Bridge, Midlothian** | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.04 | 0.00 | 0.00 |
| **Balmaha, Loch Lomand** | 0.01 | 0.01 | 0.00 | 0.00 | 0.25 | 0.16 | 0.02 | 0.01 |
| **Almondvale Park, West Lothian** | 0.09 | 0.06 | 0.01 | 0.00 | 2.80 | 1.83 | 0.23 | 0.07 |
| **Dunoon, Argyll and Bute** | 0.15 | 0.10 | 0.01 | 0.00 | 4.49 | 2.94 | 0.37 | 0.10 |
| **Great Glen Way, Scottish Canals** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

## 3.2 What-If Analysis based on Norwich Connect2

### 3.2.1 Introduction

The air quality model has been applied to case studies of existing Sustrans Connect2 schemes and the appropriate impact data, but it can also be used to conduct 'What-If' analysis – testing future options to change existing schemes, attract more people to active travel or target specific types of user, or even test the potential impact of new schemes. This section of the report demonstrates some ways of conducting What-If analysis based on the Norwich Connect2 scheme.

The model results in Table 22 shows the existing Connect2 scheme in Norwich to have a positive overall benefit in terms of air quality health impacts. This is mostly due to the reduction in car journeys which results in avoided car emissions in this case, as is seen in the second column in the table. Commuters experience a personal benefit in moving to active travel as do those travelling for education whereas those travelling for other purposes experience a dis-benefit in terms of air quality health impacts. Car users in Norwich see a dis-benefit - in terms of their personal exposure to pollution - when switching to active travel in the central case, for the reasons set out in Section 3.1.2. There are more car users than public transport users in the "Others" category than is the case in the Commuting and Education categories. As a result, the overall personal exposure impact for this category is negative.

**Table 22: Headline Results for Norwich Case Study**

| | Reduction in car journeys | Impacts from route user's changed exposure to pollution | | | | Overall impact |
|---|---|---|---|---|---|---|
| | | Commuting | Education | Others | Total | |
| Connect 2 Norwich | £3,186 | £739 | £115 | -£234 | £619 | £3,805 |

### 3.2.2 What-If Scenario: Encouraging More Active Travel Users

We conduct What-If analysis by changing the model inputs for the Norwich case study. In the first instance, we can explore the impact of encouraging more active travel users. This could be delivered through additional communication and engagement campaigns or by expanding the Connect2 scheme to connect other parts of the city.

The first Norwich scheme encouraged 1,116 additional active travel scheme users per year between the pre- and post- intervention phases. In this example, we assume that the scheme is twice as successful in generating new users and this encourages another 1,116 additional active travel scheme users. Table 23 shows that, as one would expect, doubling the number of additional active travel users simply doubles the scale of the impacts because we have not altered any of the route characteristics or data about the route users.

Table 23: What-If – Additional Route Users

| | Reduction in car journeys | Impacts from route user's changed exposure to pollution | | | | Overall impact |
|---|---|---|---|---|---|---|
| | | Commuting | Education | Others | Total | |
| Connect 2 Norwich | £3,186 | £739 | £115 | -£234 | £619 | £3,805 |
| Additional Users | £6,371 | £1,478 | £230 | -£469 | £1,239 | £7,610 |

### 3.2.3 What-If Scenario: More Commuters Use Active Travel

Continuing on from the previous scenario, we consider the impact if the scheme extension project is designed to attract a much higher proportion of commuters within the same number of scheme users. Impacts are anticipated to be more substantial in this respect, as shifting this population to active travel is shown to have the greatest positive air quality benefits in the model. This targeted shift in behaviour could be achieved through the scheme design and the public engagement strategy.

Table 24 shows the results of this What-If analysis. As expected, the impacts for the individual route users increase for the commuter group, as there are now more travellers in this group; the group 'education' remains the same and 'other' category is reduced accordingly. The overall impact is therefore a greater positive benefit as a result of targeting commuters to use active travel through the scheme.

Table 24: What-If – Mostly Additional Commuters

| | Reduction in car journeys | Impacts from route user's changed exposure to pollution | | | | Overall impact |
|---|---|---|---|---|---|---|
| | | Commuting | Education | Others | Total | |
| Connect 2 Norwich | £3,186 | £739 | £115 | -£234 | £619 | £3,805 |
| Mostly additional commuters | £4,190 | £3,090 | £115 | -£136 | £3,069 | £7,259 |

### 3.2.4 What-If Scenario: Scheme Extension is mostly Off-Road

The model can also explore how the results would be affected if the scheme was able to take advantage of a route that is mostly traffic-free – i.e, changing the proportion of the route that is traffic-free. Note that the Norwich scheme is being used as a theoretical example. As such, a predominantly traffic-free extension to the scheme may not be possible in this location in practice.

Table 25 shows the results for this scenario. The reduction in car journeys is unaffected as this primarily relates to the number of additional route users rather than route length and balance of off-road and on-road sections. However, the impact for the route users who are shifting to active travel is significant. There are much greater positive air quality benefits for these individuals as they will be shifting from polluted car, taxi, bus and rail journeys to relatively unpolluted active travel journeys on the predominantly off-road route extension and so the overall impact increases significantly.

**Table 25: What-If – Scheme Extension is mostly Off-Road**

| | Reduction in car journeys | Impacts from route user's changed exposure to pollution | | | | Overall impact |
|---|---|---|---|---|---|---|
| | | Commuting | Education | Others | Total | |
| Connect 2 Norwich | £3,186 | £739 | £115 | -£234 | £619 | £3,805 |
| Scheme extension mostly off-road | £3,186 | £1,691 | £564 | £461 | £2,716 | £5,902 |

### 3.2.5 Combined Impact of all What-if Scenarios

The combined effect of the three What-if scenarios is presented in Table 26, the three scenarios being:

- More active travel route users;
- More commuters using the active travel route; and
- A greater proportion of the route is traffic-free.

**Table 26: Combined Impact of What-if Scenarios**

| | Reduction in car journeys | Impacts from route user's changed exposure to pollution | | | | Overall impact |
|---|---|---|---|---|---|---|
| | | Commuting | Education | Others | Total | |
| Connect 2 Norwich | £3,186 | £739 | £115 | -£234 | £619 | £3,805 |
| Combined Three What-if scenarios | £8,381 | £14,139 | £1,128 | £1,128 | £15,801 | £24,182 |

## 3.3 Applying the Modelling to National Strategies

The scheme-based model is not designed to develop results on the potential benefits of achieving these targets directly. However, we have used it to develop initial estimates of the potential benefit of walking and cycling by estimating the benefits arising per walking and cycling trip for specific areas. This has been done by considering separately for each scheme the benefits arising from walking and cycling. In each case, the benefits are then divided by the number of walking and cycling trips respectively, to get an estimate of the pollution benefit arising for each type of trip respectively. The estimates of impacts per trip are then scaled up to develop country-wide estimates of the potential, assuming the above targets are achieved.

It is important to note that the benefits at a local level of increases in walking and cycling will be highly dependent on a range of local factors, as was discussed in Section 3.1. These include:

- Ambient levels of pollution (relating to local traffic and transport use patterns), and population density;
- The use of public transport vs car-use in the counterfactual; and
- The proportion of off-road routes.

In areas where a high proportion of the route is on the road and where urban pollution levels are relatively high, there may be a dis-benefit for the individual scheme user associated with a shift to cycling from other modes of transport. In other areas, however, the shift to more cycling is associated with a substantial benefit particularly in areas where a greater proportion of the route is off-road.

### 3.3.1 Estimated Impacts of Cycling and Walking Investment Strategy

In this section, we have developed initial estimates of the potential air pollution benefits that might arise if Government meets its targets contained in its Cycling and Walking Investment Strategy (CWIS).[23] The CWIS is the Department for Transport's 2017 strategy for increasing walking and cycling in England. Achievement of the strategy targets would result in:

- 823 million additional cycling trips per year; and
- A new walking target of 300 walking stages per person. National survey data suggests that 22% of all journeys involve a walking stage, indicating that the current number of walking stages is 201, and suggesting there would need to be an additional 99 walking stages per person. If this is applied to the population of England, this suggests a nationwide increase of 5,243 million walking stages per year.

The derivation of the air pollution benefit per cycling or walking trip is as follows:

[23] Assuming the population of England is 53 million; the estimate assumes that the estimated number of walking stages is averaged across the population as a whole (i.e., including the impact of non-travellers).

- The scheme based case study dataset calculates a total benefit for a group of people switching to active travel made up of a number of cyclists and walkers in each case. This is made up of benefits associated with avoided car journeys, and changes in the personal exposure of scheme participants.
- To calculate the benefit obtained per trip, we separate out the cycling population from the walking population for each case study, to obtain separate totals for the benefits of cycling and walking for the area in question.
- The totals for cycling and walking are then divided by the total number of cyclists and walkers respectively, to get the benefit per cycling and walking trip.

As was discussed previously, the benefits vary depending on local scheme characteristics, such as the proportion of the route that is off-road. To illustrate potential benefits for England, we have used the results from the Dover case study, for the following reasons:

- The overall impact of the case study was £11,054 which is approximately in the middle of the range, (albeit towards the higher end of that range);
- The proportion of the new route that is traffic-free is 66% - again, a mid-range value; and
- Although the proportion of essential journeys undertaken by bus is 46% (one of the highest values in England), the proportion of essential journeys undertaken by car is 42% (which is again roughly mid-range).

The Dover case study therefore looks to be within the middle of the range of results from the case studies considered thus far, and is therefore felt to be a good basis for obtaining per-trip estimates for England, based on the available data derived thus far.

The data from Dover indicates air pollution benefits from cycling are in the order of £0.35 per trip, whilst benefits from walking are £0.02 per trip. Combining these figures with the targets from the CWIS - as set out above - yields a total annual air pollution benefit from cycling of £288 million, whilst the annual benefit from walking is estimated as £279 million – leading to a total annual benefit of both elements of the strategy of £567 million. These results are summarised in Table 27. The table also includes an estimate of the number of avoided premature deaths resulting from the achievement of these targets (calculated in this case on an annual basis).

### Table 27: Initial Estimate of the Impact of the CWIS

| **Parameter** | **Calculation output** | |
|---|---|---|
| | **Cycling** | **Walking** |
| **Air pollution benefits per trip** | £0.35 | £0.02 |
| **Estimated annual impact of CWIS** | £288 million | £279 million |
| **Avoided premature deaths** | 567 | 263 |

To further contextualise the results presented in this section, it is noted that Government's initial estimate of the *total* potential benefits of implementing Clean Air Zones (CAZ) in a number of cities across the UK was £1,100 million.[24] The figure includes benefits occurring over a number of years, and also includes other benefits beyond those associated with air pollution, such as climate change benefits.

The initial research presented in this report suggests that – notwithstanding the considerable uncertainties in calculating the benefits with both types of measures - the total air pollution benefits associated with the CWIS could be in considerable excess of those seen for the implementation of the CAZ for the following reasons:

- The above estimates of the benefits of the CWIS consider only the benefit occurring from one year, whereas the estimated benefits of the CAZ consider the total benefit. Annual benefits are expected to be reduced over time for the CWIS as the pollution emitted by vehicles is reduced, reducing the size of the benefits associated with the shift away from vehicles. However, it is important to note that benefits from the CWIS are likely to continue for longer than those of the CAZ, as the reduction in the number of cars on the road from the CWIS will bring about continued benefits in terms of the reduction in PM emissions occurring due to a reduction in car tyre wear, etc. In contrast, the CAZ is largely expected to bring about reductions in tailpipe emissions, rather than reductions in the actual numbers of vehicles.
- The estimate of benefits occurring from the CAZ also includes other benefits such as climate change benefits. The above estimate for the benefits of the CWIS considers only the potential air pollution benefit.

Indeed, with regards to the second of these points, it should be noted that the CWIS will result in a substantial additional public health benefit arising from the increase in active travel, which is not included in the above figures.

These initial figures suggest that a strong focus on increasing active travel has the potential to result in benefits that are – at least - commensurate to those expected to be achieved by implementing the CAZ across England. Further research is clearly needed to improve the quality of the estimates; however, it is noted that this is also the case for the CAZ benefits, which are due to be further considered in detailed work undertaken by local authorities in the coming months.

### 3.3.2 CAPS

In this section, we examine what the air pollution benefits of achieving the aspiration of the Scottish Government's Cycling Action Plan for Scotland might be.

The first Cycling Action Plan for Scotland was published in 2010. This was refreshed in 2013, and has been further updated in 2017. The purpose of this third iteration is to gauge

[24] It is understood that this figure was decreased in the most recent version of the analysis, published in July 2017. However, those calculations use revised figures for calculating the health benefits produced by the COMEAP team which have not yet been made publicly available.

progress since 2010, and develop a set of actions that to help achieve the shared vision of "10% of everyday journeys to be made by bike, by 2020". This aspiration is recognised as a challenge for all stakeholders. Cycling Scotland's progress report against CAPS outlined six pre-requisites for success, the most pertinent of which (to this study) is the retention of the vision for 10% modal share of everyday journeys, and a related aspiration for reduction in car use, especially for short journeys, by both national and local government.

This analysis relies on exactly the same assumptions as are applied in the CWIS analysis. Again, the analysis is caveated by the fact of the putative nature of the output. The output should be treated as indicative only.

- The CAPS vision of 10% of everyday journeys to be made by bike is applied
- The first stage is to estimate how many cycle trips are required to achieve this target
- For each year between 2007 and 2014, we take the value for all mode trips per person per year
- This is multiplied by the proportion of all mode journeys made for everyday purposes from the Scottish Household Survey (SHS).
- This gives an estimate of the all mode everyday trips per person per year (TPPPY) in Scotland;
- A two-year rolling average of change in all mode everyday TPPPY is calculated;
- This value is cumulatively added to the two year average between 2013 and 2014 to forecast the all mode everyday TPPPY in 2020;
- Multiplying these values by population forecasts for Scotland (Office of National Statistics, 2013) gives an estimate of the total number of everyday trips by all modes in 2020;
- The forecast of total everyday trips by 2020 is 3.45 billion;
- So the forecast of everyday trips required to be made by bicycle to achieve the 10% figure is 345 million;
- On current trajectories, with no additional intervention the forecast for everyday trips made by cycle is 49 million;
- The gap is therefore 294 million trips;
- We apply the value from the Glasgow study, £1.24;
- The value of these trips in air quality terms alone is therefore £364 million annually.

This is less than the value generated for the English CWIS primarily because the value is for cycle trips only, and does not include trips by pedestrians. If we exclude pedestrian trips from the CIWS analysis, the value of the trips under CAPS would be higher than the value generated for the English CWIS. Moreover, it is worth emphasising that a wide range of other benefits would add hugely to the overall benefit value of investing in cycling. However, it is also important to note that the Glasgow case study indicates the benefit per cycling trip to be almost four times greater than that calculated using the Dover case study – suggesting that the initial estimates on what could be achieved through the English CWIS may be relatively conservative.

Achievement of the CAPS vision is estimated to result in 394 avoided premature deaths on an annual basis. This is lower than the benefit estimated to occur through achievement of the CWIS cycling target. It is important to note that the relationship between the total monetised benefits from the schemes and the number of avoided premature deaths is not a linear one, as different methodologies are used to calculate avoided premature deaths arising as a result of changes in personal exposure, compared to those that are associated with a reduction in vehicle mileage.

Overall, output from the above calculation and those of Section 3.3.1 confirm that a concerted focus in England and Scotland on cycling and walking has the potential to bring about significant benefits in respect of air pollution alongside other benefits to public health and other beneficial outcomes.

In addition, as indicated in Section 5.2, the scheme-based model is not able to properly consider potential benefits that may occur in terms of the reduced pollution exposure of scheme users occurring as a result of the reduction in the number of car journeys. For interventions that bring about a substantive change in active travel – such as that considered in this section - the approach used in the scheme-based model is expected to underestimate potential benefits to a more significant extent. This is discussed further in Section 4.0, where an alternative (top-down) approach to estimating the potential health benefits from active travel is set out.

# 4.0 Modelling Area-Wide Interventions

## 4.1 Introduction

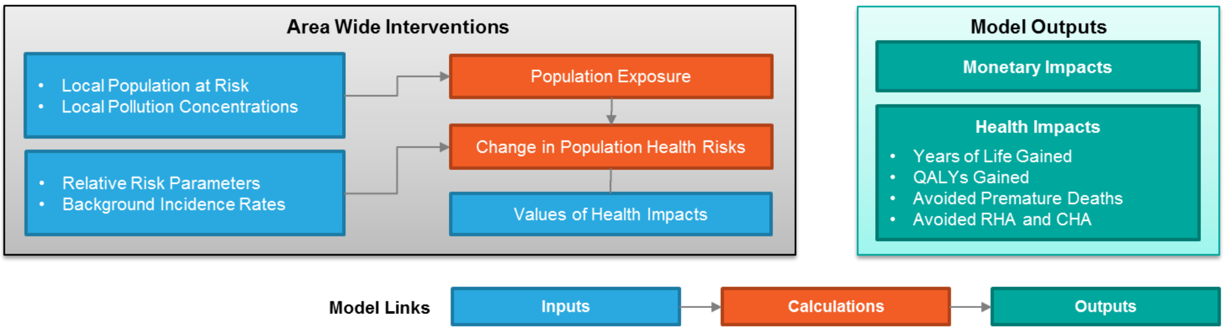
The scheme-based on model is not able to fully consider the benefits to the local population of the reduction in inhaled pollution levels that might occur as a result of a reduction in car journeys. Impacts on the local population are partially taken into account in the damage cost data, which is used to calculate the benefits arising from the reducing the number of car journeys, as set out in Section 3.1.1. However, the amount of inhaled pollution for active travellers is based on Defra's measured atmospheric air pollution data (taken from monitoring stations), prior to the shift to active travel taking place. This is not so problematic when the number of car journeys avoided as a result of active travel interventions is relatively small, as in this situation ambient pollution levels would not be expected to change by much. However, a wide scale intervention across part of (or all of) a city might change ambient pollution levels to a more significant extent, if the intervention were to result in a statistically significant reduction in local air pollution levels. This would be expected to reduce the amount of pollution inhaled by active travellers, as well as bringing about more substantive health benefits for local residents. In this situation, the approach used in the scheme-based model risks underestimating the full benefits of the intervention.

For this reason, in this section we set out an alternative approach to estimating the air pollution benefits of active travel interventions. Whereas the scheme-based model uses a bottom-up approach to calculating the impacts, using the number of travellers as a starting point for calculating atmospheric emissions impacts, the approach used here estimates the potential benefits based on changes in the concentration of key air pollutants occurring as a result of the intervention. This is then used to calculate the potential health benefit arising as a result of the intervention for the population of the city as a whole.

## 4.2 Summary of Approach

The starting point for undertaking this assessment is the model originally developed by Eunomia for NICE. The model considers health benefits to the population arising from interventions to tackle air pollution. The benefits are modelled based on area-wide changes to the dispersed atmospheric pollution occurring as a result of the intervention. The advantage of this approach is that it allows for a relatively high-level consideration of the potential results of a more substantial intervention affecting larger numbers of people.[25] Figure 2 illustrates the main steps involved in modelling the air pollution impacts of area-wide interventions using the NICE model.

**Figure 2: Modelling Air Pollution Impacts of Area-Wide Interventions**




*Source: Eunomia*

The scheme based model and the NICE model take the same approach when calculating the health impacts arising from changing pollution levels (for the most part using standard government datasets), as is set out in Section 2.3.3 and Section 2.3.4. However, unlike the scheme-based model, the area-wide model does not consider in detail the changes in travel patterns - such as changes in the numbers of cars on the road, or in the number of active travellers – that bring about the change in atmospheric pollution levels. It only considers the changes in pollution arising from a high level consideration of transportation changes. As such, it is not possible to use the top-down model to estimate the potential benefits that would arise from the cycling and walking investment strategy, which requires calculation of impacts relating to the number of walking and cycling stages.

Key assumptions used in the area-wide model are:

- Sustained changes in atmospheric pollution levels for key pollutants occurring as result of the intervention. Both $NO_2$ and $PM_{2.5}$ were considered in the original model, although the analysis set out here focuses on $NO_2$ only due to time constraints on the project;

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[25] Further information on the technical details behind the modelling work is set out in Eunomia / UWE (2017) Air Pollution: Economic Analysis, Final Report for NICE, April 2017

- The number of people affected by the change in atmospheric pollution levels.

We initially considered the potential changes in recorded atmospheric $NO_2$ levels that might occur as a result of the walk to school week, which were set out in a paper written by Grace Gardner, a student at Southampton University.[26] This paper is one of relatively few studies in the literature to try to link changes in travel behaviour to atmospheric pollution levels. It suggested that relatively large potential reductions in the levels of local pollution might occur in the short term as a result of the intervention in several schools – a short term reduction in $NO_2$ levels of up to 25% was seen in the research, and there was also some indication that the reduction may have been sustained beyond the initial study period. However, only a relatively small number of data points were presented in this study as evidence of the potential impacts on dispersed pollution. Given this, there was felt to be a relatively high risk of the data being influenced by climatic factors, which could reduce the accuracy of the estimated impacts considerably.

To improve the accuracy of estimates on the potential pollution reduction that might occur through this type of intervention, we have therefore considered other data that exists in respect of the variation in pollution levels between school holiday time and term time. As this is a longer term data-set, this should allow the potential impact for climatic factors to be reduced.

Extensive monitoring data exists for Newcastle, some of which is held and developed by Newcastle University. Initial discussion with the University has suggested that $NO_2$ pollution levels outside of term-time in Newcastle are reduced by 5-7% in comparison to pollutant levels seen during term time based on the long-term time series data the University has obtained in recent years.

No data is available at present directly linking changes in atmospheric pollution levels to changes in transport use occurring as a result of active travel interventions, so assumptions must be developed to consider the impacts. In modelling the potential effect, we have assumed a city-wide intervention is successful in making a long-term reduction in 10% of the vehicles that are assumed to cause the normal drop in school-related travel in Southampton. This is assumed to be roughly equivalent to a sustained reduction in 10% of school-related traffic across the whole city. The Newcastle monitoring data indicates the pollution levels outside term-time are reduced by 5-7%. To develop our initial estimate of the impact of a city-wide intervention in Southampton, we have taken the lower figure of 5% as the starting estimate.

The model therefore assumes a net reduction in $NO_2$ of 0.5% occurring as a result of the intervention (i.e., considerably less than the 25% reduction seen in the Southampton dataset). Baseline pollution levels for Southampton were taken from the above cited paper by Gardner; this data, in turn, is derived from longer term monitoring data published by Defra.

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[26] Grace Gardner (2017) A Critical Evaluation of a Sustainable Transport Initiative in Southampton, assessing the impact on NO2 concentrations and Childhood Asthma, Dissertation for Southampton University

Southampton has a population of approximately 249,000 people. In the case of a city-wide intervention, the change in atmospheric pollution levels would be expected to affect most residents of the city. We have taken a slightly conservative approach and have assumed that 75% of the population of Southampton is affected by these changes.

## 4.3 Results

Initial results developed using the above approach suggest that health benefits in the order of £477k per year would be seen, based on the reduction in $NO_2$ emissions modelled above, i.e., assuming a sustained reduction in $NO_2$ of 0.5% is achieved through the intervention. In calculating these estimates, we have used a relatively conservative assumption in respect of the proportion of local residents who would be affected by the change in atmospheric pollution levels. It is further noted that the above analysis considers reductions in $NO_2$ – additional benefits would also be seen if $PM_{2.5}$ impacts were considered. These results therefore suggest that if sustained campaign activity can bring about a long term reduction in car usage across a whole area, it has the potential to bring about a substantial health benefit from a reduction in air pollution – provided suitable infrastructure is in place locally to support the shift to greater levels of active travel.

The results presented here are an initial, high level indication of the potential air pollution benefits of an area-wide intervention bringing about a wide-ranging shift to active travel. Use of the data from Newcastle is a starting point from which to estimate the potential reduction in emissions occurring out of term time in Southampton. It is not known to what extent the data from Newcastle is applicable to other areas, and further work is required in this respect to firm up emissions reductions estimates in this respect.

More generally, further research linking changes in atmospheric pollution levels to changes in travel behaviour in the same area is required, in order to establish the potential benefits of a city wide intervention as a result of concerted campaign activity. In the event that the latter data becomes available, this should enable the output from the two modelling approaches (i.e., the scheme-based and area-wide) undertaken in this study to be effectively linked, such that a more complete estimate of the air pollution benefits of active travel interventions could be made.

# 5.0 Implications of the study

We identify three primary areas for discussion in the context of this study. The first concerns the extent of alignment of the two approaches to modelling, in the context of whether two distinct approaches are telling a consistent story. The second concerns policy interfaces and what we consider to be the role of the modelling study. The third considers the limitations of the study and the potential for further work.

## 5.1 Comparing the two modelling approaches

The two approaches to modelling, the scheme-based approach and the area-wide approach, are fundamentally quite different, and do rather different jobs. In some respects the area-wide model is not particularly innovative. The area-wide model considers the impacts on the wider population of a reduction in pollution emissions. It postulates changes in active travel at the population-level, and consequent changes in levels of car travel and in concentrations of pollution. The change in exposure at the population level is then estimated, and calculations of the value are made accordingly. This is the approach used by, for example, Webtag, and is reasonably widely practised already. The innovative elements are the inclusion of new data from Newcastle University on levels of change in motor traffic during school holiday time relative to term time (unpublished – publication is forthcoming). This approach also opens up the possibility to incorporating better local pollution measurement data. The Southampton case shows promise, but we need more local data that we can be more confident in.

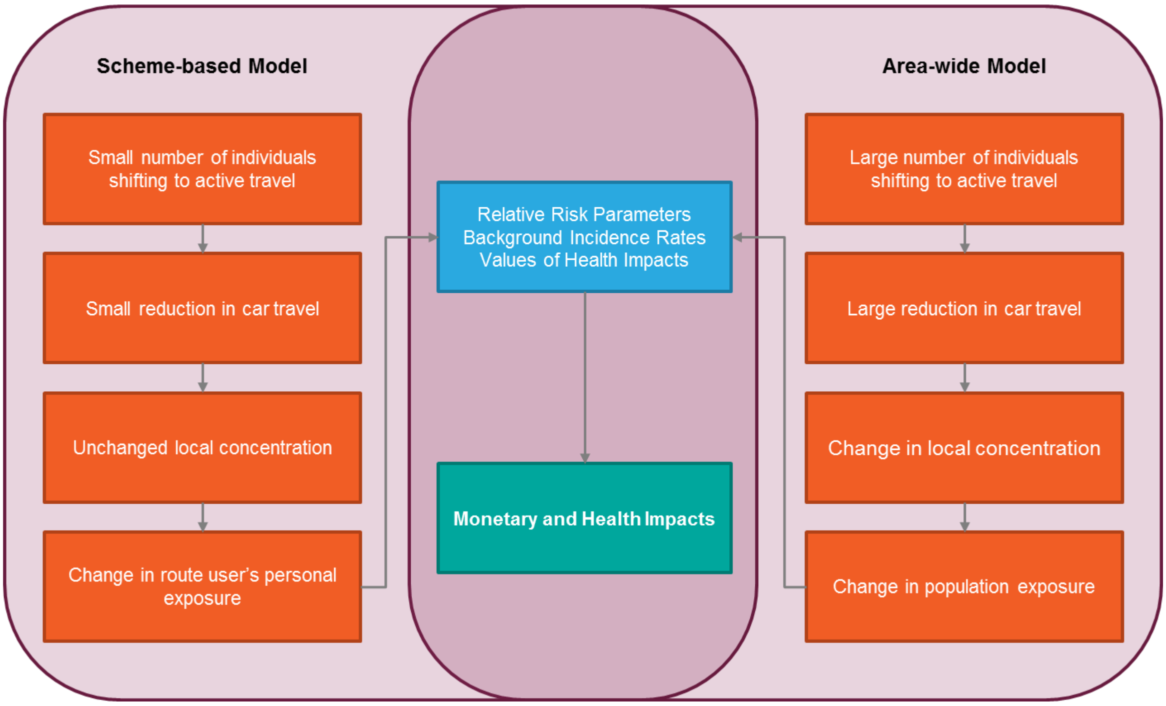
The scheme-based model differs in that, although changes in active travel and implications for motor vehicle traffic are forecasted, on the one hand there is no adjustment of local concentration data, and on the other hand a measure of personal exposure of the traveller is forecasted. The following figure describes the differences in approach of the models.

Within this broad approach, there are quite a number of assumptions and inputs, some of which are more subtle than others. For example, the area-wide model deals only with NOx pollutants, whereas the scheme-based model incorporates NOx and PM; the scheme-based model does not offer the means to express changes in local concentrations; and rates of change in traffic-levels are 'small but measured' at the scheme-based level, and 'large but uncertain' at the area-wide level. More work is needed to set out exactly the differences in approach, and the implications of these differences. But we wanted to set down both approaches so that we could:

- Showcase the work done from both directions
- Test whether there was a consistent narrative emerging from the two approaches – are there differences by orders of magnitude that suggest an underlying problem with the construct of the model
- Examine the differences in approach in the contexts of their strengths and weaknesses
- In identifying the extent of differences, understand the drivers and the possible further work in developing the models
- And in particular, where we apply the scheme-based approach in a context that may or may not be reasonable, i.e. with the CWIS and CAPS analysis, are the model outputs within expected bounds of reason

The key differences are described in figure 4, below.

## Figure 4: Overlap between Scheme-based Model and Area-wide Model




*Source: Eunomia*

In the very simplest form, we are comparing the £477,000 per annum benefit value for a single city for school travel interventions only from the area-wide model, with the £567 million per annum benefit value for achieving the CWIS targets.

Although we do not set out the full analysis here, the review and comparison suggests that, on the one hand, there are marked differences between the outputs from the two approaches. But on the other hand, the values do not differ by orders of magnitude, and large parts of the differences may be explained by the different input parameters and the approaches applied. At one level, this gives us the confidence that the outputs of the exercise ‘look right’. We can have reasonable confidence that the values forecasts are not wildly out of kilter with reality. But there are a number of areas where the models and the approaches used will benefit from further research. Some of these are set down in the following section.

## 5.2 Limitations and Further Work

Currently, a number of the key variables used within the model to establish the exposure of cyclists and walkers to pollution are based on modelling assumptions. Key variables of this nature include:

- The length of journey for each of the different journey purposes;
- The speed at which active travellers cycle or walk their journeys;
- The regularity of the journeys undertaken by users of the schemes.

The model would therefore benefit from further research to establish more robust values for each of the above, perhaps using data obtained from local travel diaries from scheme users. In particular, further data is required on the length of journeys undertaken by active travellers both when using the scheme and prior to doing so (i.e., when using cars or public transport). In this respect, the route user intercept survey data collected by Sustrans is not ideally structured to collect the required data for the scheme-based model. For this reason, we supplemented the survey data with assumptions from the NTS, the data from which is also not ideally suited for this purpose; as such, assumptions may not be valid for all areas.

The scheme-based model is not able to properly consider potential benefits that may occur in terms of the reduced pollution exposure of scheme users resulting from the reduction in the number of car journeys – these values being based on current (pre-intervention) pollution levels. This is of less importance when the number of scheme users switching away from cars and taxis is small enough for there to be no likely significant impact on local pollution levels. However, it means the model is unable to properly consider the full benefits from a large-scale intervention.

Pollution monitoring data in most areas is relatively limited. In some cases, the nearest station was some distance away, and values may therefore not be representative of actual pollution levels on the scheme. Ideally, the monitoring data would allow for a distinction between both the pollution levels at busy kerbside locations, as well as the background level of pollution associated with off-road routes. In many urban locations, this data did not exist; Glasgow was one of the few urban centres where this data was available. In the case of Glasgow, however, the scheme crosses a motorway at one point using a bridge (albeit that the path is some distance above the road), which may increase the pollution exposure of route users at this point. The effect of this pollution hotspot could not be captured in the air pollution datasets produced by Defra. The model could therefore be improved by incorporating more detailed local pollution datasets reflecting these hotspots.

The relative risk factors are calculated based on data for the population as a whole. This includes people of a wide range of fitness and activity levels. The regular active travel commuting community, in contrast, is likely to be fitter than the average person. As such, application of the population-wide relative risk factors to the active traveller commuters is slightly problematic. In practice, this means an over-estimation of both the dis-benefits and benefits associated with the changes in personal exposure to pollution, due to increased active travel. However, it is important to note that as the number of scheme users increases, this effect will tend to diminish, because more people with lower fitness levels will start to use the scheme. In this respect, the estimation of air pollution benefits should improve in its accuracy as scheme participation widens within the community.

In this respect, it is also important to note that the data on the physical health benefits of cycling overlaps somewhat with the estimation of the air pollution benefits accounted for within the scheme-based models. The physical health benefits are considered using epidemiological evidence, i.e., using datasets that consider the overall health benefits for the population as a whole, using data on health collected over a period of time. Since it takes some time to collect this data, in most cases estimates are based at least in part on historical data recorded at a time when air pollution levels were higher than they are now in most cases. In this respect the negative effects of exposure to air pollution on the health of the cycling and walking cohort will therefore be considered along with other beneficial impacts such as changes in heart rate, reduction in obesity, etc.

The additional exposure to pollution in the past would be expected to have greater negative impact on the health of the active travellers than more recent datasets. Calculations of the physical health benefits based on this older epidemiological data are thus likely to be somewhat underestimated as a consequence.

Care is therefore needed when combining both the air pollution benefits seen in this study with the estimated benefits associated with physical health derived from models such as HEAT, as there is some overlap in the scope between the two models.

A further area of uncertainty surrounds the calculation of relative inhalation rates for the different microenvironments. The literature provides these for a range of locations and situations. In order to make the different datasets comparable, we have developed scaling factors using expert judgement. However, ideally we would have been able to use a recent dataset that covers all the different microenvironments of most relevance to the UK. Furthermore, there is considerable uncertainty associated with the development of inhalation rates for walkers and cyclists, given that this must take into account fitness levels, terrain, etc. More research in this area would also improve the accuracy of the model's outputs.

Taking into account the above limitations as well as the prevailing policy environment, the next steps in terms of the research are therefore expected to include:

- Consideration of how the model may need to develop if it were to support the production of local authority clean air plans;
- The integration of more detailed modal change data;
- Consideration of integrating this type of intervention with traffic restraint measures, and linking of the corresponding modelling outcomes; and
- Better linking of atmospheric emissions data with travel data.

# 6.0 Concluding Remarks

Although the air quality impact values of many of the individual schemes are relatively modest, it is important to consider that air pollution is only a small part of the overall benefit value of such schemes. In this respect, it is important to note that the above results reflect the benefits that would be obtained from one year only. Furthermore, benefits from the CWIS and CAPS are likely to continue for longer than those of other interventions aimed primarily at tackling tailpipe emissions - such as the Clean Air Zones (CAZ) proposed by Government - as the reduction in the number of cars on the road from the CWIS and the CAPS will bring about continued benefits in terms of the reduction in PM emissions occurring due to a reduction in car tyre wear and related impacts.

The modelling work has demonstrated which factors drive higher benefit values in respect of individual schemes. These include increasing scheme user numbers, targeting regular travellers, focussing in on more densely populated urban areas, whilst reducing rates of exposure to air pollution of scheme users through the use of off-road routes. These factors are explored in the modelling work both through “what-if” analysis. Alongside this, outputs from the area-wide model latter in particular suggests that the potential benefits from a more substantial intervention are very considerable. Wider benefits could be brought about with more complete networks, denser networks, behaviour change accompaniment, measures to reduce exposures, better targeting of specific user groups. Such measures could bring about a reduction in the impacts of air pollution in the local area, as well as representing more effective delivery of measures to support walking and cycling.

To bring about this level of change, delivery of the above measures needs to happen as part of a large scale, integrated package of intervention/delivery, potentially in tandem with effective traffic-restraint measures. In this way, the two types of interventions could be mutually supportive, as cycling and walking is an important part of the local mobility solution when motorised mobility is necessarily constrained.