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Key household behaviours impacting on outdoor air quality: An evidence review

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Key household behaviours impacting on outdoor air quality: An evidence review

Final report - November 2023

Report commissioned for the Scottish Government by The James Hutton Institution

Kathryn Colley, Jianyu Chen, Phoebe Somervail, Andrea Britton and David Miller

The James Hutton Institute

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Contacts
Dr Kathryn Colley (Kathryn.Colley@hutton.ac.uk)
Dr Jianyu Chen (Jianyu.Chen@hutton.ac.uk)
Phoebe Somervail (Phoebe.Somervail@hutton.ac.uk)
Dr Andrea Britton (Andrea.Britton@hutton.ac.uk)
Prof. David Miller (David.Miller@hutton.ac.uk)

Executive Summary

Introduction

The Scottish Government's Cleaner Air for Scotland 2[1] air quality strategy sets out an integrated framework for air quality improvement in Scotland. In the strategy, public engagement with air quality issues and behavioural changes across society are recognised to play an important part in future progress in this area. This report provides evidence on behavioural aspects of air quality issues, drawing on a rapid review of academic and grey literature, to help to inform future public engagement on air quality improvement.

The primary objective of the review was to identify the behaviours that have the most impact on improving air quality, discussed here as 'key behaviours'. The review also sought to identify factors influencing the uptake of the key behaviours. In doing so, we adopted the COM-B (Capabilities-Opportunity-Motivations-Behaviour) behaviour change model as a framework to classify factors influencing the key behaviours. This framework considers factors internal to the individual (individuals' Capabilities and Motivations) as well as those external to the individual which influence their Opportunity to act.

Key findings

The review highlighted that, of the large body of literature on air quality issues, very little frames air quality specifically in behavioural terms. We found no review papers evaluating the relative impacts of different behaviours across the spectrum of behaviours relevant to air quality. The review also highlighted the challenges in quantifying and comparing the impacts of different behaviours. As a result, we were not able to draw direct conclusions about the relative impact of different behaviours that would allow us to rank behaviours in order of importance. However, we were able to synthesise a set of eight behaviours – six key behaviours for air quality improvement, plus two additional behaviours. These two additional behaviours are those which the evidence suggests can impact on air quality but where the evidence base is less well developed or less persuasive in terms of impacts on air quality specifically. These key behaviours are shown in Table 1, with factors influencing each of the behaviours summarised in Table 2. Several of these behaviours align closely to those recommended in Transport Scotland's route map to reduce car use[2].

The report also highlights other messages for policymakers in relation to behaviour change for air quality improvement:

- Public engagement strategies should be sensitive to the potential trade-offs between behavioural specificity and simplicity of messaging. High-level behaviours (such as reducing car use) convey simple messages for public communications, while focusing on more specific behaviours may be necessary when designing interventions.

[1] Scottish Government Cleaner Air for Scotland 2 Strategy
[2] Transport Scotland route map to achieve 20% reduction in car kms by 2030

- The framing of behaviour change in relation to air quality should take care to avoid transferring responsibility for change onto the individual. Public engagement strategies should acknowledge the role of actors across society in facilitating behaviour change.
- Public engagement through communication strategies is only one part of an integrated approach to behaviour change. Approaches are most likely to be successful where communications are supported by other interventions to create the social, environmental and economic conditions conducive to behaviour change.

Table 1: Key behaviours for air quality improvement

Six key behaviours for air quality improvement	
Reducing car use	Walking, cycling or wheeling for short journeys
	Using public transport instead of driving
	Working flexibly or from home
Switching vehicle	Switching to an electric vehicle
Heating the home differently	Burning less at home
	Ensuring good practice when burning fuel (including use of efficient appliances)
Additional behaviours to consider	
Reducing car use	Using local shops and services
Driving differently	Using eco-driving techniques (including stopping engine when stationary)

Table 2: Capability, Opportunity and Motivation (COM) factors influencing behaviours. Only factors highlighted in the literature review are shown; it is likely there are additional factors also apply

Behaviours	Capability factors	Opportunity factors	Motivation factors
Key behaviours			
Walking, cycling or wheeling for short journeys	• Physical abilities and mobility constraints • Cycling skills • Confidence in abilities	• Cycling infrastructure • Walkable environments • Access to equipment • Social networks	• Safety concerns • Weather conditions • Perceived (in)convenience • Habits
Using public transport instead of driving	• Knowledge about public transport • Confidence in using public transport	• Public transport networks • Social norms • Cost	• Perceptions and experience of public transport • Habits
Working flexibly or from home		• Job type • Systemic support • Digital infrastructure • Post-pandemic remote working norms • Home environment constraints	• Individual benefits from flexible/remote working • Social connectedness
Switching to an electric vehicle	• Knowledge about range	• Cost • Charging infrastructure • Social norms	• Environmental concerns • Fuel saving

Burning less at home	• Lack of knowledge of impacts	• Access to cleaner energy • Policy and regulatory environment	• Cost of switching energy source • Environmental motivations • Comfort and aesthetics
Ensuring good practice when burning fuel	• Knowledge of good practice	• Costs	• Effort
Additional behaviours			
Using local shops and services		• Suitable local infrastructure and amenities • Cost	• Quality and range of offering • Habit
Using eco-driving techniques (including stopping engine when stationary)	• Eco-driving skills •	• Institutional support	• Fuel saving • Safety • Travel time • Driving habits

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1 Introduction

1.1 Context

Poor air quality is recognised to be a major threat to public health. It is responsible for premature death, increased prevalence of respiratory and cardiovascular diseases, as well as other health impacts such as increased risk of poor mental health and adverse pregnancy outcomes (Annesi-Maesano, 2017; Health and Environment Working Group, 2019; Roberts et al., 2023). Beyond the serious health impacts that result in deaths and hospitalizations from respiratory and other health impacts of air pollution, there is an underestimation of the social and economic impacts of air pollution on labour productivity and human capital resulting from lower-level health impacts (Zivin & Neidell, 2018).

In 2021, the Scottish Government launched the Cleaner Air for Scotland 2 (CAFS2) air quality strategy. The Strategy provides a framework for air quality improvement that brings together relevant policy areas including transport, climate change, planning, health and energy. CAFS2 recognises that whilst there have been significant improvements in air quality over the last 50 years, progress on reducing pollutant emissions is slowing. There may be opportunity for interventions focused on behaviour change to support future improvements in air quality. Such interventions should be sensitive to the complex factors influencing behaviours impacting on air quality.

To support the development of CAFS2 a literature review assessing public attitudes and behaviour relating to air pollution was commissioned by the Scottish Government. The review offered insights from the literature on promising approaches to public engagement, as well as identifying existing examples of air quality public engagement in Scotland (Barnes et al., 2020). Whilst identifying components of behaviour change theory of relevance to promoting behaviours supporting air quality improvements, the objectives of the review did not include an assessment of the specific behaviours which should be targeted through public engagement.

A recent baseline survey of the Scottish population, conducted to support monitoring of CAFS2, highlighted that public concern about air pollution is high – 79% report concern (BMG Research, 2023). Whilst 42% of the public believe they can do things to make their daily activities less harmful to air quality, compared to 33% who do not, respondents tended to perceive that it is primarily the private sector and government that can make a significant impact on improving air quality (BMG Research, 2023). This is also reflected in the priority given to different options for addressing air quality in Scotland, with only 56% prioritising actions to address emissions from private vehicle use, compared to 62% prioritising emissions from commercial vehicles and buses and 69% prioritising emissions from industry (BMG Research, 2023).

1.2 Aim and objectives

The aim of this report is to provide evidence on the key behaviours that impact on air quality to inform future public engagement on the issue. The report focuses on the actions of households and the general public (rather than business and industry), and on behaviours impacting on outdoor (rather than indoor) air quality. In line with the focus on households and the public, the pollutants of key interest for the report are nitrogen dioxide (NO_2) and particulate matter (PM2.5 and PM10[3]), although other pollutants subject to air quality standards and objectives[4] may also be relevant.

The objectives of the research were to:

- Undertake an evidence review, building on the 2020 review, with a particular focus on **identifying behaviours which have the most impact on improving air quality**, together with associated motivations and barriers; and
- **Assess these behaviours within a relevant model or framework** to provide a direction for policy consideration of next steps on public engagement.

The following sections outline the approach adopted for the review and the analytical framework used as a lens for assessing the key behaviours and highlighting opportunities for future intervention.

2 Approach

2.1 Review method

A rapid review of the available evidence was undertaken, using a pragmatic approach to identifying and synthesising relevant academic and grey literature within the time and budgetary constraints of the project. Given the broad nature of the research objectives and the anticipated availability of existing literature reviews on relevant topics such as transport mode choice (reducing the need for systematic evaluation of original studies), a traditional literature review approach was considered appropriate for the research. Elements of systematic review and Rapid Evidence Assessment methods have been incorporated where possible, such as reporting databases and organisational websites searched, standardising and reporting search terms used.

The review was undertaken in two phases:

- Phase 1: Broad search to identifying key behaviours and impacts

[3] PM2.5 refers to particles less than 2.5 micrometres in diameter; PM10 are those less than 10 micrometres.
[4] For Air Quality Standards and Objectives applying in Scotland see: https://www.scottishairquality.scot/air-quality/standards

- Phase 2: Behaviour-specific searches to fill gaps on impacts and factors influencing the key behaviours.

Further details on the methods used in the literature review are provided in Appendix A.

2.2 COM-B as a framework for understanding air quality related behaviours

In discussion with Scottish Government policymakers, the COM-B (Capabilities, Opportunities, Motivations – Behaviour) model was selected to provide a basis for the analysis of public behaviours impacting on air quality. The COM-B model of behaviour forms part of a broader framework for analysing and designing behaviour change interventions – the Behaviour Change Wheel (Figure 1). The COM-B component forms the 'behaviour system' (Michie et al., 2011) at the centre of the Behaviour Change Wheel. It sets out the broad conditions that are necessary for behaviour change to occur, and therefore provides a useful framework to help inform directions for future public engagement on air quality.

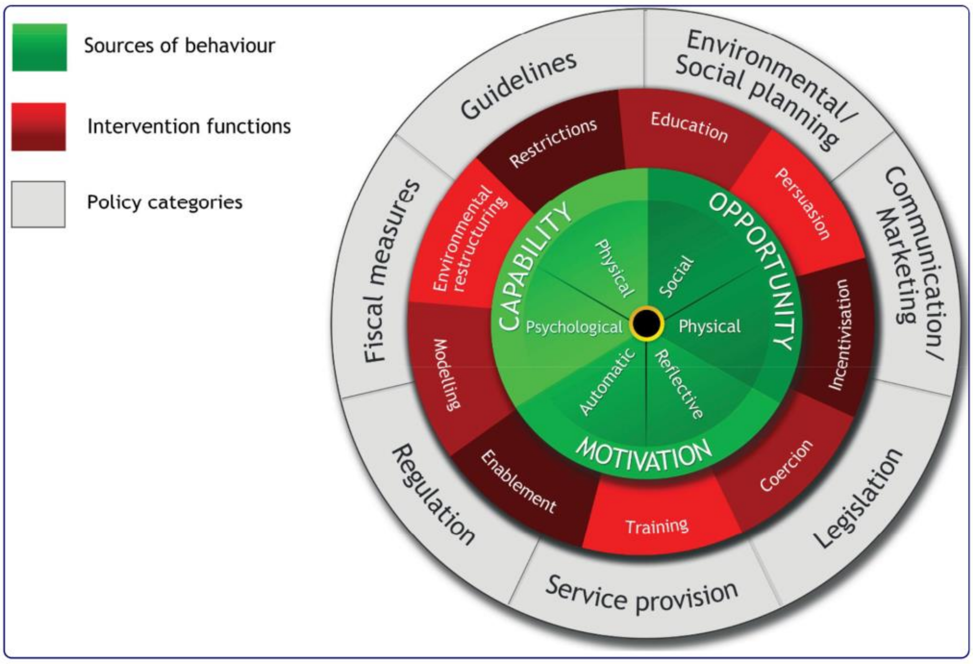

Figure 1. Behaviour Change Wheel (reproduced from Michie et al., 2011 under open licence CC by 2.0)

The COM-B model frames factors enabling or constraining behaviour change in terms of the individual's Capability, Opportunity and Motivation to engage in the behaviour in question (Figure 2, with definitions in Table 1). All three components are necessary to facilitate behaviour. Motivation has a direct influence on behaviour, but the extent to which motivation actually leads to behaviour depends on the individual's capability and the opportunity afforded by their physical and social environment.

The COM-B model is just one of a multitude of conceptual models that can be used to understand and analyse behaviour. The advantages of using the COM-B for this research are:

a) It provides a high-level interdisciplinary framework, compatible with analysis of drivers and barriers of behaviour from across academic disciplines.
b) It broadly encompasses the relevant determinants of behaviour, some of which (particularly context and automatic processes) tend to be lacking or inadequately represented in other widely used behavioural models.
c) As part of a wider framework for behaviour change intervention, analysis of COM determinants of behaviour can lay the foundation for the development of interventions and policies using the Behaviour Change Wheel.

In this report we use the COM-B framework to categorise the factors that drive or constrain behaviours impacting on air quality. For each of the key behaviours, the relevant factors highlighted in the literature reviewed are outlined in a table, classified according to whether they relate to Capability, Opportunity or Motivation. The COM-B framework is being used in behaviour change research in several areas of the RESAS Strategic Research Programme, including in relation to waste and the circular economy, and outdoor recreation behaviour[5].

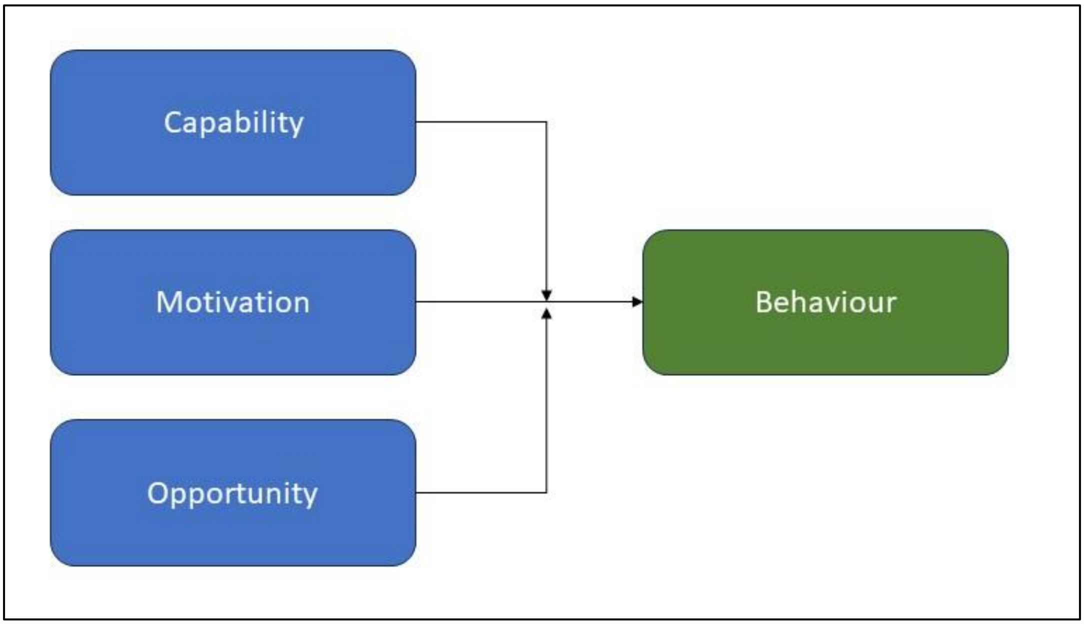

Figure 2: COM-B model of behaviour (Michie et al., 2011; West & Michie, 2020)

Table 1: Definitions of COM-B components (adapted from West & Michie, 2020)

Capability	Capability is an attribute of a person that together with opportunity makes a behaviour possible or facilitates it. Capability encompasses people's physical capabilities (e.g. physical abilities) and psychological capabilities (e.g. knowledge, memory).

[5] This research is part of Hutton work on the C4 (Circular Economy) and C6 (Use of the outdoors and greenspace) topics

Opportunity	Opportunity is an attribute of an environmental system that together with capability makes a behaviour possible or facilitates it. Opportunities can consist of physical opportunities (e.g. available infrastructure) and social opportunities (e.g. enabling social norms and social networks).
Motivation	Motivation relates to the mental processes that energise and direct behaviour. The Motivation component of the behaviour system encompasses reflective motivational processes (factors driving conscious intentions and planned behaviour) and automatic motivation (driven by emotions, habits or instincts).

3 Overview of key behaviours impacting on Scotland's air quality

3.1 Overview of key behaviours for air quality in Scotland

Our rapid evidence review highlighted that, although there is a large body of evidence on air quality issues and interventions, very little of this literature frames such issues explicitly in behavioural terms. Cowie et al. (2015) noted that no reviews of the impacts of behaviour change on air pollution existed at that time, and likewise we found no review papers specifically tackling the subject. Rather than asking questions about the contribution of householder behaviours to air quality, it is more common for research to be framed in terms of sources of emissions (usually at sectoral level) and the effectiveness of specific policies and interventions (which may contain a behavioural component). Riley et al. (2021) in a review of air quality communication campaigns classifies behaviours relating to air quality in terms of avoidance behaviours (avoiding exposure to poor air quality, such as by staying indoors), contributing behaviours (behaviours that impact on air quality), and civic engagement behaviours (such as engaging in discussions about air quality with family/friends, writing to an MP etc). In common with Riley et al. (2021), we found that the majority of literature taking a behavioural perspective on air quality primarily focuses on avoidance behaviours, with much less on the contributing behaviours that form the focus of this review.

Looking at the literature that does focus on contributing behaviours, our review highlighted a number of challenges to quantifying and comparing the impacts of different behaviours, both in terms of a) emissions of pollutants and b) impacts on ambient concentrations of pollutants. In terms of emissions, we found limited evidence on the individual-level emissions associated with specific behaviours. Part of this may be down to the variability of impacts associated with a given behaviour. For example, the emissions saved by avoiding a car journey will depend on the length of the journey, type of fuel used by the car, driving speed/type of roads, condition of traffic flows etc. (Keyvanfar et al., 2018; Pandian et al., 2009). The emissions saved will also depend on what replaces that journey – for example, if working from home instead of commuting results in extra emissions from heating the home. Impacts of behaviour change on air quality are likely to be even more variable due to the range of different factors influencing air quality (including spatial distribution of emissions, climate and geographical factors, vegetation, regional transport of pollutants etc.) (Jacob & Winner, 2009; Zhan et al., 2018). Due to the complexity of these impacts, studies using modelling techniques to estimate the impact of behaviour change were particularly useful sources of information for the review (e.g., Jamriska & Morawska, 2001). Before-after evaluations of policies or interventions that include a behaviour change element also provide useful evidence, however isolating impacts of behaviours of the public (as opposed to commercial activities and agricultural/industrial production) and establishing causality remains a challenge.

Given these challenges, the review did not find sufficient data to enable ranking of behaviours in terms of their impact. However, it was possible to identify a set of behaviours that are supported by sufficient evidence to be considered 'key behaviours'. We consider these behaviours under four broad behavioural categories (see

Table *2*). In addition to the six key behaviours identified, we also highlight two additional behaviours to consider. These additional behaviours are those which the evidence suggests can impact on air quality but where the evidence base is less well developed or less persuasive in terms of the magnitude of impacts on air quality specifically.

Table 2: Key behaviours impacting on air quality

Six key behaviours for air quality improvement	
Reducing car use	Walking, cycling or wheeling for short journeys
	Using public transport instead of driving
	Working flexibly or from home
Switching vehicle	Switching to an electric vehicle
Heating the home differently	Burning less at home
	Ensuring good practice when burning fuel (including use of efficient appliances)
Additional behaviours to consider	
Reducing car use	Using local shops and services
Driving differently	Using eco-driving techniques (including stopping engine when stationary)

When analysing the drivers and barriers to behaviours, it helps to be as specific as possible about what the behaviour is. In this sense, many of the key behaviours above could be broken down into a number of more specific behaviours. At the same time, when considering key behaviours as a focus for public engagement, is it important to distil clear and simple messages about what people can do to make an impact. Our categorisation of key behaviours in

Table *2* attempts to balance these competing priorities. The eight key behaviours identified also map broadly onto several of the behaviours explored in a recent survey on public engagement with air quality in Scotland (BMG Research, 2023), which gives some baseline data on the uptake of the key behaviours and perceptions about their impact on air quality.

In the following sections, we outline evidence on the air quality impacts associated with each of the four broad behavioural categories – reducing car use, switching vehicle, driving differently and heating the home differently. For each category, we go on to summarise the evidence on drivers and barriers to uptake of each of the identified behaviours associated with that category, using the COM-B framework. In proposing the set of key behaviours above we recognise that not all of the behaviours are possible for everyone. For example, many people will not be able to work from home, and some people in rural areas may rely on solid fuels to adequately heat their homes in winter. The COM-B analysis reflects these constraints.

3.2 Risks of framing air quality issues in terms of behaviour

Before discussing the evidence relating to the key behaviours outlined above, it is worth highlighting some important points for policymakers to consider when adopting a behavioural lens on air quality issues. Framing environmental protection and sustainability issues in terms of behaviour change is a subject of ongoing debate in the academic literature (Batel et al., 2016; Nash et al., 2017; Somerwill & Wehn, 2022). Whilst there is an increasing recognition of the need for environmental policy to incorporate understanding of the complex social and psychological factors underpinning environmentally (un)sustainable behaviour, critics argue that a focus on behaviour change deflects responsibility away from powerful institutions and on to individuals (Kaufman et al., 2021; Shove, 2010). Riley et al. (2021) note the risk of this perception in relation to public engagement work on air quality. It is important that research and policy focusing on behaviour change avoids placing emphasis solely on voluntary actions of individuals and interventions that focus on education and persuasion. To avoid this, it is useful to view behaviour change from a systems perspective – focusing not on convincing people to do something differently but asking what elements of the current system could be changed to provide supportive conditions for behaviour change. The COM-B framework, and the wider Behaviour Change Wheel, have potential to help combat misperceptions around behaviour change as a political objective, since together they highlight the importance of the structural conditions (including infrastructure, regulation, service provision) that underpin individuals' opportunity to change their behaviour. The Behaviour Change Wheel and COM-B can also help policymakers to identify the intended agents of change from across society (e.g. government, institutions, workplaces, schools, third sector) with responsibility for delivering behaviour change (Rode et al., 2022).

4 Reducing car use

4.1 Evidence on air quality impacts of reducing car use

The transport sector is responsible for a large share of air pollution in Scotland, as it is in the UK as a whole and internationally (Li et al., 2017; Marinello et al., 2021; NAEI, 2023). In 2019, transport was responsible for approximately 59% of Scotland's total NOx emissions (Hector et al., 2022). Of these transport emissions, passenger cars (mainly diesel cars) were responsible for approximately 28%, with the rest coming from rail, aviation, shipping, and other road transport (Hector et al., 2021). Transport was also responsible for approximately 25% of the total PM2.5 and 20% of PM10 emissions (Hector et al., 2022). It is evident that transport is a key contributor to air pollution, but from these data, drawn from the National Atmospheric Emissions Inventory, it is not clear what share of Scotland's emissions are associated with private car use (as opposed to car use for business, taxis etc.).

Reducing car use is the most common focus in literature linking behaviours of the public and air quality (Keyvanfar et al., 2018; Quarmby et al., 2019; Riley et al., 2021), and road transport emissions form the focus of most air quality strategies and technologies (Quarmby et al., 2019). There has been much interest in the recent literature on the impact of reduced travel due to COVID-19 restrictions on air quality. The COVID-19 lockdowns can be viewed as a natural experiment on the impacts of reducing car use (see Box 1). Interventions such as Low Emission Zones/Ultra Low Emission Zones and congestion charging, designed to reduce traffic in priority areas, can make significant impacts on air quality (Chamberlain et al., 2023; Holman et al., 2015; Mudway et al., 2019; Quarmby et al., 2019) although mixed results are also reported (Holman et al., 2015). As well as impacts on air quality outcomes, positive impacts on behaviours (reductions in car use and shifts to active travel) are also reported (Tarriño-Ortiz et al., 2022).

Box 1: Impacts of COVID-19 restrictions on air quality

Numerous studies around the world report the impacts of COVID-19 lockdowns on air quality. Many report large reductions of observed ambient concentrations of air pollutants, especially NOx, during lockdown periods (Han et al., 2023), but such reductions vary widely across studies. An early review by Marinello et al. (2021) found that reductions, where they were recorded, ranged from 6-90% for NO_2, from 9-60% for PM10, and from 7-86% for PM2.5. Very few case studies recorded unchanged pollutant levels. The largest reductions in pollutants were recorded for large Asian cities where pre-COVID concentrations were high (Marinello et al., 2021). It is difficult to establish the extent to which improvements in air quality during COVID-19 were a result of reductions in car use, as opposed to reductions in other types of transport and industrial activity. Wang et al. (2020) attempted to attribute air quality improvements during COVID lockdown in China to changes in different types of activity. Generally, reductions in industrial activity were more strongly associated with air quality improvements, although both transport and industry were seen to contribute significantly. For NOx emissions, there was evidence that reductions in transport activity explained more of the improvement in air quality than did reductions in industrial activity.

Kramer (2021) analysed impacts of COVID-19 on air quality in Scotland. Comparing the observed data to a business-as-usual scenario for the period they estimate that the first lockdown reduced NOx and NO_2 by 58% and 52% respectively, with the largest reductions occurring during the daytime (particularity at times that would normally have been rush hour periods). This aligns with the decrease in cars on the road observed (Transport Scotland data reported car traffic levels fell to 25% of 2019 levels but had almost recovered to pre-pandemic levels after 6 months). The estimated decrease in urban PM2.5 because of lockdown was very small, and estimates are more uncertain due to the complexity of modelling PM, given regional transport of PM and the variety of natural and anthropogenic sources. These findings for Scotland reflect findings for the UK more broadly, for which several studies reported significant reductions in NOx (Mohajeri et al., 2021; Ropkins & Tate, 2021; Wyche et al., 2021), but less clear impacts on PM2.5 (Wyche et al., 2021). A study comparing four UK cities – Edinburgh, London, Cardiff and Belfast – found that the greatest reductions in air pollution were found in Edinburgh, where the greatest reductions in driving and public transport use were observed (Mohajeri et al., 2021).

Quarmby et al., (2019), in a review of air quality strategies and technologies, highlight improvements in active travel infrastructure as one of the most promising interventions for improving air quality, but noted a lack of evidence quantifying the impacts of switching to cycling. Modelling carried out for Sustrans, aiming to estimate air quality-related health impacts of improvements in active travel infrastructure across the UK, found mixed results (Ballinger et al., 2017). The impacts of schemes depended on levels of active travel uptake associated with the scheme, exposure to air pollution when walking/cycling, population density and other factors. The greatest estimated health impacts related to the Glasgow scheme, which involved the completion of the 'Bridge to Nowhere' across the M8 motorway. The air quality health impact of the reduction in car journeys associated with the scheme was estimated at equivalent to £104,820 a year, with the majority of the benefits experienced by those switching to active travel for their work commute. The authors estimate that, extrapolating from the benefits of the Glasgow case study, achieving a target of 10% of all journeys in Scotland by bike could result in air quality benefits equating to £364 million per year (Ballinger et al., 2017).

International studies modelling large-scale shifts to active travel (mainly cycling) indicate that shifting from car journeys to active travel has the potential to reduce air pollution (especially NOx) and result in overall benefits to the population in terms of reductions in mortality, respiratory disease, cardiovascular disease, cancer, adverse birth outcomes, loss of productivity associated with illness, and road traffic fatalities (C. Johansson et al., 2017; Mueller et al., 2015; Rabl & de Nazelle, 2012; Rojas-Rueda et al., 2012). In these studies, increased physical activity is often found to be responsible for the majority of the health benefits (Mueller et al., 2015). Additionally, the modelling studies highlight that where cycle routes are not separated from motorised traffic there can be negative impacts for those switching to active travel, as a result of increased exposure to pollutants, which can offset the health benefits experienced by individuals (Ballinger et al., 2017; Mueller et al., 2015; Rabl & de Nazelle, 2012).

Quarmby et al. (2019) highlight the importance of public transport networks, including frequent services and integrated transport hubs, for air quality improvement. In their profiling of three case study cities ranking highly for air quality (which included Edinburgh), public transport networks were identified as a critical success factor along with a good cycle network, and financial incentives to buy electric vehicles (see section 5). Per passenger kilometre, overall NOx and CO emissions are substantially lower for urban public transport than car travel (Potter, 2003). Modelling studies estimate air quality improvements from increasing public transport by bus. An evaluation of a national financial incentive scheme for public transport use in Germany finding that the scheme reduced air pollution index scores by 6% (Gohl & Schrauth, 2022). A study in China estimated that for every 1% increase in buses on the road, air quality index score drops by 0.08% (Sun et al., 2019). Other studies indicate that public transport provision is, on its own, not necessarily effective in improving air quality (Ma et al., 2021). Evaluation of the air quality impacts of the Jubilee Line Extension of the London Underground found only small impacts on air pollution and only at some locations (Ma et al., 2021). The air quality impacts of behaviour changes in use of public transport (as opposed to specific infrastructure improvements) will also vary depending on public transport mode and fuel types (e.g. diesel-powered or electric buses or trains, hydrogen-powered buses) (Potter, 2003).

Remote, hybrid and flexible working arrangements have the potential to reduce car use significantly. A review by Moglia et al. (2021) highlights air quality benefits of remote working, particularly with respect to the wide-scale adoption of home working practices during the COVID-19 pandemic, however Spear et al. (2022) noted that no studies have yet measured the specific contribution of working from home to the air quality improvements observed during COVID-19 lockdowns. Kylili et al. (2020) modelled the life cycle impacts of three different scenarios: office working, working from co-working spaces, and remote (home office) working. In both the co-working and remote working scenarios, it was assumed that employees would still have to work in the office at least 2 days per week. Their analysis found that in the home working scenario, NOx emissions were reduced by more than 50% compared to the office working scenario, with the co-working scenario associated with a reduction of more than 40%, with results for PM10 and PM2.5 emissions of a similar magnitude for the different scenarios. This analysis aligns with other life cycle assessments of greenhouse gas emission reductions associated with home working practices (Spear et al., 2022), however it should be noted that building energy consumption associated with the different working practices was assumed to be equal in the Kylili et al. assessments.

Ge et al. (2018) modelled impacts of workplace sharing initiatives/flexible working hubs, reporting CO_2 emissions reductions associated with the reduced commuting travel. We can anticipate that the environmental impacts of such schemes would also extend to reduced emissions of other pollutants. As rush hour congestion is largely a result of commuting, flexible working arrangements (including flexible working hours as well as locations) has considerable potential to reduce air pollution through reducing congestion (Yu et al., 2019), as well as reducing emissions through reduced car use overall.

Particularly relevant to commuting, car-sharing /car-pooling has received interest as a route to reducing car use. Car-sharing has the potential to lower both the emissions per passenger by promoting shared travel as well as reducing the overall number of vehicles on the road (Correia & Viegas, 2011). There is, however, a lack of evidence on the effectiveness of car-sharing initiatives for reducing emissions (Keyvanfar et al., 2018).

Car use reduction can also be achieved through minimising travel for non-commuting journeys. Accessing shops and services locally can mean reduced journey lengths and greater opportunity for switching from car to active travel for these journeys. Improvements in air quality are one of the potential impacts of ‘20 Minute Neighbourhoods’ (20MN) i.e. places that enable people to live more locally through easy access to services and amenities particularly by active travel (Al Waer & Cooper, 2023). The 20MN concept highlights that behaviour change in reducing car travel to everyday services and amenities relies on supportive built environments and planning processes. While it is important to highlight the value of staying local as part of the behavioural changes involved in reducing car use, we return to the factors affecting people’s ability to do so, as highlighted by the literature on 20MN, in the COM-B analysis of the following section. Minimising unnecessary travel has large potential impacts in terms of reducing car use, however we did not find specific literature on the associated air quality impacts beyond that focusing on commuting to work.

Overall, it is clear that reducing car use is a key behavioural category to prioritise for air quality improvement. In addition, reducing car use has multiple social and environmental benefits, including for public health, communities and mitigating climate change. From the review we identify three key behaviours to prioritise, plus one additional behaviour for consideration:

Reducing car use	**Key behaviours**
	Walking, cycling or wheeling for short journeys
	Using public transport instead of driving
	Working flexibly or from home
	Additional behaviour for consideration
	Using local shops and services

4.2 Factors influencing key behaviours around car use reduction

A range of factors (both motivating and constraining factors) influencing the key car use reduction behaviours were identified from the literature. These are outlined in relation to Capabilities, Opportunities and Motivations in Table 3-6 below. It should be noted that, throughout this report, the factors outlined in the tables represent those that were highlighted from the literature reviewed and do not necessarily represent an exhaustive list of the multiple factors influencing each of the key behaviours.

Table 3: Capability, Opportunity and Motivation factors influencing switching to active travel

Walking, cycling or wheeling for short journeys	
Capability	
Physical abilities and mobility constraints	Choosing active travel for short journeys can depend on individuals' mobility and physical ability to undertake journeys on foot, by bike etc. Physical capabilities can be a major barrier to walking and other forms of active travel in certain groups, particularly older people and disabled people (Currie et al., 2021; Centre for Ageing Better, 2021). Enabling environments can reduce barriers associated with physical capability constraints.
Cycling skills	Cycling requires certain skills and competencies. Developing cycling skills in childhood and adolescence, before young people are old enough to drive may be particularly important for developing a culture of cycling (Colley et al., 2022).

Confidence in abilities	Individuals' feeling of self-efficacy - beliefs about their own capability to walk/cycle/wheel - influence active travel behaviour. This includes confidence and self-belief in one's abilities (Voorheis et al., 2023). Lack of confidence can be a particular barrier to cycling (Centre for Ageing Better, 2021).
Opportunity	
Cycling infrastructure	Low-stress facilities (e.g. protected bike lanes, slow or car-free streets) makes cycling a more attractive option (Buehler & Pucher, 2023). Safe cycle networks are important to support cycling both in urban and more rural environments (O'Gorman & Dillon-Robinson, 2021).
Walkable environments	While destination proximity is associated with more active travel behaviour (Aldred, 2019), the walkability of neighbourhoods is also influenced by factors such as land-use mix, street connectivity, pedestrian safety, and residential density (Dovey & Pafka, 2020).
Access to equipment	Cycling requires access to suitable equipment. Schemes providing bikes, including bike share schemes can lead to increased active travel. Improving access to e-bikes, cargo bikes, and bikes with seats for children, as well as traditional bikes, can promote cycling to more diverse groups, including families (Colley et al., 2022).
Social networks	Voorheis et al (2023) stress the importance of social environment on active travel behaviours (especially for the older population), e.g. companions to walk with, support of neighbours, walking as a generalised social norm.

Motivation	
Safety concerns	Concerns about safety reduce motivations for active travel. This is a major constraint, particularly for cycling (Colley et al., 2022). Concerns about personal safety can be a barrier to walking for women especially, including use of green active travel routes (Irvine et al., 2022).
Weather conditions	Warm and dry weather has a positive impact on active travel behaviours, while rain, snow, windy, cold and too hot weather encourage a switch to sheltered transport modes (Bocker et al., 2013).

Perceived (in)convenience	Switching to active travel can be perceived as less convenient than alternatives. A recent survey of Scottish residents found this to be the most commonly reported barrier to walking, cycling or wheeling instead of travelling by car or van, stated by 49% of respondents (BMG Research, 2023).
Habit	For frequently-made journeys, the choice of mode is often one which is habitual and automatic rather than a decision which is considered each time. Feeling that habits are hard to break was the second most commonly cited barrier to active travel (reported by 39% of respondents) in a recent Scottish survey (BMG Research, 2023).

Table 4: Capability, Opportunity and Motivation factors influencing switching to public transport

Using public transport instead of driving	
Capability	
Knowledge about public transport	Information available to people influences their choice of using public transport (transport lines, stops, time of service, estimated travel duration) (Chowdhury & Ceder, 2016). Personalised travel plans can help increase knowledge about public transport options for regular journeys.
Confidence in using public transport	Confidence can be a barrier to using public transport for some people. Getting supported first-hand experience of public transport can help children to develop the competencies to travel independently by public transport (Colley et al., 2022).
Opportunity	
Public transport networks	The provision of a low-carbon infrastructure of public transport can encourage individuals' transport mode change (Javaid et al., 2020). Well-developed public transport networks, which include frequent services and integrated transport hubs are necessary to support high uptake of public transport (Quarmby et al., 2019).
Social norms	Seeing low-carbon travel behaviours as the norm and as socially desirable will encourage people to use more public transport (Chowdhury & Ceder, 2016; Javaid et al., 2020).
Cost	The cost of public transport, compared with the use of private cars, influence travel mode choice (Chowdhury & Ceder, 2016). Fare subsidies and concessions can support an increase in share of trips made by public transport, although there is also risk that free public transport can result in shifts from active travel for short journeys (Colley et al., 2022).
Motivation	
Perception & experience of public transport	People's perception and lived experience of public transport can (de)motivate them to use public transport, such as the reliability of transport, safety, waiting time for connections, comfort (Chowdhury & Ceder, 2016). Perceived inconvenience is the barrier to switching to public transport cited most commonly by Scottish residents (BMG Research, 2023). Such perceptions also interact with opportunity and capability factors as lower levels of both will likely increase perceptions inconvenience.

Habit	As with active travel, habits can form a barrier to switching from car to public transport for frequent trips, with 30% of Scottish residents reporting habits as a barrier (BMG Research, 2023).

Table 5: Capability, Opportunity and Motivation factors influencing working flexibly or from home

Work flexibly or from home	
Opportunity	
Job type	Many are unable to work flexibly or from home due to their occupation and the nature of their work. Working from home is primarily an option for those doing office-based work (Beck & Hensher, 2021).
Systemic support for flexible working or work from home	Achieving a successful transition to more flexible working method requires systemic support, such as redesigning physical and digital workplaces to accommodate the diverse needs of employees (Babapour Chafi et al., 2022; Bentley et al., 2016; Bérastégui, 2021). In a recent survey of Scottish residents, the fact that this behaviour relies on the agreement of others (in this case primarily employers) was the most commonly cited barrier to working from home (BMG Research, 2023).
Digital infrastructure	Working flexibly or from home often depends on access to the internet, particularly high-speed internet, as well as appropriate IT equipment (Beck & Hensher, 2021).
Post-pandemic remote working norms	The COVID-19 pandemic led to a significant rise in remote work, and this trend is continuing in the post-pandemic period (Alfanza, 2021; Hu et al., 2021). The development of remote working norms during COVID provides a conducive social environment for the continuation of such working practices.
Home environment constraints	Working from home requires suitable space for working, which is a constraint experienced by many working from home during the COVID pandemic (Beck & Hensher, 2021).
Motivation	
Individual benefits from flexible/remote working	There is an increasing preference on working from home, due to the improvement of work-life balance (Erro-Garcés et al., 2022; Nguyen & Armoogum, 2021), commute time saving (Beck & Hensher, 2021) and productivity (Aczel et al., 2021).
Social connectedness	Maintaining social connectedness to colleagues and face-to-face collaboration is a motivator for people to spend at least some of their working time at a physical workplace. Remote working hubs may provide opportunities for in-person social contact closer to home (Beck & Hensher, 2021).

Table 6: Capability, Opportunity and Motivation factors influencing use of local shops and services

Using local shops and services*	
Opportunity	
Suitable local infrastructure and amenities	Proximity of local amenities is key to reducing private car use (Chau et al., 2022), shorter distances makes it more viable to access amenities by active travel or public transport (Handy, 2017). As well as proximity, the accessibility of amenities is important – a destination may be close by but not accessible due to e.g. main roads, railway lines (O'Gorman & Dillon-Robinson, 2021). The number of local amenities, their variety and the specific types of amenities available also impact on whether people can meet their needs without having to travel by car (Elldér et al., 2022). The level of quality and experience, not just their presence or absence, will play a part in whether they are used (O'Gorman & Dillon-Robinson, 2021). In 20-minute neighbourhoods, people are more likely to walk for transport than those not in 20-minute neighbourhoods. Across Scotland there are communities that have suitable infrastructure and services allowing them to be 20-minute neighbourhoods, although less is known about the quality of services available and whether these communities are functioning as 20 minute neighbourhoods (O'Gorman & Dillon-Robinson, 2021).
Cost	In a survey of Scottish residents, 40% reported cost to be a barrier to shopping more locally/minimising travel (BMG Research, 2023).
Motivation	
Habit and lack of desire for change	The choice to use local shops and services may depend on existing habits. In a survey of Scottish residents, when asked about barriers to shopping more locally/minimising travel, 32% of respondents stated liking how things are now and 31% stated that it is a hard habit to break (BMG Research, 2023).

*Factors influencing active travel and public transport use are also interconnected with choice of where to go for shopping and services (see Tables 3 and 4).

5 Switching to a less polluting vehicle

5.1 Evidence on air quality impacts of switching to a less polluting vehicle

Alongside supporting an overall reduction in car use, the review highlighted other transport-related behaviours that have the potential to impact on air quality. The most significant of these relate to vehicle choices. Most interest in the literature centres on the potential benefits of switching from conventional vehicles to electric vehicles (EVs), whether battery electric vehicles (BEVs) or hybrid electric vehicles (HEVs). In this section we focus primarily on switching to EVs, given the considerable potential benefits for air quality, as well as the alignment of this behaviour with Net Zero objectives around decarbonising the transport sector. However, some sources highlight differences between petrol and diesel cars (European Environment Agency, 2018) (which may depend on the age of the car, and vary depending on the type of pollutant of interest) and others focus more on replacing older, less fuel-efficient cars with newer ones (El-Dorghamy, 2014), or on the impacts of smaller versus larger cars (Gillies et al., 2005; Kim, 2007).

Air quality benefits accrue due to the use of EVs compared to combustion engines, due to the absence of exhaust emissions from BEVs (European Environment Agency, 2018). However, EVs are not entirely pollution-free, as particulate matter is still produced by tyres and brake wear of the vehicle (Quarmby et al., 2019). These sources of PM can be considerable. It is reported that in the UK in 2015, more than two-thirds of PM10 emissions were from tyre and brake wear and road abrasion (Quarmby et al., 2019) – although regenerative braking technology helps to reduce the emissions from brake wear in EVs (European Environment Agency, 2018). The extent of the benefits of EVs over conventional vehicles in terms of PM emissions will also depend on driving conditions and vehicle weights, as EVs tend to be heavier than combustion vehicles (European Environment Agency, 2018). Whilst impacts of switching to EVs on PM may be variable, these is clear evidence of considerable benefits in relation to air quality more broadly. Studies modelling the impacts of wide scale switching to EVs, have estimated large reductions in NOx concentrations (Ferrero et al., 2016; Requia et al., 2018; Rizza et al., 2021; Soret et al., 2014) and improvements in air quality indices (Christensen & Salmon, 2021), as well as benefits to human health (Hooftman et al., 2016; Rizza et al., 2021). For example, Ferrero et al (2016) estimated that shifting 50% of light vehicles in Milan to EVs could result in a 14% reduction in NOx. Another study, modelling a 100% shift of light vehicles to EVs in Taiwan could result in an estimated 27% reduction in NOx (Requia et al., 2018). A recent study by Rizza et al. (2021) estimated that, for the city of Turin, Italy, a shift in vehicle fleet away from primarily diesel and petrol vehicles to a 2030 scenario of 20% electric, and 50% hybrid vehicles (with only 4% of cars fuelled by diesel) could result in an 87% reduction in NO2 concentrations.

One of the major factors influencing the extent of the air quality benefits from switching to EVs is the energy mix used in electricity production (EPRI & NRDC, 2015; Hawkins et al., 2012). Where the electricity grid is powered primarily by fossil fuels, while there might be improvements to local air quality around roads, emissions are shifted to power stations (European Environment Agency, 2018; Requia et al., 2018). Whilst coal contributes very little (only 1.5%) to the UK's electricity generation mix, contributions from biomass (5.2%) and gas (38.5%) mean that some of the air quality benefits of switching to EVs will be offset by displaced emissions from electricity generation across the UK (European Environment Agency, 2018; National Grid, 2023). Therefore, the decarbonisation of electricity production is central to the future air quality benefits of the transition of the vehicle fleet to EVs.

On the basis of the evidence reviewed, we propose one key behaviour relating to switching to a less polluting vehicle:

Switching vehicle	Switching to an electric vehicle

5.2 Factors influencing switching to electric vehicles

A range of motivations and barriers to switching to EVs were identified in the literature. These are summarised below in

Table *7* in relation to capabilities, opportunities and motivations.

Table 7: Capability, Opportunity and Motivation factors influencing switching to electric vehicles

Switching to electric vehicles (EVs)	
Capability	
Knowledge about range	"Range anxiety" is a typical concern for potential EV users, as most people either do not have sufficient knowledge on the technological advancement of EVs' actual travel range (Franke et al., 2012; Haddadian et al., 2015), or their related perception is psychologically biased (Bonges & Lusk, 2016; Jensen et al., 2013; Quak et al., 2016). Being able to try out an EV (e.g. through rental or a car club) can help to reduce range anxiety, which may help encourage people to consider purchasing an EV (European Environment Agency, 2018).
Opportunity	
Cost	At present, the purchasing price of EVs is considered as the most significant barrier for switching from conventional cars to EVs (Keyvanfar et al., 2018; Krupa et al., 2014; Mock & Yang, 2014). In a Scottish survey, 67% of respondents reported the initial cost as a barrier to switching to an ultra-low emission vehicle (BMG Research, 2023). Reducing the purchasing price by providing subsidies is a route to broader access to affordable EVs (Quarmby et al., 2019).

Charging infrastructure	"Range anxiety" can be related to the lack of charging stations or parking slots devoted to EV (Bonges & Lusk, 2016; Harrison & Thiel, 2017; Mock & Yang, 2014). Concerns about the range of cars in relation to access to charging infrastructure can be a greater barrier for rural residents compared to those living in large urban areas in Scotland (BMG Research, 2023).
Social norms	Current social norms and policies encourage people to switch to EVs (Hawkins et al., 2012; Pielecha et al., 2020). Cherchi (2017) found that, in an experimental environment, high social conformity (many others use the EVs) can largely overcome the financial barrier to encourage people to purchase EVs.
Motivation	
Environmental concerns	With the rise in concerns about the environment, people may opt for EVs. Singh et al. (2023) demonstrated that psychological factors such as perceived value, personal norms, etc. can be significant contributors to promote the transition. In a survey of Scottish residents, 31% reported the reduced environmental impact of EVs as a motivator for buying them (BMG Research, 2023).
Fuel and cost saving	EVs are generally considered as advantageous for reducing fuel dependency (Jochem et al., 2016), with financial benefit also an important motivator for using EVs. Lower running costs are the most common perceived incentive for buying an EV, reported by 32% of Scottish respondents (BMG Research, 2023).

6 Driving differently

6.1 Evidence on air quality impacts of changing driving behaviour

A third broad behavioural area highlighted in the literature relates to changing behaviour when driving. Changes to the way we drive, often discussed under the broad banner of eco-driving, have the potential to offer fuel efficiency gains which may translate into reduced pollutant emissions and improved air quality. A review on driving behaviour by Keyvanfar et al. (2018), highlights that driving style plays a significant role in fuel consumption, as more aggressive driving, and more stop-start driving leads to higher fuel use. Eco-driving techniques, which include slow acceleration and deceleration, early gear changes, adherence to speed limits and avoiding vehicle idling are argued to significantly reduce fuel consumption and emissions of NOx, hydrocarbons and greenhouse gases (Keyvanfar et al., 2018). Reviews on eco-driving report that fuel consumption can be significantly reduced - empirical research conducted in various contexts demonstrates an average fuel saving range of 5 - 25% (Coloma et al., 2018; Fafoutellis et al., 2020; Miotti et al., 2021; Wang & Boggio-Marzet, 2018), Alam & McNabola (2014) and Huang et al.,(2018) even report reductions up to 40%. However, The impacts on air quality are less clear. The focus in the literature has tended to be on fuel consumption and CO_2 emissions (Huang et al., 2018), whereas emissions of pollutants such as NOx, CO and hydrocarbons are known to correlate less highly with fuel consumption than CO2 emissions (Kurani et al., 2015).

Rodríguez et al. (2016) estimated reductions of 24% for NOx as a result of improving vehicle flow and reducing frequent abrupt accelerations. Fonseca et al. (2010) found no advantage of eco-driving over a 'normal' driving style in terms of NOx, however both compared favourably to aggressive driving which increased NOx emissions by an estimated 40%. The evidence of the impacts of eco-driving on air pollutants such as NOx appears mixed. Estimated impacts will likely depend on the specific driving behaviours modelled and the assumptions embedded in emissions models. In relation to driving speeds there is some evidence that reduced speed limits can help reduce emissions due to an improved flow of traffic (Connected Places Catapult, 2019; Owen, 2005; Quarmby et al., 2019). However, a review of evidence on the health impacts of 20 mph urban speed limits, found that whilst 20 mph zones are associated with greater road safety, there is less robust evidence on air pollution impacts (Cleland et al., 2020).

Whilst there are potential benefits from eco-driving, and interventions aiming to increase uptake of eco-driving are seen to be cost-effective ways to reduce emissions (Keyvanfar et al., 2018), evaluations of eco-driving schemes have shown mixed results in terms of behaviour change, especially in relation to long-term maintenance of behaviours (Alam & McNabola, 2014; Barkenbus, 2010; Quarmby et al., 2019).

Avoiding idling (running the engine when car is stationary) is often considered as part of eco-driving but can also be targeted as a behaviour in and of itself. It is reported that when a car is idling for 10 seconds or longer, the fuel consumption and emissions exceed those associated with stopping and restarting the engine (Rumchev et al., 2021). Emissions associated with idling do, however, depend on the type of car. Although both petrol and diesel cars emit CO_2 while idling, the NOx emissions associated with an idling petrol car are minimal in comparison to those emitted by idling diesel cars with PM emissions also lower (Barlow & Cairns, 2021; Shancita et al., 2014). Targeted campaigns focusing specifically on anti-idling can reduce idling behaviour, for example around schools (Rumchev et al., 2021) and at level crossings (Abrams et al., 2021; The Behavioural Insights Team, 2022), with associated improvements to air quality (Abrams et al., 2021; Mendoza et al., 2022; Rumchev et al., 2021), but more evidence is needed on their long-term effectiveness. Idling reduction technology in vehicles can also address idling emissions without the need for behaviour change (Shancita et al., 2014).

Overall, the evidence suggests that changes in driving behaviour have the potential to impact significantly on the emissions released when driving combustion-fuelled vehicles. However, it is important to note that such measures to increase efficiency are of lower impact than more fundamental changes that shift travel behaviour away from combustion-fuelled vehicles. Given the potential gains, we propose eco-driving as a key behaviour. In doing so we recognise that eco-driving is a suite of different behaviours, which could make communications to public audiences about what they comprise more complicated. Whilst the impacts of changing driving behaviour differ between petrol and diesel vehicles, encouraging these behaviours (particularly those that are most visible) across all car drivers has the potential to reinforce positive social norms.

Driving differently	Using eco-driving techniques (including stopping engine when stationary)

6.2 Factors influencing eco-driving

Motivations and barriers to the uptake of eco-driving were identified in the literature. These are summarised below in Table 8 in relation to capabilities, opportunities and motivations.

Table 8: Capability, Opportunity and Motivation factors influencing eco-driving behaviours

Eco-driving	
Capability	
Eco-driving skills	Generally, eco-driving skills are straightforward to comprehend and implement. It is expected that any regular car user should be able to incorporate eco-driving practices (Keyvanfar et al., 2018). Training programmes can equip people with the skills and knowledge to use eco-driving techniques (Huang et al., 2018).
Opportunity	
Institutional support	The implementation of generalised eco-driving requires systemic support (Ando et al., 2010; Ando & Nishihori, 2011), and public training is crucial to raise awareness about eco-driving (Johansson et al., 2003).
Motivation	
Fuel-saving	Eco-driving is often highlighted for its dual advantages in reducing pollution and conserving fuel. The potential financial gains from fuel savings serve as motivation for individual drivers to adopt this driving approach.
Safety	Passenger safety has been strongly correlated with driving style, and eco-driving is proven to increase road safety (Alam & McNabola, 2014; Cristea et al., 2012), while aggressive driving styles provokes more accident risk (Bachoo et al., 2013; Rundmo et al., 2011, 2011).
Travel time	Research also indicates that eco-driving may lead to varying degrees of travel time increase (Coloma et al., 2018; Miotti et al., 2021), potentially reducing its public acceptability.

Driving habits	Driving habits appear to be a significant deterrent for individuals considering a shift towards eco-driving (Chung, 2015; Tseng et al., 2013). Habits are the most commonly cited barrier both to avoiding idling a vehicle (44% of respondents) and wider eco-driving behaviours (35% of respondents) amongst Scottish residents (BMG Research, 2023). However, while entrenched driving habits are hard to shift, new positive habits once established can support long-term behaviour change.

7 Heating the home differently

7.1 Evidence on air quality impacts of home heating behaviour

The literature review highlighted impacts from home heating behaviour, specifically in relation to burning of solid fuels. There was a lack of literature on other types of domestic heating fuel in relation to air quality. Domestic burning of solid fuels is a significant source of air pollutant emissions. Burning solid fuels, which can include wood (biomass) burning as well as solid mineral fuel like coal, releases a range of pollutants in the form of PM, including ultrafine particles (with a diameter of ≤100 nm), fine particles (PM2.5), and larger particles (PM2.5-10), as well as gaseous pollutants like carbon monoxide (CO), and NOx (Hector et al., 2022; Font & Fuller, 2017). Domestic solid fuel burning has impacts on both outdoor and indoor air quality (Wood et al., 2023).

In Scotland in 2019, residential and other combustion sources (which exclude combustion in industry, energy production and transport) accounted for approximately 38% of the total emissions of PM2.5, 22% of PM10 emissions and 14% of the total NOx emissions (Hector et al., 2022). This makes residential and other burning the greatest source of PM2.5 and the second greatest source of PM10 (after industry) and NOx (after transport). It is not, however, clear from these data how much of these emissions are associated with solid fuel burning versus more prevalent types of home heating fuel like gas and oil. Residential emissions of CO have been on the increase since 2005, in line with increased wood burning at home, despite the otherwise downward trend in CO emissions (Hector et al., 2022). The major contribution of domestic fuel burning to PM2.5 in Scotland is a particular concern, as finer particles pose greater health risks than larger particles (Cowie et al., 2015). As with all emissions sources, the spatial distribution of emissions will affect the overall impact on air quality, and so geographical differences in solid fuel burning should also be taken into account. Although only around 1% of homes report using solid mineral fuel as their primary fuel type (Scottish Government, 2023), 79% of these households are located in rural areas (Scottish Government, 2021). Similarly, although the use of biomass as a primary fuel source is low (<1%) overall in Scotland, reliance on biomass is highest in rural areas, where the majority of homes are located off the gas grid (Scottish Government, 2023). Research examining the air quality and health impacts of domestic biomass burning in Scotland is currently underway as part of the Scottish Government's Strategic Research Programme[6].

The international literature highlights that the use of solid fuels such as wood for cooking and heating is a principal source of air pollution at the global level (Chowdhury et al., 2023; Lelieveld et al., 2015). It is reported that for every 1 million households using solid fuels, emissions equivalent to 2.3 million diesel trucks are released (Chowdhury et al., 2023). Household burning overall has been estimated to contribute to 19-31% (depending on the study) of ambient PM2.5 globally, and at the European level household burning may be responsible for more than half of overall PM2.5 emissions (Chowdhury et al., 2023; Wood et al., 2023).

Domestic wood burning has increased in the UK in recent years, a trend that is reflected elsewhere in Europe (Chowdhury et al., 2023; DEFRA, 2023). Emissions of PM2.5 from wood burning at home increased by 124% between 2011 and 2021, and wood burning has now by far overtaken coal burning as a source of PM2.5, with wood burning accounting for three-quarters of PM2.5 emissions from domestic combustion (DEFRA, 2023). Heydon (2023) reports that of the 8% of UK households which use wood burning stoves, 95% have access to other sources of heat. Increases in wood burning in urban areas, where people are less likely to be reliant on wood as a primary heating source, is a particular concern as it is there that emissions from wood burning have the greatest potential to impact on ambient air quality and human health (Font & Fuller, 2017). Wood burning is estimated to be responsible for 23-31% of the urban-derived PM2.5 in London and Birmingham, and it is thought likely that the case will be similar for other cities (Font & Fuller, 2017). Domestic wood burning also varies in relation to seasonal and diurnal rhythms of heating. It primarily happens in winter and is greatest in the evening when people are more likely to be home. However wood burning behaviour correlates quite poorly with daily temperature, suggesting that a large part of wood burning might be related to taste and aesthetics rather than reliance on wood for heat (Font & Fuller, 2017). For example, Kantar (2020) found that wood burning fireplace is a broadly associated with homely and cozy feeling in rural households.

The air quality impacts of solid fuel burning can be reduced through using properly installed and maintained stoves rather than open fires, and the use of modern, more efficient stoves since stoves sold in the UK now have to conform to strict emissions standards (Burki, 2018; Kantar, 2020). The use of properly dried and seasoned wood with a water content of 15-20% (compared to up to 50% in freshly cut firewood), or smokeless coal rather than standard house coal, can also reduce the smoke and therefore pollutant emissions produced from burning (Burki, 2018; Kantar, 2020). In a survey of UK householders who burn solid fuels at home, half of those who burned wood said that they bought their wood pre-dried or seasoned, and a quarter seasoned it themselves (Kantar, 2020). Of those who burned wood,

[6] This work is taking place within the D1 air quality topic of the Strategic Research Programme.

20% used wood classed as wet (either seasoned for less than 12 months or not at all) (Kantar, 2020). The survey also found that 31% of respondents burning solid fuels at home used an open fire, 26% used stoves installed prior to 2010, and 9% did not know how old their stove was (Kantar, 2020). Two-thirds of respondents with an appliance installed before 2000 said they were not at all likely to replace their appliance, and a further 21% said it was fairly unlikely (Kantar, 2020).

In light of the evidence reviewed, we have identified two key behaviours relating to home heating for prioritisation:

Heating the home differently	Burning less at home
	Ensuring good practice when burning solid fuel (including use of efficient appliances)

7.2 Factors influencing home heating behaviour

C-O-M factors influencing key home heating behaviours (burning less; ensuring good practice when burning) identified from the evidence review are presented below in

Table *9* and

Table *10*.

Table 9: Capability, Opportunity and Motivation factors influencing burning solid fuels at home

Burning less at home	
Capability	
Lack of knowledge of impacts	Indoor wood burning significantly increases health risks for individuals. However, the absence of direct sensory experience diminishes people's awareness. In turn, this reduces their motivation to shift away from solid fuel burning (Heydon & Chakraborty, 2022). Even when indoor air quality monitors are provided the information they convey is not well understood (Heydon & Chakraborty, 2022).

Opportunity	
Access to cleaner energy	To reduce reliance on solid fuels, access to different types of cleaner energy source is necessary. There are some differences between urban and rural areas with respect to the variety of different options available. The majority of rural areas in Scotland lack access to a natural gas network (National Gas, 2023) and there are fewer opportunities for district heating schemes in areas where there is a lower heat demand density (Element Energy, 2020). However, other options for low carbon heating such as heat pumps and electric heating exist in off-gas-grid rural areas. The suitability of different types of low carbon heat technology will also vary depending on the specific characteristics of individual properties (Element Energy, 2020).
Policy and regulatory environment	The existing legislation concerning domestic combustion emissions is rooted in the Clean Air Act of 1993, which is being reviewed (Scottish Government, 2020). The recent passage of the Heat Network Bill by the Scottish Parliament, along with the ongoing development of large-scale heat infrastructure (Scottish Government, 2022), presents a favourable opportunity for households currently utilising solid fuels for heating to consider changing their heating method. At the time of writing, proposals on a heat in buildings bill, addressing clean heating in existing buildings, are in development.
Motivation	
Cost of switching energy source	Costs of switching to a cleaner energy source may be a barrier to reducing reliance on solid fuel. Direct electric heating can be costly to operate, and installation of low-carbon heat technology not already present in the home has upfront cost implications (Element Energy, 2020).
Environmental motivations	Despite its contribution to high levels of air pollution, wood burning is often regarded as a carbon-neutral method of energy acquisition (Acton et al., 2023; Clean Heat, 2016).
Comfort and aesthetics	The primary motivations individuals cite for indoor burning are often to create a cozy, homely atmosphere, and in some cases, purely for aesthetic reasons (Kantar, 2020).

Table 10: Capability, Opportunity and Motivation factors influencing adoption of good practices when burning solid fuel

Ensure good practices when burning solid fuel (including use of efficient appliances)	
Capability	
Knowledge	To mitigate particulate emissions, greater emphasis should be placed on optimizing wood log burning conditions (Fachinger et al., 2017). This requires knowledge of good practice by users. There is a general lack of education on the right burning appliance and good burning techniques (fuel, installation/maintenance of devices) (Scottish Government, 2020). Burning practices are rarely questioned, and there is a lack of knowledge regarding the specifics of which type of fuel to burn and the necessary seasoning requirements. These factors can vary significantly, e.g., individuals often assume that the wood they purchase will already be properly seasoned (Kantar, 2020).
Motivation	
Costs	While there is not a quantified cost associated with upgrading outdated home burning appliances (as it greatly depends on the local market), it is evident that households will incur additional financial costs to enhance or replace outdated heating equipment (Kantar, 2020). Switching to less polluting solid fuels may also add additional costs for households (Masey et al., 2023).
Effort	Good practice includes ensuring wood is thoroughly dried and cutting it into smaller pieces before burning (Fachinger et al., 2017) which may require extra effort and inconvenience.

8 Conclusions

8.1 Key behaviours impacting on air quality

This rapid evidence review aimed to provide evidence on the key behaviours that impact on air quality to inform future public engagement. Specifically, we sought to identify the behaviours that have the greatest impact on improving air quality, and assess the motivations and barriers associated with these behaviours in relation to the COM-B framework for behaviour change.

The review highlighted that, of the large body of literature on air quality issues, very little frames air quality specifically in behavioural terms. We found no review papers evaluating the relative impacts of different behaviours across the spectrum of behaviours relevant to air quality. As highlighted in section 3, quantifying and comparing the impacts of different behaviours is challenging for a range of reasons. As a result, we were not able to draw direct conclusions about the relative impact of different behaviours that would allow us to prioritise behaviours. We were, however, able to synthesise a set of eight key behaviours for air quality improvement that are supported by evidence. These behaviours centre around the areas of reducing car use, switching vehicle, driving differently and heating the home differently.

8.2 Use of the COM-B to underpin design of policy interventions

Our high-level analysis of the factors influencing the key behaviours using the COM-B framework highlights the wide range of motivations and barriers at play. It is essential that the design of interventions for behaviour change take into consideration the full range of factors influencing behaviour. The COM-B model highlights that increasing motivations to perform a behaviour will not result in behaviour change in the absence of supporting conditions that foster opportunity (such as supporting infrastructure and social norms) as well as individuals' capability. Behaviour change interventions often focus solely on persuasive communications (targeting motivation) or raising awareness, both of which are limited in their effectiveness when employed alone (Whitmarsh et al., 2021). Part of this is a result of the conceptual models that we use (explicitly or implicitly) to understand behaviour, with models such as the knowledge-deficit model and psychological models of motivation having had enduring influence on intervention design. Integrative models such as the COM-B (and the Scottish Government's Individual-Social-Material, ISM, framework) offer promise in that they can help to underpin the design of more effective combinations of interventions that can create the necessary conditions for behaviour change.

The COM-B framework may also help to tackle perceptions that policy focusing on behaviour change seeks to shift responsibility for change onto individuals and away from government and institutions. In highlighting the importance of capability and opportunity as well as motivation, it prompts intervention designers to consider possibilities for intervention at different points in a system, engaging actors from across society in delivering change.

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10 Appendix A: Literature review methodology

10.1 Identification of relevant literature

Literature searching was conducted in two phases:

Phase 1: Broad search to identify relevant behaviours and their impacts

Academic literature

In order to get a broad view of the academic literature on air quality related behaviours, we conducted searches on the Web of Science database. The search terms used in this initial search are noted in the table below. The search was confined to English language papers. The search results were screened by one of the team (JC) for relevance. Sources taken forward for review were classified as high, medium or low priority. Review papers of relevance were given high priority for reviewing. Relevant data was extracted in note form by two members of the team (JC and KC).

Table A.1: Search terms for phase 1 academic literature searching

Search terms	Total articles	Review articles	Selected articles
ALL = ("air quality" AND "behav*")	4537	251	0
ALL = ("air quality" AND "behav*" NOT "indoor")	3217	144	16
ALL = ("air quality" AND "behav*" NOT "indoor") refined by document type: review article	467	230	4
ALL = ("air quality" AND "human impact")	22	5	2
ALL = (source AND air pollution)	15047	2140	0
ALL = ("source" AND "air pollution" NOT "indoor")	13599	601	
ALL = ("source" AND "air pollution" NOT "indoor" NOT "health?")	13466	590	3
ALL = ("household" AND "emission")	2837	130	8
ALL = ("household" AND "emission" AND "air quality" NOT "indoor")	146	2	1

Grey literature

Grey literature was searched using Google's site search function, which allows Boolean searching of webpages. Searches were performed (by PS) for the websites of the key organisations listed below, using combinations of the same keywords used in the search terms listed above. Search results were screened for inclusion – only research reports or data reports relevant to behaviours impacting on air quality were included. Other website material (e.g. news stories, policy documents) was excluded.

Table A.2: Key organisational websites searched for grey literature reports

• The Scottish Government • Scottish Environmental Protection Agency • Scottishairquality.scot • Friends of the Earth • Cycle in Scotland • Living Streets	• DEFRA • Gov.uk • European Environment Agency • British Heart Foundation • Asthma + Lung UK • Air Quality Expert Group (DEFRA) • Local Authorities

Additional sources

In addition to the sources identified through the searches of academic and grey literature, other relevant material was included based on our knowledge of literature from previous projects carried out by ourselves and other Hutton colleagues, and 'snowballing' (identification of relevant material from reference lists of reviewed papers).

Phase 2: Behaviour-specific searches

Having completed the broad searches to identify the relevant behaviours, ad hoc searching was done using Web of Science and Google Scholar to provide more information about the specific behaviours identified (e.g. on active travel, domestic burning etc.). The purpose of these additional searches was to address gaps in evidence from the broad searching and gather evidence specifically on the factors influencing uptake of behaviours (which was only partially captured in the previous searches that excluded sources that did not focus on air quality specifically).

10.2 Limitations of the approach

Due to time and budget constraints, it was not possible to employ a more systematic review method incorporating structured screening and data extraction. This means that although we have aimed to provide as comprehensive as possible an overview of the relevant literature and transparency about the search strategy adopted, the review methodology was not standardised or replicable.

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