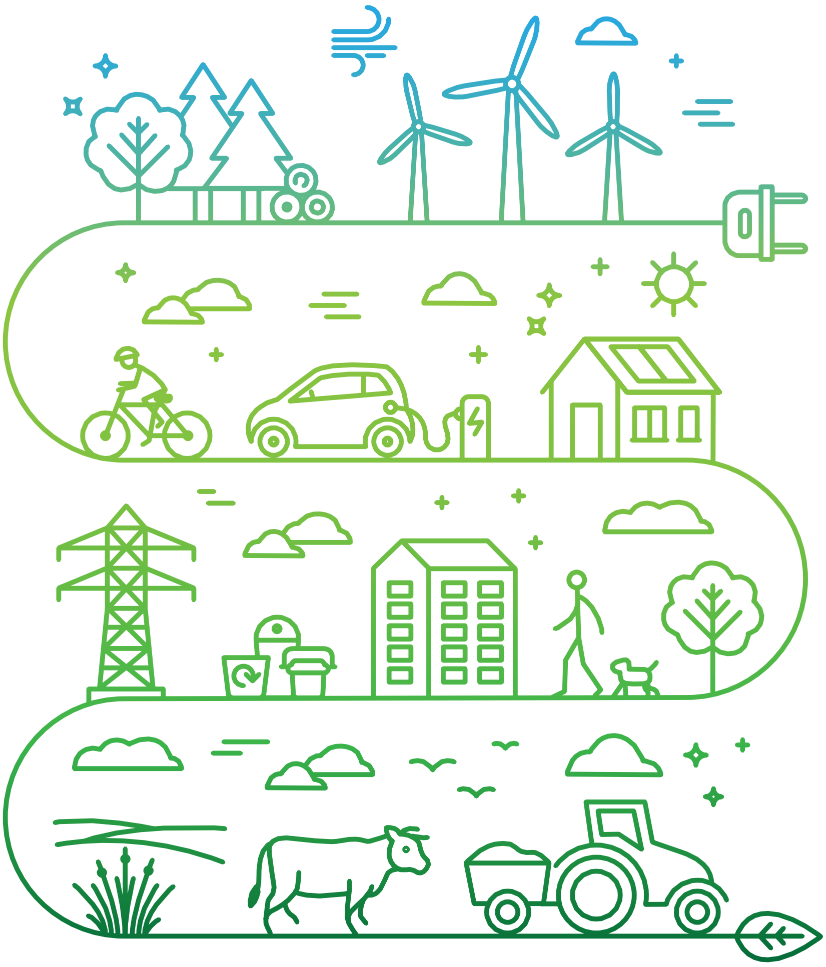
Evidence Review of the Potential Wider Impacts of Climate Change Mitigation Options: Transport sector

Report to the Scottish Government



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List of Abbreviations

AHS – Automated Highway Systems

ATM – Active Travel Management

CEDAR – Centre for Diet and Activity Research

DALYs – Disability-Adjusted Life Years

DECC – Department of Energy and Climate Change

Defra – Department of Environment, Food and Rural Affairs

DfT – Department for Transport

EC – European Commission

EEA – European Environment Agency

ESPRC – Engineering and Physical Sciences Research Council

ESRC – Economic and Social Research Council

GBD – Global Burden of Disease

GHG – Greenhouse gas

HEAT – Health Economic Assessment Tool

I'DGO – Inclusive Design for Getting Outdoors

IEA – International Energy Agency

ISA – Intelligent Speed Adaptation

ITHIM – Integrated Transport Health Impact Modelling Tool

JEG – Joint Expert Group

LPG – Liquefied Petroleum Gas

MAC – Marginal Abatement Cost

MET – Metabolic Equivalent of Task

NERC – Natural Environment Research Council

NHS – National Health Service

RPP – Report on Proposals and Policies

SPLiCE – Sustainable Pathways to Low Carbon Energy

SROI – Social Return on Investment

STAG – Scottish Transport Appraisal Guidance

TfL – Transport for London

WHO – World Health Organisation

YLD – Years Living with a Disability

YLL – Years of Life Lost

Executive summary

- This evidence review is based on a systematic literature review of over 100 papers on the wider impacts of climate change mitigation in the transport sector. The review looked at qualitative and quantitative sources of relevance to the Scottish context. Particular consideration was given to the impacts from an equalities perspective.
- Overall the evidence base suggests there are a number of potential co-benefits associated with transport climate change mitigation measures. Health benefits associated with increased levels of walking and cycling dominates the literature. Reductions in car vehicle kilometres whether through modal shift or demand reduction (e.g. through teleworking) can offer air quality improvements, noise and congestion reduction. There is also an emerging evidence base on the co-benefits of improved transport efficiencies. However, the extent of these benefits, particularly from an equalities perspective, is dependent on how and where policies are implemented and the extent of consumer uptake and acceptance.
- Transport is a major contributor to air quality pollutant emissions. An emerging literature base suggests that improvements in vehicle efficiency for example, through the use of electric vehicles can offer benefits here. Further understanding relating to population exposure and the spatial distribution of these vehicles to ensure these benefits is required. The evidence base suggests links between socially deprived neighbourhoods and exposure to higher levels of air pollution, thus consideration should be given to the geographic positioning of demonstration schemes and grants to help facilitate equitable, social and distributional benefits of these vehicles.
- There are opportunities too with regard to the potential for noise reduction through the use of electric vehicles, however a fuller understanding of the implications of the European Commission’s required introduction of sound generating devices (for safety purposes) on these vehicles is necessary to better understand the extent of this potential reduction.
- Modal shift from car to public transport and walk and cycle can potentially bring about reductions in noise, air pollution and congestion. The level of benefit depends on the extent of modal shift in terms of car vehicle kilometres reduced, and where and when these reductions take place. For public transport modes, the impacts will be greatest when the modal shift is to cleaner vehicles. To capture these potential benefits, guidance is available at the UK and Scottish level. In terms of quantitative approaches, recent Defra modelling work may be highly relevant. Identification of opportunities from an equalities perspective is required e.g. the location of bike share schemes in areas where the numbers of existing cyclists is limited.

- There is strong evidence that active travel interventions can, through increased physical activity, bring about substantial health benefits. These health benefits relate to reductions in disease and mortality. Quantitative tools and models exist to capture these benefits. To quantify the benefits of reductions in disease in the Scottish context, further work is required. Scottish based research is making important contributions to the real life evidence base with regard to the increased adoption of active travel measures. In terms of ensuring equitable distribution of benefits, further understanding is required to help ensure those that are currently less likely to walk and cycle are reached. This could include innovative methods such as electric bicycles.
- Action may be required to lock in these benefits, for example through demand management. Demand management offers opportunities in terms of congestion reduction and can be used as an incentive to facilitate the adoption of lower emission vehicles. There are close links with land use planning and the facilitation of modal shift.

1 Introduction

1.1 Background

The Climate Change (Scotland) Act 2009 (Scottish Parliament, 2009) created a statutory framework for greenhouse gas (GHG) reductions in Scotland by setting an interim 42 per cent reduction target for 2020 and an 80 per cent reduction target for 2050 compared to 1990. As of today Scotland is on track to meet this target, with recently published data for 2014 indicating that the 2020 interim target had been met six years ahead of schedule (Scottish Government, 2016). Section 35 of the Act placed a duty on Scottish Ministers to lay before the Scottish Parliament a Report on Proposals and Policies (RPP), setting out specific measures for reducing GHGs to meet Scotland's statutory targets. The second Report (RPP2) was published in June 2013 and covered the period 2013 to 2027 (Scottish Government, 2013a). The Climate Change Plan sets out proposals and policies for meeting targets to 2032.

There is increasing recognition that actions designed to reduce GHGs not only mitigate the risks of climate change but might also help or limit the achievement of other societal objectives such as improved air quality, health and energy security (Committee on Climate Change, 2016). Together, these benefits and potential adverse impacts of climate change mitigation might provide additional incentives or potentially disincentives for strong actions to reduce GHG emissions.

A more detailed understanding of such potential co-benefits and adverse side effects is an important part of the foundation underpinning the development of future Scottish Government policies. Information on the impacts of climate change mitigation across the transport sector helps improve understanding of social and economic benefits and the role these could play in helping to create a fair, equal and prosperous Scotland.

The Scottish Government therefore commissioned Aether to provide a synthesis of qualitative and quantitative evidence to indicate the direction and magnitude of the potential wider impacts of climate change mitigation actions in the transport sector, which would be relevant to the Scottish context. Where possible quantitative models and tools were identified, with impacts in terms of equalities evaluated correspondingly. This is the final report of the study.

1.2 Definitions and framing

Climate change mitigation action is typically evaluated in terms of the GHG emissions avoided per unit of expenditure, often expressed as cost per tonnes of CO_2 equivalent. The GHG savings will lead to benefits arising from reduced climate change, such as lower sea level rise and less extreme weather. However, these actions usually have other impacts – both positive and negative – beyond the benefits of avoided climate change and the direct financial costs of the mitigation action. These wider impacts are referred to as co-benefits if they are positive and adverse side-effects if they are negative, sometimes jointly referred to as co-impacts. In the transport sector, for example, increased levels of walking and cycling could give rise to a range of co-benefits including the health benefits from increased physical activity and cost savings through reduced hospital admissions. However, adverse side-effects could include a potential increase in cycling related injuries as the number of people who cycle increase.

When considering the financial costs of energy consumption, it can be hard to define the boundary between direct costs or benefits and co-impacts. For example, increased efficiency in vehicles should lead to reduced fuel consumption and hence a reduction in the amount spent on fuel. These energy cost savings are widely treated as a co-benefit in the literature, but they are also often included in the cost-benefit assessments that contribute to the GHG mitigation investment decision – in other words, they are included in the calculation of the cost per tonne of CO_2 avoided. It is important to avoid double-counting these benefits. However, changes in energy costs can be treated as co-impacts if they have unintended side-effects, e.g. if they fall disproportionately on particular sectors of society either increasing or decreasing social inequality.

Although most co-benefit studies refer to the wider impacts of climate change mitigation policies, as described above, some address the impacts of non-climate policies, such as air quality legislation, on greenhouse gas emissions. For example, a reduction in the use of diesel vehicles because of air quality concerns could have impacts on carbon savings. There are also studies that take a more holistic view, assessing all the impacts of a technology or policy on an equal basis, including both climate and non-climate impacts. Although some early studies defined co-benefits as ‘benefits not related to the primary aim of a policy or action’, it is now acknowledged that not all policies or actions have a single primary aim, and it could be better to assess all impacts within a ‘multiple objective, multiple impact’ framework (Ürge-Vorsatz et al., 2014). A number of papers now refer to ‘multiple benefits’, including GHG savings alongside other impacts, rather than co-benefits. All these different framings are addressed in this report.

This report places climate change mitigation in a sustainable development framework considering broader environmental, social and economic impacts of action. These wider impacts need to be considered alongside the cost-effectiveness and abatement potential of each mitigation option for greenhouse gas reduction so that climate targets can be met while maximising co-benefits and reducing adverse side-effects.

1.3 Research aim and objectives

The aim of this project is to improve the Scottish Government’s understanding of the potential wider impacts for Scotland of climate change mitigation measures in order to support the development of the Climate Change Plan.

The objectives of this project are:

- To produce a synthesis of qualitative evidence which indicates the direction (positive / negative) and potential magnitude of the potential wider impacts of climate change mitigation actions which would be relevant to the Scottish context.
- To identify the most robust quantitative models and tools which would enable quantification and, where possible, monetisation of the potential wider impacts of climate change mitigation actions which would be relevant to the Scottish context.

These objectives are underpinned by the following research questions:

1) What is the evidence, both quantitative and qualitative, of potential wider impacts (co-benefits and adverse side-effects) arising from climate change mitigation actions which would be relevant to the Scottish context?
2) Based on a review and synthesis of qualitative evidence: what are the key sources of robust evidence; and what is the balance of evidence, in terms of the direction (positive / negative) and potential magnitude, of those wider impacts relevant to Scotland?
3) Based on a review and synthesis of quantitative evidence: which models and tools are assessed as the most robust to quantify and, where possible, monetise such wider impacts? What quantitative data would be required to apply these models to Scotland? What key assumptions are required?
4) From an equalities perspective, what evidence is there about the potential distribution of wider impacts relevant to Scotland across the population?
5) What are the most significant gaps in research and evidence about potential wider impacts which are relevant to Scotland?

2 Approach to the evidence review

The study involved a detailed evidence search to better understand the current knowledge base. The evidence search used a three-way approach.

- Systematic literature search,
- Call for evidence,
- Review of current research grant programmes.

Certain areas of interest have already been covered by two recent studies. First, the Department of Energy and Climate Change (DECC)[1] funded co-benefits project (Smith et al., 2017) identified key research areas and relevant literature for a UK (and international) context. This work provided particularly good coverage on health-related co-benefits in the transport sector. Secondly, the Department for Environment, Food and Rural Affairs (Defra) funded SPLiCE project (2015) summarised evidence on the positive and negative impacts of energy technologies, by conducting a 'review of reviews'. This study, for the Scottish Government, provides an opportunity to consider the role of quantitative models and the implications of co-impacts for social equality in particular detail.

2.1 Literature search and key outcomes

The literature search for the Scottish context study took place from July to August 2016 and covered four sources:

- Scopus (research articles, including articles in press, and books)
- Repec (economics articles and working papers)
- ResearchGate (articles, working papers and conference papers)
- Google Scholar (all of the above)

Relevant grey literature was searched for on the websites of key organisations including the European Environment Agency (EEA), the International Energy Agency (IEA), the World Health Organisation (WHO) and the World Bank. Some further references were added by 'snowballing', i.e. adding important papers referred to by some of the papers reviewed. A particular point of relevance is that there is a large transport research evidence base that is not necessarily framed as co-benefits. For example, there is historic literature on congestion reduction that does not use a co-benefits terminology. Where appropriate, therefore, more focused searches were undertaken to cover these areas.

[1] In July, 2016, the Department of Energy and Climate Change was merged with the Department for Business, Innovation and Skills (BIS), creating a new department for Business, Energy and Industrial Strategy (BEIS).

In total over 300 relevant papers were identified, with over 100 of relevance to the Scottish context. Their bibliographic details were entered into a database. Most papers in the transport literature as it relates to co-benefits were framed in terms of active travel, but a number also considered energy efficiency including electric vehicles.

2.2 Call for evidence and research grant analysis

A call for evidence was directed at key research organisations, identified by: the Scottish Government; from the literature search and other networks from Scotland and the rest of the UK. This resulted in over fifteen submissions with responses from a broad range of organisations. These were added to the evidence database.

A research grant analysis was undertaken to understand current and planned research relevant to the co-benefits agenda within the UK and internationally. Research funding sites reviewed included the Engineering and Physical Sciences Research Council (EPSRC), the Natural Environment Research Council (NERC), the Economic and Social Research Council (ESRC), the Department for Transport (DfT) and Scottish Government websites. Relevant examples include work funded by the National Institute for Health Research to evaluate the health and wellbeing impacts of major change in the urban environment – the introduction of the M74 motorway in Glasgow and associated urban improvements. The final outputs from the work will be published in July 2017.

2.3 Framework for the report

Climate change mitigation in the transport sector can be framed around a shift / reduce / improve framework (e.g. Dalkmann and Brannigan, 2007). This approach is used in this study to reflect the broad range of mitigation options available to the Scottish Government.

This captures:

- Shift to lower carbon modes [Chapter 4]
  - Increased levels of walking and cycling (i.e. shifting from motorised to non-motorised transport)
  - Increased use of public transport and car clubs (i.e. shifting from private to public transport)
- Reduction in the need to travel [Chapter 5]
  - Land use planning
  - ICT - teleworking
  - Demand management
- Improvements in efficiencies [Chapter 6]
  - Lower carbon transport modes
  - Increased network efficiencies

The above framework is used to set out the literature review findings in Chapters 4 to 6 with an overview of results presented in Chapter 3. Chapter 7 summarises the main co-benefits and adverse side-effects as they relate to air quality, noise and congestion reduction reflecting the relevance of these outcomes across shift / reduce / improve mitigation actions. Chapter 8 presents conclusions and recommendations.

3 Overview of results

3.1 Direction and magnitude of impacts

This Chapter provides an overview of the direction and magnitude of impacts under the shift, reduce, avoid framework, this is complemented by a summary table, and framed within the research questions identified in Section 1.3.

Shift to more sustainable modes (Shift)

- **Active travel** (increased levels of walking and cycling) dominates the co-benefits literature in qualitative and quantitative (modelling) terms. A key focus is on the **health** (and associated monetisation) of increased levels of physical activity. However, consideration is also given to the benefits of reductions in car travel including improved air quality and less traffic congestion. The literature and outcomes as they relate to health can be considered mature in many aspects. There are, however, still research gaps. Of particular relevance from an equalities perspective is the social and distributional aspects of these benefits.
- Broader benefits of **public transport** and **car clubs** such as facilitating access to employment, and reducing congestion are not typically framed in co-benefits terminology. These benefits can potentially be significant though further evidence is required.

Reduce the need to travel (Avoid)

- **Land use planning** such as high density mixed use development can reduce the need to travel (by car) and result in associated benefits (in quantifiable and less quantifiable terms) such as reduced travel time and the regeneration of local communities. Land use planning can also help reduce community severance (e.g. physical barriers which can occur due to the challenges pedestrians face in crossing busy roads) which is particularly pertinent from an equality perspective.

- **Teleworking** can offer employers and employee benefits. Care is, however, required with regard to work-life boundaries. In addition, heating and lighting costs may increase if energy is used less efficiently in the home than in an office serving many people.

Improve efficiency (Improve)

- There is increasing interest in the **air quality** and **noise benefits** of a move towards electrified and other low carbon vehicles e.g. Liquefied petroleum gas (LPG). While the emphasis is on qualitative aspects there is an emerging literature regarding quantification. Targeted introduction of electric and other vehicles could offer opportunities in terms of reducing the current inequalities around population exposure to higher levels of air pollution.
- With all efficiency improvement measures, there is a possibility of a **rebound** effect. This is because increased fuel efficiency cuts the costs to the consumer

per vehicle kilometre travelled and therefore may result in increased transport activity.
- In terms of **network efficiencies**, there is current, limited research, but the existing evidence suggests the potential for reductions in road accidents.

In terms of the overall direction and magnitude of impacts, a number of key studies (e.g. Woodcock et al., 2009; Smith et al., 2015, Brown et al., 2016) that consider positive and negative impacts of climate change mitigation conclude that for transport mitigation actions that the positive impacts can outweigh potential adverse side effects. A qualitative summary is provided below in Table 3-1, which sets out the direction and magnitude of impacts for the different mitigation actions with the rationale covered in the following Chapters.

Table 3-1 Magnitude and direction of co-impacts for transport mitigation actions

Mitigation action	Economic competitiveness[2] Resource costs, resource security, innovation	Health (AQ, lifestyle, accidents, noise)	Social (equity community, poverty)
Active travel	+	++	+
Public transport	+	+	+
Land use planning	+	+	+
Teleworking	+	+	
Demand Management	+	++	+/-
Electric vehicles	+	+	+/-
Biofuels	+/-	+/-	+/-
Average speed cameras	+	++	
Intelligent Transport systems	+	+	
Fuel efficient driving	+	+/-	+/-

Legend	
++	Strong positive effect
+	Positive effect
0	No significant effect
+/-	Variable effect
-	Negative effect
- -	Strong negative effect
	Weak evidence
	Moderate evidence
	Robust evidence

[2] Includes potential economic benefit of reduced congestion. Excludes direct investment cost – this focuses only on additional costs or benefits

Weak evidence relates to there being limited evidence currently available or that the available evidence is less robust. Robust evidence relates to stronger evidence base relating to the quality of and number of papers. Where there was no current evidence identified through this study the cells were left blank. It should be noted that there could be future evidence e.g. on the equity benefits of average speed cameras - reflecting that road accidents can disproportionately affect disadvantaged socio-economic groups.

There are potential benefits on **natural capital** (including water, soil, biodiversity, waste) through avoided fuel production for several of the mitigation options including demand reduction and modal shift to active travel. The extent of these benefits will depend on the level of the reduction in fuel use. Biofuels can have potential adverse impacts on natural capital, for example on biodiversity and water quality. The extent of this impact is dependent on fuel stocks used and whether the fuels are first or second generation. For electric vehicles the need for further evidence for example relating to impacts of the extraction of materials to produce the vehicles is identified.

4 Shift to lower carbon transport modes

Mitigation options which involve a shift to lower carbon travel includes the use of walk and cycle modes (often termed “active travel”); modal shift to public transport and the use of car clubs. These are considered in turn below.

4.1 Active travel

4.1.1 Overview

Modal shift to walking or cycling modes dominates the transport related co-benefits literature (e.g. Woodcock et al., 2009; Haines et al., 2009 and Shaw et al., 2014). Examples of co-benefits arising from active travel include improved health through physical activity, and (alongside public transport and demand management measures) can contribute to improved air quality through reduced fossil fuel use, reduced congestion and reduced noise pollution (Smith et al., 2016), as well as increased economic benefits through increased footfall – the ‘pedestrian pound’ (Lawlor, 2014).

While there is the potential for adverse side effects from the risks of increased accidents or exposure to pollution faced by cyclists and walkers, modelling studies conclude that the **benefits** of **physical activity** outweigh these risks (de Hartog et al., 2010: Woodcock et al., 2009, 2014; Rabl and de Nazelle, 2012). However, this may not apply to younger age groups where the risks of accidents is higher (Woodcock et al., 2014).

The costs of **physical inactivity** in Scotland to the **NHS** in terms of diseases are estimated to be approximately £94.1 million annually (Foster and Allender, 2012). Social Return on Investment (SROI) evidence indicates a return of approximately £8 per £1 invested in walking and path development projects (Paths for All, 2013). The **‘Let’s get Scotland Walking’** strategy (2014) identifies a range of co-benefits from strategies to increase walking - connecting the elderly with their communities, a healthier and more productive workforce, carbon reductions and local economy benefits (Scottish Government, 2014). As an example of benefits for local economies, the Fife Coastal Path generated approximately £24–29 million expenditures among local businesses each year, supporting 800 – 900 full time jobs (Fife Coast and Countryside Trust, 2007). While investing in making streets more accessible for walking and cycling could increase retail sales by 30% due to increased footfall (Lawlor, 2014). The provision of good urban spaces and effective urban design can also lead to increases in both house prices and rental rates as the ability to walk to local services and shops can be linked to higher property value (Lawlor, 2014). There is on-going economic analysis with regard to health and broader benefits, summaries include, for example, the systematic review by Brown et al. (2016) updating the work by Cavill et al. (2008).

Research gaps exist with regard to the evaluation of **real world active travel** interventions (Smith et al., 2016). Here an emerging Scottish orientated literature can contribute to reducing these gaps: for example, the evaluation of the Scottish Government's Smarter Choices, Smarter Places pilot programme which ran from 1999-2012 assessed the impact of active travel initiatives funded by the pilot (Halden et al., 2013). The programme aimed to encourage people to reduce car use in favour of more sustainable modes. Achieving such behavioural change was intended to save people money, help to make them healthier, reduce transport emissions and develop more cohesive communities. Seven areas across Scotland took place in pilot programmes with outcomes then implemented more broadly. The evaluation highlighted that in terms of outcomes, individuals in areas where measures had been implemented were on average 6% more likely to achieve physical activity guidelines than those in areas without sustainable travel measures (Norwood et al., 2014).

In terms of air quality, congestion and noise reduction benefits, impacts relate to reductions in car vehicle kilometres driven, with potential benefits being substantial. For example, Smith et al. (2015) suggests that the congestion reduction benefits can have a Net Present Value of £48 billion for the UK over the period from 2008 to 2030. A broad evidence base suggests that interventions result in less car driver trips for example, in all seven Smarter Choices, Smarter Places study areas, the decrease in the proportion of car driver trips was greater than the background trend from comparable areas (Halden, 2013). In congestion reduction terms, opportunities exist in terms of work place travel (reflecting the peak time nature of congestion). A recent systematic review (Petrunoff et al., 2016) on the potential for active travel in work place settings suggested a median result of an 11.1% reduction in employees driving private vehicles to work. The potential for bias in a number of the studies was, however, identified. In terms of broader benefits, it will also be important to see active travel as part of an **integrated package of measures** (e.g. Sloman et al., 2010), particularly at the city level. Congestion and air quality benefits will accrue depending on the potential for modal shift from car users. Thus, this package of measures could include public transport, car clubs and potentially demand management. For example, in the Petrunoff et al., (2016) study the greatest decrease in car use (a 42% reduction) was found in the intervention which combined active travel with strategies to manage travel (increased parking charges and restrictions in parking places).

4.1.2 Quantitative approaches

Transport modelling approaches aim to quantify co-benefits of active travel, with the focus predominantly on the **health benefits.** This project identified two key existing sets of models which were of relevance to the Scottish context. These models are:

- Health Economic Assessment Tools (HEAT)
    - Walking

    - Cycling

- Integrated Transport Health Impact Modelling Tool (ITHIM) – covers walking and cycling

Future work of relevance includes the development of the Cycling Scotland – Cycling potential tool. This is of particular relevance given its broadening to include a number of co-benefits.

Health Economic Assessment Tool

The Health Economic Assessment Tool (HEAT) was developed by the World Health Organisation (WHO) and performs economic assessments of the health benefits of **walking** or **cycling**. It estimates the value of **reduced mortality** that results from specified amounts of walking or cycling. The HEAT models are used for assessments for groups of people and are designed to analyse habitual behaviour such as regular leisure time activities and commuting through walking and cycling.

The HEAT models for walking and cycling use **internationally agreed methodologies** and **data assumptions**. For **walking** the applicable age range is set to approximately **20 – 74 years** and for cycling the applicable age range is set to approximately **20 - 64 years.** These **assumptions** reflect insufficient information on relative risks in younger and older populations. The models enable the assessment of interventions to increase levels of walking and cycling, quantifying impacts based on the value of a statistical life, quantifying impacts for a period of up to 50 years, including benefit-cost calculations and discount rates.

Caution should be applied when utilising the tool in predominantly **sedentary** populations as the underlying risk estimates underpinning the models are derived from populations with a broad distribution of activity levels. The same applies for groups with very high average levels of physical activity.

The HEAT approach is currently used by Department for Transport (DfT) web based Transport Analysis Guidance (WebTAG) and STAG guidance. DfT WebTAG is in the process of being updated e.g. to capture premature mortality (years of life lost impacts).

Example: HEAT

A local authority wishes to implement a cycling campaign to increase cycling amongst a population of 200 individuals. Before the cycling campaign, the population with an average age structure (20 – 64 years) did not cycle at all.

One year after the cycling campaign, the cycling amongst the population increases to 30 minutes per day, 260 days per year. This is the equivalent of 130 hours of cycling per year and a 15% reduction in the risk of mortality.

With the UK specific mortality data of 249 deaths per 100,000 persons per year, the value of a statistical life (VSL) of £3,229,114 (UK specific value in HEAT), and a 5% annual discount rate, the annual benefits averaged over the next 10 years can be estimated to £131,000, or accumulated to £1,308,000 over the ten years.

Data required by the HEAT models largely depends on the level of detail required. The model enables users to quantify co-benefits at either a **single point in time** or **before and after an intervention**. Levels of physical activity can be input as either duration (time), distance, steps, or trips per person. Subsequently, data on the number of people benefitting from the action can be inputted, enabling a quantification of mortality risks with and without intervention. Users can further select data on the value of a statistical life, national mortality rates, and discount rates. HEAT is developed in the European context and respectively the default values employ European values. These values can, however, be adjusted to reflect local situations.

Table 4-1 Data requirements for HEAT and potential Scottish sources

Data requirement	Scottish data source
An estimate of how many people are walking or cycling	Census 2011 • Method of travel to work • Data available at a range of areal units e.g. Output Area and ward level Scottish Household survey • Method of travel to work • National Travel survey Trips per person per year
An estimate of the average duration spent walking or cycling (can be duration, distance, trips)	Census 2011 • Method of travel to work by distance travelled to work • Data available at a range of areal units e.g. Output Area and Ward level Scottish Household Survey • Average distance travelled per person per year by main mode

Values for
• mortality rate
• value of a statistical life
	HEAT provides a **default** value
	Data for the Scottish specific context can include:
	• Mortality rate
	    ○ National Records of Scotland
	    ○ Scottish Neighbourhood Statistics
	    ○ Scottish Public Health Observatory
	• Value of a statistical life
	    ○ UK DfT Road accidents data

The Integrated Transport and Health Impact Modelling Tools

The Integrated Transport and Health Impact Modelling Tools (ITHIM) are a group of related models and tools developed at the Centre for Diet and Activity Research (CEDAR) to provide an integrated assessment of the health effects of transport policies and scenarios at a national and urban level. The models include **walking, cycling** and other types of physical activities.

The effects are modelled through **health benefits associated with physical activity, road traffic injury risk, and exposure to fine particulate matter ($PM_{2.5}$) air pollution**. In addition, some versions of ITHIM also predict changes in **CO_2**

emissions. The health benefits covered include reductions in cardiovascular diseases, depression, diabetes, dementia, breast cancer, and colon cancer. Road traffic injuries are modelled using a risk, distance and speed based model, including differentiated risk levels based on gender and age. The tool models exposure to physical activity, comparing distributions of weekly physical activity under different scenarios. Walking, cycling and other types of physical activities are quantified as Metabolic Equivalent of Task (MET)[3] hours per week. In ITHIM version 2 individual exposure to air pollution while walking and cycling is taken into account.

ITHIM offers the opportunity to capture, in addition to mortality:

- Premature mortality (years of life lost - YLL)
- Morbidity (years living with a disability - YLD)
- Combined morbidity and mortality (disability-adjusted life years – DALYs). This is the total of premature mortality and morbidity.

ITHIM is currently used in research and by health and transport professionals to compare the impact of travel patterns, estimate health impacts of various scenarios, and model the impact of interventions, and can work either as stand-alone models, or linked to other models.

Data required for the ITHIM models include population census data (including age and gender), census travel data, and Global Burden of Disease (GBD) data.

Table 4-2 Data requirements for ITHIM and potential Scottish data sources

Data requirement	Scottish data sources
Travel patterns	Scottish Household Survey
Physical activity data including walking, cycling, household activity and work related activity, by age and gender	The Scottish Health Survey: Chapter 5 Data Activity
Global Burden of Disease – adjusted to take into account population size, age, sex and gender distribution and depending on scale - health data e.g. mortality rates and Ischemic Heart Disease ratios (IHD)	Census 2011, data Scotland Health Statistics Scottish Health survey

[3] MET is a physiological measure expressing the energy cost (or calories) of physical activities

Cycling Scotland – Cycling Potential

Cycling Scotland (a charity that aims to increase the uptake of cycling and make it part of everyday life) (Cycling Scotland, 2016) worked together with Steer Davies Gleave and Clackmannanshire Council to develop a methodology for evaluating the potential for higher uptake of cycling in urban areas. The study built on a wide selection of available data to identify areas where cycling levels could potentially be increased with additional support, investment and infrastructure. The tool applies to urban areas with a population higher than 10,000 people and has been run as a pilot study for Clackmannanshire Council. The pilot consists of four modules: environment, schools, tourism and development, and enables the user to weight models based on priorities set by the local authorities. The model considers population density, topography, national cycling network, local cycle network, average road speed, average distance to work, average distance to school, access to services and existing mode shares

Cycling Scotland aims to include additional co-benefits into the methodology by incorporating climate change emissions, health & wellbeing benefits and the economic benefits of active travel.

Quantification of the impact of reductions in car use

Reductions in noise, congestion and air quality pollutants are all linked with reductions in car use. There is overlap here with modal shift to public transport and reductions in the need to travel. Methods to capture the impacts with regard to reductions in car use are therefore discussed in a separate Chapter – Chapter 7.

In terms of data sources to help quantify these impacts, Web-TAG Unit 5.4 draws attention to the use of data from the use of Smarter Choices in the UK Sustainable Travel Towns (Sloman et al., 2010), correspondingly data on level of impacts in the Scottish context could be drawn from the Smarter Choices, Smarter Places study, associated follow on projects, and broader quantitative Scottish studies.

4.1.3 Equality

Active travel can offer the potential for very large health benefits from increased physical activity, as discussed in section 4.1. Challenges, however, relate to achieving behavioural change in the groups that could benefit most, including **ethnic minorities** and **women**. For example, ethnic minority groups can also suffer higher levels of cardiovascular disease, coronary heart disease and diabetes, and consequently an increased uptake of active travel could lead to even greater social and economic benefits than for the population at large (Transport for London, 2011).

Safety aspects of active travel, cycling in particular, also need to be taken into consideration. Statistics from DfT indicate that there is a **gender disparity** in cycling accidents, indicating that women might be more likely to experience accidents with

HGVs and buses, potentially due to differences in biking patterns and speeds (Transport for London, 2011). Research indicates there might be a gender discrepancy in road fatalities, with women in London up to twice as likely to be killed in collisions involving HGVs (>3.5 tonnes) compared to men despite lower cycling levels (Woodcock et al., 2014).

While women have a higher propensity to walk, they are underrepresented in the number of cyclists in Scotland (Sustrans, 2016). A study by Sustrans identified the following factors as barriers to uptake of cycling for women: not feeling safe, age, lack of fitness and concerns around appearance. 67 % of women identified cycle lanes separated from traffic as the primary measure to increase their cycling, and 21% wanted reduced speed limits for road vehicles (Henry, 2013).

Action has been taken across the UK to consider the role of biological sex and gender identity with regards to cycle uptake and use. One such example includes the 'Beryl's Night' initiative by the Oxford-based Broken Spoke bicycle co-op, providing a space for women and trans people to fix, teach, socialise and learn about bikes and to participate in the wider cycling community (Broken Spoke, 2016).

Active travel such as cycling among the older population can influence health co-benefits and social benefits related to independence and wellbeing by providing a means of engaging with the outdoor environment for relaxation and recreation. Cycling accounts for only 1% of all journeys among those aged 65 and older in the UK, compared to 23% in the Netherlands, 15% in Denmark, and 9% in Germany. CycleBOOM (which ran between 2013 – 2016) was aimed at understanding cycling among the older population and how this affects independence, health and wellbeing in order to advise practitioners and policy makers on how the environment and technologies can be designed to assist people to reconnect with cycling and continue cycling in older age (Black and Street, 2014, Cycle-BOOM, 2016).

Taking forward opportunities and overcoming barriers will involve a greater understanding of behaviour change (Smith et al., 2016) including challenges to sustained change in behaviours (Uttley and Lovelace, 2016) and cultural factors (e.g. Aldred and Jungnickel, 2014) ensuring that existing interventions are inclusive as possible. In the Scottish context recent research in Glasgow (Clark and Curl, 2016) highlights the potential opportunities for broadening of bicycle hire schemes to ensure inclusivity and uptake by a broader demographic (who may receive greater health benefits) reflecting that the current cycle hire schemes tend to be in areas where there is already a high proportion of people cycling to work. There is emerging research funded by Public Health England on opportunities and barriers for functional walking for disabled people (Living Streets, 2016) and research on the role that electric bikes can play in facilitating active travel in harder to reach groups, (e.g. Cairns et al., 2015).

4.2 Public transport

4.2.1 Overview

Public transport can potentially offer large co-benefits from reductions in congestion and noise. This shift can include moves from car to bus and rail and from road to rail freight. The level of these benefits will depend, however, on the extent of modal shift from existing car and road fleet users. In terms of the academic literature the focus, especially with regard to congestion reduction benefits tends to be on fixed infrastructure related projects typically light or heavy rail. For the latter, the impact of new schemes such as the impact of Manchester Metrolink scheme (e.g. Senior, 2009) dominates the literature. Bus transport can, however, be included in a mixture of measures, e.g. in relation to improvements associated with the UK Sustainable Travel Towns (Sloman et al., 2010) and Smarter Choices Smarter Places Scotland (Halden et al., 2013).

Modal shift to public transport can be seen as an integrated package of measures including walk and cycle modes. Walking and cycling will be used, for example, to access bus stops and rail stations. The potential for savings is considerable for example, in the Sloman et al. (2010) evaluation of the three UK sustainable travel towns car driver trips by residents fell by 9% per person, while in the Smarter Choices Smarter Places Scotland research statistically significant decreases in the proportion of trips made as a car driver were observed in Barrhead, Dumfries, Kirkintilloch/Lenzie and Larbert/Stenhousemuir, with reduction ranging from 19.4 percentage points to 1.6 percentage points in Glasgow East End (Halden et al., 2013). Furthermore, there is a broad existing literature highlighting the importance of ‘locking in’ the benefits of modal shift through for example road space reallocation (e.g. Cairns et al., 2004; Sloman et al; 2010; Skinner et al., 2011). For active travel, public transport, and demand management the suggested savings in congestion reduction are estimated to be £8.4 billion per year for the UK as a whole in 2030 (Smith et al., 2015).

Public transport and car clubs can also offer employment and broader well-being benefits. These benefits are considered further in the section on equalities.

The wider implications of modal shift from plane to train currently receives limited consideration in the literature, and in the Scottish context will predominantly apply to domestic travel. Drawing from the wider evidence relating to the use and value of time, working time availability on trains may be of benefit (e.g. Lyons et al., 2008) and warrants further investigation. The broader literature suggests the potential for there to be induced travel (D’Alfonso et al., 2016) whereby there is generated demand following improvements (e.g. improved capacity, speed, comfort and frequency) (Givoni and Dobruszkes, 2013) and this would need to be taken into consideration in any evaluation.

4.2.2 Quantitative approaches

As with modal shift to walking and cycling the potential for reductions in congestion, noise, and air quality pollutants is linked to the potential for a modal shift from the car to these modes. Reflecting the overlap here across the climate change mitigation options this is addressed in Chapter 7. WebTAG provides data on the potential for modal shift from car to rail – Table 1 in Tag Unit A5.4 (Marginal External Costs). Data on shifts from car to bus is captured in a certain extent in guidance on Modelling Smarter Choices (TAG Unit M5.2) e.g. in relation to new conventional bus which serve the workplace.

4.2.3 Equalities

Public transport is the main transport alternative to car use, with the 2011 Scottish Census indicating that 52% of non-car users commute (to work and study) by public transport modes, followed by active transport at 42% (Scotland's Census, 2011). Public transport offers a number of opportunities from an equalities perspective. Scotland's concessionary fare scheme (e.g. Hupert and Galilee, 2015; Rye and Mykura, 2009) is identified as helping reduce social exclusion. This scheme provides free or subsidised travel on buses for those aged over 60 or who have a disability (Transport Scotland, 2016). While innovative shared transport schemes (e.g. Wright et al., 2009) in rural Highland Scotland offers opportunities in terms of providing access to employment and training in areas which are harder to reach by conventional schemes.

In terms of achieving the broader benefits of public transport, steps need to be taken to ensure that existing barriers are addressed. For example, disabled people can face barriers when using public transport, these can be physical (such as a lack of accessible vehicles), attitudinal (a lack of knowledge among transport staff) and economical (reflecting potential lower incomes) (Rees, 2016). On average, the number of trips made by those with mobility disabilities is significantly fewer than those without and this gap grows as people get older (DfT, 2012). As Rye and Mykura (2009) note, while concessionary fares reduce cost, other significant barriers to socially inclusive public transport exist. These barriers include the need for suitable facilities such as benches and bus stop shelters, as well as real and perceived safety concerns (Mackett et al., 2008; The Coalition for Racial Equality and Rights, 2008a; Yavuz and Welch, 2010). The lack of awareness and knowledge of the needs of disabled people is also harder to change (Rees, 2016).

For women **personal safety** can be a barrier, and they tend to self-limit their activities and movement to a larger degree than men due to such perceptions and actual risk (GenderSTE, 2016). Public transport can also serve as the scene for discrimination based on gender identity and sexual orientation. The Diversity Trust (2014) found that 36 % of surveyed respondents had been discriminated against at some point, with 32% of incidents taking place on public transport.

Overcoming barriers to increased use of public transportation and reducing perceived as well as real threats are an essential part of reducing transport inequality and subsequent mitigation of greenhouse gases (Andrich et al., 2013; Hargreaves et al., 2013; Yavuz and Welch, 2010). Here policy makers need to understand the key disadvantaged groups and their travel needs, with engagement with groups essential in the design and implementation of policy (Skinner et al., 2011).

5 Reduce the need to travel

Transport options to reduce the need to travel can include: land use planning resulting in shorter distances travelled or making modal shift more plausible, and the use of teleworking to reduce trips made. Demand reduction can also include the use of fiscal measures for example parking or congestion charges to reduce demand and encourage the use of more sustainable modes.

5.1 Land use planning

5.1.1 Overview

Well planned cities can reduce the need to travel and facilitate the use of active travel and public transport modes (Rode et al., 2014). The proposition is that higher density cities result in shorter travel distances meaning that travelling by walking, cycling and public transport becomes more attractive (Karathodorou et al., 2010). In the Scottish context research by Waygood and Susilo (2015) identifies that living within “reasonable walking distance” to a school was a key explanatory variable for children commuting through walking, with attention to the development of urban areas identified as a need. There are clear synergies therefore with the co-benefits arising from the use of public transport (see Chapter 4). In terms of broader thinking with regard to co-benefits, one challenge with potential urban sprawl and reliance on private vehicle use is ‘community severance’, this severance can encompass three key themes (Bradbury, Tomlinson and Millington, 2007): physical barriers, e.g. a busy road limiting interaction; psychological challenges e.g. related to traffic noise; and longer term consequences relating to isolation and barriers. Those who are already disadvantaged may be most vulnerable to this severance. There is comparatively limited quantification and consideration of these outcomes within a co-benefits framework.

5.1.2 Quantitative approaches

The impacts of land use planning can be captured in a number of ways. At a broad, overview level, the Transport Model for Scotland and the Transport and Economic Land-use Model of Scotland allow the capture of aspects related to land use planning and associated transport demand related aspects e.g. the potential for increased use of public transport and increased levels of walking and cycling. However, further analysis would then be required to capture wider impacts of this. Here, existing key quantitative approaches of relevance are covered in Chapter 7

5.1.3 Equalities

Land use planning which facilitates the increased viability of public transport and walking and cycling as modes contributes to the equality agenda as identified in Sections 4.1.3 and 4.2.3 One aspect of particular relevance is with regard to the role that the built environment can play in facilitating access to outdoor environments and the role that this can play in improving older people’s quality of life. Key research in this area includes the Inclusive Design for Getting Outdoors (I'DGO) consortium with outcomes considered further in the Evidence Review of Wider Impacts of Climate Change Mitigation - Built Environment research report, which accompanies this work. Similarly there is also the Place Standard Tool, developed by the Scottish Government in partnership with Architecture & Design Scotland and NHS Health Scotland. This tool allows the user to evaluate the quality of an area and identify their priorities, for example access to public transport, natural space or social interaction, with these aspects being key in facilitating well-being.

5.2 Teleworking

5.2.1 Overview

Teleworking involves the use of working from home for some or all of the time, where it is appropriate for the job. Teleworking can have potential benefits for **organisations** for example:

- Reductions in their property portfolio (since less desks are required). For example, BT – a long time user of teleworking - have reduced their portfolio by 40% since introduction in 2005. This has allowed a reduction in rental costs and utility bills (Scottish Government, 2013b).
- Recruitment of broader, potentially higher skilled, range of staff.
- Increase in staff productivity. For example, BT reported a 30% increase in productivity and a 20% reduction in absenteeism from implementing teleworking (Scottish Government, 2013b).

Benefits to **employees** can include:

- Flexible hours and potential for work-life balance
- Reductions in travel costs and commute time savings.

Potential adverse side effects, however, can also be identified: for example, for employees with regard to the setting of appropriate work-life boundaries. In addition, it is possible that heating and lighting costs may increase if they are less efficiently provided in the home than in an office serving many people.

For the majority of teleworking high speed **broadband** access will be key. Here potential challenges exist in terms of a Scottish rural urban divide with respect to internet access (e.g. Philip et al., 2015). This is discussed further with respect to equalities below.

5.2.2 Equalities

Digital exclusion refers to those where '… a discrete sector of the population suffers significant and possibly indefinite lags in its adoption of ICT through circumstances beyond its immediate control' (Warren, 2007, p 375). In the Scottish context, there are distinct differences in the average and maximum sync speeds between urban, accessible rural and remote rural areas of Scotland (e.g. Philip et al., 2015). These speeds are identified as being to the benefit of urban inhabitants but can limit the participants of rural residents and business to benefit from ICT. In terms of accessibility steps to reduce this exclusion are required. In terms of determinants for uptake – income levels play a role – with uptake by higher incomes more likely (e.g. Popuri and Bhat, 2003), thus these opportunities may be less available to those in lower income roles.

5.3 Demand management

Demand reduction includes the use of fiscal measures for example parking or congestion charges to reduce demand and encourage the use of more sustainable modes, including the adoption of lower emission vehicles.

5.3.1 Overview

As with modal shift from car, the benefits of demand management are linked to reductions in car use, with benefits including air quality improvements and noise reduction. The availability and cost of parking is one of the key factors influencing car use (Tsamboulas, 2001). Mechanisms include limits on the number of parking spaces and other parking restrictions. Parking fees can act as a significant deterrent to car use with an increase in the price resulting in a decrease in car use.

Urban congestion charging has been introduced to manage traffic, with key European examples including London and Stockholm. In Stockholm traffic levels have reduced by 22% and this has resulted in a reduction in congestion (travel time) of 30–50 %, with emissions decreasing by 12–14% within the central charging zone (JEG, 2010). In London, the congestion charge zone resulted in traffic levels being reduced by 15 % (JEG, 2010). This has synergies with public transport for example, there was an increase of 37 % in the number of bus passengers entering the congestion charge zone in London, in the first year of introduction of the scheme, with half linked to the introduction of the zone (TfL, 2004).

The role of up-front incentives, for example, exemption from congestion charging and parking charges in taking forward lower carbon vehicle ownership is also well established (Gallagher and Muehlegger, 2008; Ozaki and Sevastyanova, 2011). Exemption from congestion charging has played a key role in the take-up of hybrid vehicles in London (Ozaki and Sevastyanova, 2011) and in Stockholm, where clean vehicles as a proportion of vehicles entering the charging zone increased from 3% in 2006 to 14% in 2009, decreasing to 10% in 2011 reflecting the removal of the exemption in 2008 (Börjesson et al., 2012).

5.3.2 Equalities

Policies such as congestion charging and parking charges could be considered to be potentially progressive, as higher income groups own and use cars more than those on low incomes (Skinner et al., 2011). Care is required, however, since potentially the most adversely affected groups will be low income groups who need to use a car to access the affected zones for example, for employment purposes. Ways to reduce potential negative impacts, include additional funding for alternative transport modes (e.g. buses) and infrastructure (walk and cycle) which would be used by the most vulnerable (Skinner et al., 2011). Revenue from the congestion charge could be hypothecated for these measures, as occurred when the charge was first introduced in London.

6 Improve transport efficiencies

6.1 Lower carbon vehicles and fuels

6.1.1 Overview

The use of **lower carbon fuels** and vehicles can offer **energy security** and **air quality** benefits (e.g. Smith et al., 2016). The air quality benefits will, however, depend on the fuels used, with the use of diesel (for carbon reduction) potentially having adverse impacts on air quality. For **electric vehicles** there is the potential for substantial **local air quality** benefits (especially in cities e.g. Jochem et al, 2016) reflecting that transport is a major source of air quality emissions. The air quality benefits of electric vehicles can be reduced by emissions produced during electricity generation (e.g. Buekers et al., 2014) and so these benefits can be influenced by the power generation mix and the number of people exposed to pollution from the power plants. The need for further research on the potential adverse side effects on land and water from mining and manufacturing processes required for electric vehicle materials is identified in the SPLiCE (2016) work. In terms of economic benefits Wells (2012) identifies the potential for wealth and employment related impacts. There is limited consideration within the co-benefits literature of the impacts of an electrification of the rail network – anticipated benefits could include reductions in air quality pollutant and journey time savings.

For **biofuels,** there is a range of potential adverse side effects on land use (direct and indirect changes), biodiversity, food security, health, water use and water quality (e.g. Renewable Fuels Agency, 2008) which depend strongly on the biofuel feedstock, with second generation biofuels (e.g. waste or woody material) generally being far less damaging than those from food crops (such as maize, soy and sugar beet). These impacts need to be factored in and mitigated, for example through the enforcement of strict sustainability criteria (e.g. Smith et al., 2016). Rushton et al. (2014) provides a good synthesis of key issues for UK produced and imported crops. The potential for benefits, for example, in terms of employment opportunities and rural development is also identified. The study suggests that there is limited evidence on these social impacts for waste products. However, recent work by the ICCT (2015) highlights that the use of wastes (and residues) could offer economic benefits including additional jobs. In the Scottish context Celtic Renewables, based in Edinburgh, have received £11 million to develop a new plant to make biofuels from whisky by-products with a further 3 plants planned[4].

Noise pollution from transport vehicles can have a broad range of negative health impacts including disturbed sleep patterns, reduced cognitive function, raised blood

[4] https://www.gov.uk/government/news/winners-from-25-million-prize-to-develop-greener-fuel-technology-announced

pressure, stress, and cardiovascular disease (Boer and Schroten, 2007; WHO, 2011). Electric and hybrid vehicles offer the potential for noise reduction especially in urban areas (Jabben, 2012). Here, it is important to note that tyre noise and the vehicle itself dominates the noise profile at over 25 mph (Jochem et al., 2016). Any potential for noise reduction also need to be seen in the context of broader reductions in noise limit values and the associated reduction in vehicle noise (EC, 2014) and safety concerns related to people not hearing the vehicles (e.g. Czuka, 2014; Altinsoy, 2013), especially when driving speeds are lower and where there is background noise (highly relevant in the urban context). Reflecting this, the European Commission (EC, 2014) has confirmed that electric and hybrid vehicles are to be fitted with sound generating devices. In any modelling of noise-reduction benefits, the impact of these sound generating devices would need to be taken into consideration.

6.1.2 Quantitative approaches

There is an emerging literature and publically available datasets which will assist in the **quantification** of the **co-benefits** associated with moves towards lower carbon vehicles and fuels. For **air quality**, quantification can occur at a detailed, local level (for example through air quality models) or at a higher, overview level. For the latter, which is typically more appropriate for the appraisal of broader policies the quantification needs to capture 1) potential reductions in the level of pollutants emitted and 2) the cost of the pollutants.

To capture potential reductions in pollutants Defra and the Devolved Administrations publish the Emissions Factor Toolkit which allows users to calculate road vehicle pollutant emission rates for air quality pollutants - NO_x, PM_{10}, $PM_{2.5}$ (and CO_2) for a specified year, road type, vehicle speed and vehicle fleet composition (Defra, 2016). The current version of the tool was updated in August, 2016 and includes Emission Factors for lower carbon vehicles (alternatively fuelled vehicles). For the cost of pollutants Defra provide detailed guidance on Economic Analysis and Air Quality (Defra, 2015). In terms of **modelling approaches**, there are currently limited, publicly available models.

For **noise** co-benefits again there is a need to capture the level of potential noise reductions. Again there is a need to understand the level of noise saving from the use of electric vehicles. Here there is an emerging literature on **noise savings** which takes into account vehicle speeds and tyre noise (e.g. Pallas et al., 2016). These noise savings would then need to be placed into the context of monetary values. Here it is useful to note the differences between STAG and Web-TAG with regard to the treatment of noise including monetisation (discussed further in Chapter 7.1.1

6.1.3 Equalities

Social distributional impacts of electric vehicles are a research priority (SPLiCE, 2016): while there is a limited consideration in the co-benefits literature, evaluation is increasing elsewhere (e.g. Skinner et al., 2011; Lucas and Pangbourne, 2014; Wells, 2012). For example, Wells (2012) highlights the exclusion of disadvantaged groups from electric mobility. Car clubs could offer the opportunity for broader range of socio-economic groups to access this mobility though further evidence is required to better understand this potential. The requirement for better understanding of access to opportunities e.g. the skill sets required for electric vehicle production is also identified (SPLiCE, 2016) and within this there may be equity considerations.

One particular aspect of relevance is the need to take into account the current **spatial distribution** of **air quality impacts.** There are clear links between socially deprived neighbourhoods and exposure to higher levels of air pollution (Namdeo and Stringer, 2008; King and Healy, 2013). Since lower emission vehicles such as hybrid vehicles and electric vehicles can offer GHG emission reduction and air quality benefits there are opportunities that warrant further exploration. For example, the geographic positioning of demonstration schemes and grants could also target lower income households helping ensure the social and distributional benefits of policies (Skerlos and Winebrake, 2010).

6.2 Network efficiencies

Improvements in **network efficiencies** include the use of **average speed cameras, intelligent transport systems** and **fuel efficient driving**. These are considered in turn below. Reflecting the relatively limited information available, qualitative, quantitative and equalities perspectives are considered together.

6.2.1 Average speed cameras

Soole et al. (2013) in a wide ranging review of the literature draw on a number of **benefits**. These benefits include:

- **Road safety benefits** including reductions in crash rates. These reductions are, in particular, in relation to fatal and serious injury crashes, with a **decreasing trend** of the **magnitude of 33% to 85**%.
- **Improvements in traffic flow** due to reductions in speed variability.
- Favourable **cost-benefit ratios** are suggested though there was less evidence and less analysis for this.

A **high level of compliance** was noted reflecting a corresponding level of **public acceptance**, reflecting the perceived fairness of the approach.

Equalities perspectives were not identified in the literature. Road accidents can be more likely to impact on vulnerable socio-economic groups e.g. those in areas of higher deprivation (Jones et al., 2008), and this is, therefore, an area worth further consideration.

6.2.2 Intelligent transport systems

Intelligent transport systems include Active Traffic Management (ATM), Intelligent Speed Adaptation (ISA) and the Automated Highway Systems (AHS). There is limited literature on wider benefits. However, all three are evaluated in a study by Kolosz and Grant-Muller (2015) which identifies, in addition to fuel and vehicle emission savings, the potential for **accident savings** across all three options. In terms of cost benefit ratios only ATM had favourable levels: these were around 5.89 in the shorter term, but decreased over time reflecting assumptions with regard to increased energy cost.

6.2.3 Fuel efficient driving

Fuel efficient (eco-driving) driving facilitated through training can benefit private and fleet drivers. These benefits typically involve fuel cost savings (Zarkadoula et al., 2007; Barkenbus, 2010; Sivak and Schoettle, 2012). However, these could be reduced through the rebound effect. Literature exists which suggests that there are potential reductions in accident risk (e.g. SenterNovem, 2005; Cristea et al., 2012). However, others (e.g. Saniul Alam and McNabola, 2014) suggest that if eco-driving occurs at the individual rather than group level then this ‘unusual’ driving behaviour can affect other drivers and in turn alter their behaviour e.g. due to annoyance increased over-taking could occur (Ando and Nishihori, 2011). Thus, the evidence here could be considered potentially inconsistent at this stage. Furthermore, the use of driver assistance could increase the accident risk (e.g. Saniul Alam and McNabola, 2014).

Lucas and Pangbourne (2014) consider the equity impacts of fuel efficient driving highlighting that benefits would typically accrue to those that already owned cars (therefore not typically considered a more vulnerable group). There is however the potential, if the fuel savings result in air quality benefits, for there to be broader distributional benefits.

7 Quantification of air quality, noise and congestion

7.1.1 Quantitative approaches

For a number of the options, the benefits in terms of congestion, air quality and noise reduction relate to modal shift from the car and other private transport modes. In terms of guidance Web-TAG and STAG provide information relating to impacts on air quality and noise, a summary of which is provided below.

For **air quality** an understanding of the impact in terms of:

- Changes in passenger car unit/vehicle kilometres travelled by mode by study area
- Changes in speed by mode by study area
- Emission factors (in the context of the above)

is required, with a comparable approach used for Web-TAG (Marginal External Costs) guidance and Scottish Transport Appraisal Guidance (STAG) (Technical database Section 7.43.). STAG suggests the use, where possible, of changes in the level of population exposed to the pollutants. Here the use of an emissions exposure estimate is suggested with reference to emissions and the population per zone. Associated spreadsheets for this analysis are provided. In terms of the economic valuation STAG highlights that air quality impacts should be calculated using a hybrid approach. This combines damage cost and marginal abatement cost (MAC) methodologies.

For **noise** STAG highlights that the approach taken is different from that employed by WebTAG, with the DfT having recently published new guidance on noise, including monetisation. At the strategic level STAG suggests a qualitative treatment and a broad range of data sources relevant to the Scottish context are identified, including the use of land-use maps - location of areas which are particularly sensitive to noise e.g. schools and hospitals. At the project level, the emphasis is placed on the outcomes of the use of spatially detailed transport models which will allow an in-depth understanding of transport flows. WebTAG guidance focuses on the use of spatially detailed models. The importance of estimations of the affected population and monetary values are made with reference to Defra guidance, modelling tools and research (Defra, 2014).

For **congestion,** reference is made in WebTAG but not STAG. For example, congestion is covered in A5.3 rail appraisal and A5.4 Marginal external costs.

In terms of models, there is comparatively limited number of models in the public domain. Recent relevant examples do, however, include the **Urban Transport Roadmaps scenario tool** (European Commission, 2016). The tool allows the development and assessment of a number of sustainable transport scenarios. Including the introduction of **modal shift measures** - bike sharing, walk and cycle infrastructure, bus and tram network and the prioritisation of public transport and **demand management measures -** congestion charging and parking charges. Output of relevance includes associated reductions in air quality pollutants and road accidents. The **Defra model – Assessing the Wider Impacts of Air Quality Policies** captures outcomes associated with changes in vehicle kilometres including (Green et al., 2015):

- Congestion
- Safety
- Noise

While the model references Air Quality Policies the focus on outcomes associated with changes in vehicle kilometres means that it is applicable in this carbon mitigation context. The user can select where changes take place i.e. Scotland can be selected. The model follows the same principles outlined above in that inputs relate to changes in vehicle km driven. The model draws heavily from the DfT's Marginal Economic Costs including its approach for monetisation of noise. Thus consideration needs to be given to how this would fit with STAG's current approach.

8 Recommendations

This evidence review found a large literature demonstrating that the co-benefits of climate change mitigation action in the transport sector could be substantial. In determining policy, consideration needs to be given to the scale of carbon reduction offered relative to the potential for additional benefits.

Significant research gaps under the shift, reduce and improve framework are detailed below.

Shift to more sustainable modes

- Where co-benefits are established, i.e. with regard to the physical activity associated with active travel, there is need to understand how these benefits can be socially and equitably distributed. There are opportunities here to build on existing Scottish research to better understand how harder to reach groups can be accessed, this includes real world practice and engagement with users.
- The full extent of these health benefits in the Scottish context needs to be better understood. For example, capturing impacts as they relate to years of life lost and years of life living with a disability. Here, links with the proposed updates to WebTAG guidance could be considered.
- Synthesis of existing evidence on the potential for car vehicle kilometre reduction to inform the potential for congestion, noise and air pollutant reduction is necessary. The outcomes of this synthesis can be used to better understand research gaps and identify further data collection requirements.
- The wider implications of modal shift from plane to train currently receives limited consideration in the literature. Drawing from the wider evidence relating to the use and value of time, working time availability on trains may be of benefit and warrants further investigation. The broader literature suggests the potential for there to be induced travel (e.g, due to increased comfort) and further research is required here.

Reduce the need to travel

- The role and extent to which demand management can facilitate take up of walk, cycle and public transport modes could be considered further, with options in the Scottish context evaluated alongside modal shift interventions. This may be particularly relevant to understand the steps required to lock in modal shift benefits, preventing erosion through induced traffic.
- A more detailed understanding of teleworking opportunities and means to overcome barriers especially in the Scottish rural context is required.

Improve transport efficiencies

- For lower carbon vehicles, where there is an indication of benefits e.g. with regard to air quality, the required uptake, including spatial distribution, of these vehicles (to achieve the benefits) needs to be fully understood in the Scottish context. This could for example result in their introduction in vehicles which are in higher use – e.g. taxis or fleet vehicles or in more socially disadvantaged areas (where there tend to be higher levels of air quality pollution).

- Understand the role that car clubs could play in facilitating access to newer technologies to a broader range of socio-economic groups than private ownership would allow.
- For network efficiencies, further consideration of the equalities aspects is potentially required.

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