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Air Quality, Health, Wellbeing and Behaviour

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Executive Summary

This report presents the findings from evidence reviews of the health and wellbeing impacts of air pollution and of behaviour change related to air pollution, which were carried out as part of a programme aimed at developing key messages for use to promote improvements in air quality and in public health, and thus contribute to addressing health inequalities in Scotland. For the investigation of air pollution and physical health, which has been studied intensively in recent times, it was decided to focus on recent major reviews in this area: the REVIHAAP (World Health Organisation, 2013) report and the Health Effects Institute report on transport-related air pollution (HEI, 2010). The reviews of air pollution in relation to wellbeing and of behaviour change were carried out using systematic searches of the published and grey literature, including peer-reviewed papers, government reports and theses.

Results from the review of health and wellbeing in relation to air pollution showed that air pollution is causally linked to a range of adverse health outcomes mostly affecting the heart and lungs (cardio-respiratory system). It acts as one of many factors which increase the risks of these conditions. Long-term exposure to particulate matter (PM) results in a 3% increase mortality in adults per 5µg/m^3 of PM <2.5 micrometres in diameter ($PM_{2.5}$), mortality from heart attacks, stroke, lung cancer, and chronic non-cancer lung disease are most affected; short-term exposure to particulate matter is associated with asthma attacks, increased visits to doctors, increased hospital admissions and earlier death and short term exposure to ozone is associated with a range of respiratory conditions including earlier death (from cardiovascular as well as respiratory causes).

There were relatively few studies on air pollution and wellbeing. A few studies show a tentative link between air pollution and subjective measures (from happiness surveys or self-reported life satisfaction), and there is some limited evidence that living in a neighbourhood which provides infrastructure and green spaces encouraging walking and cycling is associated with better mental health and quality of life.

The review of behaviour change showed that reductions in pollutant levels are amongst the public health benefits likely to be associated with an increase in active travel. Actions shown to be effective included increasing road charges which is likely to reduce car use and increase public transport use; preferential taxes for lower emission cars results in increased sales and a potential reduction in air pollution and use of travel plans with individualised information is found to increase public transport use. In addition, the presence of crossing areas increases the likelihood of primary school age boys walking to school and feelings of safety and security increased the likelihood of girls walking to school.

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1 INTRODUCTION AND BACKGROUND TO THE PROJECT

1.1 THE STUDY AND THE FORMAT OF THIS REPORT

1.1.1 Background to the study

Scottish Environment Protection Agency (SEPA) in collaboration with NHS Scotland (Health Protection Scotland (HPS) and NHS Health Scotland (HS)) with funding from Scotland's Environment Web (LIFE-funded project), are leading a programme of component research projects, with the overall aim of developing key messages for use to promote improvements in air quality and in public health, and thus contribute to addressing health inequalities in Scotland.

The research project has adopted a process for investigating complex environment and health issues prototyped via the Scottish Government's "Good Places, Better Health" (GPBH) initiative. This involves populating modified DPSEEA models using the GPBH approach, to identify and explore links between air pollution and health[1]. In addition the project called for an evidence review of what works to change behaviour related to air quality and a review of the health impacts of air pollution with a specific focus on transport-related air pollution.

This report presents the findings from the two evidence reviews of health impacts of air pollution and of behaviour change related to air pollution. A consortium of scientific research organisations was commissioned to carry out the reviews, led by the Institute of Occupational Medicine (IOM), in collaboration with the NERC Centre for Ecology & Hydrology (CEH), and Professor George Morris. The report describes the results of the two reviews and their overall conclusions.

1.1.2 Components of this report

The report is in three main sections:

- An introduction to air pollution (Sections 1.2 and 1.3)
- Results from the review of air pollution in relation to health and wellbeing (Chapters 3 and 4)
- Results from the review of air pollution in relation to behaviour change (Chapter 5)

[1] Good Places Better Health Methodology Report: http://www.gov.scot/Topics/Health/Healthy-Living/Good-Places-Better-Health/Approach/Methodology

It also includes details of the methods used to carry out the study (Chapter 2) and the overall conclusions from the work (Chapter 6).

1.2 INTRODUCTION TO AIR POLLUTION

1.2.1 What is outdoor air pollution?

In this report, air pollution is used as a generic term for substances present in the air at heights where people may breathe them which are generally considered to be undesirable due to their potential for being inhaled and for then having adverse effects on people's health.

Outdoor air is the air present normally in the outdoor environment. In the present report, outdoor air pollution means air pollution as measured outdoors, and in particular, air pollution whose outdoor concentrations are subject to regulatory limits. Much outdoor air pollution comes from outdoor sources, such as transport, wind-blown dust and forest fires. (The present report is concerned especially with outdoor air pollution from road transport.) Some comes from indoor sources where emissions from homes and factories are directed outwards via chimneys or high stacks. Outdoor air pollution also penetrates indoors, to homes and other buildings where many people spend a large proportion of their time, so that the relationship between outdoor air pollution concentrations and personal exposures to outdoor pollutants is not straightforward.

Despite these complexities, outdoor air pollution can be looked at simply as air pollution in air outdoors, whatever its source; and its health effects are those that are related to outdoor concentrations, whether or not the exposure is experienced outdoors or indoors.

1.2.2 Variations in outdoor air pollution and what this means for studies of health

Outdoor air pollution varies in time and space leading to differences both in the concentrations of individual pollutants (gases and particles) and in their relative importance within the overall air pollution mixture. Outdoor air pollution varies over time within the same location, both in the short-term (e.g. over time within a day) and in the longer-term (e.g. by month, season and year). It also varies between locations (spatially), between cities and rural areas, between one city and another, and between locations within a city.

There are many reasons for this variation; e.g. differences in pollution sources, in intensity of emissions, in atmospheric conditions, and in how pollution travels. However, the present report focuses not on the causes of these variations over time and location, but on how they enable a range of types of epidemiological study to be carried out, relating variations in outdoor air pollution to variations in the health of populations and individuals. Such studies can therefore consider variations in air pollution and health over time (e.g. based on daily variations in pollution and health – time series and panel studies) or across space (e.g. based on air pollution and health differences between cities or neighbourhoods or regions – cohort and longitudinal studies). Sometimes studies use a combination approach involving comparisons of health and air pollution over both time periods (usually years) and geographically defined areas. Different kinds of epidemiological study are described further in Section 3.1.3.

1.3 AIR POLLUTION FROM TRANSPORT

1.3.1 Main pollutants and sources

Pollutants affecting concentrations and exposure from sources in cities (urban areas) are of particular concern because most people now live in urban or suburban environments and are therefore exposed to urban air pollution. Urban air pollution consists of a mix of primary particles (directly released into the atmosphere by wind, combustion processes, or human activities) and secondary particles (formed in the atmosphere from other gaseous pollutants) and is highly variable, both spatially and temporally. The main components are particulate matter (PM) and nitrogen oxides, specifically nitric oxide (NO) and nitrogen dioxide (NO_2), which are commonly referred to as nitrogen oxides (NOx, a sum of NO + NO_2).

Nitrogen oxides are directly emitted from combustion processes (e.g. car engines), forming at high temperature from nitrogen contained in combustion air or fossil fuels. The design of the combustion process, the ratio of fuel to air and other parameters determine the rate at which nitrogen oxides are emitted. NOx are a precursor for ground level ozone formation (together with volatile organic compounds, VOCs) and so ozone can be considered as a transport-related pollutant (Section 3.2.3). NO_2 itself is a component of photochemical pollution (often referred to as smog) contributing directly to adverse health effects (Section 3.2.2).

Primary particulate matter, usually measured as the mass in one c.c. of air of very small particles with an aerodynamic diameter of less than 10 micrometres (µm) (PM_{10}), respectively less than 2.5 µm (fine particles: $PM_{2.5}$), are both emitted directly from mechanical processes (e.g. tyre and brake wear from vehicles (although this may contribute more to coarser fractions of PM), construction activities) and as exhaust from internal combustion engines. PM components comprise a variety of chemicals and physical characteristics, including Black Carbon (BC), Elemental Carbon (EC) and Organic Carbon (OC), and often heavy metals (HM) or persistent organic pollutants (POPs) are released in the combustion process and adsorbed to particles. Currently, even finer particle sizes are considered important by researchers (e.g. Ultrafine Particles (UFP), corresponding to particles with an aerodynamic diameter of less than 0.1 µm) due to their ability to not only penetrate the lungs and alveolae, but even enter the blood stream with the potential to cause systemic inflammation and cardio-vascular diseases. In addition to the primary particles, i.e. those directly emitted by sources in urban areas, secondary aerosols, in particular secondary inorganic aerosols (SIA, ammonium nitrates and sulphates) contribute to concentrations of $PM_{2.5}$ in urban areas. These particles are transported over long distances and originate from chemical processes in the atmosphere with contributions from agricultural ammonia emissions, NOx and sulphur dioxide. The health effects of PM, especially $PM_{2.5}$, and its components, are summarised in Section 3.2.1.

The main sources contributing to urban air pollutant concentrations, in the UK generally and in Scotland also, are road transport and residential and commercial combustion processes for heat and power generation. Public power generation and industry sources contribute to a lesser extent, depending on the location and meteorological conditions e.g. when exhaust plumes are advected across a city. Regional sources such as ammonia emissions from agriculture may contribute to the regional and background variability, which can be substantial as recently observed in high spring peak concentrations of $PM_{2.5}$ over the UK in 2014 and 2015, driven by both meteorological conditions and spring spreading of manure and application of mineral fertilisers across continental Europe.

In most urban areas, road transport has been identified as the main contributing source to NOx and PM concentrations, with NO_2 and UFP showing the strongest spatial and temporal correlation with the location, volume and temporal patterns of urban traffic. Hotspots of emissions near busy roads and intersections, street canyons and congestion can amplify the problem locally. Traffic-related emissions show distinct peaks during the morning and afternoon/evening rush hour, and are generally higher during weekdays compared to weekends or holidays. Combinations of local emissions and regional/long-range transport can lead to persistent peaks of concentrations, where short-term, local measures have limited effect.

1.3.2 Environmental fate of emissions and relation to behaviour and behavioural change

In order to quantify both the contribution of behavioural factors to emissions, and the potential for behavioural measures to have a measurable effect on ambient concentrations, models and sensors can be deployed. Sensors provide detailed information on the temporal patterns of concentrations and, if they are available in sufficient numbers and distributed across urban areas in a representative manner, the spatial variability of concentrations over time. Models, applied at different spatial scales, can quantify the contribution of long-range vs. local emissions to ambient pollutant concentrations. Furthermore, models are capable of quantifying the effect of policy measures, for instance the introduction of low-emission zones or other traffic management measures, on concentrations.

A combination of models and sensors can, for instance, use real-time observations to calibrate and drive models to forecast air pollution levels for periods ranging from a few hours to several days, and project forward to potential episodes of high pollutant concentrations. This is of particular importance for those pollutants where long-range transport makes a major contribution (e.g. $PM_{2.5}$), or for the secondary formation of pollutants, e.g. for ground level ozone. However, even for urban air pollution where the predominant contribution is from local emissions, such forecasting capability is essential to supply the quantifiable evidence necessary to support information strategies. The temporal patterns and local hotspots of air pollution can usefully trigger early warnings and the implementation of short term behaviour changes to limit concentration build-up. For longer term behavioural change, models can provide the capability to quantify the effect of e.g. modal changes in transport behaviour or they can inform urban planning processes concerning the degree of public or active transport infrastructure required to sustain such change.

Most research thus far has focused on the spatial variability of urban air pollutant concentrations. For instance, research has enabled greater understanding of the effect of the distance to roads on exposure, or the deposition of pollutants and how this influences the gradient in concentrations from the source. As an example, road emissions quickly tail off with distance to the road for NO_2, whereas for $PM_{2.5}$, the regional contribution, rather than local traffic, plays a major role, leading to a more smoothly distributed concentration field even in urban areas. Infrastructure and the built environment can have substantial effect on the distribution and fate of pollutants, e.g. street canyons affecting wind speed and direction, or vegetation along busy streets or around recreational areas acting as barriers for air pollution, which can locally improve air quality.

1.3.3 Exposure to air pollution

Outdoor concentrations

Ambient concentrations of air pollutants can lead to exposure of human receptors and, ultimately, adverse health effects. Especially urban areas with high population densities and sources of air pollutants are affected. Air pollution is ubiquitous and at the same time highly variable in space and time. This is particularly so in complex environments such as urban areas. At the same time, people constantly move within and across towns and cities, commuting to school or work or spending time shopping, or in public buildings. Thus it is important to not only address the spatiotemporal variability of air pollutants but also keep in mind the spatiotemporal patterns and other characteristics of citizens themselves.

It is generally impossible to attribute adverse health outcomes in an individual with their exposure to a specific pollutant or pollutants. Sources, chemical reactions and meteorological influences are responsible for a vast variety of pollutants and pollutant mixes which all have to be considered harmful. Also while people who are present at the same place at the same time have ostensibly comparable exposures, their dose and how it affects them may differ depending on factors such as activity and respiratory rate, metabolism and general physical condition.

As discussed in Section 3.1.5 later, it is difficult to identify individual pollutants as cause of adverse health impacts of the overall air pollution mixture. Sources, chemical reactions and meteorological influences are responsible for a vast variety of pollutants and pollutant mixes which all have to be considered harmful. Nevertheless, as described in Section 3.2, remarkable progress has been made in identifying the adverse health effects of key pollutants such as $PM_{2.5}$, NO_2 and O_3, to the extent that there is widespread agreement among researchers of the benefits to health of reducing exposure to these pollutants, individually or in combination.

With particulate matter, the different size fractions impact differently on the human body such that smaller particles are able to penetrate deeper into the respiratory system where they can cause more damage whilst larger particles will lodge in the upper part of the respiratory tract producing different effects. The health implications of different size fractions of PM are discussed briefly in Section 3.2.1.

Traditionally exposure to air pollution is assessed using data from fixed-monitoring sites e.g. from the national Automatic Urban and Rural Network (AURN). These sites are equipped with expensive reference instrumentation providing data in most cases as hourly or daily averages. These data are used for population wide exposure assessment based on annual averages and interpolation of the results. The downside of such an approach is the limited spatial coverage that provides the basis for interpolation as well as the lack of information on time-activity patterns of the population (Steinle et al., 2013).

Personal exposures

It is well known that people in industrialised countries spend the largest part of their time in indoor environments, the European average is 90% (Fernandes et al., 2009; EnVie. Co-ordination Action on Indoor Air Quality and Health Effects). Indoor air is however influenced by outdoor air through air exchanges. When attention shifts from concentrations of outdoor air pollution to the actual exposures of individuals and groups, it is therefore necessary to assess both indoor and outdoor air quality, especially considering that the most vulnerable groups are also spending a large part of their time indoors.

Individual exposure is important to get a better understanding of the influence of variability and mobility on personal air pollution related risks, but it does not fulfil the same purpose as population level exposure. Individual exposure assessment is undergoing an exciting period of development where research is being driven by greater use of personal monitors and technologies which support the collection of information on the individual's daily activity-patterns. Exposure is dependent on multiple factors and can for instance be investigated by age, gender, socioeconomic status, neighbourhood characteristics or activity levels (Steinle et al., 2015). Particularly vulnerable groups are the elderly, children and those with pre-existing health conditions. For exposure assessment it is relevant to investigate the usual mobility and activity patterns for these groups, identify the environments where they are likely to spend a lot of time and assess the air quality for these environments. However, for overall exposure assessment it is crucial to move away from investigating individual environments to cover the full heterogeneity of environments visited during daily routines. The focus on individual environments for exposure assessment only, means important exposure situations can be omitted leading to incomplete assessments and inaccurate conclusions on total exposure. (Steinle et al., 2013).

Snyder et al., (2013) have observed that the move away from a few, highly accurate stationary monitors to many, low-cost and less accurate sensors represents a paradigm shift in exposure assessment. The number of sensors and moving of them into the vicinity of where people are likely to spend time is a promising approach. One option here is personal monitoring which is intrusive and still requires a lot of research to develop fit for purpose monitors and to produce them in a commercially-available form. A further option is the use of urban networks, based on low-cost sensors, which offer a much denser spatial coverage than national networks. These can be used in combination with data on mobility patterns e.g. to generate exposure maps (Mead et al., 2013).

The transport environment is complex and influenced by many factors such as choice of transport mode, meteorology but also urban structure and design. Critical locations in terms of exposure to transport exist where dense traffic and high pedestrian concentrations coincide which naturally happens in city centres. A dense network of monitors can help improve the assessment of pollution and exposure patterns within an urban area.

Implications for studies of air pollution and human health

The implications for studying relationships with human health are discussed later, in Section 3.1.5. Briefly, current epidemiological evidence is based largely on studies of relationships between human health and concentrations in outdoor air, and this is sufficient to inform regulation of outdoor air concentrations. The newer methods, being much more targeted to the experience of individuals, offer hope of a better understanding of the mechanisms of action of individual pollutants, but it is too early in their development for these approaches to as yet have major substantial results.

2 METHODOLOGY

2.1 LITERATURE REVIEW METHODS

At an early stage in the project, it was agreed that two literature reviews would be carried out: one to investigate air pollution, health and wellbeing, and the second to investigate air pollution and behavioural change. For investigation of air pollution and physical health, which has been studied intensively in recent times, it was decided to focus on recent major reviews in this area. Two major reviews were identified – the REVIHAAP (World Health Organisation, 2013b) report and the Health Effects Institute report on transport-related air pollution (HEI, 2010).

For the literature reviews, the first stage of work was the development of draft search protocols. These were separately compiled for the topics of health and wellbeing, and behaviour and are presented in Appendix 1 and Appendix 2. This process involved the development of the research questions to be addressed by the project, the search terms and search phrases to be used and identification of relevant search databases and grey literature to identify relevant materials.

Following the preliminary searches, the first 100 references identified for each topic were screened for inclusion (yes/no/unknown) by members of both the project team and the project steering committee. A meeting was then held to discuss the ratings and to ensure that the scope of the studies was agreed between the two groups. Consistency in inclusion ratings between the reviewers was high.

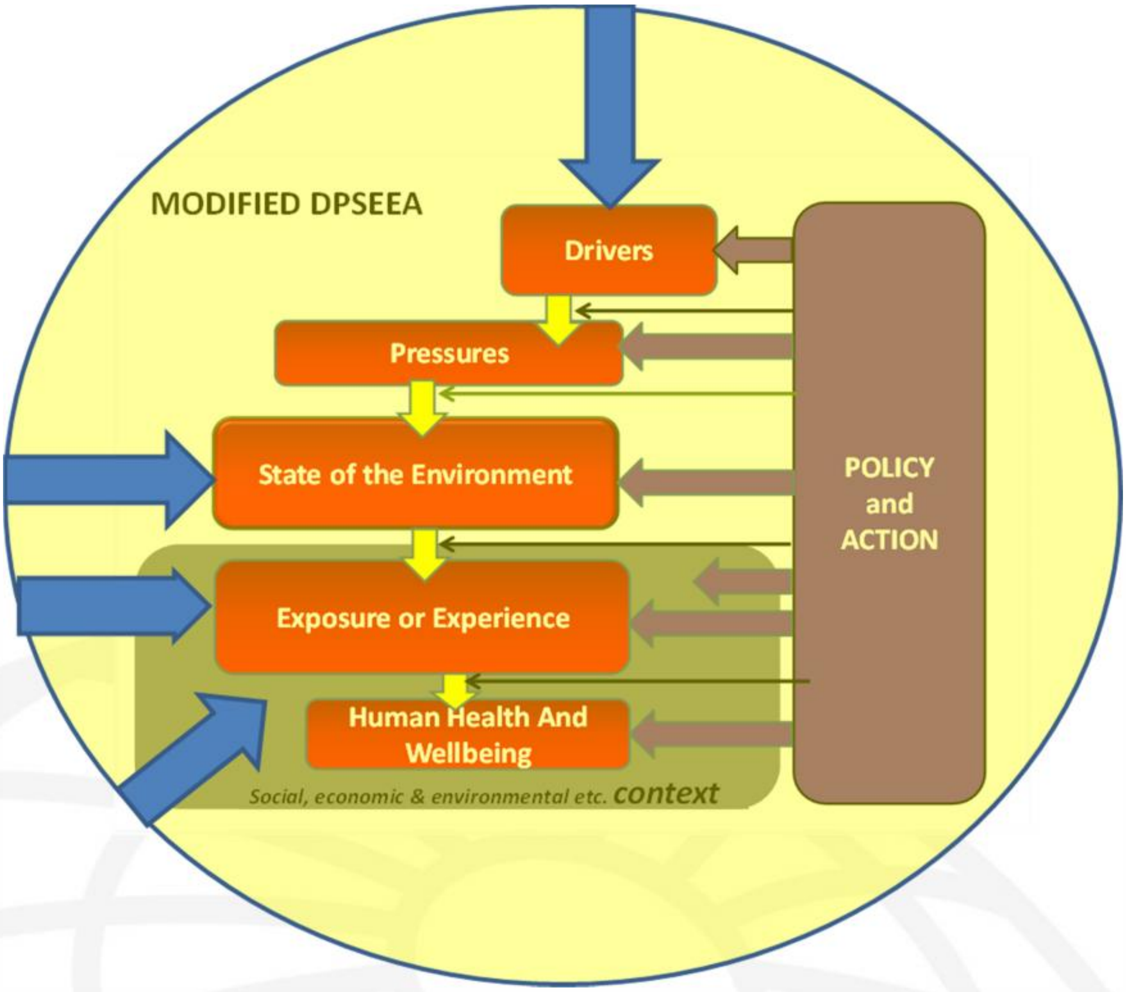
The next stage in the review process was to carry out full literature searches and to store all identified references in the on-line reference management software package RefWorks. These searches were carried out in January to April 2015. This allows full traceability of references throughout the project. All of the identified references were screened on the basis of their title and abstract to identify studies of relevance. This was done by a researcher with knowledge of the topic area who manually filtered out the references that did not meet the inclusion criteria for the current reviews prior to production of a recommended list of publications to be obtained and reviewed. In all cases a conservative strategy was adopted where, if the relevance or otherwise of a paper was not apparent from the title (and, where available, abstract), the paper was retained for full text scanning and possible review.

Full papers were then obtained and data extracted from each paper included for review. At this point the papers were graded as to the quality of evidence obtained within them, using an existing spreadsheet designed and piloted for this purpose and adapted for this specific study.From the data extracted, evidence tables were prepared to aid the assessment process and to provide accessible documentation of the evidence on which the review is based. Wherever possible, quantitative estimates for effects from published works were extracted. The data extraction was undertaken independently by 4 reviewers with the division of papers being allocated randomly.

2.2 A FRAMEWORK FOR AIR POLLUTION, BEHAVIOUR AND HEALTH

The modified DPSEEA model (Morris et al., 2006) has been applied in an environmental health policy context in Scotland[2] and can be used as a simple framework for describing the relationship between air pollution and health. Figure 1 shows the model graphically, with the blue arrows indicating where behaviour is likely to have the greatest bearing on the pathway and ultimate outcome.

Figure 1 The modified DPSEEA model

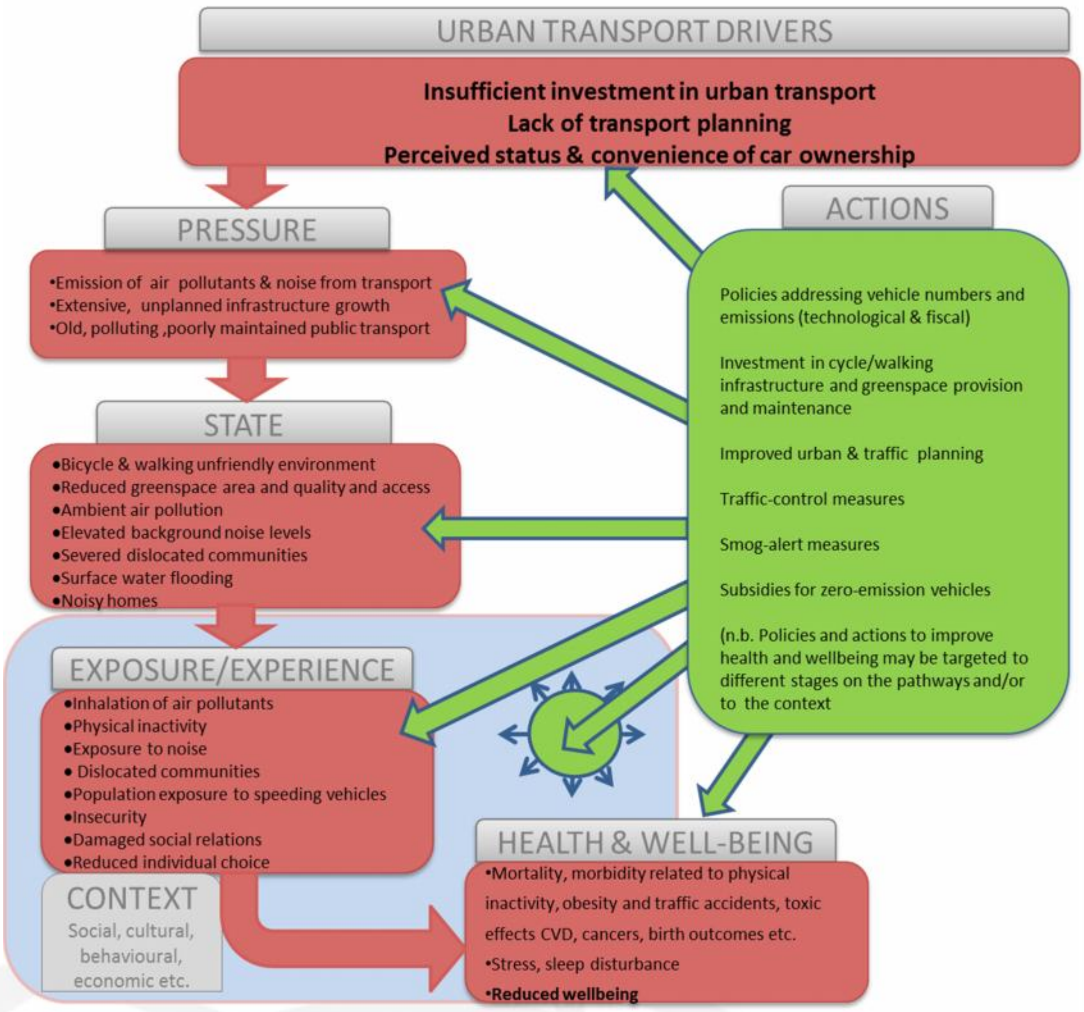


An example of a modified DPSEEA model populated for transport and health is shown in Figure 2. This example (included for illustrative purposes only) is based on the outcome of a workshop conducted for the European

[2] http://www.gov.scot/Publications/2008/12/11090318/10

Environment Agency "Foresighted Reasoning on Environmental Stressors and Health (FRESH) project"[3].

Figure 2 Example of a populated DPSEEA model



[3] www.eea.europa.eu/ehwb

3 HEALTH AND AIR POLLUTION

Section 3.1 overviews some general issues about studying the relationships between outdoor air pollution and health. This sets the context for the two subsequent sections. These are Section 3.2, which reviews evidence on the adverse health effects of three important pollutants – particulate matter (PM), ozone (O_3) and nitrogen dioxide (NO_2) – each of them important to the air quality effects of traffic; and Section 3.3, which focuses on evidence of the effects of the traffic pollution mixture as a whole, including living close to busy roads.

3.1 AIR POLLUTION AND HEALTH

3.1.1 Adverse health effects of outdoor air pollution

Outdoor air pollution is associated with a very wide range of adverse health or health-related outcomes, primarily, but not only, of the cardio-respiratory system. The present report is concerned principally with adverse health effects which can be identified by the individual themselves, or by simple medical examination, and so are amenable to epidemiological investigation, rather than the results of studies of disease mechanism at the cellular level, because these more easily identifiable effects are more closely linked with policy development.

The adverse effects of outdoor air pollution have been reviewed on many occasions by different expert groups, including two relatively recent linked assessments led by the World Health Organisation (WHO) in support of the development of air quality policy in Europe (REVIHAAP: WHO, 2013b, WHO, 2013a). The present report looks to these reviews as principal sources of evidence and so doesn't attempt to reference individually each of the relevant health and health-related outcomes where some causal role for air pollution is accepted or strongly suspected. These include:

a. minor and possibly reversible physiological changes in functioning of heart, lung and other organs (e.g. lung function changes, heart arrhythmia)

b. various measures of pregnancy outcome e.g. prematurity, birth-weight, survival

c. respiratory symptoms, asthma attacks, use of bronchodilators

d. other indices of health service usage (the specifics vary with how health services are organised) e.g. consultations with GPs or equivalent, visits to hospital emergency rooms (in North America), emergency hospital admissions (typically for respiratory or for cardiovascular causes)

e. behavioural aspects such as days off work (Work Loss Days – WLDs), days off school, days when normal activity is restricted because of health (Restricted Activity Days – RADs)

f. defined diseases – doctor-diagnosed diseases, asthma, chronic bronchitis (based on reporting of respiratory symptoms such as chronic cough and/or phlegm) or COPD (Chronic Obstructive Lung Disease, based on lung function measurements), cancer (especially lung cancer)

g. (earlier) death (or, equivalently, higher age-specific death rates), in adults, in infants, in people of all ages

3.1.2 Outdoor air pollution increases the risk of commonplace diseases and conditions

Air pollution doesn't cause exclusive or distinctively new diseases or causes of death. Instead, like smoking tobacco, it acts as one of many factors that increase the risks of commonplace health conditions. This makes it difficult for the general public to notice the adverse health effects of air pollution, it creates challenges for the study of relationships between air pollution and health, and it complicates communicating the findings in an accessible way.

First, because each of these health conditions is affected by many other factors also, it is difficult for people generally to notice that air pollution is having a detrimental effect. The main exception is in occasional periods of very high air pollution, as in the London smogs of the 1950s, when it was clear that the number of deaths per day in the days immediately following the very high pollution levels was much higher than normal. The conclusion that air pollution at high daily levels (of black smoke and sulphur dioxide) caused earlier death, and other health effects, was unavoidable; and in the UK and elsewhere this led to restrictions on burning coal for domestic heating in cities, which reduced greatly the severity and frequency of air pollution episodes. (It appeared that this had also solved the wider problem of air pollution and health but later research, from the late 1980s, showed that effects also occur at much lower levels and indeed that long-term annual average pollution, and not pollution episodes, is the main driver of adverse public health effects.).

Secondly, because air pollution acts to increase the risk of commonplace health conditions, epidemiological research on air pollution and health is complicated by the need to take account of other health determinants also, especially those that vary along with air pollution. If this is not done well enough, there is a danger of attributing to air pollution an effect of these other confounding factors. Exactly which other factors may be acting as confounders depends on study design, and how both health and air pollution are measured; examples are given in Section 3.1.3 later.

Finally, the fact that air pollution increases the risk of commonplace or everyday health conditions, rather than causing distinctively new diseases, also complicates efforts to communicate with people about the health effects of air pollution. It means statistics about the effects cannot be illustrated with the personal stories of identifiable victims whose disease or death was caused by the risk factor of interest, something that is possible with other issues such as crime, or road traffic accidents, or where there are distinctive diseases like mesothelioma following asbestos exposure, or where the risk factor has a very major influence, such as smoking and lung cancer. In contrast, the way that the large public health effect of outdoor air pollution is dispersed across the population is unknown (COMEAP, 2010) but large numbers of people are affected because everybody is exposed.

3.1.3 Epidemiological studies of outdoor air pollution and health

There are two main kinds of epidemiological studies of outdoor air pollution and health, distinguished according to the combination of the length of exposure being investigated and how soon afterwards the health effects being studied occur. Time series and panel studies deal with short-term or acute exposure, typically one day or less, in relation to health effects on the same or immediately following days. They are designed to identify the more-or-less immediate effects, or 'triggering', effects of air pollution. Cohort and longitudinal studies deal with long-term or chronic exposure, typically represented as an annual average, in relation to the risk of death or of showing or developing disease. They are designed to identify the role of air pollution over time, possibly over a lifetime, in the development or acceleration of disease and consequent earlier death. This section describes both kinds, by way of background. It also includes some remarks on what are called 'natural experiments', when policy changes lead to major changes in air pollution whose health consequences can be investigated directly.

Epidemiological studies of short-term exposure; and an important policy implication

Typically these studies examine relationships between daily levels of air pollution and the health of individuals or of a population on that same day or on immediately following days, and typically within a week. A small number of studies look at health effects up to about 6 weeks from the day of exposure. Typically exposure is represented as 24-hour average pollution for that day, though for some pollutants, especially ozone which depends on sunlight, shorter time periods are studied also – see Section 3.2.3.

Some studies of short-term exposure are based on a whole population, for example all residents in a city, without identification of individuals. This is possible where relevant daily health data in a population are routinely gathered or relatively easily collected, for example number of daily deaths or hospital admissions in a city. Because such time series studies of daily air pollution in relation to mortality and hospital admissions are relatively easy to conduct and the health outcome is severe, they have now been carried out in many cities and regions in Scotland, the UK and worldwide.

Routine data collection, enabling time series study of the whole population of a city, is usually available only for the most severe health outcomes. For other, less severe, health outcomes (e.g. daily presence or absence of respiratory symptoms, or measures of lung function, or use of bronchodilators by people with asthma), it is necessary to explicitly identify panels of individuals and engage them directly and explicitly in the research study, by recording information each day about symptoms or use of medication or results from simple tests of lung function that an individual can do her or himself. Then the analyses examine relationships in individuals and aggregates results over the panel as a whole. These panel studies of individuals are more difficult to do than time series studies of populations and consequently there are fewer such studies internationally.

Both kinds of studies have several characteristics in common. Both examine pollution characterised by concentrations in a given day. Both are designed to detect the more-or-less immediate effects of air pollution in “triggering” any of the wide range of health outcomes studied. And in both, the study population changes very little over the time course of the study. Consequently many of characteristics which are relevant to health (e.g. age, gender, ethnicity, smoking habit, socio-economic status) change very little over the time-course of the study and so it is not necessary to measure them explicitly in order to take account of their effects. This limits the number of potentially confounding variables to factors that vary day-by-day such as temperature, humidity, season, perhaps day-of-the-week (relevant for hospital admissions), making studies of short-term exposure much less resource intensive than studies of longer-term exposure and consequently much more numerous.

One very important finding, which emerged in the late 1980s and has been strongly supported by numerous studies since then, is that adverse health effects are not restricted to days of unusually high air pollution. This has been shown most clearly for particulate matter (PM), where effects occur right across the range of typical air pollution concentrations found in different cities with different pollution mixtures, populations and health care systems, though of course typically health effects are more numerous following days of higher air pollution. Indeed, for particulate matter expressed as $PM_{2.5}$ or PM_{10}, there is no known population threshold or ‘safe level’.

This has a very important implication – that public health is best protected by reducing the average concentrations experienced by the population as a whole (exposure reduction strategy), even where daily and annual average levels are already quite low, rather than by focusing on eliminating the highest pollution days, or other pollution hotspots.

Epidemiological studies of longer-term exposure: these show the largest public health impact

Earlier studies, reviewed e.g. in COMEAP (1995) with respect to PM, investigated associations between mortality and longer-term exposure to air pollution by geographical region, and as far as practicable took account also of other risks to health (e.g. poor socio-economic status) at area level also. Some of these analyses did show associations between annual average PM pollution and mortality but it was difficult to use the results for policy purposes because it could not be assumed that the effects of non-pollution factors had been sufficiently taken into account(COMEAP, 1995).

The situation changed in the mid-1990s following the publication of results from two cohort studies in the USA (Dockery et al., 1993, Pope III et al., 1995) which showed relationships between annual average $PM_{2.5}$ and age-specific death rates in US cities, after adjusting for other factors (e.g. gender, ethnicity, smoking habit, educational attainment) at the individual level. In due course, and with evidence from other cohort studies also, these relationships were understood as causal, and it came to be appreciated that they represented an impact on public health far greater than that of the studies of short-term exposure. This is partly because the estimated % increase in mortality (e.g. per 10 $\mu g/m^3$ $PM_{2.5}$) was higher than that from studies of daily variations. But also, it was understood that the cohort study results, because of their long-term nature, represented an effect not just on people who were already vulnerable, but on people generally; so that when mortality effects were represented in terms of years of life lost, rather than premature deaths, the effects of long-term exposure dwarfed those of short-term exposures. This further supports a strategy of exposure reduction for everybody rather than elimination of occasional hotspots in time or space.

The role of “natural experiments”

There have however been occasions when, because of policy changes or other factors, there have been strong reductions in pollution and consequent reductions in mortality have been identified. Among such ‘natural experiments’ are a ban on burning coal for domestic purposes in Dublin, Ireland (Clancy et al., 2002) and de-sulphurisation of fuel in Hong Kong (Hedley et al., 2002). For a fuller review, see Pope III, (2012). Results such as these give some reassurance to otherwise sceptical people that it is justified to base policy on the epidemiological and other evidence summarised here.

3.1.4 How pollution is measured in population studies of air pollution and health

This Section summarises briefly some of the ideas of Section 1.3, about concentrations of and personal exposure to air pollution from traffic; and focuses on implications for the study of relationships with health.

Measurement and modelling of ambient air pollution concentrations

Population studies of outdoor air pollution examine relationships between the health of people and the concentrations of pollutants in outdoor air near where they spend their time, and especially near where they live. Estimates of the concentrations where individuals live are typically based on measurements at a limited number of fixed-point sources e.g. within a city. Typically the number of monitors is very small relative to the size of the population and so individual monitors need to give information that is useful not only for people who live nearby, but also for people at much greater distance. For that reason, they are usually located at ground level and in the background, i.e. where their measurements are not dominated by particular local sources.

While measurements from a small network of fixed point monitors can provide useful information about concentrations of air pollution throughout a city, their usefulness can be greatly enhanced by modelling what happens to air pollutants after emission into the environment, where they interact with one another and with the wider environment, such as ammonia, and taking account e.g. of sunlight and other climate characteristics.

Measurement and modelling of personal exposures to air pollutants

There is currently a lot of interest in modelling and measuring personal exposures, rather than simply concentrations at their home. The reason, perhaps obviously, is that people spend only part of their time at home. For pollutants that are well-dispersed, such as $PM_{2.5}$, this may not be a major limitation. It is more important for other pollutants, like NO_2, where there is greater local spatial variation within cities.

Modelling, or indirect measurement, is well-established. In studies of short-term exposure, it involves tracking the time-activity patterns of individuals, i.e. time spent in a variety of micro-environments (e.g. indoors at home, at work, in vehicles, outdoors close to traffic, outdoors elsewhere) and associated concentrations of air pollution; and linking these to estimate personal exposures over say a day, or some longer time-period. In studies of longer-term exposures it includes tracking changes of residence and other major life changes that might affect exposure to air pollution.

Direct measurement typically involves a person wearing a sampling instrument for a period of time as they go about their daily life. This kind of measurement is becoming increasingly popular, and is likely to expand greatly, as small sensors become more precise and accurate, more reliable to use, more widely available and cheaper. These technological developments, together with people’s increasing engagement with environmental issues, has led to a growth of interest in the possibility of citizen science in the context of air pollution in cities (Cowie et al., 2014).

Strengths and weakness of the various approaches in studying health effects of outdoor air pollution

As noted, there are limitations in basing studies of outdoor air pollution and health on ambient concentrations of pollution rather than on personal exposures. Concentrations relate to outdoors at residence and people spend time away from home and indoors at home; and the concentrations used are estimates, based on limited measurement and modelling. The main advantages are that they are easier to conduct than studies of personal exposures, there is a consistency in results from different times and locations, and they are relevant to developing policy, in that outdoor concentrations can be relatively easily monitored, and are public, and so are amenable to regulation. They are limited in the information that they can provide about the mechanism of action of air pollutants at the individual level, because they by-pass the detail necessary for such a study; and one use of studies of personal exposures is to understand better such mechanisms. But studies of concentrations do give useful information, important for policy purposes and regulation, about the relative importance of the various components of the air pollution mixture. We now describe briefly how they achieve this. Evidence about individual pollutants is summarised in Section 3.2, following.

3.1.5 The effects of mixtures, sources and single pollutants

Some epidemiological studies aim to examine the effect of the air pollution mixture as a whole; for example studies that focus on how health varies with distance from major roads (Section 3.3, later). Most try to identify the effect of individual pollutants, especially the major regulated pollutants such as PM, ozone, NO_2, sulphur dioxide (SO_2) and carbon monoxide (CO). The relationship with health is examined for pollutants individually, and then in combination.

There are several difficulties in doing this well. A widespread complication is that the concentrations of different pollutants tend to be correlated with one another, i.e. tend to go up and down together; and this makes it difficult, and sometimes impossible, to identify reliably the separate effects of the various pollutants. Formally this shows as high uncertainty (high standard error) in the risk coefficients as estimated from multi-pollutant models. Also, it may be that some health relevant aspects of the air pollution mixture have not been measured and so are not available for analysis. Finally, the toxicity of individual pollutants is not necessarily constant – it may be affected by the mixture of which they are a part.

In interpreting results from such analyses, judgement is needed on whether a statistical association between a particular pollutant and health occurs because that pollutant affects the health outcome in a causal way, or whether the pollutant is operating as an indicator of the wider mixture from a particular source. For example, NO_2 and CO are often considered as indicators of pollution from traffic, while SO_2 is often looked on as a marker of air pollution from industrial sources.

In terms of practical health protection it may not matter greatly whether or not the individual pollutant is itself the cause or is acting as an indicator, if it is necessary to control the mixture as a whole in order to control the individual pollutant. It used to be that this was so for NO_2 and traffic. Nowadays however it is possible to reduce NO_2 without reducing the mixture as a whole, and then it does matter whether or not NO_2 is itself causal. As discussed later (Section 3.2.2), current thinking is that, at least in part, NO_2 itself is the cause of at least some of the adverse health effects associated with it (WHO, 2013b).

PM, expressed as PM_{10} or $PM_{2.5}$, is itself a mixture that functions also as a carrier of metals adsorbed on to the surface of small particles. One important issue of interpretation, which in turn is an important issue for health protection, is the extent to which the health effects associated with PM and often attributed to it are in fact being driven by surface or other characteristics of the inhalable particles; and the related issue of the relative toxicity of different kinds of PM. This is addressed in Section 3.2.1.

Interpretation is helped by the consistency, or not, of findings across epidemiological studies in various times and locations. It is also informed by evidence from experimental studies – toxicology and human laboratory studies. We describe these briefly, next.

3.1.6 Other kinds of scientific evidence – study of mechanisms

The kinds of study described up to now in Section 3.1 are called observational because the research is based on observing what happens with pollution and with people as experienced in ordinary daily life, and occasionally in more extraordinary but nevertheless real-life situations of air pollution episodes. And the present report focuses on these observational studies because, despite the difficulties in carrying them out well and in interpreting the results, as described earlier, there is a great deal of evidence internationally, the studies focus on people in their natural settings, and they deal with health outcomes which are readily meaningful in terms of illness, disease, disruption of daily activities, use of health services and death. As such, they form the core of evidence used for quantifying the likely health benefits of reducing various pollutants (e.g. WHO, 2013b) and for the development of messages to inform the general public.

There are however other sources of evidence, from toxicology and human experimental studies, which complement the observational studies described earlier, and give new perspectives especially on the role of individual pollutants (singly or in combination), on causality, on the existence or not of safe levels (or more strictly, on No Observed Adverse Effect Levels (NOAELs)), and on mechanisms of action. Traditionally there are three main kinds of study:

a. In vitro toxicology studies of how human cells, e.g. cells obtained by broncho-alveolar lavage from the lining of the human lung, respond to dust and other pollutants;

b. In vivo toxicology studies of how laboratory animals respond to sometimes high exposures; and

c. Human clinical studies, whereby apparently healthy people, and people from known disease groups, are exposed for short periods to controlled levels of pollution and their short-term response is monitored, to see whether there are identifiable impacts on the performance of lung or heart, or whether chest tightness is induced.

Some people would now add a fourth kind:

d. In silico studies of computer modelling based on experimental toxicology and designed to minimise the use of experimental animals by making best use of available experimental data.

These experimental studies all share the advantages that they are carried out under controlled conditions where the researchers can define the conditions of the experiment, and in particular how much of what kind of pollution is administered for how long, with added control of the measurement of outcomes. On the other hand, there is with toxicology an important issue of extrapolating to humans and human health the knowledge gained about how cells or particular species and strains of animals respond to pollution; and the human experimental studies are necessarily restricted to concentrations and duration that are acceptable both ethically and to participants. Nevertheless, these experimental studies inform interpretation of epidemiological evidence and make an important contribution to clarifying to what extent individual pollutants, or particular components of PM, are hazardous and so, for example, the REVIHAAP assessments of the role of individual pollutants (WHO, 2013b), to which we frequently refer, draw strongly on laboratory experimental studies in forming their conclusions.

3.2 THE HEALTH EFFECTS OF SPECIFIC POLLUTANTS ESPECIALLY THOSE RELATED TO TRANSPORT

Although ambient air pollution contains multiple constituents, the following three sections review and summarize the health effects of three of these: particulate matter (PM), ozone (O_3) and nitrogen dioxide (NO_2). All three are regulated pollutants and (as noted in Section 1.3.1, earlier), traffic plays an important role in all three: some PM is directly emitted from fuel combustion, other PM comes from abrasion and from re-suspended road dust; and emissions of NOx (i.e. of NO and of NO_2) lead over time and distance not only to NO_2 but to increased PM (via the formation of nitrate PM) and to increased ozone. Also, when as part of health assessments to support the Clean Air for Europe (CAFE) programme about 10 years ago the European Commission formulated various questions for a World Health Organisation (WHO) expert group, the questions focused on PM, O_3 and NO_2 (Hurley et al., 2005). The more recent WHO evaluations to support development of air quality policy in the EU (the REVIHAAP project) focus principally also on PM, $O_3$and NO_2, though other pollutants are considered briefly also (WHO, 2013b), with recommendations for quantifying effects of ambient air pollution (the HRAPIE project) being for these three pollutants only (WHO, 2103a).

3.2.1 Particulate Matter (PM)

Everybody is exposed to outdoor air pollution, though the precise mixture and the concentrations of individual pollutants vary over time and space; and as noted in Section 3.1, it isn't easy to determine the contribution of individual pollutants to the impact of the mixture as a whole. However the strongest evidence of greatest health effects relates to PM, in the sense that when quantifying the effect of air pollution on health, there are more relationships linked with PM than with other pollutants (WHO, 2013a) and typically also they lead to a greater public health burden. The most wide-ranging evidence of damage attributable to PM comes from time series studies of short-term exposure to PM, i.e. studies of 'daily variations' in PM_{10} and $PM_{2.5}$. The greatest public health impact, however, typically comes from cohort studies of longer-term exposure to PM, represented as annual average $PM_{2.5}$. There is some support also from studies of interventions, as well as laboratory studies of the mechanisms of disease. There are numerous reviews, including US EPA, (2009), Brook et al., (2010) and Rückerl et al., (2011), all of which informed the assessments of REVIHAAP (WHO, 2013b); the present report draws on all of these.

Mortality from long-term exposure

There is widespread agreement that the greatest impact of air pollution on public health is through an increased risk of earlier death in adults, from long-term exposure to air pollution represented as annual average of fine PM ($PM_{2.5}$). Typically this is estimated as a 3% increase in age-specific death rates for all-cause mortality in adults, per 5 $\mu g/m^3$ $PM_{2.5}$, which is close to a typical population annual average exposure level in Scotland (COMEAP, 2010). This estimate of % increase comes originally from the major US American Cancer Society (ACS) cohort study (Pope III et al., 1995, Pope III et al., 2002) whose estimates, after careful review of alternatives, were endorsed by the UK Advisory Committee (COMEAP, 2009), among others. More recent expert assessment (WHO, 2013a), for applications EU-wide, chose estimates from an up-to-date meta-analysis of 13 cohorts of adults in Europe and North America Hoek et al., (2013) which amazingly gave almost exactly the same central risk estimate as the ACS, though with a smaller uncertainly interval. The main causes of death affected are deaths from heart attacks (acute myocardial infarction – AMI) and stroke (cerebrovascular disease), from chronic non-malignant lung disease (asthma and COPD: chronic obstructive pulmonary disease) and from lung cancer (see, e.g., COMEAP 2009).

Mortality from long-term exposure to outdoor air pollution characterised as $PM_{2.5}$ is a major public health issue internationally. The international Global Burden of Disease (GBD) project, which estimates the impact of 67 risk factors and clusters of risk factors worldwide, recently estimated that, in 2010, long-term exposure to $PM_{2.5}$ was responsible for over 3.2 million deaths worldwide (Lim et al., 2012). GBD used a more complicated risk function than the 3% increase per 5 $\mu g/m^3$ $PM_{2.5}$ discussed above, to take into account that the increase per $\mu g/m^3$ $PM_{2.5}$ seems to level off at high annual average concentrations (Burnett et al., 2014), much higher than are experienced in Scotland but which do affect other countries worldwide, e.g. China. This estimate of annual attributable deaths for the year 2010 made ambient pollution from $PM_{2.5}$ the 9th most significant risk factor overall in terms of disability adjusted life years (DALYs), and the 5th most important environmental risk factor, after active smoking, alcohol use, household air pollution and low fruit diet. This ranking varies widely by region being highest in East Asia and South Asia, where sources include coal-burning for power generation and other uses, household burning of solid fuels, and road transport, and lowest in Oceania, Tropical Latin America and Australasia. In Western Europe ambient pollution from $PM_{2.5}$ was ranked the 11th most significant risk factor.

For Scotland, COMEAP, (2010) estimated that long-term exposure to $PM_{2.5}$ leads to earlier mortality across the population equivalent to about 1,500 deaths per year at usual ages, i.e. about 2.8% of the annual mortality in Scotland. This is much more than Road Traffic Accidents, but because unlike Road Traffic Accidents there are not identifiable victims, it is not easy to communicate the size of the problem using these sorts of figures without running the risk of being misleading. The whole population is exposed and how the effects of air pollution on risks of mortality are distributed across the population is strictly unknown (COMEAP, 2010). However, air pollution is generally considered to have some degree of health impact on everyone but a more severe impact on more vulnerable people, especially those with already poorer health. This means the impacts are not spread equally as increased risks to the whole population but are experienced unequally by those least able to cope with additional harmful exposures. Yap et al., (2012) used two historic Scottish cohorts to look at the associations between long-term exposure to air pollution, measured as black smoke, and mortality. They found consistent black smoke–mortality associations with hazard ratios (HR) (per 10 $\mu g/m^3$ increment in 10-year average) in the Renfrew/Paisley cohort for all-cause mortality HR 1.10 (95% CI 1.04 to 1.17); cardiovascular HR 1.11 (1.01 to 1.22); ischaemic heart disease HR 1.13 (1.02 to 1.25); respiratory disease HR 1.26 (1.02 to 1.28)). The associations were largely unaffected by additional adjustment for area level deprivation category. However the authors noted that the results were sensitive to the different exposure models used thus highlighting the critical importance of reliable estimation of exposures on intra-urban spatial scales to avoid potential misclassification bias.

There is no evidence of a threshold or safe level of PM for the population as a whole; indeed, there is evidence of an effect at levels as low as about 5 $\mu g/m^3$ $PM_{2.5}$. Below this, there is absence of evidence, i.e. a lack of studies with sufficient power and data to show an effect (as distinct from sufficiently powerful studies which failed to show an effect). For example, a recent study (Shi et al., in press) reported that the dose-response relationship between chronic exposure and mortality among those aged 65 or more in New England appeared to be linear for $PM_{2.5}$ concentrations down to 6 $\mu g/m^3$, with a positive (though weaker and less precise) dose-response slope continuing below this level. The authors note that the lack of power is likely due to the small population exposed in the areas with annual $PM_{2.5}$ below 6 µg/m^3, which were quite rural, and note that more evidence is needed to confirm the association at level below 6 µg/m^3. So, strictly, there is some significant lack of evidence about effects at annual average $PM_{2.5}$ concentrations typical of at least some of Scotland; but the indirect evidence is strong.

In addition to increased mortality in adults, there is evidence, including from large-scale studies in the USA (Woodruff et al., 1997; 2008), that longer-term exposure to outdoor air pollution (i.e. averaged over months) increases death rates in infants, i.e. between ages of 1 month and 12 months. WHO (2013a) considered the evidence strong enough to recommend it for quantification, though recognising that it is less strongly supported than that for mortality and adults.

Mortality from short-term exposure

Time series studies of short-term exposure to PM also show effects on mortality, with strong evidence of relationships between daily PM concentrations and number of deaths on the same or immediately following days. Evidence is principally from North America and Europe but also from many cities worldwide, e.g. in East Asia, in Latin America. Because air pollution is one factor among many, and is not the principal driver of daily deaths (except perhaps occasionally, during extreme air pollution episodes), advanced methods of statistical modelling are needed to identify the effect. Initially this, together with a lack of an obvious mechanism whereby air pollution at typical levels could trigger death by heart attack, led to some scepticism about whether or not this effect was real. However, already by 1995 the evidence was sufficiently strong for COMEAP, (1995) to conclude that it “would be imprudent not” to consider the effect as causal. Not long afterwards some plausible mechanisms were suggested (Seaton et al., 1995) and further research has elaborated others. These have been reviewed e.g. by COMEAP, (2006), by Rückerl et al., (2011), and by Brook et al., (2010) who identify “systemic inflammation, oxidative stress and alteration of the electrical processes of the heart” as “likely biological mechanisms, strongly supportive of a causal association between $PM_{2.5}$ and cardiovascular disease and mortality” (WHO, 2013b).

Although suitable statistical analysis identified a clear ‘signal’ from time series studies that short-term exposure to PM_{10} was associated with increased risks of mortality at all ages, the overall effect on public health was not great. Partly this is because the estimated increase per µg/m^3 PM_{10} or $PM_{2.5}$ was small. In 1995, estimates were for PM_{10}. More recent estimates are for $PM_{2.5}$, where e.g. WHO (2013a) proposed an increase of daily mortality of 1.23% per 10 µg/m^3 $PM_{2.5}$. This estimate was based on APED study meta-analyses of results from 12 single-city and one multi-city study in Europe and gave an estimated % increase somewhat higher than that of other meta-analyses (WHO, 2013b), but clearly lower than the % increase for long-term exposure. Additionally, it is believed that the most severe triggering effects occur only in people with pre-existing serious lung or heart disease and whose life expectancy was in any case short, relative to people generally of the same age (see e.g. Hurley et al., 2005). Also, it is unclear to what extent the deaths attributable to PM from short-term exposure are already included in those attributable from long-term exposure. Usually these are not added, to avoid double-counting (e.g. Hurley et al., 2005; WHO, 2013a).

Studies in Scotland of mortality in relation to particulate matter have tended to focus on black smoke. Prescott et al., (1998) found positive associations over the period 1981–95 in Edinburgh between black smoke as a mean of the previous three days and daily all-cause mortality in people aged >65, and respiratory mortality also in this age group (3.9% increase in mortality for a 10 µg/m^3 increment in black smoke). An extension of this study to Aberdeen and Glasgow as well as Edinburgh and covering 1981-2001 found a significant association only with respiratory mortality with no notable variation in different seasons of the year (Carder et al., 2008).

Morbidity

There are varying degrees of evidence for many other effects of PM, apart from the effects on mortality of both long-term and short-term exposure. For example, Section 3.1.1, earlier, lists a very wide range of cardio-respiratory health effects, from minor symptoms in many people, through asthma attacks and increased visits to doctors, to days off school or work and increased hospital admissions; and most, if not all, of these health outcomes have been shown to be associated with ambient PM air pollution. Greatest evidence comes from time series studies of how air pollution on a given day contributes to ill-health and mortality on the same or immediately following days; and, as for mortality, while effects are more numerous on or following high pollution days, effects occur on or following low pollution days also. As for mortality, there is no convincing evidence of a population threshold or safe level.

While effects on multiple aspects of the cardiorespiratory system have been known for more than 20 years (e.g. COMEAP, 1995), and evidence has continued to strengthen (US EPA, 2009; Brook et al., 2010; Rückerl et al., 2011), research in recent years has established or suggested other kinds of effect also. One established area of research concerns air pollution and adverse birth outcomes. There are methodological difficulties, including issues related to critical time-windows of exposure during pregnancy and possible confounding with nutrition (Slama et al., 2008). Nevertheless, more than 10 years ago, WHO, (2005) already concluded that air pollution was implicated in a range of adverse pregnancy outcomes; and in a recent systematic review, Shah et al., (2011) reported associations between $PM_{2.5}$ and pre-term birth, low birth weight, and being small for gestational age. WHO (2013b) found that epidemiological evidence for an association between $PM_{2.5}$ and diabetes has strengthened considerably in recent years, and is supported by mechanistic studies. It also reports suggestive but inconclusive evidence of neurological effects in both adults and children. For more detailed review, see e.g. Rückerl et al., (2011).

Within Scotland, a study of long-term exposure to PM_{10} focussing on Glasgow, Edinburgh, Aberdeen and Dundee found that exposures to PM_{10} over 3-years (2002-2004) were significantly associated with respiratory hospital admissions in Lothian and Greater Glasgow (RR: 1.06-1.10 for 1.7 $\mu g/m^3$ increase in PM_{10}) but lower and non-significant in Dundee and Aberdeen (Lee et al., 2009). Willocks et al., (2012) in a study in Glasgow and Edinburgh between 2002 and 2006 found no consistent associations between PM_{10} concentrations and cardiovascular hospital admissions in either of the cities studied. The authors suggested this could be because in small cities, where air quality is relatively good, then either PM_{10} concentrations have no effect on cardiovascular ill health, or that the routinely available data and the corresponding study design are not sufficient to detect an association. A 14.5 year time series study in Edinburgh from 1981-1995 found a positive association of PM_{10} as a mean of the 3 previous days with hospital emergency admissions for cardiovascular disease among those aged 65 or over (Prescott et al., 1998).

Relative harmfulness (toxicity) of different kinds of PM

While ambient air pollution is a mixture of particulate matter and gases, PM is itself a mixture of various kinds of small particle from different sources and it's hard to tell what aspects are more dangerous. There is a lot of research to try to understand the relative harmfulness but so far there is no real consensus on relative toxicity of different kind of PM in the same size range. Leading expert review groups have suggested that there are likely to be differences in toxicity associated with PM from different sources or of different solubility or with different surface properties such as transition metals but have concluded that there is insufficient evidence to enable such differences be expressed quantitatively. For example, in 2007 a special 3-day conference concluded that "Current knowledge…does not allow precise quantification or definitive ranking of the health effects of PM emissions from different sources or of individual PM components"[4].

This conclusion has significant implications for traffic-derived PM which includes (i) primary combustion particles emitted from motor vehicle exhausts ("tailpipes"); (ii) other primary PM e.g. from abrasion while braking or from re-suspended road dust; and (iii) secondary PM, especially nitrate PM, formed over time and distance through chemical reactions between NOx and e.g. ammonium. Treating these various components of $PM_{2.5}$ as equally toxic (rather than e.g. considering that primary combustion $PM_{2.5}$ is more toxic per $\mu g/m^3$ than nitrate $PM_{2.5}$) implies that a significant part of the health effects of traffic pollution occurs at distance from source.

[4] http://www.euro.who.int/__data/assets/pdf_file/0007/78658/E90672.pdf

WHO expert groups have continued to recommend mixed anthropogenic PM as the best basis for understanding and controlling health effects of particulate matter (e.g. WHO 2013a). It has been proposed that black carbon be used as the basis for quantifying the local health impacts of air pollution from traffic (Janssen et al., 2012); WHO, (2012) supported its use in supplementary analyses of health effects, but supported mixed anthropogenic $PM_{2.5}$ as primary. More recently, COMEAP, (2015b) concluded that there is not a basis in evidence for differentiating between the toxicity of different components of PM even qualitatively, i.e. it was unable to recommend that (based on PM toxicity) control measures should be targeted towards some components of $PM_{2.5}$ rather than others.

The importance of particle size

In contrast to lack of consensus about the relative toxicity of different kinds of PM, it is widely recognised and accepted that size does matter, within the range of what a person can inhale, with evidence that a given mass of PM (usually measured as weight of PM per unit volume of air, in units of $\mu g/m^3$) tends to do more damage if it is made up of a large number of small particles rather than a smaller number of coarse ones. So, for example, 1 $\mu g/m^3$ reduction in $PM_{2.5}$ is likely to be more beneficial than 1 $\mu g/m^3$ reduction in general PM_{10}.

This understanding has developed over time. Early studies, e.g. of the London smogs, used PM measured as “black smoke”[5]. This is a good and relevant metric for the local (i.e. close-to-source) effects of combustion PM, and so of domestic coal burning or traffic in cities. Many studies and measurements in the late 1980s were in the metric of Total Suspended Particulates (TSP). Then, attention switched to smaller PM, up to about 10µm aerodynamic diameter, measured in terms of mass as PM_{10}. From the late 1980s onwards, there are numerous time series studies, linking daily pollution as PM_{10} with daily deaths and hospital admissions in cities in North America, Europe and, over time, elsewhere worldwide (see. e.g. COMEAP. 1995); and in the UK and elsewhere, this emerging evidence informed regulatory standards in the metric of PM_{10} (EPAQS, 1995).

However toxicology studies, including of workplace dusts, had suggested that surface area might be a better metric than particle mass to represent the adverse effects of inhaled particles; and a given mass of PM_{10} has higher surface area insofar as it is made up of finer particles. The significance of fine PM, i.e. of particles up to about 2.5µm aerodynamic diameter, and measured in terms of mass as $PM_{2.5}$, became clearer in the mid-1990s when two US cohort studies, the Six-Cities Study (Dockery et al., 1993) and the ACS study (Pope III et al., 1995), both reported relationships between long-term exposure to $PM_{2.5}$ and risks of mortality in adults, and the public health significance of these results became apparent.

[5]Black Smoke consists of fine particulate matter. It is emitted mainly from fuel combustion and, following the large reductions in domestic coal use, the main source is diesel-engined vehicles. Black smoke if measured by its blackening effect on filters.

Subsequent increased monitoring of $PM_{2.5}$ made it easier to carry out epidemiological studies of short-term exposure to (or of daily variations in) $PM_{2.5}$ as well as PM_{10}; to the point where globally (e.g. Global Burden of Disease, Lim et al.,(2012), in the USA, (US EPA, 2011) and in Europe (WHO 2013a)), health impact assessment of PM uses the metric of $PM_{2.5}$ – sometimes with ‘conversion’ of relationships on PM_{10} to ones in $PM_{2.5}$.

Other size ranges and metrics are important also. It is well-established that coarse PM (i.e. PM in the size range 2.5µm to 10µm, sometimes written $PM_{10-2.5}$) also has adverse health effects (Brunekreef et al., 2005, WHO, 2013a), though not as severe in overall public health terms as those from $PM_{2.5}$. There is particular interest in very small (ultrafine) particles, typically defined as 100nm or smaller, which arise e.g. from diesel vehicles close to source. Such small particles tend to agglomerate quite quickly into larger clusters. They are of interest partly because early hypotheses about how ambient PM might lead to heart attacks included a hypothesis that very small PM might outwit the lung defences and enter the cardiovascular system; and there is now a wealth of research on the health effects of engineered nanoparticles which are in the same size range. Among other properties, these ultrafines have large surface relative to their mass and have very large numbers per unit volume, (e.g. per c.c.). There is a growing body of evidence linking particle number with adverse health effects. Close to source (e.g. traffic outdoors, use of a gas cooker indoors), particle number is correlated with NO_2 (Seaton et al., 2003). This report does not attempt to review the evidence on particle number, but the health effects of NO_2 are considered below.

3.2.2 Nitrogen Dioxide (NO_2)

Short-term and long-term exposures to NO_2 are adversely associated with a range of health outcomes.

There is now a wealth of studies showing statistically significant associations between short term exposure to (i.e. daily variations in) NO_2 and a range of health outcomes. REVIHAAP Question C2 summarises an extensive set of studies linking daily NO_2 with all-cause, with cardiovascular and with respiratory mortality; in most studies, including in Europe, relationships persisted after adjustment for PM (mainly PM_{10}, sometimes $PM_{2.5}$ or black smoke) (WHO, 2013b). It also reviews extensive evidence of relationships with hospital admissions for respiratory causes (especially asthma), where relationships were generally robust to adjustment for PM; and for cardiovascular and/or cardiac causes, where relationships were less clear after adjustment for PM. There is also evidence from panel studies of exacerbation of asthmatic symptoms in children. WHO (2013b) also concludes that “chamber and toxicological evidence provides some mechanistic support for a casual interpretation of the respiratory effects”. Within Scotland results from a study of 3-year exposures from 2002-2004 show that long-term exposures to NO_2 are significantly associated with respiratory hospital admissions in Edinburgh and Glasgow, whereas the risks for Aberdeen and Dundee are generally positive but non-significant (Lee et al., 2009).

Longer-term (annual average) exposure to NO_2 is also associated with increased risks of mortality in adults. The meta-analysis of Hoek et al., (2013) aggregated results from 11 cohort studies and found overall a statistically significant increase in mortality hazards (i.e. in the probability of dying at a particular age among people who had survived to that age) of 5.5% per 10 $\mu g/m^3$ annual average NO_2.

The issue then has not been lack of evidence of an association; it has been how to interpret that evidence. In many circumstances NO_2 and PM have a similar pattern of higher and lower days; this makes it difficult to identify which pollutant is causing what damage. Consequently, for many years there has been no consensus on causality, i.e. it has been unclear to what extent the most serious effects (e.g. on mortality) are directly an effect of NO_2 itself, or reflect NO_2 as a marker of traffic pollution. This issue is very important practically because in Scotland, and elsewhere in the UK, failure to comply with current EU air quality standards often occurs as failure to comply with standards for NO_2 and especially for annual average NO_2; and it is important to understand the significance to health of these failures.

The effects are at least in part caused by NO_2 itself

The REVIHAAP Review (WHO 2013b) came to two very important conclusions regarding the health effects of NO_2. First, it concluded that there are adverse health effects of NO_2, or something associated with NO_2, that are in addition to the effects of PM mass and of ozone. One reason for this conclusion came from examining the results of two-pollutant models, i.e. statistical models which seek to explain variations in daily deaths, hospital admissions and other health outcomes not only via associations with individual pollutants (e.g. daily concentrations of $PM_{2.5}$ and of NO_2), but also via the combined effect of these pollutants. The strength of relationship with one pollutant, having already taken into account ("adjusted for") the effect of the other, is informative about which is driving the relationship; and across many studies there was evidence of an effect of NO_2 after adjusting for PM. Another reason for the conclusion is that there are increased adverse health effects in populations close to busy roads. This is unlikely to be attributable to $PM_{2.5}$ because it typically does not decline rapidly with distance from busy roads whereas NO_2 does, as do other pollutants such as particle number.

The second major conclusion is that, to some extent at least, these adverse health effects (additional to those of PM mass and of ozone) are caused by NO_2 itself; i.e. NO_2 is not simply acting as a marker of a pollution mixture, it is partly responsible for the adverse health effects associated with it. In the UK, COMEAP considered these conclusions and the evidence underlying them, and endorsed them (COMEAP, 2015a).

The implications are big, including that (i) it confirms the importance of compliance with regulatory standards in NO_2, including when compliance is achieved by reducing NO_2 itself rather than reducing the overall pollution mixture of which it is a part; and (ii) it suggests that current estimates of the overall adverse health effects of ambient air pollution are too small, because typically they ignore the effects associated with NO_2. In fact the under-estimation may in due course be shown to be substantial, if and when effects on mortality of long-term exposure to NO_2 are included in major health impact assessments. The recommendations of the HRAPIE project (WHO, 2013a) in this regard are cautious: that the effect of annual average NO_2 on mortality be included but only when annual average NO_2 exceeds 20µg/m^3; and that the quantification not be considered as one of the group of pollutant-health combinations that is most strongly grounded in evidence. In the event, quantification of NO_2 was not included in the EU's assessment of the health impacts of various future air quality scenarios (Holland, 2014) but when some remaining difficulties in quantification are overcome, it is likely that the estimated effects will be found to be large: the corresponding pathway for $PM_{2.5}$, of effects of long-term exposure on mortality in adults, is by far the most significant one in public health terms overall, and HRAPIE estimated that the amount of double-counting implied by the pathway annual average NO_2 and adult mortality overlaps with that of $PM_{2.5}$ by no more than one third.

While most attention is focused on cardio-respiratory outcomes, there may be other effects also, e.g. Freire et al., (2010), in a cohort study of children in Spain, found evidence (not statistically significant) of associations between exposure to NO_2 and cognitive function, including working memory, suggesting that “traffic-related air pollution may have an adverse effect on neurodevelopment, especially early in life, even at low exposure levels”.

NO_2 also acts indirectly on health, via its role in causing other pollutants

There is another reason why control of NO_2 leads to benefits for health; that is, that emissions of NOx (i.e. NO + NO_2) lead to increases in other health-related pollutants also. One of these is an increase in nitrate PM, formed as NO_2 interacts with other airborne constituents, especially ammonium. This happens over time and a distance from source. There is limited evidence on the health effects of nitrate PM specifically, but as discussed earlier, current expert assessment is not to distinguish components of PM in terms of their relative toxicity. Emissions of NOx also lead to increases in ozone though the situation is complicated: while ozone levels a distance from NOx emissions may increase, close to source in cities there may be reductions in ozone (if ozone production in the city is already “NOx saturated”).

Both of these effects emphasize that (i) the benefits to human health of reducing NOx emissions need to take into account health benefits via reductions of $PM_{2.5}$ and ozone also; and (ii) in assessing those health benefits, it is insufficient to look at health effects ibn the local population only – the benefits to health at distance from source may be substantial.

3.2.3 Ozone (O_3)

Effects of short-term exposure – daily variations in O_3

It has long been recognised that there are ‘triggering’ effects of short-term exposure to ground-level ozone, represented variously as 1-hr daily maximum, daily maximum 8-hr average, and 24-hr average. These affect a wide range of respiratory conditions including earlier death (from cardiovascular as well as respiratory causes) in vulnerable people, respiratory and possibly cardiovascular hospital admissions, and various indices of less serious respiratory morbidity (WHO 2013a, 2013b). Evidence comes not only from North America and Europe (Katsouyanni et al., 2009) but also from Asia (HEI, 2010, HEI, 2011) and has for many years been used in quantification studies e.g. for the Clean Air for Europe (CAFE) cost-benefit analyses (Hurley et al., 2005). The health effects of short-term exposure to (daily variations in) ozone seem to be independent of those of PM, once due account is taken of the different patterns of high and low days for both pollutants. In public health terms, this means that the effects of both pollutants can be added together in assessing the overall impact of air pollution, and this is usually done (Hurley et al., 2005, US EPA, 2011, WHO, 2013a).

Effects of longer-term exposure

There may be additional effects of longer-term exposure to ozone, i.e. the effects of longer-term exposure may be greater than simply adding the ‘triggering’ effects of ozone on individual days. REVIHAAP (WHO, 2013b) reviews several studies showing associations between long-term exposure to O_3 and respiratory morbidity (lung function growth in children; various measures of asthma incidence and severity) and emerging evidence of possible effects on preterm birth and on cognitive development. Two studies, using data from the ACS cohort in different ways, suggested that long-term exposure to ozone increased the risks of mortality. Smith et al., (2009) found effects on cardio-respiratory causes generally, in analyses adjusted for elemental carbon and for sulphates. Jerrett et al., (2009) found effects of summertime ozone (average of 1-hr daily maximum O_3) on respiratory causes in particular, in analyses adjusted from $PM_{2.5}$, with suggestive evidence either of effects only in warmer climate. WHO (2013a) proposed quantification of effects based on Jerrett et al., (2009), with a threshold at 35 ppb (70 μg/m^3) average of 8-hr daily maximum O_3. Effects have been used for policy development by the EU, as part its work on the Gothenburg Protocol (Miller et al., 2011) and by US EPA (2014) in its analysis of the effects of ozone.

3.3 THE LOCAL HEALTH EFFECTS OF THE 'TRANSPORT MIXTURE'

3.3.1 Traffic exposure, local air pollution and health – an overview of the issues

Purpose, scope and methods

Much of the evidence about the health effects of traffic-related air pollution comes from studies of individual pollutants where traffic is an important source, both those emitted directly and those formed subsequently through chemical reactions in air. These include PM and some of its components; NO_2; and ozone, all of which have been considered in Section 3.2, above. This present section focuses on another, less extensive but important, body of evidence, which tries to study the health effects of the transport pollution mixture as a whole. It focuses on road traffic (motorised road vehicles) rather than on air travel or shipping , and on local effects only, i.e. the present Section does not deal with ozone or with nitrate PM, though they are important aspects of the health effects of air pollution from road traffic.

This Section draws substantially from two major reviews, the World Health Organisation (2005) report "Health effects of transport-related air pollution", in particular Chapter 4, and especially "Traffic-related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects (Health Effects Institute (HEI), 2010). It is supplemented by information and conclusions from a more recent, brief but high-level assessment of air pollution close to roads and its health effects, as Question C1 of the REVIHAAP Review (WHO, 2013a, Question C1), which explicitly cross-refers to the HEI report as a major source of information up to 2010.

The local road traffic pollution mixture

Following WHO (2010), WHO (2013a) describes both combustion and non-combustion emissions from road traffic. Combustion emissions, from motor vehicle exhausts (tailpipes) include CO_2, CO, NOx, hydrocarbons, PM, benzene, 1,3-butadiene, formaldehyde, acetaldehyde. Non-combustion emissions include abrasion PM from tyres and brakes, and re-suspended road dust. It also summarises how roadside concentrations of these pollutants tend to be higher than background, and decay with distance from roads, the rate of decay varying by pollutant and being influenced by wind direction. A meta-analysis of results from 30 studies indicated that the spatial extent of impact was on the order of 100–400 m for elemental carbon or particulate matter mass concentration (excluding background concentration), 200–500 m for nitrogen dioxide and 100–300 m for ultrafine particle counts" (Zhou and Levy, 2007).

Choice of exposure metric

One of the main challenges in identifying the health effects of transport-related air pollution, rather than those of air pollution more generally or of specific pollutants, is how to characterise exposure. The HEI review excluded papers that used an inadequate or nonspecific estimate of traffic exposure (e.g. self-reports, PM concentrations without identification of a traffic source, etc.). Traffic exposure metrics that were accepted in the review included:

- Distance to main road or highway
- Distance to street canyons
- Traffic density measures
- Modelled traffic exposures (e.g. dispersion models)
- People occupationally exposed to traffic
- Traffic pollution surrogate measures (e.g. NO_2, elemental carbon) from roadway-specific monitoring

The WHO (2005) review also notes the difficulty of attributing the effects of exposure on health to a particular source, and similarly excludes studies which use surrogates for traffic-related air pollution which it considered to be inadequate, such as self-reports, street type or frequency of traffic jams at junctions.

Other, non-pollution explanations

Other, non-pollution factors may affect the health of people living close to roads. WHO (2013a) lists a wide range of health outcomes shown as elevated in people close to roads, after adjustment for socioeconomic status (SES) and other factors, and concludes that while SES may have a role, it alone does not explain the health effects, nor does co-exposure to noise pollution from traffic. It concludes that air pollution from traffic is a factor, and that “association with tailpipe primary PM is identified increasingly”. Also, by examining toxicological studies of metals from “engine abrasion (iron, manganese and molybendum) and brake wear (copper and antimony)”, WHO (2103a) concludes that there is also a contribution of traffic non-exhaust pollutants.

Priority of pollutant-specific evidence

The remainder of Section 3.3 concerns particular health outcomes in relation to distance from roads or other indicators of the road traffic pollution mixture. Sometimes the evidence from the mixture studies is inconclusive, even for health outcomes where there is strong evidence about individual traffic-related pollutants, especially PM and NO_2. In those circumstances we strongly suggest giving priority to the pollutant-specific evidence (because there is a lot more of it and there is greater agreement on what to measure), and looking on the mixture-specific evidence as supplementary. It may be helpful nevertheless to see to what extent the mixture studies support the pollutant-specific conclusions. Of possibly greater interest is whether the mixture studies, or studies of proximity to roads, suggest any additional effects and on this there is evidence, regarding onset or prevalence of asthma.

3.3.2 Traffic exposure and mortality

HEI (2010) concluded that, in contrast to the evidence for particular pollutants such as $PM_{2.5}$ (and black carbon as a particular constituent), NO_2 and O_3, the evidence linking traffic pollution generally to increased risks of mortality was “suggestive but not sufficient” to infer a causal relationship. This applied both to studies of long-term and studies of short-term exposure, and to studies of all-cause and cause-specific mortality. The main reason for this assessment is that HEI (2010) found very few studies meeting its inclusion criteria. This is in contrast to the pollutant-specific evidence reviewed earlier and, as noted above, we consider that the pollutant-specific evidence has priority.

3.3.3 Traffic exposure and respiratory disease

Onset of asthma

There is a long-held view (e.g. COMEAP, 1995) that while air pollution exacerbates asthma in people who already have the disease, contrary to popular belief there is no strong evidence that air pollution contributes to the development of asthma. In particular, there is no strong evidence that air pollution is responsible for or contributes importantly to the increase in asthma noticed in Western industrialised countries. Two relatively recent reviews of traffic-related pollution and asthma onset or prevalence suggest that there may be a relationship after all.

Associations between traffic exposure and the onset of asthma have been studied separately in children and adults. HEI (2010) reported on seven cohort studies and one case-control study of children and asthma onset. All of the studies showed positive associations between traffic exposure and asthma onset, but not all were statistically significant, i.e. some of the associations could have occurred by chance. Associations were seen with NO_2, traffic density and distance from a major road (< 50m vs ≥ 50m). Similar associations were seen in studies of traffic exposure and prevalence of asthma (the percentage of cases of asthma in the study population), with 11 studies showing mostly positive associations although again several were not statistically significant. On the basis of these studies HEI concluded that living close to busy roads is an independent risk factor for the onset of childhood asthma, but that the evidence was not sufficient to conclude that this association was causal.

HEI identified only one study of the onset of asthma in adults in relation to traffic-related pollution, which was a case control study of Swedish adults (aged 20-60). Results indicated that individuals with asthma, identified from primary healthcare, local and county hospitals, private clinics and occupational physicians, had a tendency to have higher residential exposure to traffic flows and NO_2 concentrations than the controls but no significant association was seen between exposure and hospitalisation for asthma (Modig et al., 2006).

In a separate review at about the same time COMEAP released a statement that concluded also that exposure to air pollutants might play a part in the induction of asthma, but only amongst those living close to busy roads with a lot of truck traffic[6]. The statement emphasises that, in comparison with other factors, the role of air pollution is likely to be small among people affected, and that only a small proportion of the overall population is affected.

Exacerbation of respiratory symptoms

Studies of respiratory symptoms in children are typically cohort or cross-sectional studies, where the child's parent(s) report occurrence of symptoms during a set period of time (often 12 months) prior to interview. Much of the focus of the studies is on the occurrence of wheezing, given its important role in the definition of asthma. HEI (2010) report a high consistency in the reporting of positive associations in the more than 20 studies looking at the relationship between traffic and wheezing, associations that are apparent for model-based local concentrations of traffic-related pollutants, proximity to traffic and traffic density. Associations with traffic proximity are very sensitive to the spatial scale used, with health effects steadily decreasing in each 30m buffer from the road, reaching baseline levels after 90m. Associations were also seen with occurrences of cough and dry cough and some evidence of an association between traffic exposure and use of asthma medication. These studies show sufficient evidence for a causal association between traffic-related air pollution and exacerbation of asthma symptoms (mainly wheezing) in children with existing asthma but insufficient evidence for such an exposure among children without asthma.

There are relatively few studies of respiratory symptoms in relation to traffic exposure among adults, and most of these used traffic proximity or density measure rather than measurements of traffic-specific pollutants. All of the studies based on proximity to roads (though using various measures of proximity) reported clearly positive associations with wheezing, cough or phlegm. Evidence for association between traffic exposure and hospital admissions for respiratory symptoms was inconsistent, one study finding a strong association between being hospitalised for respiratory problems and living near traffic hot spots and two other studies reporting null findings, though this could have due in part to poor characterisation of exposure. The conclusion from these studies is that there is suggestive but not sufficient evidence to infer a role for traffic in the exacerbation of respiratory symptoms among adults.

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[6] COMEAP http://webarchive.nationalarchives.gov.uk/20140505104658/http://www.comeap.org.uk/documents/statements/39-page/linking/53-does-outdoor-air-pollution-cause-asthma

Lung function

Measures of lung function, such as Forced Expiratory Volume in one second (FEV_1) or Forced Vital capacity (FVC) are indicators of lung health. Changes in lung function can be considered as early markers of the effects on the lung of external risk factors such as air pollution and smoking. Studies of traffic exposure and lung function at a point in time (cross-sectional studies) show the association between achieved levels of lung function and long- and short-term exposure to pollution. Cohort studies which follow the same individuals over a period of time (longitudinal studies) investigate associations between traffic exposure and changes in lung function. Smoking is the most important cause of reduced lung function levels and so studies which are focussed on lifelong non-smokers or which appropriately adjust for the effects of smoking, both active smoking and exposure to second hand smoke, provide the most reliable evidence on the effects of other factors.

Several studies of lung function in relation to traffic exposure have been carried out in children, adolescents and adults, with the most commonly used health outcomes being the odds of having a low FEV_1 and percentage decline in FEV_1. Lung function measurements have been examined in relation to traffic density, pollutant surrogates, benzene and distance to a major road. There was a consistency in the results of the studies, showing an increased odds of a low FEV_1 or a small % decrease in FEV_1 in both adults and children. However, for many of the studies the effects were small and/or not significant statistically. In addition, it is difficult to assess the public health implications of small, short-term decreases in lung function. Nonetheless, HEI (2010) conclude that although several studies support the hypothesis that living close to high concentrations of traffic-related pollution is associated with reduced lung function, the evidence to data is suggestive but not sufficient, partly because it is based on limited studies using a wide range of different methodologies, making comparisons of consistency between studies difficult to judge.

3.3.4 Traffic exposure and cardiovascular disease

The effect of traffic exposure on cardiovascular disease has been examined using two different types of health outcome – physiologic changes to the cardiovascular system (e.g. heart rate variability) and cardiac or vascular events (e.g. acute myocardial infarction). Across studies of both health outcomes, there was suggestive evidence of a causal association between traffic-related air pollution and cardiovascular disease. For example, in two studies increased risks of coronary heart disease and coronary artery calcification, respectively, were seen among those living nearer major roads. It is notable that these associations were seen in comparisons of individuals living ≤150m and ≤100m from a main road in contrast to the shorter distances at which respiratory health effects were detected.

3.3.5 Traffic exposure and other health effects

Cancer

Among children, the most studied cancers in relation to traffic exposure are leukaemia, lymphomas and cancers of the central nervous system (brain cancer). Two studies of leukaemia and of all cancers in relation to distance to a major road, distance to a gasoline station, vehicle miles travelled and road length did not show any increased risk. Three studies showed an increased risk of leukaemia in relation to vehicles per day in front of their residence (two studies) and of Hodgkin's lymphoma in relation to NO_2 and benzene (one study).

Four studies of the association between traffic exposure and cancer in adults were identified. Three of these studies focused on lung cancer and one on breast cancer. One of the lung cancer studies also investigated bladder, lung, oral, pharyngeal and laryngeal cancer as a group. The scarcity of studies on cancers other than lung cancer mean that no conclusions can be drawn for these health outcomes. Results from the three studies of lung cancer showed, in one, a weak association between lung cancer with traffic-related NO_2 experienced 20-30 years before diagnosis, and in a second an association was found with traffic exposure. In both cases the association was apparent primarily in non-smokers. The third study showed non-significant associations between lung cancer and living near roads with heavy traffic. Taken together these few studies do not provide sufficient evidence to determine if there is an association between traffic-related air pollution and cancer in children or adults.

4 WELLBEING AND AIR POLLUTION

4.1 INTRODUCTION TO WELLBEING

Wellbeing is a broad concept and there is no consensus around a single definition. There is however "general agreement that at minimum, wellbeing includes the presence of positive emotions and moods (e.g., contentment, happiness), the absence of negative emotions (e.g., depression, anxiety), satisfaction with life, fulfilment and positive functioning"[7]. The term wellbeing comprises a range of aspects including physical, economic, social and psychological wellbeing.

Within the current report, we focused on the following aspects:

- anxiety, depression: including but not limited to, the validated Hospital Anxiety and Depression Scale (Zigmond & Snaith 1983)
- the World Health Organisation Quality of Life Tool (WHOQOL) (WHO 1997)
- The Warwick-Edinburgh Mental Well-being Scale (WEMWBS) (Tennant et al., 2007)

These three aspects cover well the physical ill health manifestation of wellbeing through anxiety and depression, the psychological aspects through the WEMWBS scale and life satisfaction/quality of life using the WHOQOL tool. We also included in the search strategy the overarching term of 'wellbeing'. This allowed us to determine whether other definitions of wellbeing are now, or have been, more commonly used in research into its associations with air quality.

4.2 CONCEPTUAL APPROACH

Wellbeing and the Physical Environment

In its simplest terms, wellbeing might be seen as a measure of what matters to people in every sphere of their lives. Especially in Western societies, the pursuit of wellbeing now seen as an important and tangible aspiration to be pursued through the organised efforts of society, with greater wellbeing considered a measure of societal progress. Growing interest in wellbeing has generated an extensive literature which considers e.g. essential nature of wellbeing, the factors which contribute it, frameworks for understanding and measuring it and indicators. Such issues are complex and frequently contested. We recognise this context but limit our reflections here, to a broad conceptual view of how wellbeing is related to the physical environment(including air quality) a brief explanation of how the relationship between the physical environment and wellbeing was conceptualised for the EEA funded "Foresighted Reasoning on

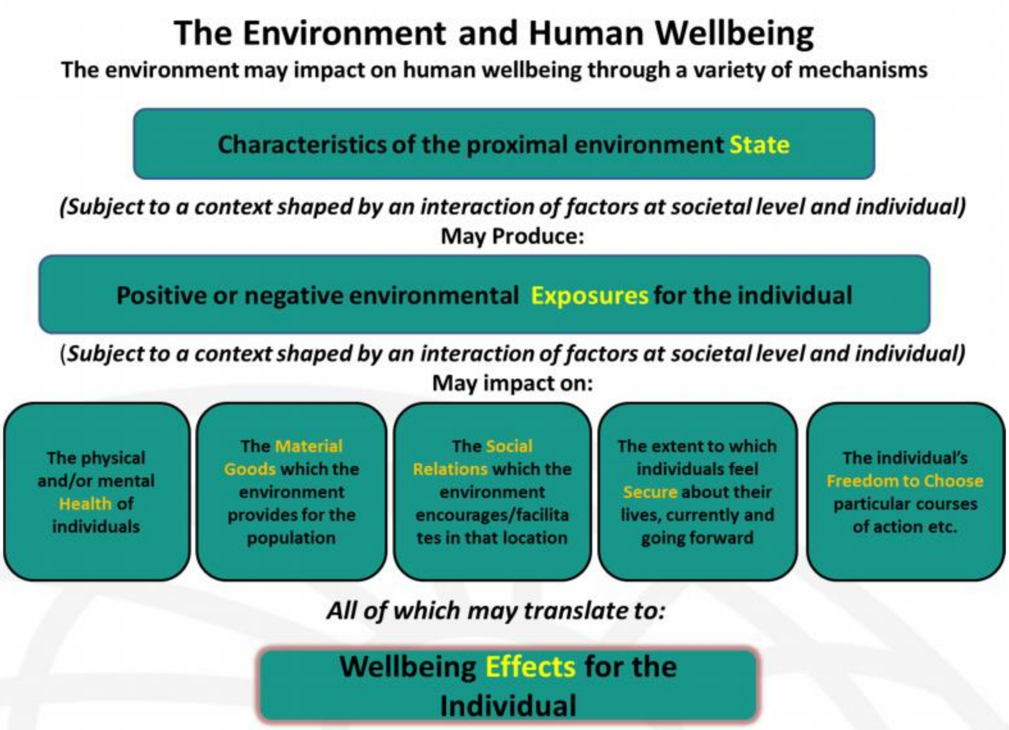
[7] http://www.cdc.gov/hrqol/wellbeing.htm

Environmental Stressors and Health" (FRESH) project[8] (Figure 3). The relevance of wellbeing to health and public health policy was very publicly acclaimed almost 70 years in the still widely quoted WHO definition of health.

"Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity"[9]

In western societies, the diminishing threat from many life threatening physical conditions, growing acceptance of an intimate connection between our feelings, our mental health and our physical health; positive notions health; the concept of salutogenesis etc. have all served to increase the societal and public health focus on wellbeing. The consistent finding that health itself and the places people live consistently rate highly in surveys to identify what matters to individuals in thinking about their wellbeing is professionally reinforcing but also challenging for those concerned with the relationship between environment and health.

Figure 3 Environmental influences on human wellbeing



4.3 QUALITATIVE REVIEW

Results from the literature review of wellbeing and air pollution showed that there are relatively few publications in this area. We summarise below the findings of the review, including some publications identified using a wider

[8] The FRESH Project www.eea.europa.eu/ehwb
[9] http://www.who.int/about/definition/en/print.html

search of the internet, in particular through Google and Google Scholar using the terms air pollution and wellbeing.

4.3.1 Wellbeing and air pollution

There is little evidence on the influence of air pollution on wellbeing reported in the literature identified. A review of children's health in relation to outdoor microclimates by Vanos, (2015) reported that links have been identified between air pollution and cognitive ability as well as an increase in aggression and irritability, but this was based on studies which were primarily concerned with heat waves and extreme heat events. There was also some evidence that air pollution is related to socioeconomic status, which may indirectly impact on individuals' wellbeing (Vanos, 2015).

An observational cohort study of over 70,000 women aged 57 to 85 in the US Nurse's Health Study (Power et al., 2015) found a significant association between higher average exposure to $PM_{2.5}$ and anxiety symptoms measured using the Crown-Crisp index (Welsch, 2003). The association was seen for exposures experienced one month, three months, six months and twelve months prior to assessment of anxiety symptoms. Nurses who lived 50-200m from the nearest major road were also more likely to have increased anxiety scores compared to those living >200m away. However there was no evidence of a dose-response pattern, with no increased odds of anxiety among those living within 50m of the nearest major road.

Welsch, (2003) used panel data from happiness surveys in 10 European countries, jointly with data on per capita income and pollution to examine how self-reported wellbeing varies with prosperity and environmental conditions. Average self-reported wellbeing was taken from the World Database of Happiness (Veenhoven, 2002) and was derived from questions such as "How satisfied are you with the life you lead?". Welsch found that air pollution plays a statistically significant role as a predictor of differences in subjective wellbeing between countries and between time periods. The association was stronger for NO_2 than for total suspended particulate (TSP) concentration, particularly when Income (GNP per capita) was taken into account. The author estimates that a drop in NO_2 concentration by 1 standard deviation results in on average 3.5% of people being lifted up one happiness category.

In a Discussion Paper in 2009, Ferreira et al.,(2009) reported that, in the Republic of Ireland, being exposed to local air pollution in terms of mass concentration of PM_{10} significantly reduces individual's wellbeing with a loss of 0.75 points in subjective wellbeing if the annual mean concentration were to increase by 150% (corresponding to 50 $\mu g/m^3$). Ferreira et al., (2013) in a Working Paper also reported a negative impact of SO_2 concentrations on self-reported life satisfaction.

4.3.2 Wellbeing and transport-related air pollution

There is no direct information about the effects of transport related air pollution on wellbeing. Hartog et al., (2011) found that people who move from car use to cycling and therefore increased their physical activity had about 9 times more gains in life-years compared to losses in life years due to inhaled air pollution and traffic accidents.

According to Maffei et al., (2014) traffic congestion has a negative impact on people's quality of life which also includes a person's wellbeing. According to the authors, traffic congestion is interfering with the person's individual sphere as well as the environment the person is living in and can play a role in the social exclusion of people. The authors suggest that it is the policy makers' choices about urban space that can assure an improved quality of life for city dwellers. New transport technologies with the aim of improving environmental quality in general are desirable too.

4.3.3 Wellbeing and transport and/or active travel?

Wellbeing in relation to transport and active travel has been addressed by de Nazelle et al.,(2011).Their literature review has shown that living in a neighbourhood which provides infrastructure and green spaces encouraging walking and cycling is associated with better mental health and quality of life. Such neighbourhoods with places to walk to and public spaces that are accessible also improve the social capital of a neighbourhood for instance by knowing the neighbours in person, trusting each other and being socially engaged.

Harlan et al., (2011) report that increased physical activity, which would include active travel, should reduce what they call "lifestyle" diseases such as obesity and cardiovascular diseases but also social isolation and improves mental health. Traffic congestion on the other hand has according to Maffei et al., (2014) a negative impact on the quality of life.

Sufficient evidence for an association between physical activity and depression as well as other health outcomes such as diabetes, obesity, cardiovascular disease is reported by Hartog et al., (2011). The authors also suggest that cycling as means of transport should in the long term reduce traffic noise for city dwellers which may reduce annoyance.

Tzoulas et al., (2007) report growing research evidence regarding positive relationships between wellbeing, health and green space. Green areas encourage a more active lifestyle and may improve air quality which will have positive impacts on the quality of life.

5 INFLUENCING AND MODIFYING BEHAVIOUR IN ASSOCIATION WITH TRANSPORT RELATED AIR POLLUTION

5.1 INTRODUCTION

The earlier sections of this report have presented evidence on possible health impacts of air pollution with a specific focus on transport related air pollution. The current section reviews evidence on “what works” in relation to changing behaviour. This work was undertaken as a systematic review on behaviour and behaviour change in relation to transport related air pollution. The objective of this is to inform messages aimed primarily at changing people’s behaviours in typical use of road transport to encourage more use of less polluting forms of personal transport. This was done both in terms of identifying opportunities to influence people’s transport choices for their benefit and the benefit of others through behaviour change and an understanding of the possible determinants of behaviour.

The reviewed research was considered within the context of the ISM model (see Section 5.2.2.). Within this framework we can inform the development of key messages to different groups (public, policymakers, government) to improve the likelihood of behaviour change.

5.2 INTRODUCTION TO BEHAVIOUR CHANGE

In recent years there have been a number of reviews and methodology developments to aid in our understanding of behaviour and how to impact positively on behaviour change in relation to environmental issues. Anable et al., (2006) published a report examining public attitudes to climate change and travel behaviour. This report highlighted the limited amount of research available at that time in relation to changing behaviour. However, it also identified a need to ensure public engagement in behaviour change processes, and that behaviour change needs to be influenced at an individual, collective and societal level with (at the time) community based interventions showing evidence of more success.

There are various items of legislation, enforcement and campaigns that focus on changing behaviour at the individual level, for example those aimed at seatbelt use in vehicles with a possible fine in the UK of £500 if a seatbelt is not worn when it is supposed to be, speed cameras to enforce road speed limits, and bike helmet use in accordance with the UK Highway Code. In addition there is legislation in the UK on drink driving, which in Scotland was updated, as of the 5th December 2014, with the alcohol limit for drivers reduced to 50 milligrams of alcohol in every 100 millilitres of blood. These examples provide instances where there are legislation, enforcement and campaigns that are in place to change behaviour to protect their health of those using transport.

5.2.1 National Institute for Health and Clinical Excellence (NICE) behaviour change guidelines

The National Institute for Health and Clinical Excellence (NICE) developed guidance that provides a set of generic principles that can be used as the basis for planning, delivering and evaluating public health activities aimed at changing health-related behaviours (NICE, 2014)[10]. The development of this guidance was influenced by a number of different theories, concepts and accounts of behaviour and behaviour change, drawn from the social and behavioural sciences. These include: resilience, coping, self-efficacy, planned behaviour, structure and agency, habits and social capital.

The guidance suggests that to bring about and encourage behaviour change, actions are required to be delivered at an individual, household, community and/or population level using a variety of means or techniques. Various recommendations have been made in the guidance and are presented in Table 1.

Table 1 NICE recommendations for behaviour change (NICE, 2014)

The recommendations include the following advice:

- Base interventions on a proper assessment of the target group, where they are located and the behaviour which is to be changed: careful planning is the cornerstone of success
- Work with other organisations and the community itself to decide on and develop initiatives
- Build on the skills and knowledge that already exists in the community, for example, by encouraging networks of people who can support each other
- Take account of – and resolve – problems that prevent people changing their behaviour (for example, the costs involved in taking part in exercise programmes or buying fresh fruit and vegetables, or lack of knowledge about how to make changes)

As can be seen in Table 1, there are various levels represented and highlighted as being important for behaviour change, including the specifics of target groups as well as working at a community level. This is in line with another model known as the Individual, Social and Material (ISM) Tool.

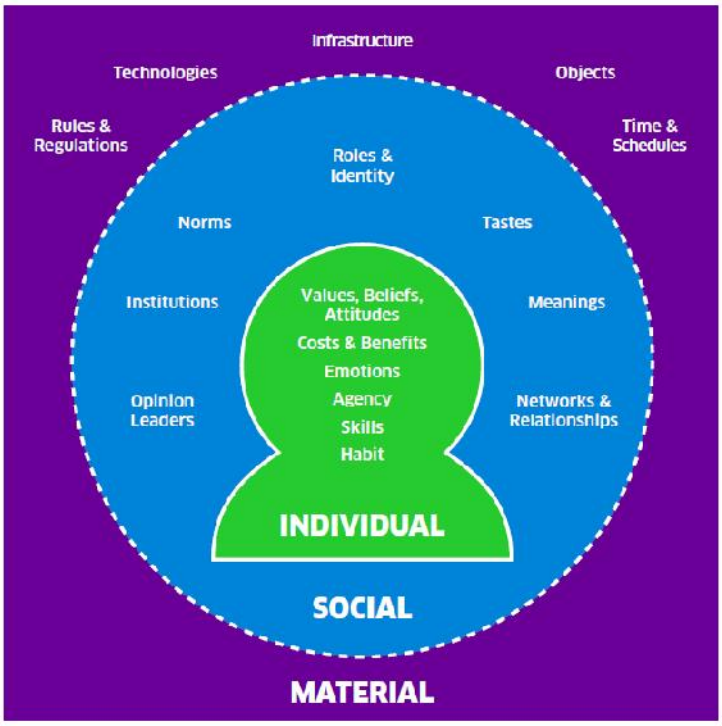
5.2.2 The ISM tool

The ISM tool presented in Figure 4 was developed by the Scottish Government based on Southerton et al., (2011) International Review of Behaviour Change Initiatives. It is a conceptual model designed to aid issue framing and thinking on behaviour change. It considers the Individual, Social and Material contexts to examine the effectiveness of environmental

[10] PH49 http://www.nice.org.uk/guidance/ph49/chapter/1-recommendations

behaviour change interventions which will of course be different according to the target audience, i.e., school children, older citizens etc. It has been suggested that in order to achieve substantive and long lasting change, interventions should take account of influences from all three contexts (I,S and M) (Darnton et al., 2013).

Figure 4 Factors that influence behaviour in the individual, social and material contexts (The ISM Model)



As can be seen the individual context contains influences on the individual that impact on their choices and therefore behaviours. These may include their beliefs, skills and the calculations they make on how to behave. The social context relates to those factors that are external to the individual and which can impact on their behaviour, such as meanings and social norms that influence them. The final of the three contexts in the ISM tool is the material context that includes factors in the wider environment which can constrain and shape behaviours, such as infrastructures and regulations.

The population are not homogeneous in how the individual, social and material contexts influence behaviours. There are various factors which influence this including different attitudes by different population groups as well as by individuals when presented with different situations, for example transport behaviour for business or leisure. The factors that influence behaviours can be context specific in relation to who, how, when and where.

The NICE guidelines and ISM tool described above indicate that there is a growing understanding that behaviour change interventions need to target the individual and the wider contexts around them, including the social and material aspects that surround the behaviour targeted for change.

In the following sections the literature from this part of the review will be discussed before being summarised in relation to the ISM tool and the factors within the three contexts described above: the individual, social and material.

5.3 BEHAVIOUR, BEHAVIOUR CHANGE AND AIR POLLUTION

In relation to behaviour and air pollution there were no specific review papers identified that examined this question. However, de Nazelle et al., (2011) did suggest that increasing active travel through cycling or walking may be associated with reduced air pollution.

When research was examined in relation to behaviour change and air pollution, two reviews were identified, both of which looked at the impact of charging on road use. The review by Hensher et al., (2013), examined referendum voting patterns in relation to congestion charging. The paper examined referenda in relation to the introduction of congestion charging defining these as unsuccessful (Edinburgh and Manchester) where charging was not accepted by the population and successful (Stockholm and Milan) where it was accepted. For Stockholm the reported result of the congestion charge after a period of seven months was an 18% reduction in vehicles with 4 or more wheels entering the charging area. In Milan, after a period of 3 years from an initial charging scheme, it was reported that there was a decrease of 14.2% in vehicles with 4 or more wheels entering the charging area. However a further referendum was held to propose a much simpler charging scheme for all vehicles and this was voted in. When voting patterns were examined in relation to the failure of congestion charging, it was identified that uncertainty on the effectiveness of the charging scheme and the lack of information provided in relation to the proposal were the main reasons.

From the success of the campaigns to allow charging in Stockholm and to continue charging in Milan, the review recommends a two-stage process, where firstly forecasting models are used to predict the likely changes under the charge and the benefits from its introduction. The second stage is to have a trial of the scheme and to have its outcomes reported before any voting takes place. However, the authors are clear that it is essential that unambiguous information is provided to the media to ensure that the public is made aware at all stages of the process. During the trial period, Stockholm's residents experienced significant benefits such as reduced travel times, improved travel time reliability and better air quality (Eliasson, 2009, cited in Hensher and Li, 2013). Completing a trial period (ideally) with positive results was suggested as being useful to do before holding referendums in the future. In Stockholm, the opportunity for residents to gain more information on the scheme was said to have closed the inconsistency gap between attitudes and behaviour (Hensher et al., 2013).

The second review was an examination of transportation choice in Australia (Iftekhar and Tapsuwan, 2010). Within the review, based on work by

Hensher (2008) using the TRESIS[11] model it was predicted that using a 10 cents per kilometre variable user charge on the main road network would reduce car trips by 11% and a 40 cents per kilogram carbon charge was predicted to increase bus use by 16% and train use by 22%. It was perceived that increasing the fuel efficiency of cars would increase car usage but other policies including increasing the frequency of buses or a reduction in public transport fares would increase the use of public transport.

At the current time there is no research directly linking behaviour to transport air pollution but it is evident that reducing car use does have the potential to reduce transport air pollution. What is unclear at the current time is the impact of public transport as a contributor to air pollution.

5.4 BEHAVIOUR, BEHAVIOUR CHANGE AND TRANSPORT RELATED POLLUTION

There is a view that although technology has changed and (internal combustion vehicle) engines have become more efficient, the continued growth in travel and transport has kept the environmental impacts of transport rising (Peattie, 2010). However, there are some indications that behaviour change can have a positive impact on transport related pollution.

The review of Hensher and Li (2013) examined the impact of congestion charging in London, Stockholm and Milan and a summary of results are presented in Table 2. These data were collected over varying time periods, in London (timescale unavailable), Stockholm (during the seven month trial period) and Milan (a three year period where existing charging was in place). All highlight the reduction in emissions after the introduction of a charge but longer time scale assessment has not been carried out.

Table 2 Reduction in Parameters after the Introduction of Congestion Charging (Hensher & Li 2013)

	London	Stockholm	Milan
Reduction in traffic (vehicles with 4 or more wheels) entering the charging zone during charging hours	18%	18%	14.2%
Increase in the use of public transport	7%	9%	6.2%
Reduction in CO_2emissions in the charging zone	16%	16%	14%
Reduction in NO_x emissions in the charging zone	8%	8.5%	17%
Reduction in PM10 emissions in the charging zone	6%	10-14%	18%

[11] http://www.thredbo-conference-series.org/downloads/thredbo7_papers/thredbo7-plenary-Hensher.pdf

Fujii and Taniguchi (2006) examined the use of travel feedback programmes (TFP). These are programmes designed to change travel behaviour from car use to public transport or active travel through use of personalised communication. One of the common features in a TFP is that participants receive information that aims to modify behaviour. However, research by DfT (2004 cited by Fujii & Taniguchi 2006) identified that the effectiveness of TFPs was dependent on location (urban versus rural), and types of messages used (personal or travel blending[12]). Furthermore, Fujii and Taniguchi (2006) suggest that the use of a classification system to describe TFPs is helpful when we consider location, techniques for behaviour change, procedures and communication method. For example, there are three main potential target locations of TFPs; these include residential areas, schools and workplaces.

In relation to the techniques for behaviour change these can be classified as to whether they motivate travel behaviour change, ask for a plan to change travel behaviour and/or provide individualised information. Fujii and Taniguchi (2006) describe individualised marketing – sending messages without motivational support and travel blending which includes motivational support. In the example cited within the review, participants in a travel blending[12] programme were given a booklet describing why travel behaviour is important and how that travel behaviour could be changed (DfT 2004, cited Fujii and Taniguchi 2006).

The use of a behavioural plan as a means of changing personal travel behaviour can be understood using the psychological framework of behavioural intentions. A behavioural intention is still only an intention and is only implemented when an implementation intention is formed. A plan is required to support the implementation intention of where and how the behaviour is performed; thus requesting a behavioural plan has a large influence on behaviour change (Fujii and Taniguchi 2006). Furthermore, the review cites previous research where non-individualised information was sent to participants who were asked to make a travel plan. The results identified that there was a 100% increase in the frequency of bus use by participants. Although making a travel plan is seen as essential to effecting successful change in behaviour, the review suggests that the provision of individualised information is desirable alongside the request for a behavioural plan.

The use of TFPs varies between different studies and includes two or three contact points for example, a simple survey or asking participants to make a travel plan (Fujii and Tanaguchi 2006). Travel blending requires four contact points with participants and these are listed below.

- Provision of information to motivate a behaviour change and complete a diary of travel

[12] Travel blending is an analysis of how people travel, followed up by suggestions of how they can change the mode of travel and then monitoring and feedback to change travel choices.

- Provision of individual comments
- Conducting a travel diary survey
- Provision of additional individualised comments.

With regard to communication media used, face-to-face, telephone and electronic media have been used. At the current time there has been no evaluation of effectiveness for particular methods. However, previous studies have included mixed contact with a telephone call first followed-up by a home visit (Fujii and Taniguchi 2006).

When investigating the impact of TFPs, this review examined their impacts on CO_2 emissions and car use in Japan. The results identified a reduction of CO_2 emissions of between 15 and 35% and the use of TFPs were identified as still having an impact one year after implementation. The study identified that the most effective reductions in personal transport were in cities where participants were asked to make a behavioural plan and where participants received individualised information. One further city, where behavioural planning was not used, did not see a decrease in CO_2 levels.

In relation to car usage, Fujii and Taniguchi (2006) identified that car use decreased by 25% for TFPs that included participants being requested to make a behavioural plan. However, for all the studies cited within the review, control groups were not used to make a comparison.

5.4.1 What works in terms of successful behaviour modification and influencing strategies and what are the drivers for this?

There are various factors that were identified within our review that can impact on behaviour modification in relation to transport and air pollution, these are discussed within the following sections; psychological theories, age, information, physical/built environment, overcoming barriers, economic influences and the interaction of influences.

5.4.1.1 Psychological theories

Panter and Jones (2010) carried out a review of quantitative studies on psychological and environmental influences on active travel. They suggested that through using the Theory of Planned Behaviour (TPB) the decision to engage in behaviour is rational and includes a conscious judgement between perceived costs and benefits; therefore highlighting the importance of information to make informed decisions on the costs and benefits associated with active travel behaviours. Others suggest that the mode of travel chosen may also be partially habitual (Verplanken et al., 1994, cited in Panter and Jones, 2010). This idea is supported by the Theory of Interpersonal Behaviour (TIB) as it considers intention, habit and facilitating conditions. Bamberg and Schmidt (2003, cited in Panter and Jones, 2010) suggest that this model has a strong relevance to active travel due to these behaviours being repetitive and performed frequently, such as travel for work, shopping and leisure.

The psychological and environmental factors of active travel suggested by Panter and Jones (2010) and their components and measures have been presented in Table 3. This demonstrates how environmental factors can correlate with psychological factors to influence behaviour.

Table 3 Psychological and Environmental Correlates of Active Travel (Panter and Jones (2010)

Domain	Components	Measures
Psychological	Habit	Habitual measures of active travel Frequency Autonomy Sub consciousness Resultant feelings Difficulty of avoidance Belonging to daily routine History/length of participation
	Perceived Behavioural control	Perceived ability to use active travel on a regular basis Perceived self-control for using active travel on a regular basis Perceived volition to use active commuting on a regular basis Perceived barriers to active commuting Self-efficacy
Environmental	Functional	Objectively measured connectivity of the street/pedestrian/cycle network Objectively measured or self-reported presence of cycle lanes and pavements
	Destinations	Objectively measured or self-reported distance to travel time to: Commercial destinations Schools Workplaces Public transport stops (bus/train) within close proximity to home.

5.4.1.2 Age

Hume et al., (2009, cited (Iftekhar & Tapsuwan 2010)) observed that the tendency to use active commuting changes as children get older, from active to inactive modes of travel. A review on encouraging walking as a means of personal transport and physical activity in children and adolescents by Giles-Corti et al., (2009), identified studies that found the likelihood of walking to school for older primary school children, (especially for boys) was increased by the presence of crossings (Timperio et al., 2004, cited in Giles-Corti et al., 2009) and having no busy roads to cross (Timperio et al, 2006, cited in Giles-Corti et al., 2009). This suggests that to encourage active travel in this group, there is a need to control traffic and create safer routes to schools, in order to increase perceived children's safety in walking to school. This is also likely to increase the likelihood of parents permitting their child to walk (Black et al., 2001, cited in Giles-Corti et al., 2009).

For adolescent girls research suggests that they are more physically active in neighbourhoods where the streets are well lit and when traffic volume was higher on the routes that they use to walk on (Evenson et al., 2007, cited in Giles-Corti et al., 2009). Reasons for this were suggested to include the presence of traffic increasing perceived and actual surveillance and therefore increasing feelings of personal safety. To increase physical activity (for girls) in neighbourhoods, the suggestion is that there is a need to ensure feelings of greater safety through the provision of street lighting. Panter and Jones (2010) also support the importance of safety, as they identified a study in their review which found that higher perceived safety was associated with higher reporting of active travel (Ogilvie et al., 2008, cited in Panter and Jones, 2010).

5.4.1.3 Information

The level of knowledge that an individual has on an issue is likely to impact on their decision on how to behave, either positively or negatively. In line with this, environmental knowledge is frequently assumed to drive green[13] consumption behaviour (Peattie, 2010). Peattie reported in a review that some of the research available supports this notion, such as the work by Bartkus et al., (1999, cited in Peattie 2010) that found having environmental knowledge had a positive effect on green consumer behaviour. This is supported by Hensher and Li (2013) who stated that, in relation to congestion charging, a lack of information is a major reason for rejection rather than support of the scheme. Therefore, in relation to successfully persuading consumers to adopt changes in behaviour, it has been suggested that there is a need for specific environmental information that relates directly to aspects of the consumers lives and behaviour (Hobson 2003, cited in Peattie, 2010), on the basis that this facilitates people in making informed decisions.

Furthermore, Anable et al., (2006, cited in Peattie, 2010) suggested that links which individuals made between other environmental topics, e.g. climate change, and their own consumption patterns and lifestyles were inconsistent. This reinforces the importance of providing specific information that is relevant to individuals on a personal basis to encourage the desired behaviour modification.

In a review on referendum voting in relation to road pricing, Hensher and Li (2013) conclude with the suggestion that a two-step approach to overcoming resistance in behaviour change should be adopted; through firstly providing forecasting models during the design stage and secondly running a trial during implementation phase. Completing these two processes is expected to provide the public with a greater level of

[13] Green behaviour in this context means environmentally friendly or sustainable

information allowing them to gain a fuller picture, and therefore in the Hensher and Li study, voting in a more informed manner on road pricing.

5.4.1.4 Physical/Built environment

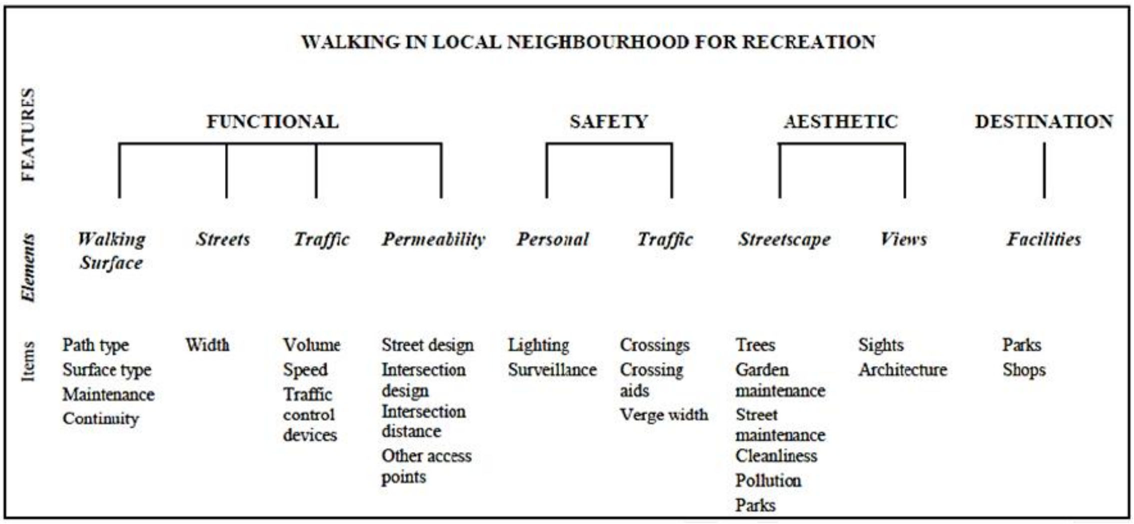
Iftekhar and Tapsuwan (2010) summarise from their review that there are various factors within the built environment that could encourage the use of more sustainable transport choices. These include the level of accessibility of bus stops, walkways and bicycle paths, the level of safety and the ease of use (Cervero, 2002 cited in Iftekhar and Tapsuwan, 2010). The evidence supports the notion that a sustainable urban design is related to sustainable transport choices, for example where there are pedestrian and cycle paths that are well connected then this encourages individuals to have less dependency on private car use.

Specifically in relation to cycling, in 11 out of 21 studies reviewed, Fraser and Lock (2011), found significant positive associations between rates or frequency of cycling and a number of factors: dedicated cycle routes, safe routes to school, separation from traffic, short distance to cycle path, and presence of greenspace. Having an aesthetically pleasing physical environment in relation to scenery, calmness and having pleasant things to look at was also suggested by Panter and Jones (2010) to result in higher levels of walking for transport, however other studies in the review provided mixed results on this. In relation to aesthetics, six studies were identified as part of this review but no consensus was found in the results. However, van Lengthe et al., (2005, cited Panter and Jones 2010) did identify that those reporting less traffic noise reported actively travelling more frequently. However, negative associations were found between active travel use and perceived traffic danger and with the presence of hills (Fraser and Lock, 2011).

Within the scope of this review we were unable to identify any evidence of the effectiveness of health based information specifically as a means of changing behaviour.

In research on active travel by Panter and Jones (2010) they examined psychological, social and physical environment issues and the impact they have on active travel. Within the introduction of the review the work by Pikora et al., (2003) was cited as they describe a framework to evaluate environmental factors including functional, safety, aesthetic and destinations that impact on recreational walking in local neighbourhoods, as presented in Figure 5. However, it is unclear if the same influences apply to walking as a means of active transport.

Figure 5 Model of the physical environmental factors that may influence walking for recreation in the local neighbourhood (Pikora et al., 2003)



The review by Panter and Jones found that with regard to physical environmental influences, there were mixed results in relation to functional factors such as availability of a pavement and walking. The level of street connectivity was found to be linked to an increase in walking in one study only. With respect to cycling, the availability of cycle paths and a cycling infrastructure were found to be associated with increased cycling.

Neighbourhood safety as a physical environmental influence on active travel was also examined in the review but there was no consensus at the time of publication with studies producing different results.

Destinations including the provision of recreational facilities were examined by Panter and Jones (2010). It was identified that the provision of recreational facilities and access to them was found to be associated with increased active transport in 15 out of 16 studies. Furthermore, those living in higher density neighbourhoods were more likely to walk as were those who lived in areas of mixed land use[14].

5.4.1.5 Economic Influences

There are various levels at which economic factors can impact on travel choices. As identified by Gross et al., (2009) in a review of interventions to encourage behavioural and technological change, fuel price can have an influence on carbon emissions due to impacting on the behaviour of the driver and how efficiently they drive their vehicle. Also fare reductions on public transport combined with measures to restrict car use, can help to ensure behaviour change. In a review on current transportation in Australia it was identified that economic factors were found to significantly affect the

[14] Mixed land use refers to different types of land use including residential, commercial, institutional, industrial, agricultural and recreational use.

transport mode choice. These included household income, transportation fare and employment status (Iftekhar and Tapsuwan, 2010).

As highlighted by Gross et al., (2009) the improvement of vehicle occupancy rates (meaning more people per vehicle, e.g. by car sharing) can offer large potential savings at individual level and the possibility to reduce the number of vehicles on the road as a low cost intervention. However in practice such savings can be difficult to deliver due to factors such as perceived convenience/inconvenience and personal choice.

Graham-Rowe et al., (2011) in their review on whether or not car use can be reduced, identified that cash incentives may be effective in the short term; however in the longer term, when the incentive is removed, the effects do not persist. Fiscal measures that influence consumers travel behaviour reported by Gross et al., (2009) included purchase taxes having a quantifiable impact on sales of lower emission vehicles, particularly when these are accompanied by subsidies for the lowest emission cars. This is supported by Yetano Roche et al., (2010) who suggested that reduced costs, tax incentives and low emissions rates would encourage households to adopt a cleaner vehicle.

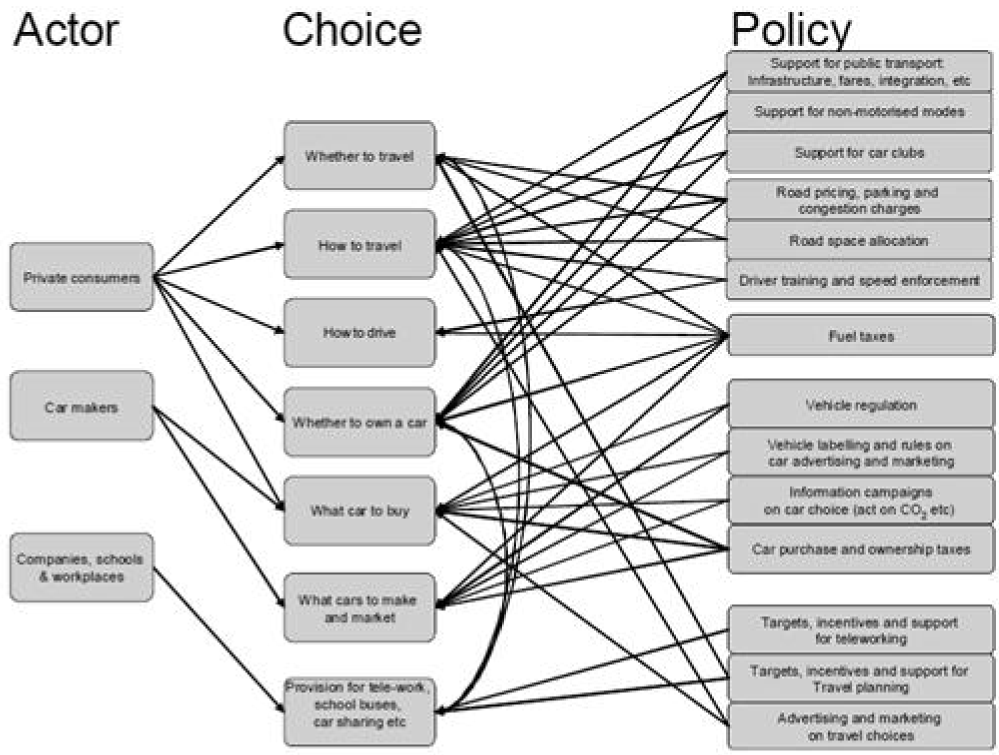
Gross et al., (2009) suggest that introducing congestion charges as a means of penalising car use, would assist the uptake of cycling. This along with other effective policies e.g. through segregation of traffic and prioritisation of cyclists over vehicles, could make cycling safer and more convenient for people.

5.4.1.6 Interaction of influences

As has been presented in the above sections there are various factors that can influence behaviours and behaviour change in relation to transport choices and behaviours.

As can be seen in Figure 6 from the review by Gross et al., (2009) there are multiple actors including consumers, car makers and companies that face various choices that have the potential to reduce CO_2 emissions. As identified by Gross et al., this framework can help to identify opportunities for policy integration to influence behaviour change.

Figure 6 Actors, choices and policies in the transport arena, Gross et al., (2009)



The work concludes that policies can change behaviour and this behaviour can impact on CO_2 emissions. These can be in the short and long term. In the short term these influence travel choices whereas in the longer term these relate to the provision for behaviour change and the development and adoption of, for example, lower carbon emission cars.

Specifically in relation to changing the behaviour of driving diesel cars, in Islington, London in June 2015 the council introduced a £96 annual (equivalent to £1.85 a week) surcharge on resident permits for diesel vehicles to protect residents from the health risks associated with diesel emissions[15]. Also, since 2002 company car drivers in the UK have been taxed according to their vehicle's CO_2 emissions and fuel type, with diesel vehicles paying a tax penalty[16], therefore discouraging diesel car driving behaviour.

To reduce car pollution at the car manufacturer level the European Union has now agreed a mandatory CO_2 target for car manufacturers, as cars are responsible for 12% of total EU CO_2 emissions. Under this legislation the average emissions of a manufacturer's vehicles sold in Europe will have to be below 130 grams of CO_2 per kilometre by 2015, and 95 g/km by 2020

[15] http://www.islington.gov.uk/services/parking-roads/parking/Pages/Diesel-surcharge.aspx
[16] http://www.environmental-protection.org.uk/committees/air-quality/air-pollution-and-transport/car-pollution/

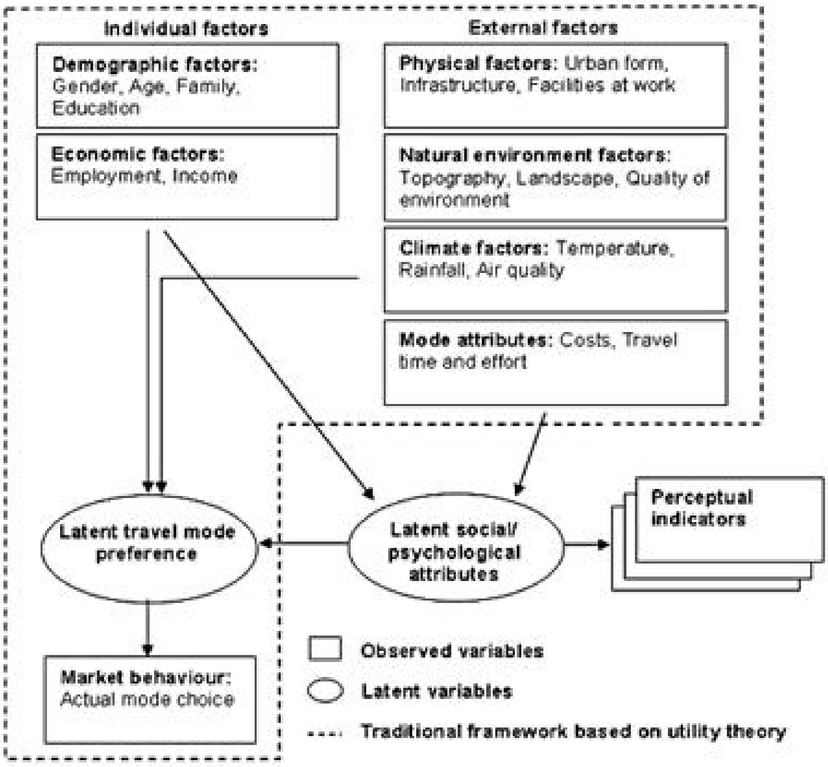
representing a planned reduction of 40%[17]. This is an example of impacting on consumer behaviour at the industry level.

At a local authority level, in some areas authorised officers can check that emissions from road vehicles comply with Construction and Use Regulations and issue fixed penalty notices to those failing the test. In England and Wales, only those local authorities that have declared an Air Quality Management Area (AQMA) may apply to use this power, but Scottish Regulations enable all local authorities to apply to use them. Drivers who leave their engines running unnecessarily, e.g. while waiting at a level crossing, can also be issued with a fixed penalty notice if they do not turn off their engine when asked by an authorised officer[17]. This impacts on individual behaviours through potential penalties.

In reviewing transportation research, Iftekhar and Tapsuwan (2010) reported on an increased awareness and acceptance of the interactions between social psychological factors and other factors affecting transport mode choice. This increased awareness has led to the development of a methodology for incorporating psychometric data and subjective rating of attributes into transport mode choice modelling. Iftekhar and Tapsuwan presented the model in Figure 7 proposed by Walker (2001) and Morikawa et al., (2002) which is based on the utility maximisation theory in economics, where 'utility' is a measure of preferences, representing satisfaction. As this cannot be directly observed it is revealed when an individual makes a decision for example on transport mode. As the model integrates social psychological attributes to affect utility and to interact with other factors including travel mode preference, the outcome is a model that better represents the complexities of people's preferences and decision making in relation to transport choice.

[17]http://www.environmental-protection.org.uk/committees/air-quality/air-pollution-and-transport/car-pollution/

Figure 7 Transport choice model with latent social psychological factors, Iftekhar and Tapsuwan (2010)



This model demonstrates the complexity and levels of factors involved within personal transport choice, with some factors that are observable and others being hidden and only visible when a choice is made. In attempting to change behaviours all these factors need to be considered to ensure a change to a more desirable behaviour as deemed by experts/policymakers and politicians.

5.5 OVERCOMING BARRIERS

The work by Blainey et al., (2012) concluded that the most effective way in which barriers to passenger rail use can be overcome is through targeting packages of improvements at small groups of people that have a potential to change their behaviour (increase rail use) such as staff in workplaces. Within this review it was identified by DfT (2002) that for travel behaviour to change at an individual level there needs to be a motivation for change and the means to facilitate this change.

Presented in Table 4 is the qualitative assessment (based on evidence reviewed in their paper) of the likely importance of particular barriers and the feasibility and cost-effectiveness of addressing them within a UK context.

Table 4 Estimated importance, cost-effectiveness and feasibility of addressing barriers to mode shift (Blainey et al., 2012)

Importance / Cost-effectiveness	High	Medium	Low
High	Conscious car dependence (p) Station access (p) Habit (d) Land use patterns (d)	Government policy (p) Employers' influence (p) Cost (d) Inaccurate perceptions (d) Sub-optimal market prices (d)	Ticketing complexity (s) Image (p)
Medium	Interchange (p) Service frequencies (p) Travel time (p) Trip chaining (d)	Crowding (p) Network limitations (d)	Cleanliness and maintenance (s) Comfort (s) Information provision (s) Station facilities (s) Lack of control (p) Goods and baggage (d) Individuality (d)
Low	Convenience and freedom (d)	Journey planning requirements (s) Age, health and disability (p) Other passengers (p) Personal security (p) Reliability (d) Structural car dependence (d)	Staff provision (s) Safety (p) Ethnicity, faith and culture (d) Locational preferences (d) Unsuitability of trips for rail (d) Weather (d)

Suffix letter indicates feasibility, with 's' straightforward, 'p' possible 'd' difficult.

Gross et al., (2009) identified how barriers can be overcome to achieve desired behaviour change in the short, medium and long term. The short term options identified to reduce emissions and change travel behaviour include: eco-driving and speed enforcement, expanding the use of non-motorised modes of transport and improving the occupancy of vehicles. The medium term options included: reallocating road space to extend bus and light rail provision, together with the provision of competitive fares and public transport service improvements. In the longer term, options included delivering a new infrastructure for public transport and non-motorised personal travel. The review concludes that the most effective policies on encouraging desired behaviour modification are: emissions regulation, purchase taxes and fuel tax, aided by rules on marketing and labelling of cars.

Travel feedback programs (TFPs) are soft measures designed to change travel behaviour from personal automobile to non-automobile travel. Fujii and Taniguchi (2006) identify in their review of 10 TFPs that their effectiveness can rely on requesting participants to make a behavioural plan, as those interventions that included a plan, resulted in the greatest reduction in car use and the greatest increase in public transport use. To create a behaviour plan there is a need for information to enable people to make informed choices. Matsumura (2004, cited in Fujii and Taniguchi, 2006) suggested that TFPs can be more effective when used to promote public transport use among those that don't frequently travel on public transport, compared to those that do. This research is supported by Fujii and Garling (2003, cited in Fujii and Taniguchi, 2006) who identified that once infrequent public transport users had experienced the benefits of public transport options, they then used them more than those that already frequently travelled on public transport.

Iftekhar and Tapsuwan (2010) identify the difference between structural or hard measures (which may alter an individual's context) and psychological or soft measures (e.g. which increase people's awareness and knowledge), these have also been separated out into push (e.g. passive) measures, such as prohibiting car use in city centres and pull (e.g. active) measures such as improving public transport. Eriksson et al., (2008, cited in Iftekhar and Tapsuwan, 2010) suggest that the public generally assume that push measures are ineffective at effecting behaviour change and are perceived as unfair, whilst considering by contrast that pull measures are effective and acceptable. Therefore to achieve successful behaviour change (i.e. to encourage uptake of the officially perceived desirable option), it is fundamentally important to understand the measures being implemented from the perspective of the public.

5.6 SUMMARISING RESULTS IN THE CONTEXT OF THE ISM MODEL

For the purposes of this review and report it was concluded that the ISM model described earlier provided a convenient mechanism to organise the findings in the context of using the material to inform the development of messages to diverse potential audiences.

5.6.1 The Individual Context

The Individual context within the ISM tool includes the beliefs/convictions held by an individual that affect their choices and the behaviours they undertake. Within the review various issues have been identified relevant to this context, which impact on personal behaviour and opportunities for behaviour change. Within the meaning of the individual context, these include: values, beliefs, attitudes, costs & benefits, emotions, agency (meaning a person's confidence that they have ability to undertake the behaviour), skills and habits. For example an individual's beliefs and attitudes towards the impact that air pollution and personal choice of transport can have on the environment, can make them more or less likely to drive a personal vehicle or use active transport.

The costs and benefits that an individual considers can have an impact in their choice regarding their own preferred transport behaviour include: fuel prices or fares on public transport, or the time that a journey is likely to take compared to other transport modes. Skills that can have an impact on the adoption of (desired) behaviour change (e.g. increased use of active transport) could include the skill required to ride a bike or to practice fuel efficient driving. Habitual behaviours as identified in the review could include, for example, commuting to work. These journeys are often habitual and not intentionally planned and alternative options are rarely considered.

5.6.2 The Social Context

The ISM Social context includes the factors that exist beyond the individual, yet shape their behaviour. Within the review social factors identified by the ISM tool have been considered as follows: opinion leaders, institutions, norms, roles & identity, tastes, meanings and networks & relationships. As highlighted in the review, media messaging and publicity campaigns need to provide the public with information that is relevant to them personally, perhaps through targeting specific geographic areas or audiences for specific interventions. The information provided to people needs to provide enough detail to allow them to make an informed decision about their transport related behaviour and provide positive reasons for change, as well as accessible solutions to facilitate change.

Aligned with this, having environmental knowledge has a positive effect on green consumer behaviour. Norms as a social factor can impact on an individual’s behaviour through reshaping their social (habitual) norms in relation to active transport use, e.g. through more people seeing others using this option and talking about it. Thus normalising active modes of transport and increasing awareness of this may be beneficial. As identified in the review, there is a need to encourage people to see that it is possible to be less dependent on private car use and this can usefully be linked to the social context of identity and social status.

When individuals see environmental issues as a problem for the next generation, this can be seen as a stereotyping as this is perceived as the social norm. To overcome these stereotypical ideas there is a need to increase awareness of simple changes that can have an impact in relation to air pollution and health.

An example of this could be to weaken the habitual norm of using a car for short journeys and increase the norm of walking if the destination is within an accessible distance. Personal networks and relationships with friends and family may help people observe and learn from behaviours of others, therefore offering the opportunity to encourage the spread of new norms. For active transport, this could be sharing information on new walking or cycling routes or information about public transport routes that an individual wasn't previously aware of.

There are a number of other areas where changes to social norms have occurred including the introduction and use of seat belts and the changes in attitudes to drink driving. Both of these had a legislative element, but increased awareness through media campaigns and advertising also influenced social norms. What is interesting is the comparison with speeding and using mobile phones in cars where this impact has not been seen.

5.6.3 The Material Context

The Material context in the ISM tool includes the factors that are in the environment and wider world, which both impact on behaviour. From the review on personal behaviour in relation to transport choices and behaviour change, the following factors highlighted as relevant in the ISM tool have been identified: rules & regulations, technologies, infrastructure, objects, time and schedules. Government and local authorities (councils) can impact on an individual's personal transport behaviour and behaviour choices through the rules and regulations that are introduced.
As identified in this review, the introduction of congestion charges can impact on the behaviour of individuals and therefore on the transport related pollution levels present in the area. The improvements to technologies available relating to motor vehicle engines in particular can impact on behaviour change, (e.g. motor vehicle engines becoming more fuel efficient can impact on the air pollution caused by transport). As these advances in motor vehicle technology become more readily available on the market, more people are likely to adopt such options as part of their personal transport behaviours

In relation to infrastructure, various methods were highlighted in the review as mechanisms to increase the likelihood of active travel, e.g. the presence of hard structural measures, cycle separation from traffic, pavement networks, developed bus services and public transport infrastructures, street lighting to increase feelings of safety and increased presence of road crossings. All these measures can impact upon the adoption of personal transport choice behaviour change by individuals. Differences in time taken to travel using different transport modes can impact on the behaviour of individuals, specifically in relation to commuting behaviours for work, as people like to use the quickest route. In some cases, for example public transport, some options available may not provide the quickest route due to the state of the present infrastructure.

The Scottish Executive's statistical bulletin (2005)[18] considers variations in percentage mode share for increasing distances between work and home. The findings can be summarised as car driver commuting increasing with distance, rail mode tending to increase with distance, car passenger mode

[18] http://www.gov.scot/Resource/Doc/47121/0020801.pdf

decreasing with distance and bus commuting peaking in the 3 to 5km distance band then falling as distance rises.

5.7 FINDINGS FROM PILOT PROJECTS

A full review of other work on the development of key messages on air quality, health, wellbeing and behaviour is outwith the scope of the current report. However, we provide here some examples of existing work in the areas of active travel and of communication and citizen engagement.

Active travel

Transport Scotland's "Long-term vision for active travel in Scotland, 2030" describes a range of changes to the local environment that it envisages would encourage higher uptake of active travel in the next 15 years. This includes:

- Increased investment in pedestrian and cycle infrastructure such as segregated cycling provision on main roads into town centres, continuity of pedestrian and cycle routes to key destinations, safe routes to schools for pupils.

- Urban planning focussed on easy pedestrian and cycle access, car-free or low-vehicle shopping streets.

- An integrated public transport system with safe and easy access to public transport stops and stations by foot and by bike.

- Behavioural change and training through information campaigns reinforcing positive messages about safe speeds in built-up areas and interaction with other road users. Messages are reinforced with improved signposting consistent throughout Scotland – signposting, route marking, mapping etc.

- Greater use of car clubs and other forms of shared provision of motor vehicles, together with appropriately reduced speed limits (including 20 mph) in urban and rural areas with a high level of pedestrian and cycle activity.

In relation to cycle infrastructure in Scotland the National Cycle Network route covers approximately 2,100 miles with over 500 of these miles being traffic-free walking and cycling routes on railways paths, canal towpaths and forest trails. This includes community links to encourage everyday journeys to be made sustainably. This network mainly follows traffic-free paths, minor or traffic-calmed roads, segregated routes through towns and re-determined rural footways. Where there is no practical alternative it may use or cross trunk roads. In addition to this infrastructure there are also promotion methods being used to increase active travel. Sustrans Scotland has a grant scheme called the Community Links Programme that promotes smart measure strategies aiming to change travel behaviour through campaigns such as active travel champions, IBike, personalised travel planning and school travel planning as well as Choose Another Way which provides information on car clubs, car sharing and eco-driving.

Specifically in Edinburgh there is an online route planner called ‘Cyclestreets’ which shows cycle routes in Edinburgh and can suggest quieter or faster routes. Also in Edinburgh in relation to walking there is a route planner called ‘WalkIt’ which suggests quieter or faster routes from A to B.

A case study from Barrhead in relation to active travel was the ‘Go Barrhead’ scheme[19] set up as part of the Better Barrhead programme. 2,859 (38%) of the total households in Barrhead took part in the Go Barrhead project. The statistics produced by the initiative found a 32% increase in walking across Barrhead since 2009 and a 334% increase in cycling across Barrhead since 2009.

A report by ODS Consulting and Research Resource, commissioned by the Glasgow Centre for Population Health investigated ‘…the views of cyclists and pedestrians using the new Kelvingrove-Anderston route in Glasgow’. They found that the route was mainly used by cyclists to commute to and from work, shopping and personal business and recreation. Users of the route liked its overall appearance and attractiveness and particularly liked the use of a small kerb to physically separate the cycle path from the traffic which made them feel safer. Disincentives included some poor signposting and the need to cross from one side of the road to the other. There were also some tensions between cyclists and pedestrians and motorists and there could be obstacles on the route such as parked cars, signs and waste bins.

Users of the route thought it provided less stressful and more pleasant journeys and some thought their health had improved due to the increase in their activity. Some had changed their mode of transport to use the route and some reported financial savings, and a quicker and more reliable way of getting to their destination. Improvements suggested included better integration with other cycle paths, raising awareness of the route among pedestrians and motorists and better signposting.

Communication and citizen engagement

A report was prepared by SNIFFER as part of the Adaptation Scotland programme providing “A practical guide to values-based communication”. The report was written with particular reference to climate change communication but many of the issues it discusses are relevant more generally. These include:

- Understand your audience and your audience’s values.

[19] http://www.pathsforall.org.uk/pfa/get-involved/active-travel-case-studies.html

- Frame your messages so that they overlap between values that are important for your audience and values such as ‘improving air quality’.

- Make your topic relevant to the lives of your audience, identify their interests and think about how air quality affects them.

- Focus more on positive messages than negative messages.

- Promote the health benefits of reduction in air pollution, connect air pollution with health problems that are already familiar and seen as important.

- Harness the power of social norms and social networks.

The European Commission published in December 2014, a bulletin on ‘citizen engagement with national policy’. This bulletin was produced in the context of an energy system project but again can be useful more widely. Lessons learned by the project were in the following areas:

- Communicating complexity – use of an online interactive tool to communicate the complexities, which allowed the user to manipulate sources and demands for energy and see the effects these had on emissions.

- Providing balanced information –new information needs to be transmitted in a balanced way, allowing the recipients to bring their own understanding and views to the process.

- Creating space for deliberation – to enable full engagement with the issues, workshops and small group style discussion can be useful.

- Accessing broader values – understanding of the recipients values can help reveal why they hold specific preferences.

Recently, qualitative research has been carried out to understand more about the public’s understanding of the nature, causes and consequences of air pollution. This work was supported by DEFRA[20]. It identified six principles as follows:

- Use information about what particulate matter is made of and where it goes to get the broader topic of air pollution onto the agenda – not statistics about health consequences
- Don’t raise public concern about air pollution unless you can at that same time satisfy people’s desire to do something to reduce their exposure.
- Focus on what is known for certain about the health consequences of air pollution

[20] http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=18580

- Talk about air pollution as a problem linked to specific places – and not as a general problem of the atmosphere
- Keep the focus of communications on practical improvements not long-term solutions
- Demonstrate leadership and empower communities, instead of just expecting individuals to change their behaviour

Results from this research, based on focus groups and workshops of 120 people around England, showed clearly that people wanted to know about the issue and how to protect themselves from it. It was also noted that people may want to take protective measures which are ineffective (e.g. wearing masks) or potentially harmful (e.g. using their cars more because they feel safer inside them). It is therefore essential to communicate effective ways of reducing exposure (e.g. using a different route).

6 CONCLUSIONS

6.1 CONCLUSIONS FROM THE LITERATURE REVIEWS

Health and Wellbeing Review

- There is relatively little evidence available on the relationship between air pollution and wellbeing, but the evidence for relationships between air pollution and physical ill health is well-studied and robust.
- Air pollution is causally linked to a range of adverse health outcomes mostly affecting the heart and lungs (cardio-respiratory system). It acts as one of many factors which increase the risks of these conditions. Specifically
    - o Long-term exposure to particulate matter results in a 3% increase mortality in adults per 5µg/m^3 of PM2.5, mortality from heart attacks, stroke, lung cancer, and chronic non-cancer lung disease are most affected;
    - o Short-term exposure to particulate matter is associated with asthma attacks, increased visits to doctors, increased hospital admissions and earlier death
    - o Short term exposure to ozone is associated with a range of respiratory conditions including earlier death (from cardiovascular as well as respiratory causes)
- The entire population is exposed to air pollution, but the health impacts of this exposure are experienced much more commonly in vulnerable people, particularly those with pre-existing health condition.
- A few studies show a tentative link between air pollution and subjective measures of wellbeing (from happiness surveys or self-reported life satisfaction), and there is some limited evidence that living in a neighbourhood which provides infrastructure and green spaces encouraging walking and cycling is associated with better mental health and quality of life.

Review of behaviour change in relation to transport behaviours

- Reductions in pollutant levels are amongst the public health benefits likely to be associated with an increase in active travel. Rejection of proposals for congestion charging are linked to uncertainties over the impacts of the charge as well as a lack of information to those who will be affected
- Increasing road charges is likely to reduce car use and increase public transport use

- Preferential taxes for lower emission cars results in increased sales and a potential reduction in air pollution
- In some locations, the use of travel plans with individualised information and the request to make a behavioural plan is found to increase public transport use.
- The presence of crossing areas increases the likelihood of primary school age boys walking to school and feelings of safety and security increased the likelihood of girls walking to school
- The need to provide information that is relevant and targeted with regard to environmental knowledge may have an impact on behaviour.
- Aspects of urban design such as pedestrian and cycle paths that are well connected reduces dependency on private car use.
- Those reporting less traffic noise reported actively travelling more frequently

6.2 OVERALL FINDINGS

- Numerous studies demonstrate the health burden arising from air pollution and by extension the public health and economic importance of measures to reduce exposure across the population.
- Evidence from numerous studies shows that reductions on air pollution air pollution leads to short and medium term health benefits but emerging evidence of life course effects implies that measures to curb exposure to ait pollution may significantly improve public health in future decades.
- Air pollution is one amongst several ways in which deprived communities may experience poorer quality environments. There are well documented inequalities in the distribution of pollutants in the UK.

    - An individual's beliefs and attitudes towards the impact that air pollution and transport choice can have on the environment can make them more or less likely to drive or use active transport.
    - The costs and benefits that an individual considers in their choice to perform behaviours in relation to transport can have an impact including fuel prices, the costs of fares and the time of journeys.
    - Providing targeted information to individuals or groups can have an impact on behaviour.
    - Development of travel plans to support behaviour change

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APPENDICES

APPENDIX 1 SEARCH PROTOCOL FOR WELLBEING LITERATURE

Questions to be addressed by the review.
What evidence is available about the impact of urban air pollution on health?
What evidence is available about the impact of urban air pollution on wellbeing? Specifically:
What evidence is available on transport related pollution and health and wellbeing?

Search Strategy

Population
Humans
Adults
Children
Older Adults
Cyclists
Drivers
Individuals with respiratory diseases
Individuals with cardiovascular diseases
Pregnant women
Inequalities
Deprivation
Pedestrians
Urban dwellers
Living close to busy roads – separate literature

Exposure
Air pollution
Transport pollution
Air Quality
Particulate Matter/PM
Black carbon
Nitrogen Dioxide/NO2
Nitrogen oxides/NOx
Ozone/O3
Sulphur Dioxide/SO2
Metals (included in chemical composition of PM)
Diesel/Petrol

Outcome
Ill-health
Health
Respiratory health
Cardiovascular health

Asthma
Wellbeing/Well-being
WHOQOL
WEMWBS
Quality of life
Anxiety
Depression
Stress
Physical health in relation to activity
Restricted activity days
Work days lost
Visits to GP
Splitting health and wellbeing when searching

Combined Search Terms

(urban AND (“air pollution” OR “air quality” OR “particulate matter” OR “black carbon” OR “nitrogen dioxide” OR “nitrogen oxides” OR ozone OR “sulphur dioxide”)) AND (ill-health OR health OR (respiratory AND health) OR “cardiovascular disease” OR CVD OR asthma OR wellbeing OR well-being OR “World Health Organization Quality of Life” OR WHOQOL OR “Warwick-Edinburgh Mental Well-being Scale” OR WEMWBS OR “quality of life” OR anxiety OR depression)

Types of Studies

Systematic reviews
Reviews
Intervention studies

Inclusion Criteria

Published 2000 onwards
English language

Exclusion Criteria

Published pre-2000

Search Databases

For academic research the following databases will be used to identify published reviews:
Cochrane Database of Systematic Reviews (CDSR)
Current Contents
EMBASE
MEDLINE
Scisearch
Scopus
Grey Literature searches will be carried out using:
- Google scholar
- Open grey

Websites

NICE

SIGN
Cochrane Collaboration
Campbell Collaboration
ScotCEN
WHO

APPENDIX 2 SEARCH PROTOCOL FOR BEHAVIOUR LITERATURE

Questions to be addressed by the review

What evidence is available on behaviour and air pollution?
What evidence is available on behaviour change and air pollution?
What evidence is available on behaviour and behaviour change in relation to transport related pollution?
What works in terms of successful behaviour modification and influencing strategies?
What are the drivers for behaviour in relation to transport and active travel?

Search Strategy

Population
Humans
Adults
Children
Older Adults
Cyclists
Drivers
Pedestrians
Active travel/ling/lers

Exposure
Short journeys
Transport choices
Transport
Structures
Infrastructures
Engine type (diesel/petrol)

Outcome
Behaviour
Behaviour change
Impact of pollution on behaviour
Impact of transport demand and behaviour
Impact of energy supply/demand on behaviour

Combined Search Terms

(“air pollution” OR “air quality” OR “particulate matter” OR “black carbon“ OR “nitrogen dioxide” OR “nitrogen oxides” OR ozone OR “sulphur dioxide”) AND (behaviour OR (behaviour AND change) OR (impact AND pollution AND behaviour) OR (impact AND (transport AND demand)AND behaviour) OR (impact AND energy AND (supply OR demand) AND behaviour)

Types of Studies
Systematic reviews

Reviews
Intervention studies

Inclusion CriteriaPublished 2000 onwards
English language

Exclusion Criteria
Published pre-2000

Search Databases
For academic research the following databases will be used to identify published reviews:
Cochrane Database of Systematic Reviews (CDSR)
Current Contents
EMBASE
MEDLINE
Scisearch
Scopus

Grey Literature searches will be carried out using:
Google scholar
Open grey

Relevant websites
NICE
Cochrane Collaboration
Campbell Collaboration
SIGN
WHO
Defra

APPENDIX 3 WELLBEING PAPERS INCLUDED IN THE REVIEW

Reference	Type of Publication	Research Question	Evidence available on the review research questions: *What evidence is available on wellbeing in relation to air pollution?* *What evidence is available on wellbeing in relation to transport-related air pollution?* *What evidence is available on wellbeing in relation to transport and/or active travel?*
De Nazelle A, Nieuwenhuijsen MJ, Antó JM, Brauer M, Briggs D, Braun-Fahrlander C, Cavill N, Cooper AR, Desqueyroux H, Fruin S. (2011). Improving health through policies that promote active travel: a review of evidence to support integrated health impact assessment. Environment International; 37: 766-777.	Review	Literature review of the most relevant fields of behaviour, environmental quality and health. We cover relationships of which the research is most extensive and the evidence strongest as well as the quantitatively less well-established links between active travel policies and health or health determinants.	...living in a more "walkable" neighbourhood (...) was associated with a healthier weight status and better mental health (p. 769) having places to walk to, public spaces...improve social capital such as knowing neighbours, trusting others and being socially engaged...deter crime and reduce fear of crime... (p. 770) Studies have linked directly walkable neighbourhoods to the physical and mental health of its residents. Access to greenspace....provide amenities for cyclists and pedestrians has been shown to improve health, particularly mental health and quality of life....large amounts of auto use on the other hand has been linked to negative mental health and social impacts ...social capital is shown to have positive effects in reducing crime, and improving physical and mental health (p. 774)
Ferreira, S., & Moro, M. (2009). On the use of subjective well-being data for environmental valuation. Environmental and Resource Economics, 46(3), 249-273.	Discussion paper	Exploration of the potential of using subjective well-being data to value environmental attributes, through using a theoretical framework to compare life satisfaction approach with the standard hedonic pricing approach.	Reported that, in the Republic of Ireland, being exposed to local air pollution in terms of mass concentration of PM10 significantly reduces individual's wellbeing with a loss of 0.75 points in subjective wellbeing if the annual mean concentration were to increase by 150% (corresponding to 50 µg/m3).
Ferreira, S., Akay, A., Brereton, F., Cuñado, J., Martinsson, P., Moro, M., & Ningal, T. F. (2013). Life satisfaction and air quality in Europe. Ecological Economics, 88, 1-10.	Discussion paper	Analysis of the relationship between air quality and subjective wellbeing in Europe	Reported a negative impact of SO2 concentrations on self-reported life satisfaction.

Harlan SL, Ruddell DM. (2011). Climate change and health in cities: impacts of heat and air pollution and potential co-benefits from mitigation and adaptation. Current Opinion in Environmental Sustainability; 3: 126-134.	Review	This review will summarize epidemiological studies ...on mortality and morbidity related to two climate hazards in cities: increasing temperatures and the modifying influence of air pollution	.... increased physical activity should reduce 'lifestyle' diseases such as obesity, cardiovascular disease and social isolation, while also improving mental health (p. 128)
Hartog JJd, Boogaard H, Nijland H, Hoek G. (2011). Do the health benefits of cycling outweigh the risks? Ciência & Saúde Coletiva; 16: 4731-4744.	Review	The main aim of this review is to assess quantitatively whether the health benefits of the use of a bicycle instead of a private car for short trips outweigh the health risks.	For people who shift from car to bicycle ...beneficial effects of increased physical activity due to cycling resulted in about 9 times more gains in life-years than the losses in life years due to increased inhaled air pollution doses and traffic accidents. There is sufficient evidence for an association between physical activity and...depression (p. 4737) cycling contribute to other benefits....and reduced traffic noise for city dwellers which may result in less annoyance (p. 4742) health effects related to air pollution, traffic accidents and physical activity - compared on mortality
Maffei L, Masullo M. (2014). Electric vehicles and urban noise control policies. Archives of Acoustics; 39: 333-341.	Review	Overview of recent urban projects and policies that deal with noise control and how these experiences will match into the next years with the sounds characteristics of new electric vehicles for private and public transport	Traffic congestion has a negative impact on the quality of life. It causes impact on the individual sphere and on the environment, it influences well-being and can play a vital role in the social exclusion of the people; In order to improve the quality of life of the urban centres, policy makers have to make choices about the urban space....manage infrastructures, defining its loads, flow and capacity...they also have to look at new transport technologies which should assure environmental quality Traffic congestion has a negative impact on the quality of life. It causes impact on the individual sphere and on the environment, it influences well-being and can play a vital role in the social exclusion of the people
Power, M. C., Kioumourtzoglou, M. A., Hart, J. E., Okereke, O. I., Laden, F., & Weisskopf, M. G. (2015). The relation between past exposure to fine particulate air pollution and prevalent anxiety:	Observational cohort study	To determine whether higher past exposure to particulate air pollution is associated with prevalent high symptoms of anxiety.	Found a significant association between higher average exposure to PM2.5 and anxiety symptoms measured using the Crown-Crisp index. The association was seen for exposures experienced one month, three months, six months and twelve months prior to assessment of anxiety symptoms. Nurses who lived 50-200m from the nearest major road were also more likely to have increased anxiety scores compared to those living >200m away.

observational cohort study. bmj, 350, h1111.			
Tzoulas K, Korpela K, Venn S, Yli-Pelkonen V, Kaźmierczak A, Niemela J, James P. (2007). Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. Landscape and Urban Planning; 81: 167-178.	Review	The aim of this paper is to integrate literature on the concepts of Green infrastructure and ecosystem health with that on human health, and to formulate a conceptual framework based on the resultant new understanding	An accumulating set of studies provide evidence, albeit still rather weak, on the positive relationship between well-being, health and green space (p.170) Green areas...may ameliorate air pollution ...and may also lead to people spending a greater amount of time outdoors and being more physically active (p. 170) Epidemiological studies suggest linking green infrastructure and health...suggest that outdoor or indoor physical activity...also promote health and well-being....(p. 174)
Vanos JK. (2015). Children's health and vulnerability in outdoor microclimates: A comprehensive review. Environment International; 76: 1-15.	Review	...literature review provided on three of the most critical environmental factors impacting children's health and well-being: heat, radiation and air pollution this review is guided by 4 objectives to provide inside in what we know...about children's health and well-being under times of physiological environmental stress... research related to atmospheric stressors of heat, air pollution.... ....outdoor spaces used by children...how their...and microclimate impact children... bio meteorological principles....children's health and wellbeing based on ambient	...and air pollution can limit cognitive ability, as well as increase aggression and irritability

		stressors,... ...	
Welsch, H. (2003). Environment and happiness: Valuation of air pollution in ten European countries (No. 356). DIW-Diskussionspapiere.	Discussion paper	Examine how self-reported well-being varies with prosperity and environmental conditions using a set of panel data from happiness surveys, jointly with data on per capita income and pollution	This paper found that air pollution plays a statistically significant role as a predictor of differences in subjective wellbeing between countries and between time periods. The association was stronger for NO_2 than for total suspended particulate (TSP) concentration, particularly when Income (GNP per capita) was taken into account. The author estimates that a drop in NO_2 concentration by 1 standard deviation results in on average 3.5% of people being lifted up one happiness category.

APPENDIX 4 EVIDENCE TABLE FOR BEHAVIOUR REVIEW

Reference	Type of Publication	Research question	Evidence available on the review research questions: *What evidence is available on behaviour and air pollution?* *What evidence is available on behaviour change and air pollution?* *What evidence is available on behaviour and behaviour change in relation to transport related pollution?* *What works in terms of successful behaviour modification and influencing strategies?* *What are the drivers for behaviour in relation to transport and active travel?*
Anable J, Lane B, Kelay T. An evidence base review of public attitudes to climate change and transport behaviour. Department for Transport, London 2006.	Review	Attitudes, climate change and travel behaviour. Overall objective to improve the evidence base for policy decisions.	This review was an examination of public attitudes to climate change and travel behaviour. Although focused on the larger issues of climate change, there were some interesting findings in relation to transport choices and behaviour. These include that transport policies can change behaviour directly and indirectly with behaviour change occurring without attitudes being changed. It does suggest that a combination may be better. It also identifies that any strategy to change travel behaviour will be more effective targeting at the community level. Thus there is a need to engage people from the bottom-up. The review does provide an excellent description of behaviour theories and their application. The focus on the climate change means that any transport related change has to be drawn out.
Bird EL, Baker G, Mutrie N, Ogilvie D, Sahlqvist S, Powell J. Behavior change techniques used to promote walking and cycling: A systematic review. Health psychology 2013;32(8):829.	Systematic Review	The use of a behaviour change taxonomy to evaluate behaviour change in relation to walking and cycling	This paper evaluates behaviour change in relation to walking and cycling using behaviour change taxonomy. As such the focus is on the use of taxonomy and that many of the included papers do not describe accurately different aspects of the intervention. It does identify that the use of intention forming techniques and self-monitoring are important in the design of interventions of this type
Blainey S, Hickford A, Preston J. Barriers to passenger rail use: A review of the evidence. Transport Reviews 2012;32(6):675-696.	Review	Reviews evidence on the importance of barriers (non-financial) to rail use in the UK (but also considering other countries)	After considering the relative importance of the different behaviours the paper concludes by suggesting the most effective ways in which the barriers can be overcome and mode shift to rail achieved - a table is provided that presents a qualitative assessment (based on evidence reviewed in the paper) of the likely importance of particular barriers and the feasibility and cost-effectiveness of addressing them in the UK context. It suggests that resources will be best used by targeting packages of improvements at small groups with particular potential for mode shift e.g. staff at workplaces. The review identified 37 separate barriers to rail use; these were grouped in to hard, soft and complementary factors. It was concluded that travellers were unlikely to consider barriers individually and that instead they would be viewed as a package, this therefore makes it difficult to identify the most significant barriers. In many cases all barriers that exist for a traveller will need to be addressed before mode shift occurs.

Cairns S, Harmer C, Hopkin J, Skippon S. Sociological perspectives on travel and mobilities: A review. Transportation research part A: policy and practice 2014;63:107-117.	Review	A sociological review in relation to travel and mobility's	In discussing the implications for transport policy and sustainable mobility it mentions that car use is not just a matter of individual choice but reflects much wider societal and cultural contextual factors. Webb (2010) suggests 'technologies if behaviour change' with interventions aimed at changing individual behaviours, based around economic and social-psychological models of behaviour have so far been ineffective because they have neglected these wider contextual factors. Shove (2010) argued that focusing on individual behaviour as a way of framing policy, an example in the review was in transport in aviation where governmental decisions about airport capacity, and the nature of the tax regime, are likely to have a more significant on the volume and nature of air travel than programmes aimed at encouraging individuals to opt for 'greener' airlines or to 'think before they fly (Cairns and Newson, 2006).
de Nazelle A, Nieuwenhuijsen MJ, Anto JM, Brauer M, Briggs D, Braun-Fahrlander C, et al. Improving health through policies that promote active travel: a review of evidence to support integrated health impact assessment. Environ Int 2011 May;37(4):766-777.	Review	A review of health impacts that from policies encouraging active transport	This paper uses a framework to enable the development of health impact assessment in relation to active travel. The paper does suggest that increasing active travel through cycling or walking may be associated with a reduction in air pollution.
Fraser SD, Lock K. Cycling for transport and public health: a systematic review of the effect of the environment on cycling. Eur J Public Health 2011 Dec;21(6):738-743.	Systematic review	What is the effect of all interventions or physical factors on cycling in any population group, including cycle paths or routes, road design and other urban planning policies including provision of parks, trails or other open spaces for cycling purposes	Significant positive associations with rates or frequency of cycling (in 11 of 21 studies) were dedicated cycle routes, 'safe routes to school', short distance of trips, separation from traffic, short distance to cycle path, presence of greenspace or recreational land. Negative associations were traffic danger, sloping terrain, long trip distance. Findings often based on studies of 'weak' quality. Policies promoting cycle lane construction appear promising in helping to reduce physical inactivity and the transport component of GHG emission, but the socio-demographic distribution of their effects on physical activity is unclear
Fujii S, Taniguchi A. Determinants of the effectiveness of travel feedback programs—a review of communicative mobility management measures for changing travel behaviour in Japan. Transp Policy 2006;13(5):339-348.	Review	Review of reported travel feedback programs (TFPs) to evaluate their effectiveness, while considering their type and the situations in which they were implemented.	The 10 TFPs implemented in Japan resulted in a 19% reduction in CO2 emissions, an 18% reduction in car use and a 50% increase in public transport use. TFPs have been implemented previously in Australia, UK, Germany and the US, where car use was reduced by 2-15% and public transport use was increased by 10-44%. TFPs in relation to behaviour change aren't solely for short term change, as shown by Matsumura (2004) rates of bus use remained equally high even after 1 year of the TFP implementation. The effectiveness of TFPs can rely on the requesting of a behavioural plan. TFPs with a behavioural plan yielded the greatest reduction in CO2, the greatest reduction in car use and the greatest increase in public transport use. Matsumura (2004) found that TFPs might be more effective in promoting public transport in non-frequent public transport users that in frequent public transport users, this is supported by Fujii and Garling (2003), who reported that once infrequent riders had experienced public transport, they used public transport more than the frequent users. It has also been suggested that TFPs are more effective in promoting public transport use for new residents than for old resident, as new residents were less likely to develop travel behaviour habits that could impede change in travel behaviours.

Gifford R, Nilsson A. Personal and social factors that influence pro-environmental concern and behaviour: a review. International journal of psychology : Journal international de psychologie 2014 Jun 2014;49(3).	Review	Personal and social factors that impact on environmental attitudes and behaviours	This was an examination of pro-environmental behaviours and influences on them. The review identified 18 personal and social factors that influenced attitudes and behaviours including childhood experience, education and knowledge, personality, sense of control, values, world and political view, goals, personality, gender, religion, ethnic group, urban/rural differences, class and proximity to problem sites. The study also highlights that other choices can be made which are not environmentally related, for example cycling for health rather than reducing pollution. All these factors are likely to have an influence but researchers do not know yet how.
Giles-Corti B, Kelty SF, Zubrick SR, Villanueva KP. Encouraging walking for transport and physical activity in children and adolescents. Sports medicine 2009;39(12):995-1009.		Examines the evidence on the association between the built environment and walking for transport as well as physical activity	There are inconsistencies in the evidence base as studies have not included behaviour-specific measures of the environment and context-specific behavioural measures and varying environmental measures and neighbourhood definitions have been adopted. Many of the environmental factors that influence adult physical activity particularly walking for transport are similar to those that influence independently mobile older children and adolescents. A number of factors are implicated as to why children and adolescents are engaging in lower levels of active transport, including demographic and parental factors. The built environment plays a critical role by influencing opportunities for and the safety of active travel.
Graham-Rowe E, Skippon S, Gardner B, Abraham C. Can we reduce car use and, if so, how? A review of available evidence. Transportation Research Part A: Policy and Practice 2011;45(5):401-418.	Systematic review	What works and what doesn't work for car travel reduction interventions	Interventions may be more effective if they target drivers who have both a strong driving habit and a strong moral motivation to reduce car use. It may also be beneficial to target people who have just moved residence and have yet to establish new travel habits. Relocating employees to reduce commuting time can also be effective. Cash incentives to encourage car reduction may be effective in the short term but the effects are not maintained when the incentives are removed. In the introduction there is an introduction to structural interventions involving modification of the physical and or legislative structures that regulate travel behaviour road closures, financial incentives, bus lanes) and also psychological interventions that are designed to change perceptions, beliefs and attitudes (travel feedback programmes, awareness of transport use, equip with knowledge and skills).
GROSS R, Heptonstall P, Anable J, Greenacre P. What policies are effective at reducing carbon emissions from surface passenger transport?-a review of interventions to encourage behavioural andtechnological change. 2009.	Review	What policies are effective at reducing carbon emissions from surface passenger transport? Focus on policies that encourage changes to behaviour (changing people's travel choices and reducing car travel.)	Reducing demand for travel: Absolute/relative price of travel - fuel price increases reduce travel & encourage mode shifts and more economic driving. Extra road or public transport capacity leads to increase in travel demand. Support for non-motorised modes: Segregation and prioritisation of cycle routes, policies penalising car use (congestion charging), individualised marketing. Support for public transport: availability of convenient and affordable public transport; but limited due to potential need for capacity expansion. Car clubs: breaking the link between car use and car ownership. Travel planning: can reduce car usage by 6-30% depending on context. Road pricing: congestion charging reduces car traffic and emissions due to reduction in congestion. No evidence on wider road pricing. Vehicle Choice: purchases taxes have most direct impact on sales of more efficient vehicles. More work needed to determine effect of more teleworking influence on car dependent lifestyles. Often synergies between individual policies and short and long-term effects may differ.

Hartog JJd, Boogaard H, Nijland H, Hoek G. Do the health benefits of cycling outweigh the risks? Ciência & saúde coletiva 2011;16(12):4731-4744.	Review	Active transport and risks on health from air pollution and accidents	This paper quantifies data from the impact of cycling, active travel and the associated reduction in air pollution. The quantification identifies that the increase in life years associated with increased physical activity is much greater than the risk from accidents or exposure to air pollution. The paper does predict a reduction in air pollution but this is not quantified.
Heath GW, Brownson RC, Kruger J, Miles R, Powell KE, Ramsey LT, et al. The effectiveness of urban design and land use and transport policies and practices to increase physical activity: a systematic review. Journal of Physical Activity & Health 2006;3:S55.	Systematic review	To review studies that addressed environmental and policy strategies to promote physical activity.	Part of the study looked at transportation and travel policies and practices in relation to interventions to increase physical activity, the search identified 3 studies from the years 1990-1998 evaluating the effectiveness of transportation and travel policies and practices, two of these studies had limited quality of execution and were not included in the review. The remaining study had fair execution and its effectiveness measure was mode choice for walking to school. Insufficient evidence was provided to determine the effectiveness of transportation and travel policy and practice interventions in increasing physical activity or improving fitness
Hensher DA, Li Z. Referendum voting in road pricing reform: a review of the evidence. Transp Policy 2013;25:186-197.	Review	Review of referendum voting behaviour in road pricing reform with a focus on congestion charging and investigation of key factors that influence public support.	Franklin et al (2009) found 24% reduction in work trips by car across Stockholm's cordon, were modal shift to public transport is the major contributor to this reduction. During the trial period Stockholm's residents have experienced significant benefits such as reduced travel time, improved travel time reliability, and better air quality resulting in a significant social surplus (Eliasson, 2009). Suggestion of having a trial for the congestion charging which should be implemented before holding a referendum, as then residents can gain more information on the scheme as a strategy to reduce resistance in the vote. The trial was able to improve psychological effect of cognitive dissonance, closing the inconsistency gap between attitudes and behaviour. Ubbels and Verhoef (2006) found that better educated people tend to have a clearer picture and better information on congestion charging so that they would show greater support for congestion charging, given that the lack of information is a major reason for the rejection of congestion charging.
Hosking J, Macmillan A, Connor J, Bullen C, Ameratunga S. Organisational travel plans for improving health. Cochrane Database Syst Rev 2010;3.	Systematic Review	Assessing the effect of organisational travel plans on health through changes in travel mode	Of 17 included studies, 10 were in schools, 2 in universities and 5 in workplaces. The results identified that two clustered RCTs found no results. One workplace RCT in the workplace on a pre-contemplative group found improved quality of life health outcomes and increased walking. Currently there is not enough evidence to show that travel plans are an effective means of changing behaviour.

Iftekhar, S, Tapsuwan, S (2010) Review of transportation choice research in Australia: Implications for sustainable urban transport design. Natural Resources Forum: Wiley Online Library; 2010.	Review	Assessment of the key factors that have been empirically shown to affect individual transportation mode choice	Hensher (2008) studied the potential impact of several policy options regarding travel behaviour with a view to reducing CO2, using the TRESIS model it was observed that imposing a 10 cents/km variable user charge on the main road network would reduce car trips by 11% and a 40cents/kg carbon charge would increase train and bus use. The review suggests three recommendations in which transport mode choice could be modelled in the context of carbon emissions. -The incorporation of psychometric data and subjective ratings of attributes (Walker, 2001); This is due to an individual's decision being influenced by situational, contextual and environmental constraints as well as mode cost, departure and arrival time and number of modes (De Palma and Rochat, 1999). - There is an importance to developing sustainable transportation systems; this requires an understanding of activity-based transportation behaviour and the drivers of people-s route and mode choice where trip chaining is involved (Currie and Delbosc, 2010). - Drivers of transport mode choice interact with each other in multiple dimensions; a generative approach such as multi-agent systems could be useful in situations to represent different objective functions such as individual utility maximisation, joint household decisions and lifecycle events. Saldarriaga-Isaza and Vergara (2009) studied the impact of a case subsidy programme implemented to encourage the use of natural gas in vehicles in a region in Colombia, they found that a large part of owners who switched to natural gas would have done so anyway without the subsidy. There are many facets of the built environment that could encourage the use of more sustainable transport mode choices (Mokhtarian and Cao, 2008), these include the level and accessibility of bus stops, walkways and bike paths, the level of safety, particularly for pedestrians and cyclists and the ease of use (Cervero, 2002). The link between sustainable urban design and sustainable transport choice is clear. A well-designed neighbourhood with convenient bicycle and walking paths that are well connected to business facilities and public transport terminals should be able to encourage less dependency on private car use (Chen et al, 2008). Badland and Duncan (2009) found that 13% of a sample of commuters in Queensland considered air pollution a major barrier to walking or cycling to and from work.
McIlroy RC, Stanton NA. A decision ladder analysis of eco-driving: the first step towards fuel-efficient driving behaviour. Ergonomics 2015(ahead-of-print):1-17.	Experiment	Fuel efficient driving and the use of decision ladders to impact on behaviour	The paper examines changing driving behaviour and provides evidence of factors associated with improved driving. Two behaviours were identified as having a significant impact on fuel economy and these were those related to braking (avoiding sudden stops) and accelerating (shifting gears to the highest level as soon as possible and smooth driving).
Moshammer H, Bartonova A, Hanke W, van den Hazel P, Koppe JG, Kramer U, et al. Air pollution: a threat to the health of our children. Acta Paediatr Suppl 2006 Oct;95(453):93-105.	Review	Exposure data and evidence of health effects from epidemiology and toxicology	The paper identifies that doctors could advise patients on the outdoor environment and pro-environmental behaviours.

Panter JR, Jones A. Attitudes and the environment as determinants of active travel in adults: What do and don't we know? Journal of Physical Activity & Health 2010;7(4).	Review	Describes current knowledge of the psychological and environmental determinants of active travel in adults and considers ways in which the domains can be better integrated	In social cognitive theory, psychological components are considered, with broader social factors and physical environmental components acting as reinforces (Bandura, 1986). Pikora et al developed a framework for assessing the environmental determinants of walking and cycling, suggesting 4 broad categories of; functional, safety, aesthetic and destination. In relation to the theory of planned behaviour, two studies found positive associations between positive attitudes toward cycling and cycling for transport (Titze et al 2007, Handy et al, 2006). Some environmental components have shown associations with active travel. In particular for walkability of neighbourhoods. The behavioural and social psychology literature presented highlights the diversity of influences on individual behaviour including past behaviours, knowledge, experience and feelings. The four main theories applied to travel behaviour are; theory of planned behaviour, theory of interpersonal behaviour, the norm activation model and they theory of trying. As individuals are increasing forced to consider the consequences of trends in car use as well as their personal responsibility to the environment the role of personal norms may gain more importance. Barriers such as the perceived practicalities of using active travel modes are factors which are also considered (Azjen et al 1986). European studies found that perceived negative barriers were important detractors of cycling for transport (de Geus et al 2008). De Bruijn et al found that habit was the strongest predictor of cycling behaviour in their sample of Dutch adults. From the psychology domain attitudes, subjective norms and perceived behavioural control are the most commonly used and well supported components of the various relevant theories. Although habit has been less frequently investigated the authors believe it is particularly relevant to travel behaviour.

Peattie K. Green consumption: behaviour and norms. Annual Review of Environment and Resources 2010;35(1):195.	Review	To review research on green consumption in relation to behaviour and norms	Despite improvements in the environmental efficiencies of car engines and other technologies, the continuing growth in travel and transport internationally has kept the environmental impacts of transport rising. Economic incentives can include direct financial rewards, penalties for specific behaviours and subsidies for particular products or services (e.g. fines for lone drivers, using car pool lanes or government incentive schemes for scrapping old cars). Anable et al (2006) found that levels of awareness about climate change were relatively high, however a deeper understanding of climate change and its consequences was more patchy, and the links individuals' made to their own consumption and lifestyles were inconsistent. Hobson (2003) found that when behaviours were most likely to be change when new information prompted consumers to think differently about aspects of their consumption. Transport behaviours tend to be very complex, reflecting many aspects of individuals, their location and lifestyle as much as their specific choices and this can make transport behaviour particularly difficult and complex to influence (Cao et al, 2005, Carlsson-Kanyama et al, 1999). Transport behaviours can be divided between relatively habitual travel for work, shopping and leisure and travel for tourism. Tourism impacts are outweighed by habitual travel but have risen significantly with increasing air travel. Although aviation still accounts for a relatively small proportion of global transport impacts, it is growing rapidly (Geyer-Allely, 2002) and for some individuals, flying may represent a significant proportion of their impact. Green might be assumed to relate only to environmental issues, but these are subtly intertwined with the social and economic strands of sustainable development. This review suggests that there is a significant gap in the research connecting the realities of current consumer behaviour with policy ambitions to develop zero carbon or sustainable economies. Closing this gap requires a move away from the current overreliance on disciplines and towards a multidisciplinary approach from economics, philosophy, sociology etc.
Shephard RJ. Is active commuting the answer to population health? Sports Medicine 2008;38(9):751-758.	Review	Commuting choice and behaviour	This review looks at commuting behaviour/active commuting. Whether or not people decide to actively commute (usually walk or cycle) depends on the distance to be covered, the size of the city/how practical it is to walk, age (younger more like to prefer cycling rather than walking). If cycling is to become more widely accepted option then substantial changes are needed to the 'built environment' (Owen et al, 2004, Sallis et al, 2006), including cycle lanes, traffic calming devices, specific traffic signals for cycles (Anderson, 1997, Boarnet et al, 2005, Pikora et al, 2006). As well as companies providing changing facilities/showers/cycle storage (Shoup, 1997). The encouragement of walking was found to be the most effective tactic in the US for the promotion of physical activity in the sedentary population (Hillsdon et al, 1996).

Steg L, Bolderdijk JW, Keizer K, Perlaviciute G. An Integrated framework for encouraging pro-environmental behaviour: The role of values, situational factors and goals. J Environ Psychol 2014;38:104-115.	Review	Development of a framework for encouraging pro-environmental behaviours	This paper proposes a theoretical framework to frame behaviour change and encourage pro-environmental behaviour. The paper suggests that goal conflict can be reduced by the hedonic and gain costs of pro-environmental behaviour such as reducing the actual price. Additionally it suggests that increasing normative goals is also important to encourage people to follow norms. As a theory paper, no evidence given to the usefulness of the framework.
Yetano Roche M, Mourato S, Fischedick M, Pietzner K, Viebahn P. Public attitudes towards and demand for hydrogen and fuel cell vehicles: A review of the evidence and methodological implications. Energy Policy 2010;38(10):5301-5310.	Review	Aims to inform future research on public attitudes and preferences towards hydrogen and fuel cell vehicles	Potoglou and Kanaroglou (2007) examined the factors and incentives more likely to influence household choice for cleaner vehicles in Hamilton, Canada. It showed that dwelling-location characteristics such as land-use mix and population density were important determinants of choices, also reduced costs, tax incentives and low emissions rates would encourage households to adopt a cleaner vehicle.

APPENDIX 5 WELLBEING PAPERS REJECTED FROM THE REVIEW

Reference	Reason for rejection
American Lung Association. (2001). Urban air pollution and health inequities: a workshop report. Environmental Health Perspectives; 109 Suppl 3: 357-374.	Does not concern transport, travel, AQ and wellbeing. Discusses health effects of exposure to AP such as asthma, COPD, cardiovascular diseases
Evans GW. (2004). The environment of childhood poverty. American Psychologist; 59: 77.	Does not concern AQ & transport, wellbeing
Hyslop NP. (2009). Impaired visibility: the air pollution people see. Atmospheric Environment; 43: 182-195.	Does not concern transport, travel, AQ and wellbeing. Relates to AQ and visibility only
O'Neill MS, Jerrett M, Kawachi I, Levy JI, Cohen AJ, Gouveia N, Wilkinson P, Fletcher T, Cifuentes L, Schwartz J, Workshop on Air Pollution and Socioeconomic Conditions. (2003). Health, wealth, and air pollution: advancing theory and methods. Environmental Health Perspectives; 111: 1861-1870.	Does not concern transport, travel, AQ and wellbeing. Discusses health effects of exposure to AP; Are they modified by SES

APPENDIX 6 PAPERS UNABLE TO BE SOURCED FOR THE WELLBEING REVIEW

Reference
Culp M, Lee EJ. (2005). Improving travel models through peer review. Public Roads; 68:
Deguen S, Zmirou-Navier D. (2010). Social inequalities resulting from health risks related to ambient air quality--A European review. European Journal of Public Health; 20: 27-35.
Evans GW, Kantrowitz E. (2002). Socioeconomic status and health: the potential role of environmental risk exposure. Annual Review of Public Health; 23: 303-331.
Maynard R, Cohen AJ. (2003). Public health significance of research results. Journal of Toxicology and Environmental Health, Part A: Current Issues; 66:

APPENDIX 7 BEHAVIOUR PAPERS REJECTED FROM THE REVIEW

Reference	Reason for rejection
Anable J, Shaw J. Priorities, policies and (time) scales: the delivery of emissions reductions in the UK transport sector. Area 2007;39(4):443-457.	This paper develops an overview and critique of how the formulation and delivery of transport policy fits in to the exposition of climate policy in the UK.
Axsen J, Kurani KS. (2012). Social influence, consumer behavior, and low-carbon energy transitions. Annual Review of Environment and Resources; 37: 311-340	Although the paper covers a number of different psychological frameworks it doesn't relate to air pollution and transport pollution
Bentley M. Healthy Cities, local environmental action and climate change. Health Promot Int 2007 Sep;22(3):246-253.	The study explores the relationship between local environmental actions of Healthy Cities programs and the adverse health impacts of climate change rather than behaviour and air pollution in relation to transport.
Bohte W, Maat K, van Wee B. Measuring attitudes in research on residential self-selection and travel behaviour: A review of theories and empirical research. Transport reviews 2009;29(3):325-357.	PhD thesis
Byrne M. The role of transport information in influencing travel behaviour: a literature review. Road & Transport Research: A Journal of Australian and New Zealand Research and Practice 2011;20(2):40.	Review identifies current view of transport information and its relationship to travel behaviour change
Edwardson CL, Gorely T. Parental influences on different types and intensities of physical activity in youth: A systematic review. Psychol Sport Exerc 2010;11(6):522-535.	Not travel behaviour and pollution, it focuses on increasing youth physical activity
Fox J, Hess S. Review of evidence for temporal transferability of mode-destination models. Transportation Research Record: Journal of the Transportation Research Board 2010;2175(1):74-83.	Methodology
Gardner B, de Bruijn G, Lally P. (2011). A systematic review and meta-analysis of applications of the self-report habit index to nutrition and physical activity behaviours. Annals of Behavioral Medicine; 42: 174-187.	Does not relate to air pollution or transport but discusses habits
Geurs KT, Boon W, Van Wee B. Social impacts of transport: literature review and the state of the practice of transport appraisal in the Netherlands and the United Kingdom. Transport Reviews 2009;29(1):69-90.	Not pollution and travel behaviour (see comment)

Kazdin AE. Psychological science's contributions to a sustainable environment: Extending our reach to a grand challenge of society. Am Psychol 2009;64(5):339.	Presidential address article
Kelly FJ, Fuller GW, Walton HA, Fussell JC. Monitoring air pollution: use of early warning systems for public health. Respirology 2012 Jan;17(1):7-19.	To do with AQ monitoring systems
Li Z, Hensher D. Prospect theoretic contributions in understanding traveller behaviour: a review and some comments. Transport reviews 2011;31(1):97-115.	A review of prospect theoretic contributions in understanding traveller behaviour - this didn't include pollution, it was more about travel times.
Li Z, Hensher DA, Rose JM. Willingness to pay for travel time reliability in passenger transport: a review and some new empirical evidence. Transportation research part E: logistics and transportation review 2010;46(3):384-403.	The review focuses on travel times, but doesn't look at pollution.
Macmillan AK, Hosking J, Connor JL, Bullen C, Ameratunga S. A Cochrane systematic review of the effectiveness of organisational travel plans: Improving the evidence base for transport decisions. Transp Policy 2013 Sep 2013;29.	This review doesn't cover pollution and travel behaviour (see comment)
Manski CF. Measuring expectations. Econometrica 2004;72(5):1329-1376.	This article doesn't mention travel, it discusses choice behaviour in relation to practice of economists, touching on the history underlying the new literature and describing what has been learnt so far.
Mitchell C, Cowburn G, Foster C. Assessing the options for local government to use legal approaches to combat obesity in the UK: putting theory into practice. Obesity Reviews 2011;12(8):660-667.	Review the current evidence for regulatory interventions to reduce obesity by local government and to identify options for translation of evidence-based policy in to practice.
Molander S, Fellesson M, Friman M, Skålén P. Market orientation in public transport research—A review. Transport Reviews 2012;32(2):155-180.	Public transport and behaviour not pollution (see comment)
Murray J, Craigs CL, Hill KM, Honey S, House A. A systematic review of patient reported factors associated with uptake and completion of cardiovascular lifestyle behaviour change. BMC Cardiovasc Disord 2012 Dec 8;12:120-2261-12-120.	Looking at influences on lifestyle change programmes generally in cardiovascular patients
Perlaviciute G, Steg L. Contextual and psychological factors shaping evaluations and acceptability of energy alternatives: Integrated review and research agenda. Renewable and Sustainable Energy Reviews 2014;35:361-381.	Paper about energy costs and although covers behaviour not convinced it's transferable to our study.

Rickwood P, Glazebrook G, Searle G. Urban structure and energy—a review. Urban policy and research 2008;26(1):57-81.	Only considers urban density in relation to use of private cars
Rissel CE. Active travel: a climate change mitigation strategy with co-benefits for health. N S W Public Health Bull 2009 Jan-Feb;20(1-2):10-13.	Not a review, summarises a number of NSW active travel initiatives
Sallis JF, Cervero RB, Ascher W, Henderson KA, Kraft MK, Kerr J. An ecological approach to creating active living communities. Annu Rev Public Health 2006;27:297-322.	Position paper
Tiwary A, Robins A, Namdeo A, Bell M. Air flow and concentration fields at urban road intersections for improved understanding of personal exposure. Environ Int 2011 Jul;37(5):1005-1018.	This paper looks at flow behaviour rather than human behaviour
Van Acker V, Van Wee B, Witlox F. When transport geography meets social psychology: Toward a conceptual model of travel behaviour. Transport Reviews 2010;30(2):219-240.	Development of a conceptual model of behaviour - no practical application
Wood W, Neal DT. The habitual consumer. Journal of Consumer Psychology 2009;19(4):579-592.	How plausible is it that the relatively simple habit cuing mechanism drives consumer behaviour

APPENDIX 8 PAPERS UNABLE TO BE SOURCED FOR THE BEHAVIOUR REVIEW

Reference
Caramia M, Storchi G. Evaluating the effects of parking price and location in multi-modal transportation networks. NHM 2006;1(3):441-465.
Lülfs R, Hahn R. Corporate Greening beyond Formal Programs, Initiatives, and Systems: A Conceptual Model for Voluntary Pro-environmental Behavior of Employees. European Management Review 2013;10(2):83-98

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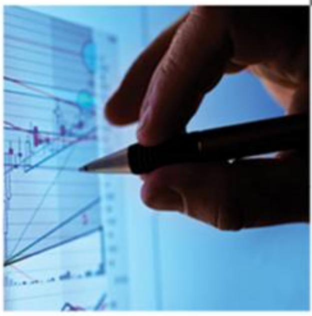

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