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Emissions impact of home working in Scotland

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Executive summary

Working from home (WFH) has the potential to reduce carbon emissions associated with commuting and office space. However, these reductions must be balanced against an expected increase in emissions from heating and other energy use at home. As a result, the net impact has been unclear, and findings from other countries are not easily transferrable to Scotland due to differences in local housing stock and commuting behaviour.

Home working has increased sharply as a result of the Covid-19 pandemic and for many people home working is expected to play an increased part of their working behaviour in the future, even if only for part of the working week. This report assesses the impact of home working on Scottish greenhouse gas (GHG) emissions by analysing:

- the Scottish-specific emissions impact of home working; and
- the drivers in personal emissions increases and decreases from a switch to home working.

The aim is to inform the policy debate around actions which can be taken to maximise emission reductions and minimise emission increases for those people who decide to work from home full or part time.

Key findings

Working from home leads to a reduction in commuting and office emissions and an increase in home emissions. How these emission changes balance out for an individual defines their emissions impact from home working.

The analysis has found that if post pandemic trends result in a higher proportion of people working from home across all types of houses and commuting behaviours, the overall impact on emissions will be small:

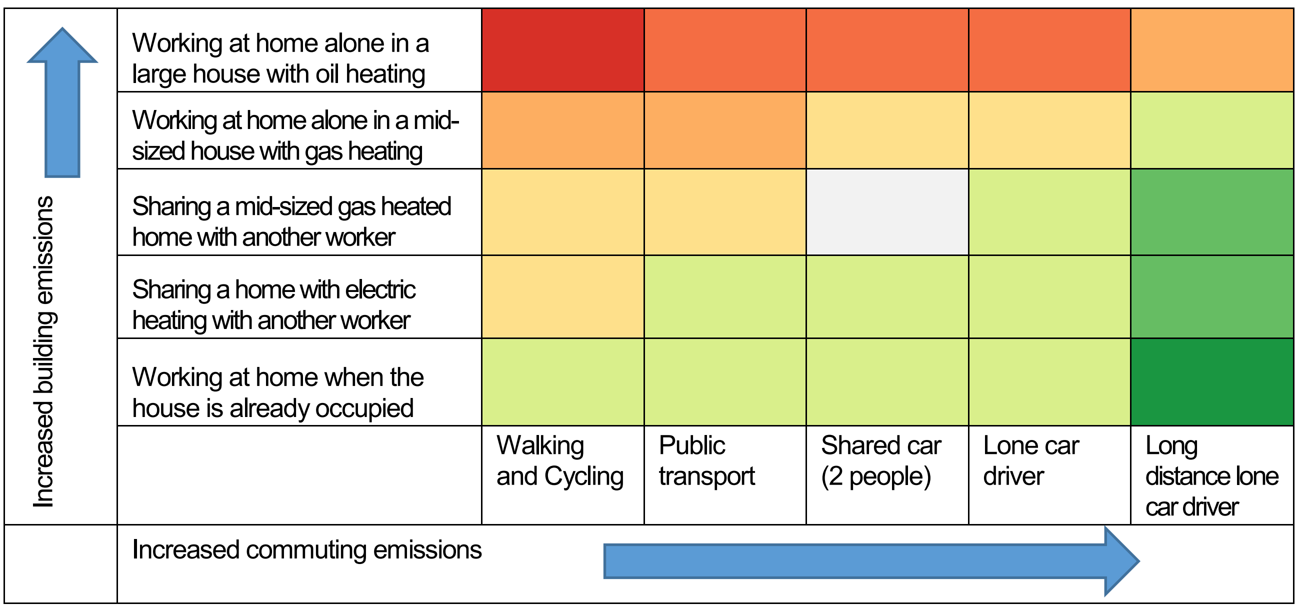
- A 0.6% reduction in buildings and transport emissions if a mix of people with different house types, and heating and commuting behaviours work from home
- A 0.6% increase in buildings and transport emissions if whole houses are heated all winter for home workers and office space remains open

- A 2.0% reduction in buildings and transport emissions if only the home office areas of homes are heated, office sizes are reduced to reflected reduced demand, and working from home proves more popular with car commuters

However, Scotland is targeting a 75% reduction in emissions between 1990 and 2030; at this level of change in such a short period, every emission reduction pathway should be considered and actions which increase emissions avoided.

The emissions outcome at an individual level depends on the house type and the commuting behaviour.

Table 1: Overview of emissions impact of home working. Green = emissions saving from home working. Red = emissions increase from home working. White = no change



As demonstrated in Table 1 above, working from home can have a wide range of positive and negative emissions impacts based on an individual's personal circumstances. Key emission trends across commuting and housing conditions are summarised below.

Findings relating to commuting behaviours

- Working from home almost always increases emissions for people who use active travel to get to work. The only exception is when the home is already occupied and heated before the switch to home working. In this case very little emission change is observed.
- For people who commute by public transport or shared car, emissions can increase or decrease from home working, depending on their house situation, although for most of these people working from home will increase emissions.
- For people who commute short distances by car, emissions can increase or decrease from home working, depending on their house situation, although for many of these people working from home will decrease emissions.
- Most people with a long car commute will see a reduction in emissions from home working with the exception of people with large rural properties heated by oil.

Findings relating to house types, heating technologies and working from home behaviours

- Working from home (WFH) always reduces emissions if the worker is joining another person who was already occupying the house during the typical working day.

- Emissions are reduced in almost all cases where WFH takes place at a home heated with a low carbon technology (such as electric storage heating or biomass).
- If multiple home workers can share the same building, this improves the emissions benefits significantly in all cases, with savings found in all cases except for the largest fossil fuel heated homes and active travel commuters.
- The impact of varying space heating, cooling and lighting energy use in the workplace is generally small compared to the dependence of emissions savings on transportation type and home type. This has major implications for businesses wishing to reduce emissions as it shows that providing information to employees that helps support informed decision making, can be as important as actions taken directly by businesses.

Conclusions

Domestic heating is a large emission source which can offset much of the transport emissions savings of home working. Limiting domestic heating emissions through the rollout of smart heating systems, which only heat occupied areas of the house, would deliver the single biggest emission benefit from home working.

Transport Scotland has committed to a 20% reduction in car kilometres by 2030 (against a 2019 baseline) as part of the 2020 update to the Climate Change Plan. This will require policies which disincentivise car use for commuting. The lowest emission future is one where people commuting short to medium distances do so by public and active travel and continue to commute to the office, while people who commute long distance shift to working from home. This divide in behaviour might be a reasonable response to policy discouraging car use, as people travelling short distances are more likely to be in urban areas where working from home might be less convenient due to smaller house sizes and access to public transport is good. Long distance commuters are less likely to have a public transport alterative and may respond by working from home.

The lowest emission working behaviour is a short commute to work in an energy efficient office. Changes to the Scottish National Planning Framework to support localism and the 20-minute neighbourhood concept could also look to support local shared office space to encourage the lowest emission working behaviour.

A clever reimagining of existing office space, freed up by more people working from home, could be supported by the planning process. This could create new opportunities for people who want to live in city centres, but have not been able to afford it in the past, to move into the city, reducing their trip distances for most trips and therefore their broader transport emissions.

Larger properties with oil heating represent the worst place to work from home in terms of emissions. Targeting these properties for early decarbonisation can help to ensure working from home reduces emissions.

The emissions impact of home working does not vary very much between employment sector and workplace type as the emissions are predominantly decided by home heating and commuting behaviour. This means similar messaging around home working can be shared across employment sectors.

People who see an emissions saving from working from home today will also see a benefit in 2030[1]. This means messaging around good working from home practices will remain relevant over time.

[1] Assuming they do not move house, thereby changing their heating and commuting needs.

Contents

1 Introduction

Restrictions during the Covid-19 pandemic have resulted in unprecedented levels of working from home. Prior to this study it was uncertain what impact a shift to working from home has on greenhouse gas emissions in Scotland. Working from home is a behavioural change with the potential to reduce carbon emissions in some cases, since emissions associated with transportation during the commute and workplace energy use are both reduced. However, these reductions must be balanced against an expected increase in emissions associated with heating and other energy use at home. As a result, the net impact has been unclear. This research was therefore commissioned to inform green recovery policies by improving the understanding of the potential impact on emissions of encouraging and supporting continued high levels of home working in Scotland.

1.1 Aims and scope of the study

The objective of this study is to understand how the positive and negative emissions impacts of working from home balance out in the specific case of Scotland and for a range of individual circumstances. In particular, the following research questions are considered:

1. What is the estimated impact of changes in the proportion of people working from home on Scotland's green-house gas emissions?
2. How do these emissions impacts vary according to the specific circumstances of home working, including:
    - Location of home and workplace
    - House type and heating system
    - Commuting travel mode and distance
    - Season
    - Employment sector
    - Impact today versus in the future
3. What are the implications of Scottish and UK Government policies and/or targets on the potential future impact of home working on achieving Scotland's emissions reduction targets up to 2045?

The scope of this study is limited to consider only the implications of working from home (WFH) on greenhouse gas emissions in Scotland. Changes in the levels of working from home will have a range of other important impacts, such as to wellbeing, the economy and equality, which are **not considered** in this work. Additionally, we consider only the direct impacts of working from home when assessing greenhouse gas emissions. These direct impacts are defined as the changes in energy use at home, at the workplace and for transportation (including changes to non-work travel) occurring when switching to work from home. Indirect effects which are excluded from consideration, include additional emissions such as those associated with greater consumption owing to increased disposable income when avoiding commuting or the impacts of changing building purposes if city office space is repurposed for housing and retail.

1.2 Context for the study

The existing body of literature on the potential impacts of remote working on energy use and greenhouse gas emissions suggests that, while emissions savings can be achieved, this is not always the case[2]. The principal contributions to be considered in assessing the emissions impact are in general found to be:

- Commuting
- Home energy use
- Office energy use
- Non-work travel

An important point made in several studies reviewed is that few studies simultaneously consider all the above changes, such that a comprehensive assessment of the full impact of working from home cannot be made[3].

The literature reviewed highlights various complicating factors which should be considered to enable an accurate assessment of the impacts of working from home in any specific case. These include:

- Occupation of the house during the working day prior to beginning WFH.
- Heating pattern of the home (e.g. whole house or one room).
- Household's heating system and level of energy efficiency.
- Season in which WFH takes place.
- Number of home-workers sharing the same household.

See appendix 6.5 for more details on the findings of the literature review undertaken.

1.3 Scotland's baseline greenhouse gas emissions

Behavioural shift towards working from home has the potential to directly and significantly impact emissions from surface transport and energy use in residential and non-residential buildings. These sectors collectively account for approximately 34% of Scotland's greenhouse gas emissions, as shown in Figure 1, below.

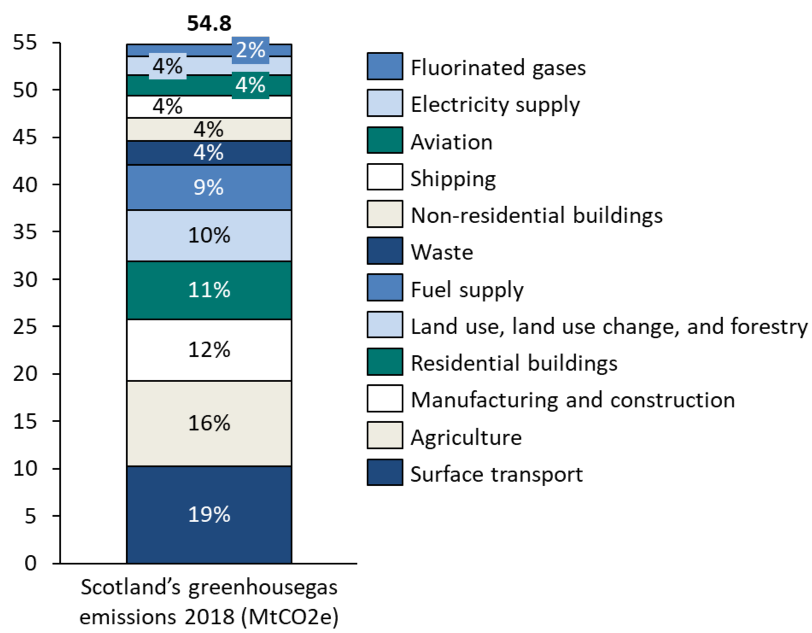


Figure 1: Breakdown of Scotland's greenhouse gas emissions by source, from the Committee on Climate Change's 6th Carbon Budget[4]

[2] For example, 26 out of 39 studies in one meta-analysis, *A systematic review of the energy and climate impacts of teleworking* – Environmental Research Letters, 2020, find that teleworking reduces energy use.
[3] For example, see *Does telecommuting save energy? A critical review of quantitative studies and their research methods - O'Briena et al.*
[4] https://www.theccc.org.uk/publication/sixth-carbon-budget/

Table 2 also shows this breakdown of emissions as an absolute value per person, in tonnes of CO_2 equivalent (CO_2e). Scotland's emissions from the surface transport, residential buildings and non-residential buildings sectors sum to 3.5 tonnes CO_2e per person.

Table 2: Breakdown of Scotland's emissions by source, and per person, from the Committee on Climate Change's 6th Carbon Budget

Sector	Percentage of Scotland's emissions	Total emissions (MtCO2e)	Emissions per person (tCO2e/person)
Surface transport	19%	10.29	1.89
Agriculture	16%	8.99	1.65
Manufacturing and construction	12%	6.5	1.19
Residential buildings	11%	6.13	1.13
Land use, land use change, and forestry	10%	5.42	1.00
Fuel supply	9%	4.78	0.88
Shipping	4%	2.37	0.44
Non-residential buildings	4%	2.45	0.45
Waste	4%	2.46	0.45
Aviation	4%	2.14	0.39
Electricity supply	4%	1.94	0.36
Fluorinated gases	2%	1.35	0.25

2 Method

This chapter provides a high-level overview of the method taken for the lay reader. For more detail on the method and assumptions used please refer to Appendix 6.1.

2.1 Overview

Figure 2 shows an overview of the method used in this study. The method combines a model of the Scottish housing stock with a model of transport patterns and land use. Once a workplace, house type and commuting pattern is assigned to each person, emissions are calculated using emission factors for home and office heating and transport, which are representative of the average in Scotland (for example, the emission factor per kilometre for cars is for the average car in the Scottish fleet).

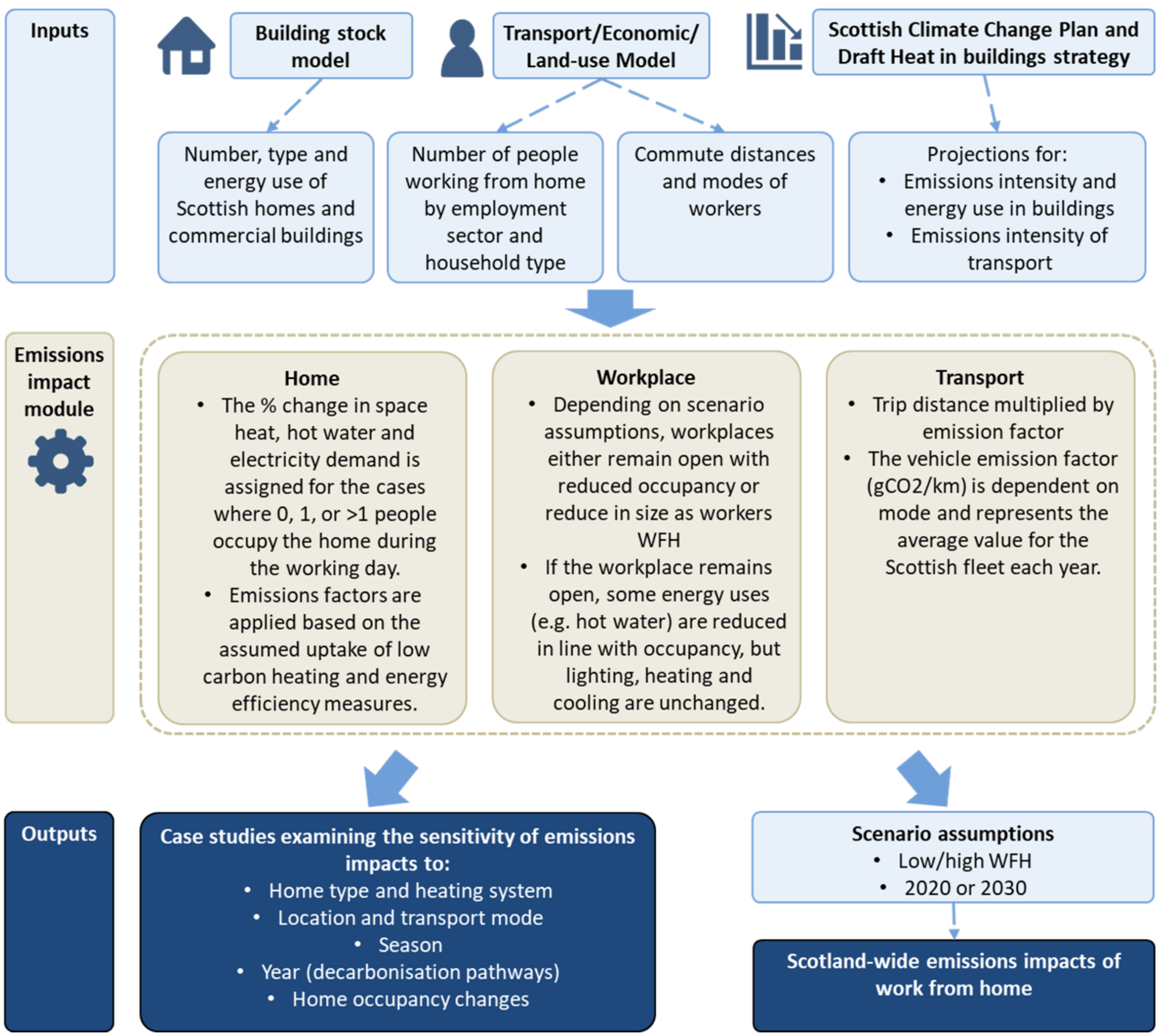


Figure 2: Overview of the study methodology

At the Scotland-wide level, we examine the emissions impact of working from home under four scenarios, defined by (i) the year, and (ii) the assumed pattern of working from home across the Scottish population. Table 3 describes these four scenarios. We take 2019 as our base case for national emissions scenarios rather than 2020 since we do not model the exceptionally high levels of working from home during the pandemic.

Table 3: Scenarios used to examine national emissions impacts of working from home

High Working from Home ↑	**Post Pandemic Working Pattern Shift** Emissions if a high proportion of people worked at home given today's building, heat and transport technology	**Long-Term Working Pattern Shift** Emissions in 2030 if a high proportion of people work from home and the carbon intensity of heating and transport has improved
Low Working from Home	**2019 Base Case** 2019 emissions	**Return Towards Old Working Patterns** Emissions in 2030 if a low proportion of people work from home but with improved carbon intensity of heating and transport
	Now →	Future

To answer the research questions introduced in 1.1, we take into account the specific context of Scotland when considering the following modelling inputs:

Table 4: Key model inputs and their data sources

Model input	Data source(s)
Scottish vehicle stock today and in the future	Element Energy vehicle sales and stock model used to model the emissions impact of the introduction of low and zero emission vehicles for Transport Scotland
Scottish building stock today and in the future	Element Energy building stock model, Scotland's Non-Domestic Energy Efficiency Baseline (Dec 2018), Scottish Household Survey, Scottish House Condition Survey
Scottish travel behaviour by region and employment sector	Transport Economic Land Use Model of Scotland (TELMoS), developed by David Simmonds Consultancy (DSC), and the Transport Model for Scotland (TMfS).
Future working from home behaviour projections	Transport Economic Land Use Model of Scotland (TELMoS)

2.2 Sector decarbonisation pathways

The building and transport emission factors used in the model have to be projected into the future to understand the fleet average home, office and transport emissions in 2030 following the decarbonisation pathway set out in the Scottish Government's Climate Change Plan update published in December 2020.

Buildings

Decarbonisation pathways for the buildings sector are defined by:

1. The deployment of low carbon heating (LCH) technologies, such as heat pumps.
2. The improvement of building energy efficiency through deployment of measures such as wall and loft insulation.
3. Changes in the carbon intensity of the electricity grid.

Our 2030 scenarios assume that the latest policies and targets set out in the Scottish Climate Change Plan Update (2020)[5] and Heat in Buildings Strategy Consultation (2021)[6] are met. The key targets used to define our 2030 scenario are set out in Table 5, below. The buildings decarbonisation pathway assumed is ambitious, with 50% of homes converted to a low carbon heating system by 2030. The targets referenced in this section are not prescriptive with respect to which technologies will make up the deployed low carbon heating. For this work, we assume these are a mix of electric heat pump systems, with a representative seasonal performance factor of 280%.

Table 5: Key targets used to define the 2030 decarbonisation pathway for buildings

Theme	Metric	Target value by 2030	Source
Low carbon heating (LCH)	Uptake of LCH in domestic buildings	1 million units deployed	Heat in Buildings Strategy Consultation (2021)
	Uptake of LCH in non-domestic buildings	50,000 units deployed	
	Uptake of LCH in off-gas homes using oil, LPG or solid fuels	75%[7]	
Building energy efficiency	Reduction in domestic energy use relative to 2020	18%	Scottish Climate Change Plan 2018[8]
	Reduction in non-domestic energy use relative to 2020	17%	
Electricity grid decarbonisation	Carbon intensity	50 g CO_2e per kWh[9]	Scottish Climate Change Plan 2018

[5] Securing a Green Recovery on a Path to Net Zero: Climate Change Plan 2018-2032 - Update, December 2020, Scottish Government
[6] Heat in buildings strategy - achieving net zero emissions: consultation, February 2021, Scottish Government
[7] This target is phrased as the “vast majority” rather than a quantitative value in the heat in Buildings Strategy Consultation
[8] Targets in the Climate Change Plan refer to a 2015 baseline (see page 96), but have been adjusted to a 2020 baseline.
[9] This target has already been achieved as of 2018, according to the Climate Change Plan (2018)

Transport

The transport emissions pathways for cars, buses and trains used in the model have been developed by Element Energy for Transport Scotland to meet Scotland's transport emissions envelopes for 2030, 2040 and 2045. This work has fed into the December 2020 update to the Climate Change Plan which shows the pathway needed to reduce domestic transport emissions by 55% by 2030[10].

2.3 Limitations of the model

There are several limitations of our modelling approach, which should be noted when interpreting the findings.

1. In our central case we assume that seasonality does not change WFH behaviour; i.e. our model captures heat and cooling demand shifts between summer and winter, but not increased/decreased WFH by season, except where investigated as a specific sensitivity in the results analysis Section 4.2.

2. We consider the "direct" impacts of WFH only; wider effects of increased WFH on society and the economy are not modelled. For example, we make no consideration of increased disposable income (and thus consumption, flights etc.), repurposing of unused office space, or the possible impact of people working from home wanting to get out and about and taking new trips (additional trips which used to be part of the commute e.g. taking children to school on the way to work, has been corrected for). Although location-related commuting effects are captured if households move to different areas (e.g. if remote working encourages relocation from urban to rural locations, non-commuting trips (and of course any continuing if less frequent commuting trips) will typically be longer).

3. Smaller direct emissions sources are neglected. For example, we do not quantify increased emissions from internet usage for more video conferencing and use of emails.

4. There is limited data linking the physical home building type (e.g. flat vs detached house) to the employment sector of occupants, increasing the uncertainty in the assignment of home-workers to particular building types within our Scotland-wide emissions scenarios.

[10] Scottish Government, 2020, Update to the Climate Change Plan, https://www.gov.scot/binaries/content/documents/govscot/publications/strategy-plan/2020/12/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/documents/update-climate-change-plan-2018-2032-securing-green-recovery-path-net-zero/update-climate-change-plan-2018-2032-securing-green-recovery-path-net-zero/govscot%3Adocument/update-climate-change-plan-2018-2032-securing-green-recovery-path-net-zero.pdf?forceDownload=true

3 Nation-wide emissions impacts of home working

This chapter looks at the Scotland-wide emissions impact of home working. This is explored through four scenarios which look at the emissions (this includes emissions from home heating and electricity; office heating, electricity and air conditioning; and commuting travel) at a Scotland-wide level if a high proportion of people work from home or a low proportion of people work from home in 2019 and 2030.

3.1 Overview of the national scenarios modelled

As set out in detail in the appendix, two models, the Transport Economic Land-use Model of Scotland (TELMoS18) and the Transport Model for Scotland (TMfS18) have been used to model working from home behaviour and the resulting commuting trips in 2019 and 2030.

ONS 2019 data on the proportion of people working at home by industry is carefully processed to estimate in the base year the proportions of workers in each employment activity and socio-economic level that work at home on an average day.

It was estimated that in Scotland in 2019, 9% of workers who have a conventional non-home workplace within Scotland worked remotely on an average working day. The agreed assumption for STPR2 (project commissioned by Transport Scotland to integrate home-working) is then that by 2025:

- under the “low WFH” scenario, remote working will increase such that, in the absence of any other changes, the number of people commuting to work would decrease by 15% compared to the pre-pandemic situation (2019); and
- under the “high WFH” scenario, remote working will increase such that, in the absence of any other changes, the number of people commuting to work would decrease by 25%, again relative to the 2019 level.

Note that these assumptions are defined as what would happen if there was no change in total employment or in the mix of jobs by activity and socio-economic level. The outcome in the 2030 model runs is expected to be (slightly) different depending on the changes in the level and mix of employment.

To implement the remote working proportions, the remote-working proportions estimated in 2018 are reapplied to the forecast year data (2019 or 2030), so as to take account of any changes in the mix of employment that would themselves change the overall level of remote working, and then adjusted so as to match the required overall level (9%, 15% or 25% as appropriate).

The scaling has been done so that:

- job type/income level combinations which have 0% remote working in 2018 continue to have 0%;
- job type/income level combinations which have very low levels of remote working in 2018 continue to have low levels; and
- none of the proportions goes above an assumed upper limit of 60%.

3.2 Results

Figure 3 shows the overall impact of our WFH scenarios on Scotland’s greenhouse gas emissions arising from domestic and non-domestic buildings, and commuting. Only transport emissions associated with commuting are included. We see that under our central modelling assumptions, increasing the number of people working from home reduces greenhouse gas emissions. In 2019, increasing the number of remote workers from 9% to 32% of the workforce decreases emissions by 108 kt CO_2e. In 2030, a smaller increase in the number of remote workers, from 23% to 32% results in a reduction in emissions of 107 kt CO_2e. The 2019 reduction in emissions associated with a high WFH scenario represents 0.2% of Scotland's total greenhouse gas emissions or a 0.6% reduction in transport and building emissions. Appendix 6.2 gives the full table of emissions under each of these scenarios, in kt CO_2e, and as a fraction of the total emissions from buildings and all surface transport in Scotland in 2018.

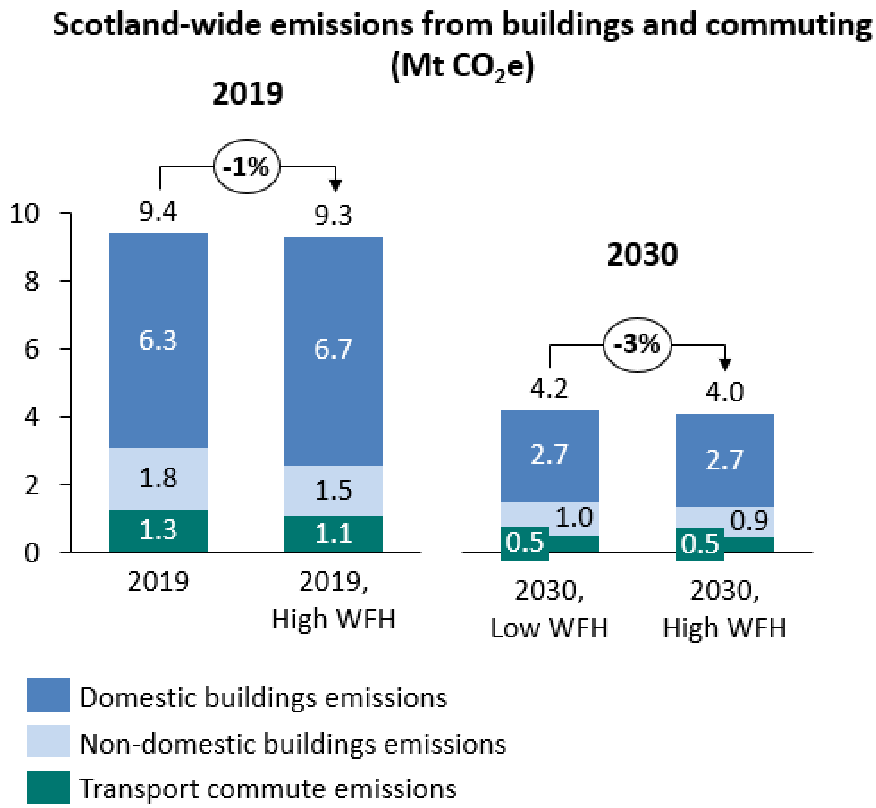


Figure 3: Emissions impact of society wide WFH scenarios, in 2019 and 2030 for Scotland

3.3 Sensitivity analysis

There are several significant assumptions within the modelling process for which values have been necessarily assumed, but for which data availability is limited. In this section, we investigate the sensitivity of the results presented above to these assumptions, which include:

- The day-time home heating behaviour of those working from home (high impact)
- The response of office space to reduced occupancy (high impact)
- Future expansion of workplace energy use for cooling (low impact)[11]

These sensitivities are examined in

Figure 4 and

[11] A corresponding increased cooling demand in homes by 2030 was not included since domestic air conditioning is much less common in Scotland and is expected to remain so even considering the expected increased average temperature in 2030. Cooling degree days (CDDs) were under 10 in Glasgow in 2020 (at base 21C), and are not expected to increase sufficiently by 2030 to drive significant air conditioning uptake – see appendix 6.1, Future cooling demand projections.

Figure 5, in which "best" and "worst" case scenarios for WFH are constructed. The "best" case for WFH is defined to assume a low home heating energy use case, in which workers at home are assumed to reduce their heated hours and/or space such that heating energy use is reduced by approx. 50% relative to the central case. In addition, the "best" case for WFH assumes that workplace floorspace reduces in proportion to the reduction in attending workers, and that office cooling energy demand decreases by 25% by 2030 relative to the central case[12].

In contrast, the "worst" case for WFH is defined to assume a high home heating energy use case, in which workers at home are assumed to heat their full house for all hours spent at home, resulting in an energy use 10-20% above the central case (depending on the number of workers sharing the home). Additionally, this "worst" case also assumes that office floor space remains unchanged despite additional homeworking. This means that energy use in the workplace for heating, cooling, and lighting are unaffected by the additional home working.

We find that under the "best" case assumptions for working from home, emissions savings in 2019 under the high WFH scenario would be 350 kt CO_2e, 3.2 times higher than the equivalent savings under the central assumptions. Under the "worst" case assumptions we see that a high level of WFH in 2019 increases the overall emissions from buildings and commuting by 1%, reversing the effect under the central case. By 2030, the sign of emissions change is reversed however, such that even under these "worst" case assumptions, increasing the WFH levels does decrease overall greenhouse gas emissions, albeit only by less than 1%.

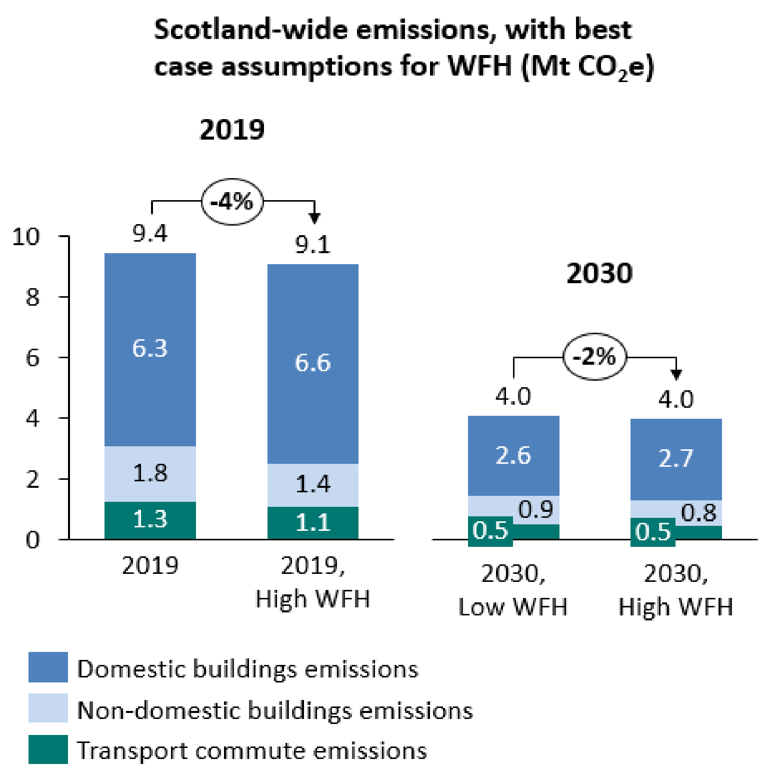


Figure 4: Emissions impact of society wide WFH scenarios, in 2019 and 2030 for Scotland, with best case assumptions on home heating patterns, workplace energy use and workplace floor space reductions

[12] The increase in cooling is taken to be equal to the increase in cooling degree days (CDDs) in London 2020-2030, which is interpolated from two data points for 2015 and 2050 (CDDs of 77 and 154, respectively). Source: *Element Energy, London's Climate Action Plan: Zero Carbon Energy Systems, Annex on Less energy efficiency and cooling uptake. Table 3-2*. The Original data source is *A. Day, P. Jones, G. Maidment, Forecasting future cooling demand in London. Energy Build, 2009*. https://doi.org/10.1016/j.enbuild.2009.04.001.

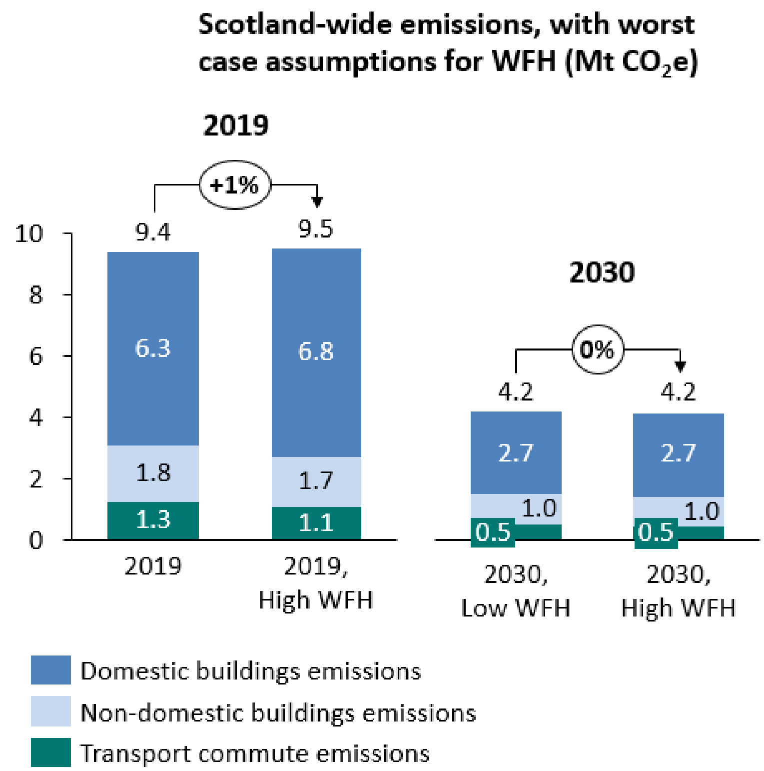


Figure 5: Emissions impact of society wide WFH scenarios, in 2019 and 2030 for Scotland, with worst case assumptions on home heating patterns, workplace energy use and workplace floor space reductions

3.4 Targeted working from home

The above results demonstrate that, averaged across all Scottish households, working from home has relatively minor impacts on emissions due to the balancing between positive and negative changes. However, in many individual circumstances, such as if the worker has a long car commute or is in a home heated with a low carbon technology, working from home will have more significant emissions savings. This is shown in more detail through the case study analysis in Chapter 4. As a result, in the scenario we explore the potential impact were policy to successfully encourage only those who stand to reduce emissions by working from home to do so. Such precise targeting is unlikely and so this scenario represents an upper bound on potential emissions savings.

In Figure 6 we show the emissions impact of the four scenarios defined in Section 3.1, if instead of the predicted cross-section of Scottish workers taking up WFH, only those workers who stand to reduce their personal greenhouse gas emissions by working from home do so. This means that the same overall number of homeworkers is assumed in each scenario, but in this case, these workers are assumed to be those with commutes taken by car, and with homes with lower energy demands and less carbon intensive heating systems.

This scenario represents an upper bound on the emissions reductions which could be achieved via highly targeted policy given the challenge of influencing specific groups through policy, assuming the number of people who can work from home is capped at the levels described in Section 3.1. However, more than the 32% of the working population which WFH under the high WFH scenario would see an emissions saving from homeworking, so the national emissions saving could be higher if homeworking is more popular than predicted. The results presented in Figure 6 also assume the central case from the sensitivities described in Section 3.3, and so a larger emissions saving could be found were the “best” case for WFH assumptions to be applied. This targeted WFH results is a 225 kt

CO_2e saving in 2019, doubling the emissions saving compared to the 108 kt CO_2e saving associated with the non-targeted high WFH 2019 scenario. This saving represents a 1.2% reduction in transport and building emissions.

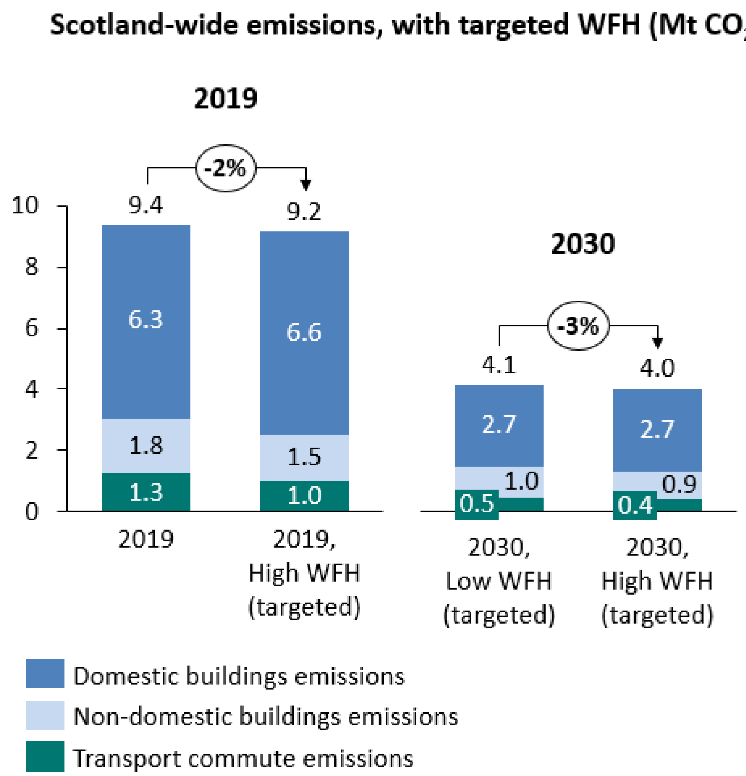


Figure 6: Emissions impact of society wide WFH scenarios, in 2019 and 2030 for Scotland, assuming only those workers who save emissions by working from home do so

3.5 Implications of national findings

This chapter has looked at the impact of home working across Scotland under four scenarios where the selection of homeworker's is based on job type, income, household type etc. and an overall estimate that 15-25% fewer people commute to work in the future relative to 2019. Under these conditions we do see an emissions benefit from home working although this is quite small as a range of people are expected to work from home who will experience both an increase and a decrease in personal emissions resulting in a smaller net benefit at a national level.

Given the broader possible impacts of home working including effects on mental health, control of working hours, and equal access to opportunities, a blanket approach to homeworking does not seem appropriate. Instead, a much more targeted approach, which focuses on specific user groups who have the most to gain from home working and can see the largest emissions savings, would deliver the greatest benefits. A detailed sensitivity analysis of different user groups is conducted in the next chapter to identify the groups current or future policy could consider supporting with home working to minimise emissions in Scotland.

4 Case study emissions impacts of home working

4.1 Overview of case studies and sensitivities modelled

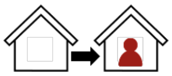
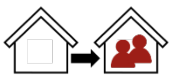
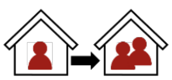
In this section, we investigate how the impact of working from home on personal carbon dioxide emissions footprints varies, according to the following factors:

Table 6: Factors affecting work from home emissions impact, which are explored through case studies

Factor	Impact
Home type	Larger and/or less energy efficient homes require greater energy use to heat when working from home
Home heating system	Fossil fuel-based heating systems cause greater carbon emissions per unit heat delivered
Location (urban/rural)	The prevalence of home types, heating system, transport mode and trip length vary by urban/rural location.
Transport mode used for commute	If a worker already travels to work using low carbon means (e.g. cycling), this reduces the potential of working from home to reduce commute emissions.
Season	Emissions associated with space heating at home are assumed to be zero in summer
Year (2019 or 2030)	Both transportation and heat in buildings are likely to significantly decarbonise by 2030, at different rates, changing the overall balance of emissions impact of WFH.
Type of home occupancy change resulting from working from home	The change in occupancy of each home during the working day caused by the specific worker who begins working from home has a large impact on the attributed emissions change. Where multiple workers occupy the same house during the day, the additional heating emissions are shared between them. Where a worker begins to work from home in a previously occupied house, the resulting additional energy use is small compared to the case where the house was previously unoccupied.

Table 7: Day-time occupancy change classes considered in case studies sets out the particular occupancy change cases we explore in the case studies below. Each case is assigned a graphic representation, shown in the left-hand column, which is used in the charts following to show which assumption is being made.

Table 7: Day-time occupancy change classes considered in case studies

Label	Description
0 to 1 	An individual begins to work from home in a house which was previously unoccupied during the day, and is thereafter only occupied by that individual.
0 to 2 	An individual begins to work from home in a house which was previously unoccupied during the day, but will thereafter be occupied by multiple home-workers.
1 to 2 	An individual begins to work from home in a house which was previously occupied during the day, and will thereafter be occupied by multiple people.

4.2 Results

Overview

Figure 7 gives the emissions change allocated to an individual worker, as a result of their switching to work from home. In this case, the assumed occupancy change is from a previously unoccupied home to one with 2 or more home workers. The "urban", "suburban" and "rural" cases impact the home type and heating system, the transport mode and trip length. The single most common home type, heating system and transport case is selected for the "urban", "suburban" and "rural" categories, except for "rural" where the two most common cases are shown[13].

[13] 41% of the rural building stock is heated using gas, and 29% using oil.

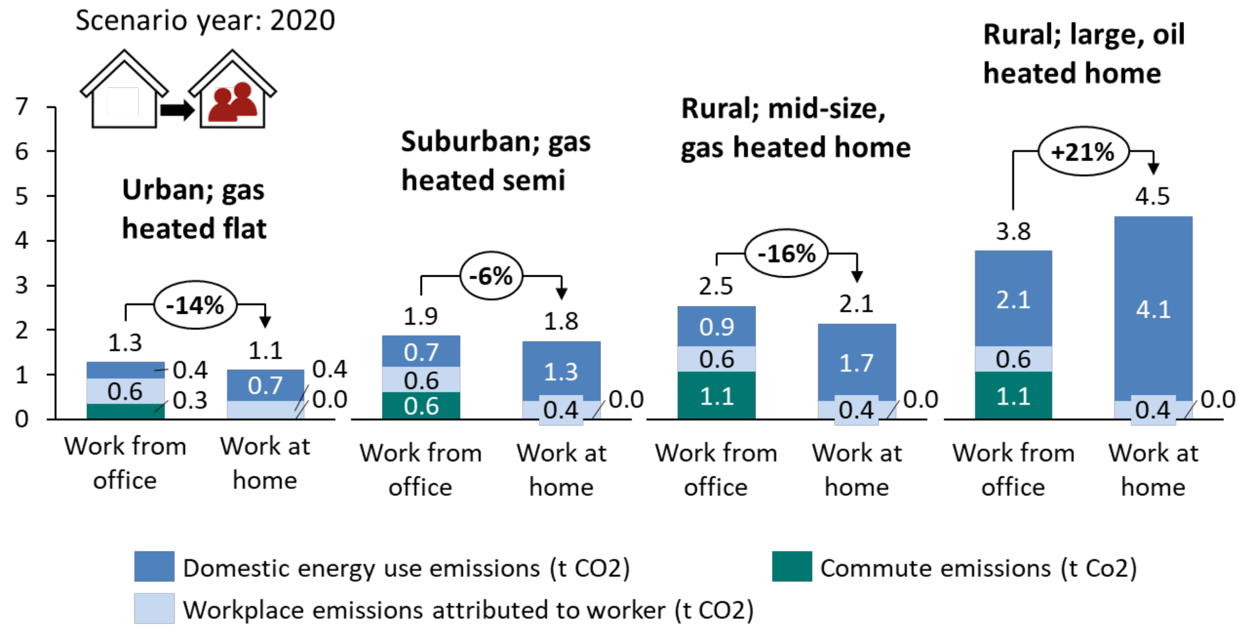


Figure 7: Change in personal emissions due to working from home in 2020, for the ‘0 to 2’ day-time occupancy change case

Figure 7 shows that working from home has the potential to reduce or increase one’s personal carbon footprint. In most cases, if the emissions associated with heating the home during the working day are shared between multiple home workers (the ‘0 to 2’ case) then the savings associated with reduced office energy use and, principally, reduced transport emissions outweigh the additional home emissions to result in a carbon saving from WFH. However, this is not the case for the largest and most carbon intensively heated homes (such as the ‘rural, large, oil heated’ case).

These results are sensitive to the assumed shift on occupancy on starting WFH. Figure 8 and Figure 9 below, show the equivalent results in the ‘0 to 1’ and ‘1 to 2’ cases, respectively. We see that where the full home heating emissions are assigned to only a single home-worker (Figure 8), switching to WFH **increases** emissions in all cases. Conversely, in the case where the home was already occupied during the working day (Figure 9), their switch to WFH only causes a slight increase in the home energy use, and as a result, working from home **reduces** that individual’s overall carbon footprint in all cases.

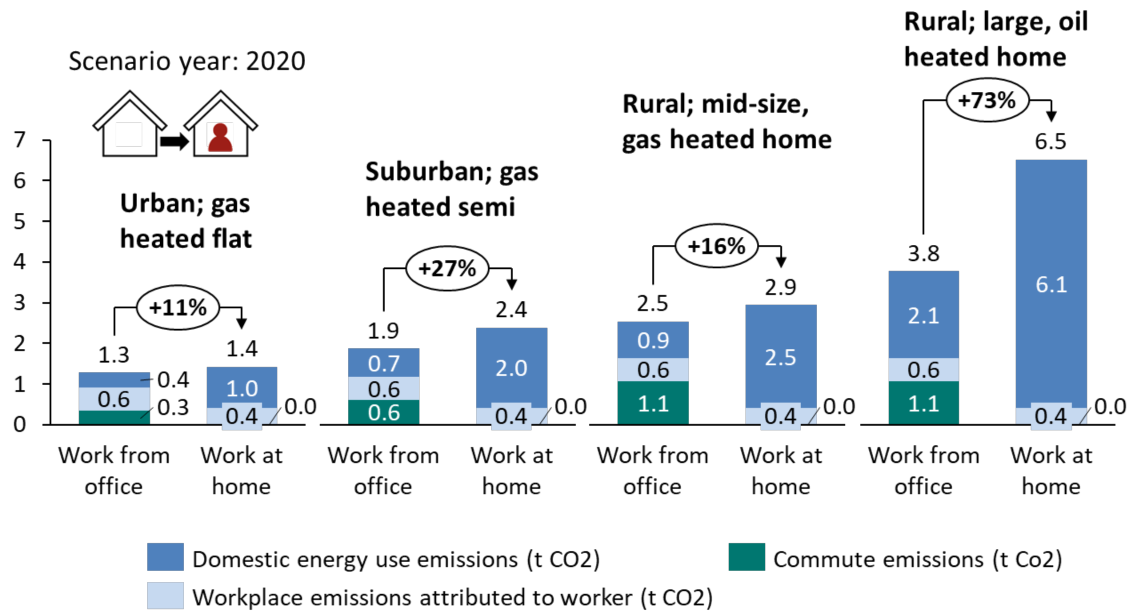


Figure 8: Change in personal emissions due to working from home in 2020, for the '0 to 1' day-time occupancy change case

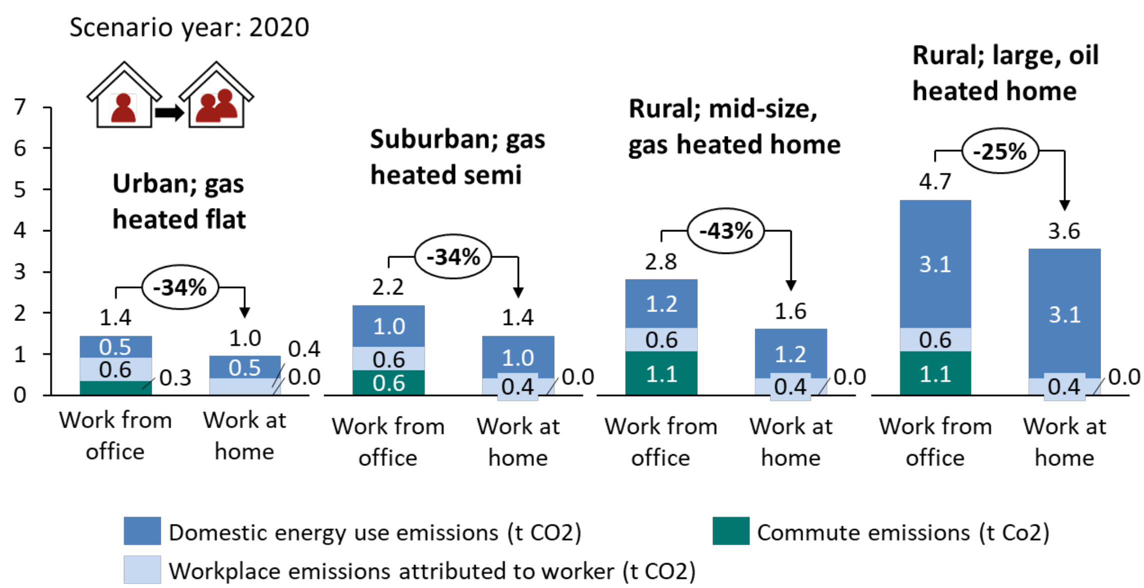


Figure 9: Change in personal emissions due to working from home in 2020, for the '1 to 2' day-time occupancy change case

The dependency of emissions impact of WFH on prior commute mode is also an important factor. In Figure 10, the change in personal carbon emissions due to WFH is shown for a range of prior commuting behaviours, in this case for a typical suburban case, with a semi-detached home heated using a gas boiler.

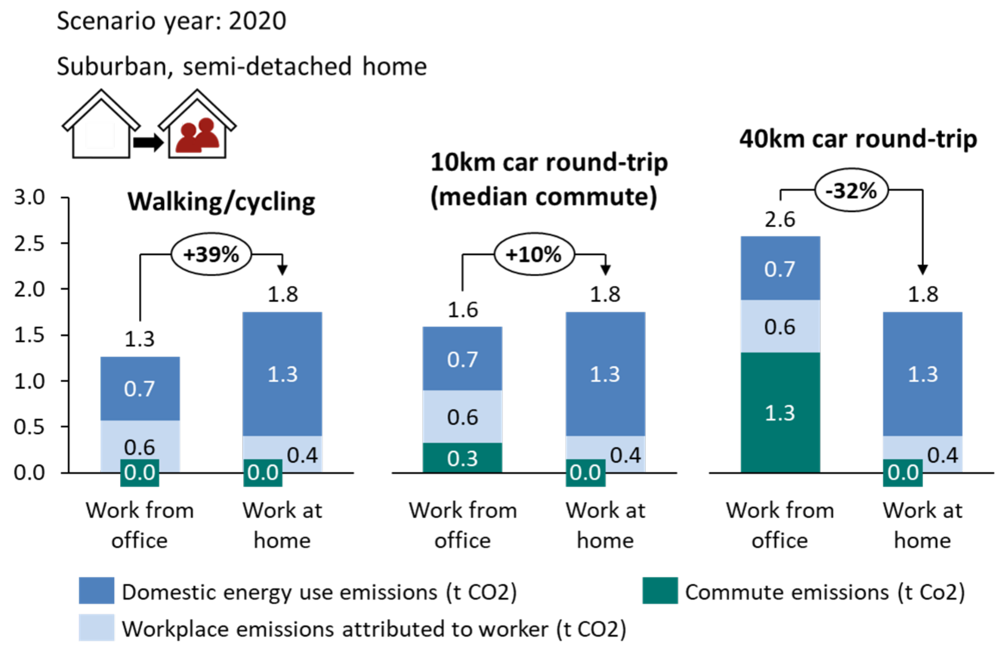


Figure 10: Change in personal carbon emissions due to working from home in 2020, with low and high (10th - 90th percentile by carbon emissions) and average commuting cases, for a typical suburban home.

Figure 10 underlines **the importance of commute mode** when considering the carbon benefits of WFH. For the same occupancy case and home, we find that the overall emissions impact ranges from a **39% increase** in emissions to a **32% decrease**, when varying between the extremes (10th and 90th percentiles) of typical commuting behaviour. In general, if the commute is by public or active transport (or a low emissions vehicle), we find that there are few cases in which working from home will result in emissions savings. Whereas for long car commutes, working from home can save emissions in many cases.

One other factor not considered here is the vehicle occupancy rates, which have a large impact on transport emissions. Carpooling such that emissions are shared between multiple commuters would be an alternate way to save a significant fraction of the transport emissions, and as a result decrease any emissions benefits from switching to working from home.

The above analysis considers the contributions to emissions changes of home energy use, workplace energy use and transport, for a series of specific examples, for the ‘0 to 2’ case, where multiple home workers begin to work in a previously unoccupied home. The sensitivity of results to this assumption is examined in Figure 11, below, which shows the overall emissions impact of working from home for each occupancy change case (see Table 7), under a range of assumed transport behaviours.

Figure 11 demonstrates that if there is already someone at home during the working day, then switching to WFH is likely to result in a significant emissions saving in all home-type and transport cases. This is because little additional home energy use is generated from working in a home which was already heated during the day, and so the emissions reductions associated with avoided transport and workplace energy use dominate. Conversely, if a large house requires heating just for the single worker, this can significantly outweigh the other impacts to result in emissions increases due to WFH.

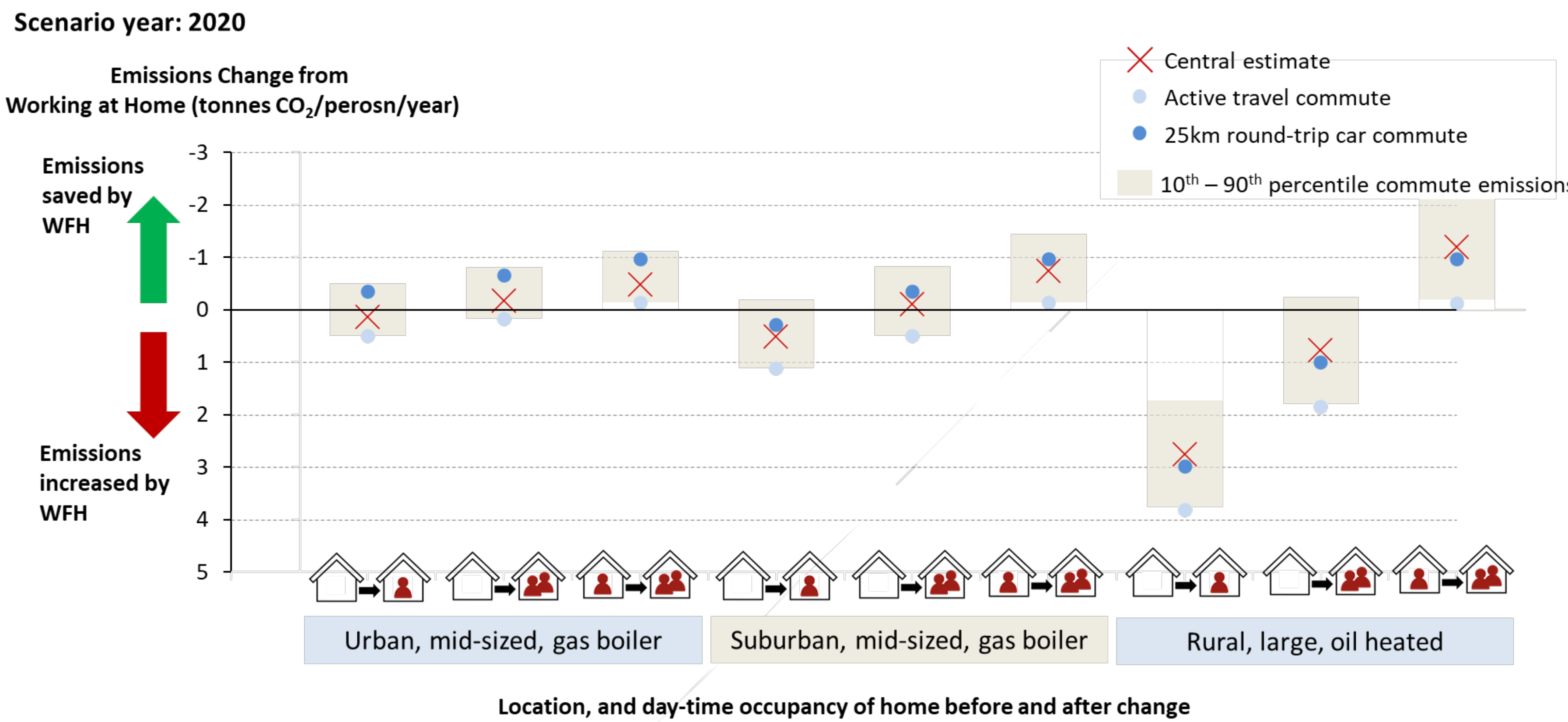


Figure 11: Change in personal carbon emissions due to WFH, under varying assumptions of location, change in home day-time occupancy, and commute. The 10th-90th percentile range and central estimate of transport emissions, are applied independently for each of the home locations (urban, suburban and rural), such that, for example, the central case and maximum rural commute are longer than the equivalent urban commutes.

Impact of sector decarbonisation

The impact of working from home on green-house gas emissions depends on the balance between positive and negative emissions changes. As discussed in section 2.2, this balance is expected to shift over time as the buildings and transport sectors decarbonise at different rates. Figure 12 shows the results for the '0-2' modelled in the year 2030, with the carbon intensity of energy use in buildings and of transportation reduced in line with policy targets. The values here reflect the **average** emissions intensity following the deployment of the projected numbers of low carbon heating systems, energy efficiency measures in buildings, and low emissions vehicles. In reality, most such individual deployments cause a more binary change in emissions; for example, a typical home's heating emissions will change from several tonnes CO_2 per year to close to zero on installation of a heat pump.

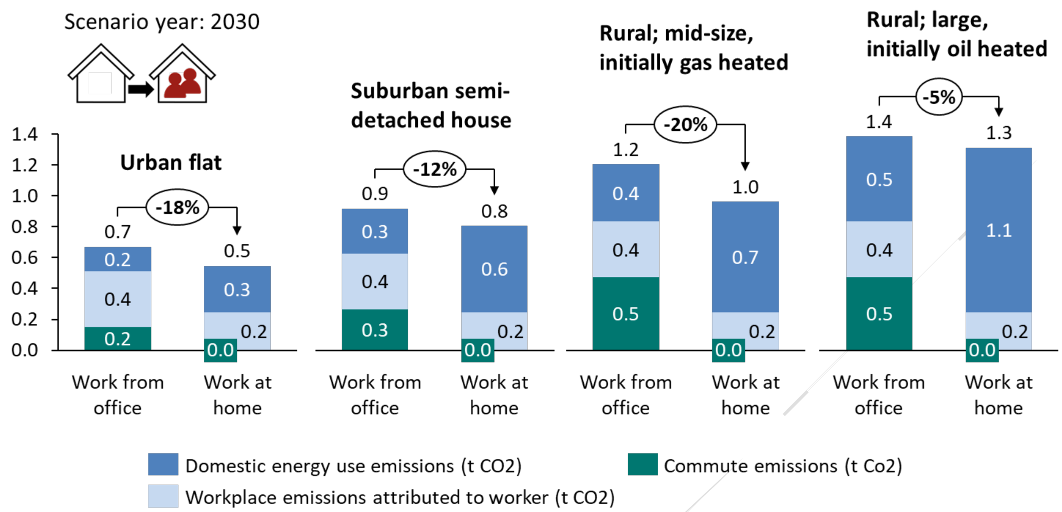


Figure 12: Change in personal emissions due to working from home in 2030, for the '0 to 2' day-time occupancy change case. Homes are labelled by their initial heating system (in 2020), since by 2030 the emissions represent a mix between this initial system and deployed low carbon heating.

When considering the 2030 scenario, we find that the case for emissions **savings** of working from home are generally larger in percentage terms, but unchanged or smaller in absolute terms. This means clear messaging on working from home best practise, to minimise emissions, based on the benefits in specific cases in 2020 will not lead to adverse consequences for greenhouse gas emissions in 2030.

The 6% of homes in Scotland using oil, LPG or solid mineral fuel (e.g. coal) for heating are expected to decarbonise ahead of the remainder of the building stock, with a target of 75% deployment of low carbon heating by 2030, as compared to 46% in the wider stock. This results in a stronger shift towards emissions savings from working from home for these buildings, as seen in the final pair of stacked bar charts in Figure 12; for the rural, large, oil heated home case, a 21% increase in emissions due to WFH in 2020, becomes a 5% decrease in emissions due to WFH by 2030. However, this result is still sensitive to the occupancy of the house. Figure 13 shows that in the case where only a single home worker will occupy the house, the emissions impact remains as an increase for these rural buildings, even by 2030.

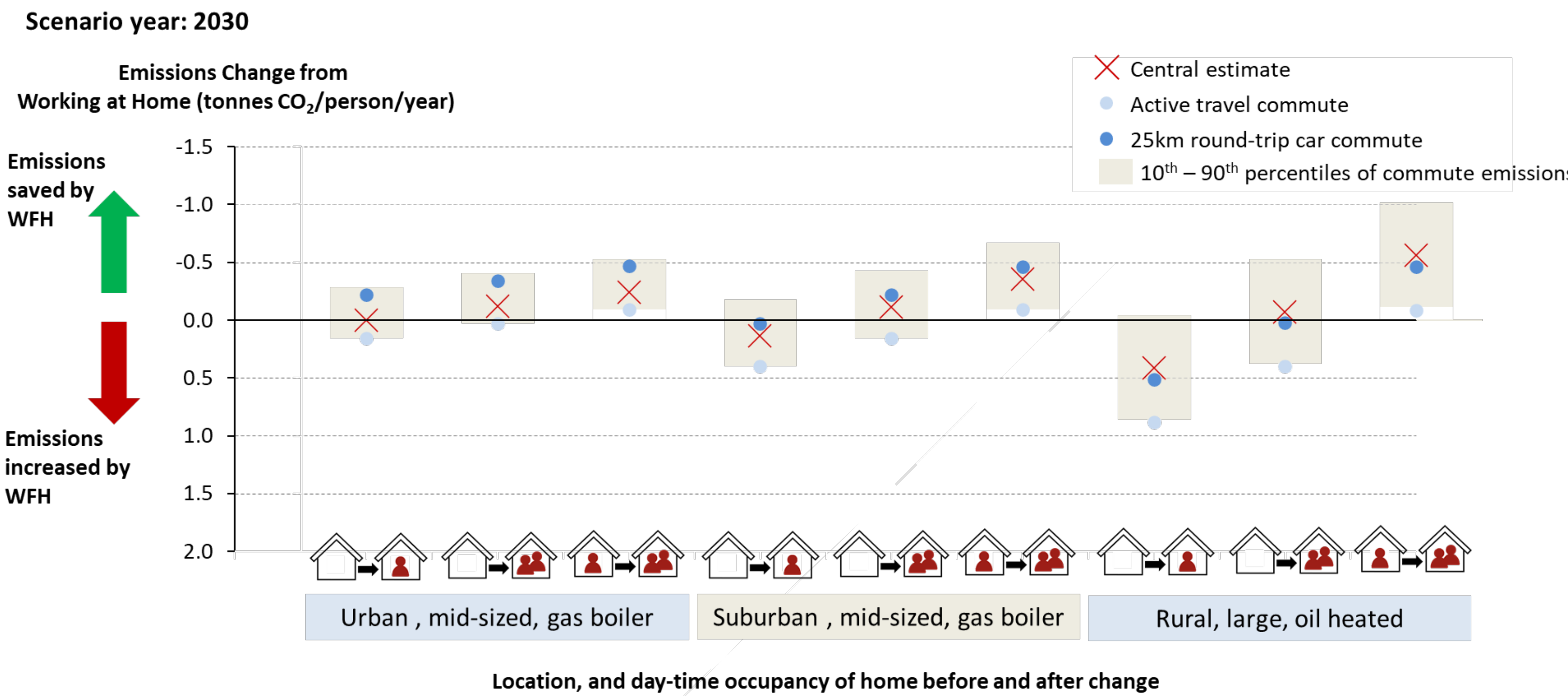


Figure 13: Change in personal carbon emissions due to WFH in 2030, under varying assumptions of location, change in home day-time occupancy, and commute

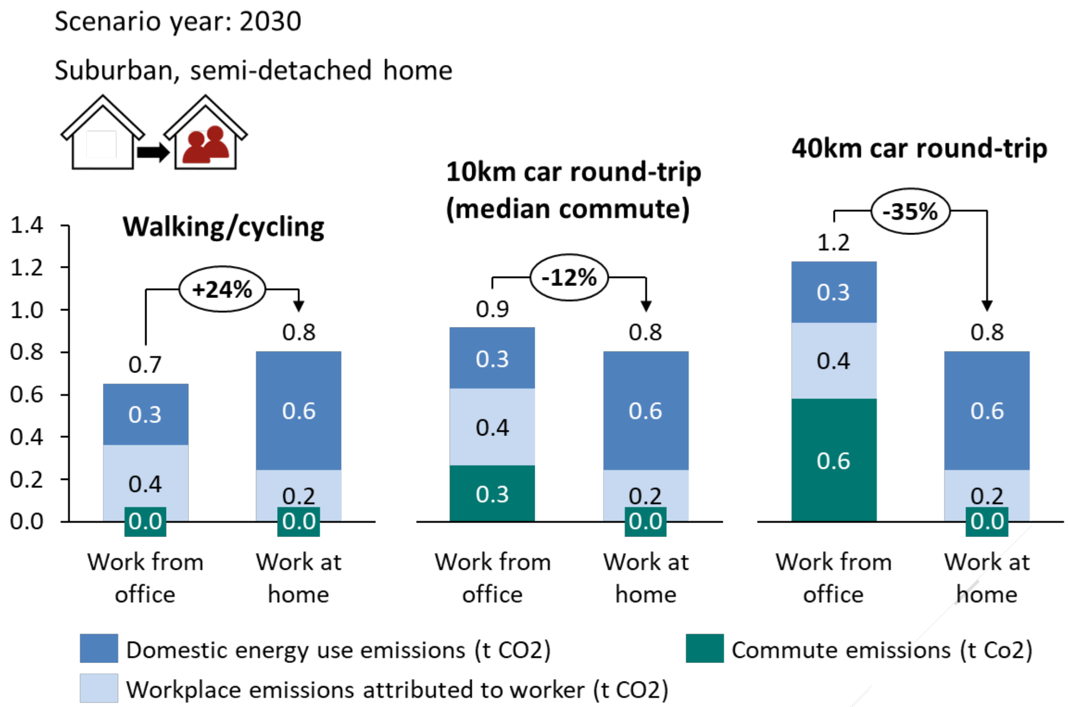


Figure 14: Change in personal carbon emissions due to working from home in 2030, with low (10th percentile), high (90th) percentile and average commuting cases, for a typical suburban home.

Impact of building heating system

The above results have demonstrated the importance of home energy use for assessing the impact of WFH. However, emissions impact also depends significantly on the specific heating system being used in each case. Figure 15 shows that where a low carbon system, such as electric storage heating or biomass boilers, is used, emissions reductions associated with the change to WFH are seen in all cases.

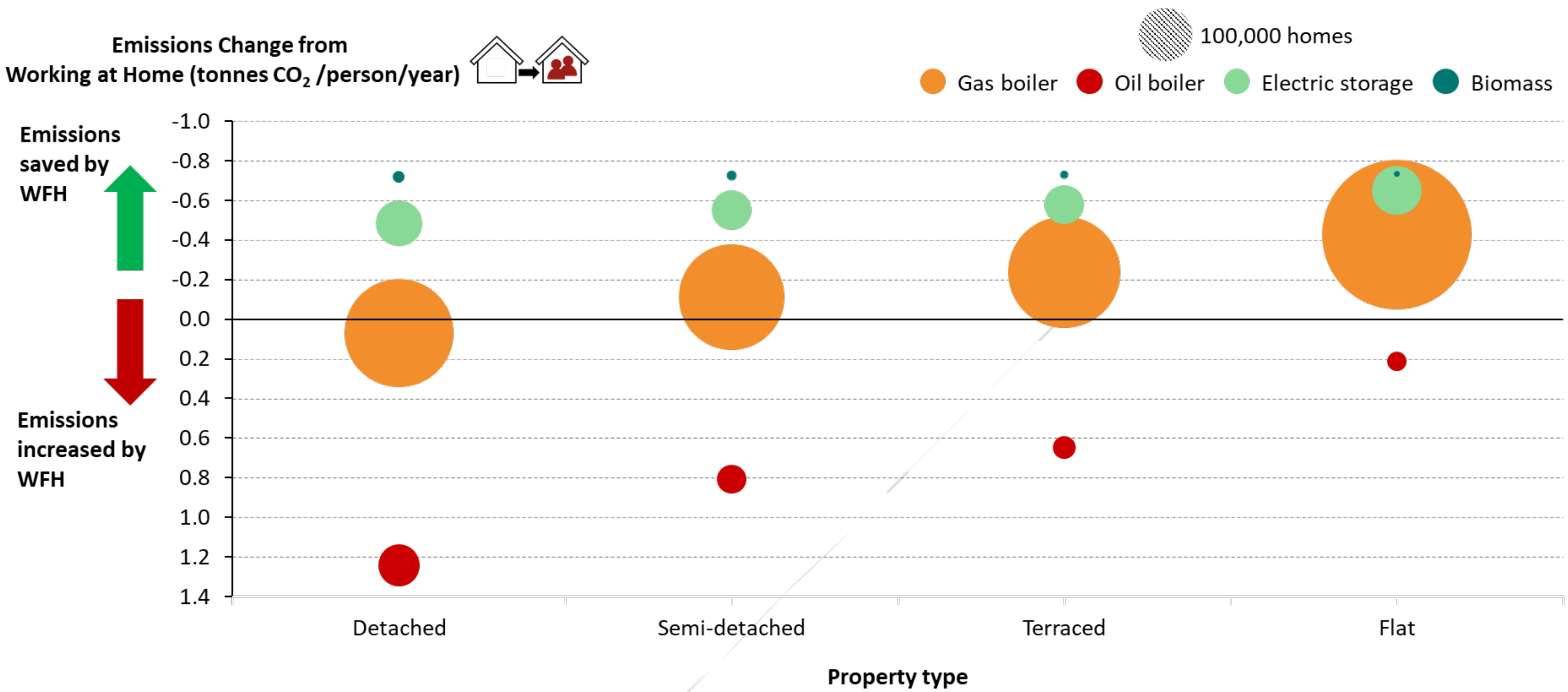


Figure 15: Change in personal CO_2 emissions after switching to WFH, shown for the average commute trip length and mode, in 2020. The bubble area is proportional to the number of Scottish households matching each category

Impact of seasons

The impact of working from home only in a particular season is explored in Figure 16 and Figure 17. Since emissions associated with space heating of the home are the most significant contribution towards emissions increases due to WFH, doing so only during the summer months results in larger overall emissions saving. Conversely, only working at home during the winter months is a worst case in which domestic emissions are increased by nearly as large a value as if the worker was to work at home all year round, but transport emissions only decrease by 50% of the year-round WFH case. Many workplaces are air conditioned, whereas this is rare in Scottish homes. Energy demand for cooling at the workplace, which is assumed to occur only in the summer months, is included in the results presented here, and is an additional factor increasing the benefits of WFH in summer. However, the low Scottish electricity grid carbon intensity means that this is only a small contribution to emissions impacts. The results suggest that WFH during the summer months leads to the lowest overall emissions. However, the mismatch in office space between summer and winter that this trend would cause is likely to offset much of the benefit as it prevents the opportunity to repurpose disused city centre office space, which could help to deliver low emission mixed use urban spaces.

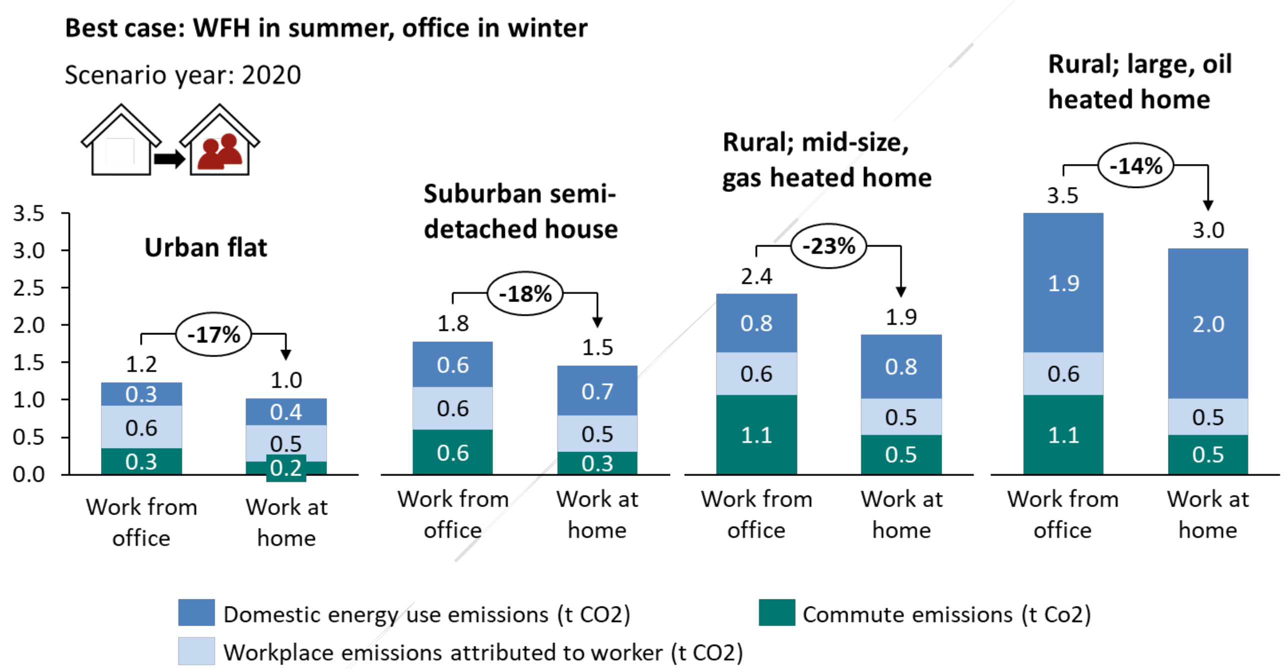


Figure 16: Change in personal carbon emissions due to working from home in 2020, if WFH during the summer months, and in the office in winter

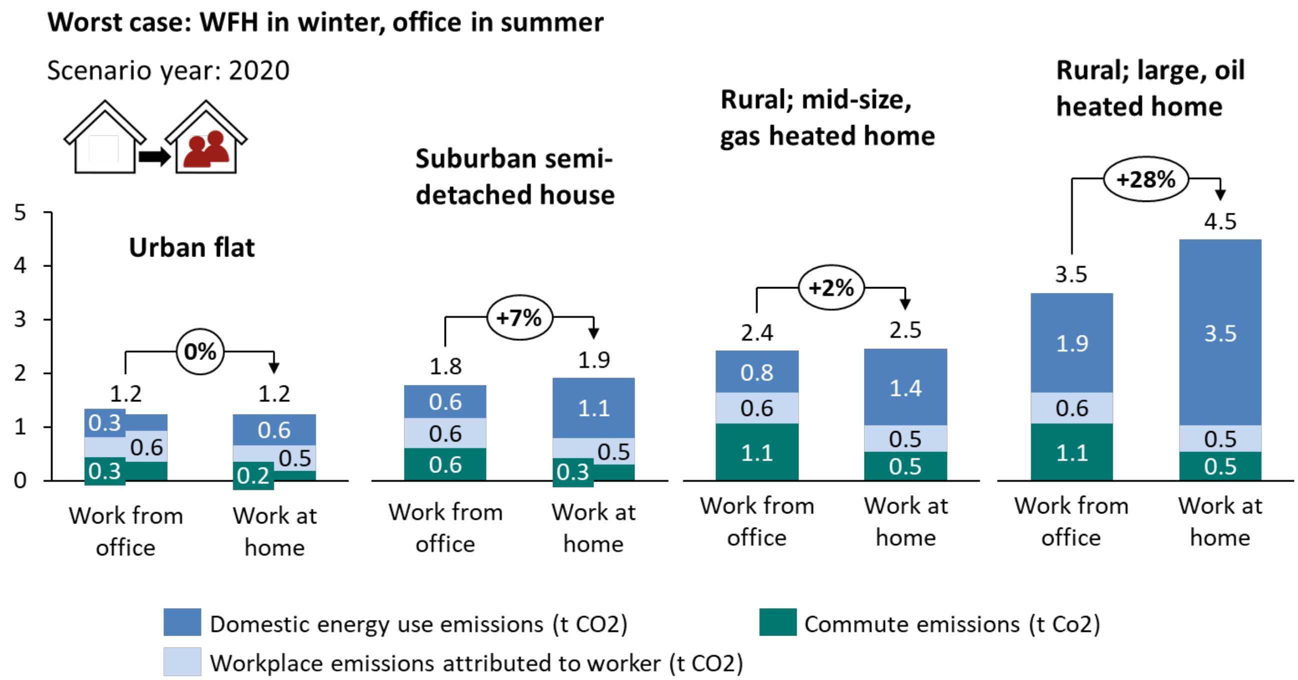


Figure 17: Change in personal carbon emissions due to working from home in 2020, if WFH in winter, and in the office in summer

Impact of working sector and workplace buildings

We have also analysed the impact of working in different workplace sectors, and in all cases the impact of variance here is much lower than the variance due to home type and heating system. This is demonstrated in Appendix 6.4

There is a strong variance in emissions benefits based on commute mode and home type, but smaller variance based on workplace sector. This means similar messaging around home working can be shared across employment sectors.

A final sensitivity examined is the response of office and other workplace buildings to reduced numbers of workers. The above case studies assume that workplaces remain open after increases in working from home, such that space heating, cooling and lighting energy uses of the workplace are unchanged. This case is the less positive case for working from home, since potential savings in energy use due to workplaces reducing in size or closing are neglected and can be seen as the likely short-term response to an increase in work from home. In the long term however, a second case, in which workplaces reduce in size in proportion to the reduction in occupancy is possible. In this case, greater energy savings are associated with working from home, and so a more positive case is made for emissions impacts. However, Figure 25 shows that the impact of varying this assumption is generally small compared to the dependence of emissions savings on transportation type and home type.

5 Key findings and conclusions

The analysis presented here aims to understand how the trend of increased working from home may impact greenhouse gas emissions. The work has found that if post pandemic trends result in a higher proportion of people working from home across all types of houses and commuting behaviours the overall impact on emissions will be small:

- A 0.6% reduction in buildings and transport emissions if a mix of people with different house types, and heating and commuting behaviours work from home
- A 0.6% increase in buildings and transport emissions if whole houses are heated all winter for home workers and office space remains open
- A 2.0% reduction in buildings and transport emissions if only the home office areas of homes are heated, office sizes are reduced to reflected reduced demand, and working from home proves more popular with car commuters

However, Scotland is targeting a 75% reduction in emissions between 1990 and 2030, and at this level of change in such a short period, every emissions reduction pathway should be considered and actions which increase emissions avoided.

The overall emissions impact of home working at a national level will be diminished as a result of a wide mix of people working from home, for some of whom working from home has an emission benefit and for others an emissions increase. This mix reduces the overall emissions savings.

5.1 Key findings

1. Circumstances leading to an **emissions reduction** from home working:
   a) People who shift to working from home where the home was already occupied (likely to include families where a parent is at home with small children etc.) see the greatest emissions saving from home working as the home is already heated.
   b) People who live further away from work and commute by car see a big emissions saving from home working. The only exception to this trend is the case of a large rural property heated by oil or gas all day for one person working from home. This could be overcome by decarbonising oil heated properties early in the heat decarbonisation transition and installing smart heating system which avoid heating the whole house.
   c) Conversely everyone using electric or biomass heating will see an emissions saving by working from home if they commute by car.
2. Circumstances leading to an **emissions increase** from home working:
   d) People with larger houses heated by oil see emissions increase from working at home if the house was previously not heated during the day.
   e) Everyone who commutes by active travel will see emissions increase from working at home.
   f) Most people who commute by public transport will increase their emissions by working from home. The exception to this will be people in an efficient house with electric heating, but the emissions saving in this case is small.
3. At a Scottish level the decarbonisation of heating and transport is expected to occur at a similar rate, meaning the results for 2020 hold true in 2030. However, at an individual level a household with an electric car and a gas boiler will see emissions increase from home working, a householder with a heat pump and a petrol car will see emissions decease from home working and a household with an electric car and a heat pump will see little emissions reduction/increase from home working. In the near term it is likely electric car sales will increase faster than low emission heating technology, meaning electric car drivers will minimise their emissions from working in the office.

5.2 Implications for policy

This report has several key findings for policy makers looking to accelerate decarbonisation.

1. Domestic heating is a large emission source which can offset much of the transport emissions savings of home working. Limiting domestic heating emissions through the rollout of smart heating systems, which only heat occupied areas of the house, would deliver the single biggest emission benefit to home workers.
2. Transport Scotland has committed to a 20% reduction in car kilometres by 2030 (against a 2019 baseline) as part of the 2020 update to the Climate Change Plan. This will require policies which disincentive car use for commuting. The lowest emission future is one where people commuting short to medium distances do so by public and active travel and continue to commute to the office, while people who commute long distance shift to working from home. This divide in behaviour might be a reasonable response to policy discouraging car use as people travelling short distances are more likely to be in urban areas where working from home might be less convenient due to smaller house sizes and access to public transport is good. Long distance commuters are less likely to have a public transport alternative and may respond by working from home.
3. The lowest emission working behaviour is a short commute to work in an energy efficient office. Changes to the planning process to support the reintroduction of local goods and services as part of 20-minute neighbourhood aims could also look to support local shared office space to encourage the lowest emission working behaviour.
4. A clever reimagining of existing office space, freed up by more people working from home, could be supported by the planning process. This could create new opportunities for people who want to live in city centres but have not been able to afford it in the past, to move into the city reducing their trip distances for most trips and therefore their broader transport emissions.
5. Larger properties with oil heating represent the worst place to work from home in terms of emissions. Targeting these properties for early decarbonisation can help to ensure working from home reduces emissions.
6. The emissions impact of home working does not vary very much between employment sector and workplace type as the emissions are predominantly decided by home heating and commuting behaviour. This means similar messaging around home working can be shared across employment sectors.
7. People who see an emissions saving from working from home today will also see a benefit in 2030[14]. This means messaging around good working from home practices will remain relevant over time.

5.3 Areas not looked at in detail in this study

The conclusions of this work could be further refined by future work looking at:

1. The cost impact of not commuting versus additional heating costs to understand if working from home leads to cost saving or a cost increase. If a cost saving is observed then work will be needed to understand if this leads to spending on other emissions intensive activities which could offset some of the saving observed here. This should also be studied to understand the equity impact of home working policies at a company and national level.
2. The impact of home working on business travel.

[14] Assuming they don’t move house changing their heating and commuting needs

3. How companies manage the reduced use of office space (downsize and at what proportion of the team working from home, repurpose space for non-desk areas, close the office etc.).
4. Impact on where people choose to live if they are not required to go to the office as regularly.
5. If people take additional trips for shopping etc. if they no longer complete these tasks as part of commuting. There is currently a lack of data here and new questions will need to be added to the Scottish Household Survey to understand these trends.

6 Appendices

6.1 Detailed modelling methodology

Working from home behaviour

In the latest version of the Transport Economic Land-use Model of Scotland (TELMoS18) and the Transport Model for Scotland (TMfS18) “working at home” can be identified as a category. This has been used for this project to estimate both the working from home behaviour and the transport behaviour.

Various versions of the TELMoS model have been created over the years, the most recent models represent Scotland disaggregated into 800 zones.

TELMoS18 interacts with the latest version of the Transport Model for Scotland (TMfS) as illustrated in the Figure 18 below, meaning it takes generalised costs of travel to calculate accessibility and provides forecasts of population and employment to the transport model to allow it to estimate how changing locations impact upon travel times.

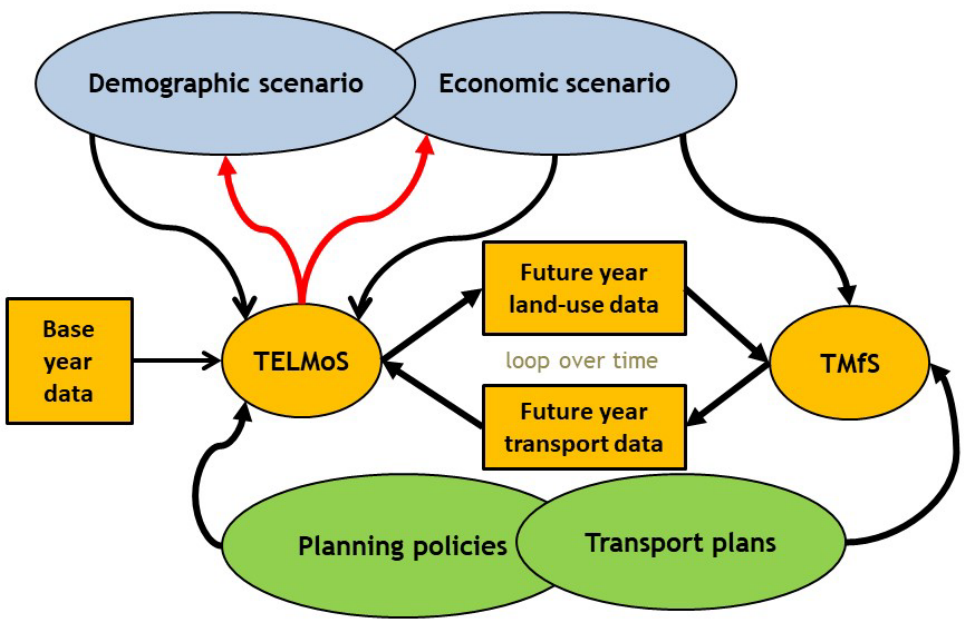


Figure 18: Overview of TELMoS18/TMfS18

Within TELMoS18 households have been classified into 33 categories. These are shown in Table 8. The household categories are based upon:

Three “life stage” categories: young, older or retired;

Households with and without children; and

Four socio-economic levels (SELs) which are based on groupings of occupations (Table 9).

Table 8: Household types

Activities	Household Description
1 - 4	Young Single (under 50) SEL 1-4
5 - 8	Older Single (50-64) - SEL1-4

9 - 12	Retired Single (65+) – SEL1-4
13 - 16	Single Parent with Children - SEL1-4
17 - 20	2 young adults or more no children (under 50) -SEL 1-4
21 - 24	2 older adults or more no children (50-64) - SEL1 - 4
25 - 28	2 adults or more + child -SEL1- 4
29 - 32	2 retired adults or more (65+) - SEL1- 4
33	Student households

Table 9: SEL classification

Socio-Economic Level (SEL)	Standard Occupational Classification (major groups)	Manual/non-manual
1. Professional and managerial occupations	1. Managers and senior Officials 2. Professional Occupations	Non-manual
2. Other non-manual occupations	3. Associate Professional and Technical Occupations 4. Administrative and Secretarial Occupations 6. Personal Service Occupations	Non-manual
3. Skilled trades, sales and service occupations	5. Skilled trade Occupations 7. Sales and Customer Service Occupations	Manual
4. Less skilled and elementary occupations	8. Process, Plant and Machine Operatives 9. Elementary Occupations	Manual

Persons in households are classified into four types:

- Children
- Working
- Non-working of working age (most but not all of whom are potential workers)
- Retired persons

The workers category includes:

- workers working mainly at or from home,
- workers working partly at home and partly by commuting to a separate workplace,
- workers working entirely by commuting,
- workers with no fixed workplace, and
- workers working offshore or outside the UK.

The latest interface from TELMoS18 to TMfS18 estimates the number of remote workers and which kinds of households, in which home zones, they belong to. It distinguishes two groups of workers, those who go to work at their usual out of home workplace on an average day, and those who are working in some other way including those who are remote working on an average day. This interface is controlled to levels of remote working, defined as the proportions of the regular workers by employment activity and socio-economic level.

Some of the assumptions considered in implementing the interface are that households with the longest/slowest commute will be more likely to work from home, and that the likelihood of workers choosing to work at home will be affected by the size of their dwelling, whether they live alone, or by the presence of children, especially pre-school ones.

Using TELMoS18 and the enhanced interface, we are able to estimate the number of people working at home and the changes in remote working over time. The model also allows us to analyse which household categories have a greater tendency of working from home, and in which industry workers are more likely to work from home. Office-based jobs (especially in business sectors) would get higher proportions of home workers than manual jobs.

Transport behaviour

The transport model, TMfS18, uses TELMoS data on people who work and commute, by home zone and work zone, and calculates the numbers of commute trips produced in and attracted to each zone. TMfS18 is also using TELMoS data on the total numbers of workers with conventional (non-home) workplaces for trip attraction models. The transport model also calculates non-commute home-based trips.

In the enhanced interface, TMfS is now able to distinguish in the resident population between working people who travel to work, working people who work at home, and non-working people, so as to take account of their different trip-making patterns.

Using TELMoS18 together with TMfS18, we can forecast the reduction of commuting trips by mode due to more people working remotely.

AECOM has provided us with outputs from TMfS18 on number of trips for car and public transport from home zone to work zone for the whole of Scotland.

Commuting trips, both for car and public transport modes, would decrease significantly if more people are home working, but overall this doesn’t seem to have a big effect on mode choices. Several factors might tend to have an effect on mode choices, such as the reduction in congestion, less public transport crowding, and less competition for parking; and those might be seen at the finer scale.

The AECOM data on commuting provided to this project does not capture the impact of trip chaining where people complete a number of other tasks as part of their commute, mostly escorting children to school. This trip still needs to happen when people are home working and this effect has been corrected for by assuming 12% of commuting trips include a trip chain, most of these intermediate stops are for escorting[15] and that escorting trips are on average 6.1km whereas commuting trips are 14.5km[16]

[15] DfT, 2014, Trip Chaining, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/509447/nts-trip-chaining.pdf

[16] DfT, National Travel Survey, Purpose of Travel, https://www.gov.uk/government/statistical-data-sets/nts04-purpose-of-trips

Transport emissions

The previous step sets out the number of commuting trips and the distanced travelled by commuting trips for cars, buses and trains for the four scenarios. In this step of the method the distanced travelled by passengers on each mode is converted into emissions in a two-step process as described below.

- Passenger commuting kilometres is converted into vehicle kilometres using a fleet wide vehicle occupancy rate.
- Vehicle kilometres are converted to emissions using an emission factor that represents the emissions of an average vehicle in the fleet for cars, buses and trains.

The output of this step is the commuting transport emissions as either million tonne CO_2 per year for the whole of Scotland, in the national analysis, or tonnes CO_2 per person per year for the individual analysis presented in the case studies.

Building emissions

Working from home behaviour is defined at the level of the household type (e.g. 2 adults or more + child -SEL1). These household types are then mapped to building types (for example, an urban detached property with a gas boiler) using correlations from the Scottish House Condition Survey (2019). Each domestic building type is then assigned an energy use for space heating, hot water, lighting electricity use, and other electricity use, in the cases where:

i. No-one is typically at home during the working day.
ii. One person is typically at home during the working day.
iii. More than one person is typically at home during the day.

This assignment of energy use is made by scaling up the typical household energy use in proportion to the number of additional occupied hours. In the case of heating, additional assumptions are made over the typical number of heated hours, using data from the Energy Follow Up Survey, 2011, to account for the variety of behaviours across the population. Emission factors are then applied for each building type based on the initial distribution of different heating systems in Scotland, and the assumed uptake of low carbon heating and energy efficiency measures.

We assume that those working from home have day-time hours (i.e. not night shifts or other non-typical working hours) and that the average working day causes the worker to be out of the home for 10 hours. Further, 25 days annual leave plus bank holidays are assumed, giving 227 working days per year.

Building stock model

Each of the 2.5 million domestic buildings in Scotland is assigned to one of a set of 80 archetypes, defined as the set of all combinations of the following attributes, chosen to capture the most relevant features of the stock for understanding emissions changes with home occupancy:

Table 10: Archetyping parameters used in the domestic stock model

Location	Property type	Heating system
Urban	Detached	Gas boiler
Rural	Semi-detached	Oil boiler

	Terraced	Electric resistive
	Tenement	Electric storage
	Other flats	Community
		Solid mineral fuel
		LPG
		Biomass

The assignment of the number of buildings in each archetype defined by the above parameters was made using data form the Scottish House Condition Survey, 2019[17]. Urban/rural classification used is the 2-fold Scottish Government Urban Rural Classification 2013-2014. This follows the classification used in the Scottish House Condition Survey (SHCS) 2019. Dwellings in settlements with over 3,000 people are considered urban by this definition.

Each of these archetypes are assigned a space heating, hot water, and electricity demand under typical occupancy (i.e. not home working conditions) using the Element Energy Building Stock model, developed in prior work for the Committee on Climate Change. This building stock model is based on data from the national housing surveys of England, Wales, Scotland and Northern Ireland, as well as the National Energy Efficiency database.

The non-domestic stock model assigns each of the 196,000 non-domestic buildings in Scotland into one of 45 archetypes defined by each combination of the following use-types and heating systems:

Table 11: Non-domestic archetypes used in the stock model

Use type	Heating system
Community, arts & leisure	Electricity
Education	Natural gas
Emergency Services	LPG/Oil
Health	Biomass
Hospitality	Other
Industrial	
Offices	
Retail	
Storage	

[17] https://www.gov.scot/publications/scottish-house-condition-survey-2019-key-findings/

The number of buildings assigned to each archetype is defined by data in *Scotland's Non-Domestic Energy Efficiency Baseline* (Dec 2018)[18]. The energy use for space heating, hot water, lighting, cooling and other electricity is then defined for each archetype based on the Building Energy Efficiency Survey (BEES) 2014–15[19], England and Wales.

Building occupancy energy modelling assumptions

Figures Figure 19 and Figure 20 show the steps used in defining how energy use changes with occupancy of the home during the working day, and changed occupancy of the workplace, respectively.

18 https://www.gov.scot/publications/scotlands-non-domestic-energy-efficiency-baseline/pages/3/
19 https://www.gov.uk/government/publications/building-energy-efficiency-survey-bees

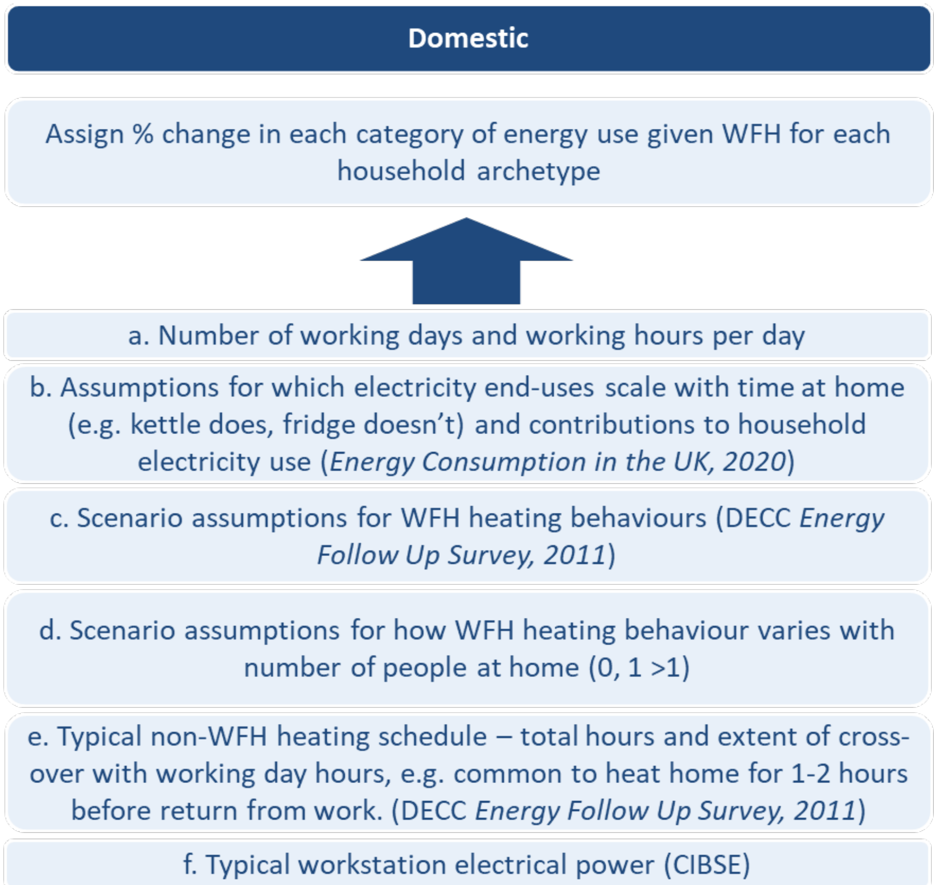


Figure 19: Domestic building occupancy energy modelling assumptions used to define change in energy use with different patterns of working from home

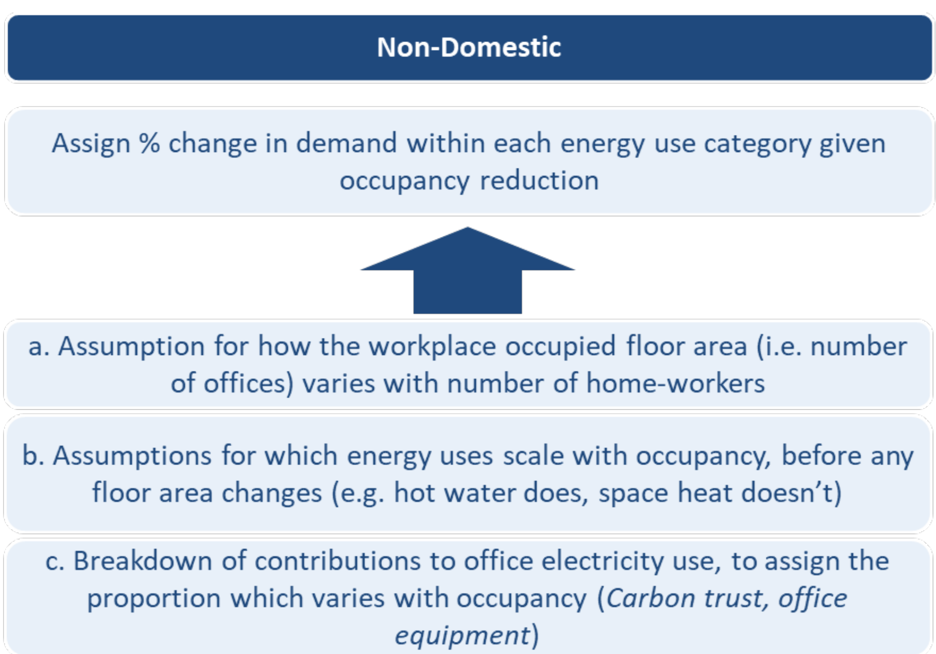


Figure 20: Non-domestic building occupancy energy modelling assumptions used to define change in energy use with different patterns of working from home

Future cooling demand projections

In this section, we justify the exclusion of domestic cooling energy demand in Scotland from our 2030 scenarios. Figure 21 shows the dependency of frequency of air conditioning equipment in domestic buildings on climate (measured in cooling degree days – CDDs) in the USA. We see that for CDD values below approx. 25 per year, a negligible fraction of households are found to take up air conditioning.

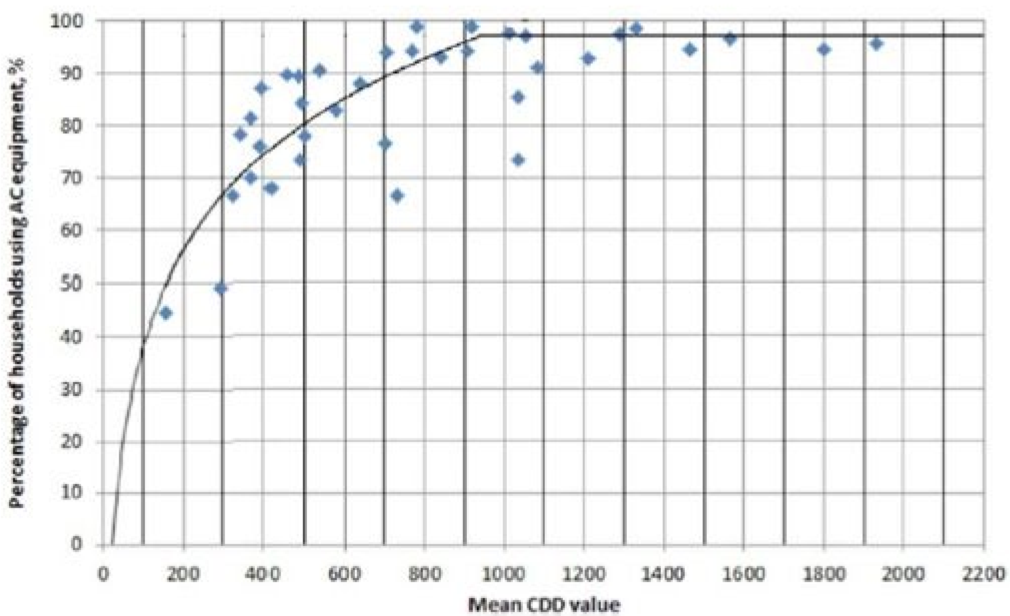


Figure 21: Dependency of air conditioning equipment use on climatic conditions in mainland USA; from *Estimation of European Union residential sector space cooling potential, M. Jakubcionis, J. Carlsson 2017*

Glasgow cooling degree days in 2020 were approx. 7.6 at base 21C, for Glasgow Airport (4.43W,55.87N)[20]. Table 12 below shows projections for London's degree days to 2050. Assuming an approximately linear change in CDDs, this represents a 36% increase in CDDs by 2030. If the same rate of increase is assumed to apply to Glasgow, we find a CDD value in 2030 of approx. 10 CDDs. Since this value is well below the minimum value for non-negligible uptake of air conditioning in the USA of 25, shown above, we therefore assume negligible domestic cooling, even in our "high cooling" sensitivity.

Table 12: London estimates of CDD change 2020 to 2050, from London's Climate Action Plan:, Cooling analysis, Element Energy.

Scenario	Cooling degree days in London
2020	77
Low cooling 2050	120
High cooling 2050	154

[20] https://www.degreedays.net/

6.2 National emissions scenarios detailed results

Central case

Table 13: Greenhouse gas emissions (kt CO_2e) from buildings and commuting, under society wide WFH scenarios, in 2019 and 2030 for Scotland

Sector	2019	2019, High WFH	2030, Low WFH	2030, High WFH
Domestic buildings	6340.6	6740.8	2664.9	2728.1
Non-domestic buildings	1815.5	1501.6	999.3	869.2
Transport commute	1253.3	1058.8	490.8	450.6
Total	9409.5	9301.1	4155.0	4047.8

Table 14: Greenhouse gas emissions from buildings and commuting, as a % of the total emissions from buildings and all surface transport in 2018, under society wide WFH scenarios, in 2019 and 2030 for Scotland

Sector	2019	2019, High WFH	2030, Low WFH	2030, High WFH
Domestic buildings	34%	36%	14%	15%
Non-domestic buildings	10%	8%	5%	5%
Transport commute	7%	6%	3%	2%
Total	50%	50%	22%	22%

Best case assumptions for WFH

Table 15: Greenhouse gas emissions (kt CO_2e) from buildings and commuting, under society wide WFH scenarios, in 2019 and 2030 for Scotland, under the best-case assumptions for WFH

Sector	2019	2019, High WFH	2030, Low WFH	2030, High WFH
Domestic buildings	6346.2	6570.0	2630.1	2667.0
Non-domestic buildings	1824.4	1444.5	927.4	837.8
Transport commute	1253.3	1058.8	490.8	450.6
Total	9423.9	9073.3	4048.2	3955.3

Table 16: Greenhouse gas emissions from buildings and commuting, as a % of the total emissions from buildings and all surface transport in 2018, under society wide WFH scenarios, in 2019 and 2030 for Scotland, under the best-case assumptions for WFH

Sector	2019	2019, High WFH	2030, Low WFH	2030, High WFH
Domestic buildings	34%	35%	14%	14%
Non-domestic buildings	10%	8%	5%	4%
Transport commute	7%	6%	3%	2%
Total	51%	49%	22%	21%

Worst case assumptions for WFH

Table 17: Greenhouse gas emissions (kt CO_2e) from buildings and commuting, under society wide WFH scenarios, in 2019 and 2030 for Scotland, under the worst-case assumptions for WFH

Sector	2019	2019, High WFH	2030, Low WFH	2030, High WFH
Domestic buildings	6340.9	6787.1	2676.5	2747.3
Non-domestic buildings	1815.5	1670.1	999.3	962.4
Transport commute	1253.3	1058.8	490.8	450.6
Total	9409.8	9516.0	4166.6	4160.3

Table 18: Greenhouse gas emissions from buildings and commuting, as a % of the total emissions from buildings and all surface transport in 2018, under society wide WFH scenarios, in 2019 and 2030 for Scotland, under the worst-case assumptions for WFH

Sector	2019	2019, High WFH	2030, Low WFH	2030, High WFH
Domestic buildings	34%	36%	14%	15%
Non-domestic buildings	10%	9%	5%	5%
Transport commute	7%	6%	3%	2%
Total	50%	51%	22%	22%

Targeted WFH

Table 19: Greenhouse gas emissions (kt CO_2e) from buildings and commuting, under society wide WFH scenarios, in 2019 and 2030 for Scotland, under the targeted WFH scenario

Sector	2019	2019, High WFH	2030, Low WFH	2030, High WFH
Domestic buildings	6309.7	6632.1	2657.5	2717.9
Non-domestic buildings	1815.5	1501.6	999.3	869.2
Transport commute	1253.3	1019.6	481.8	433.2
Total	9378.5	9153.3	4138.6	4020.3

Table 20: Greenhouse gas emissions from buildings and commuting, as a % of the total emissions from buildings and all surface transport in 2018, under society wide WFH scenarios, in 2019 and 2030 for Scotland, under the targeted WFH scenario

Sector	2019	2019, High WFH	2030, Low WFH	2030, High WFH
Domestic buildings	34%	36%	14%	15%
Non-domestic buildings	10%	8%	5%	5%
Transport commute	7%	5%	3%	2%
Total	50%	49%	22%	22%

6.3 Overview of the work from home case studies

Figure 22, Figure 23 and Figure 24 show the emissions impact of working from home for the full range of building types, heating systems and transport behaviours considered in this study.

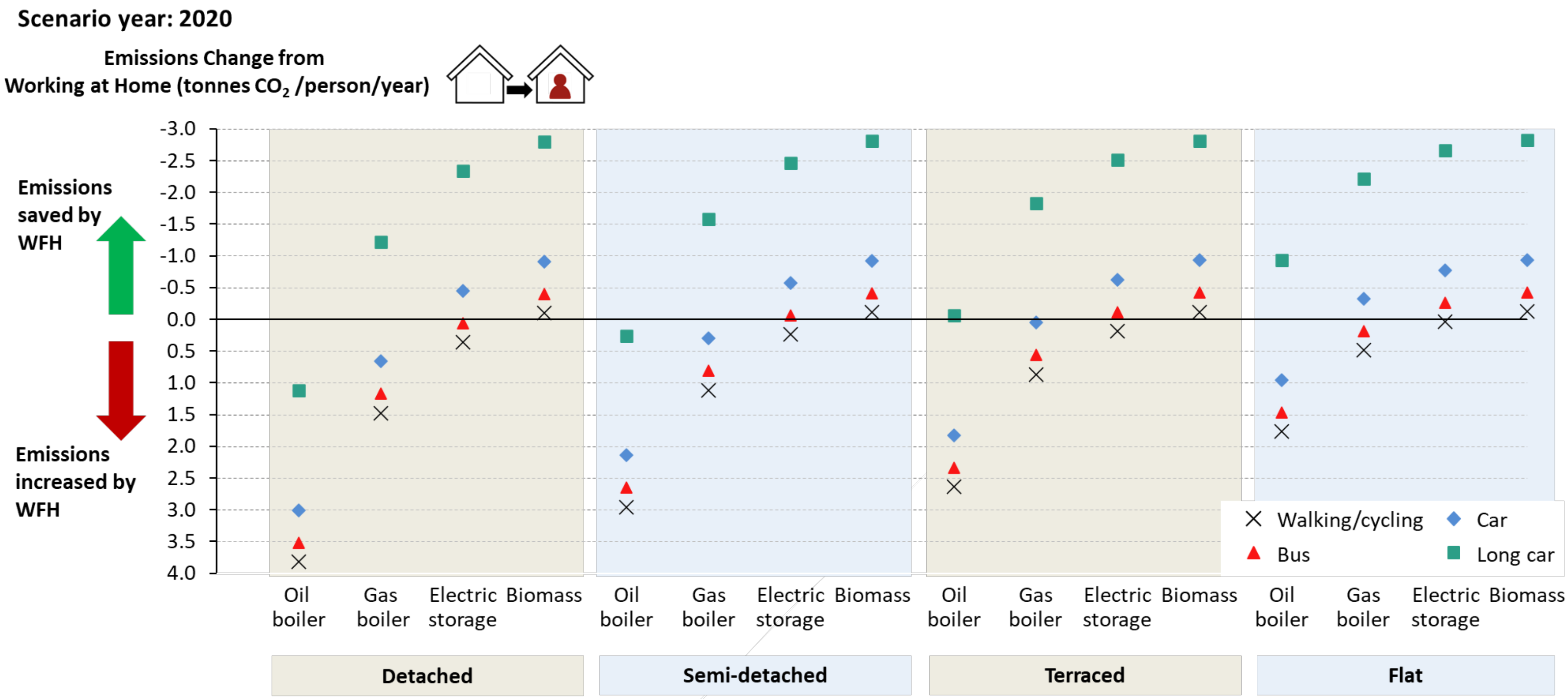


Figure 22: Emissions change due to working from home, for a range of house types, heating systems and travel behaviours, in the case where 1 worker now occupies a house previously unoccupied in the working day

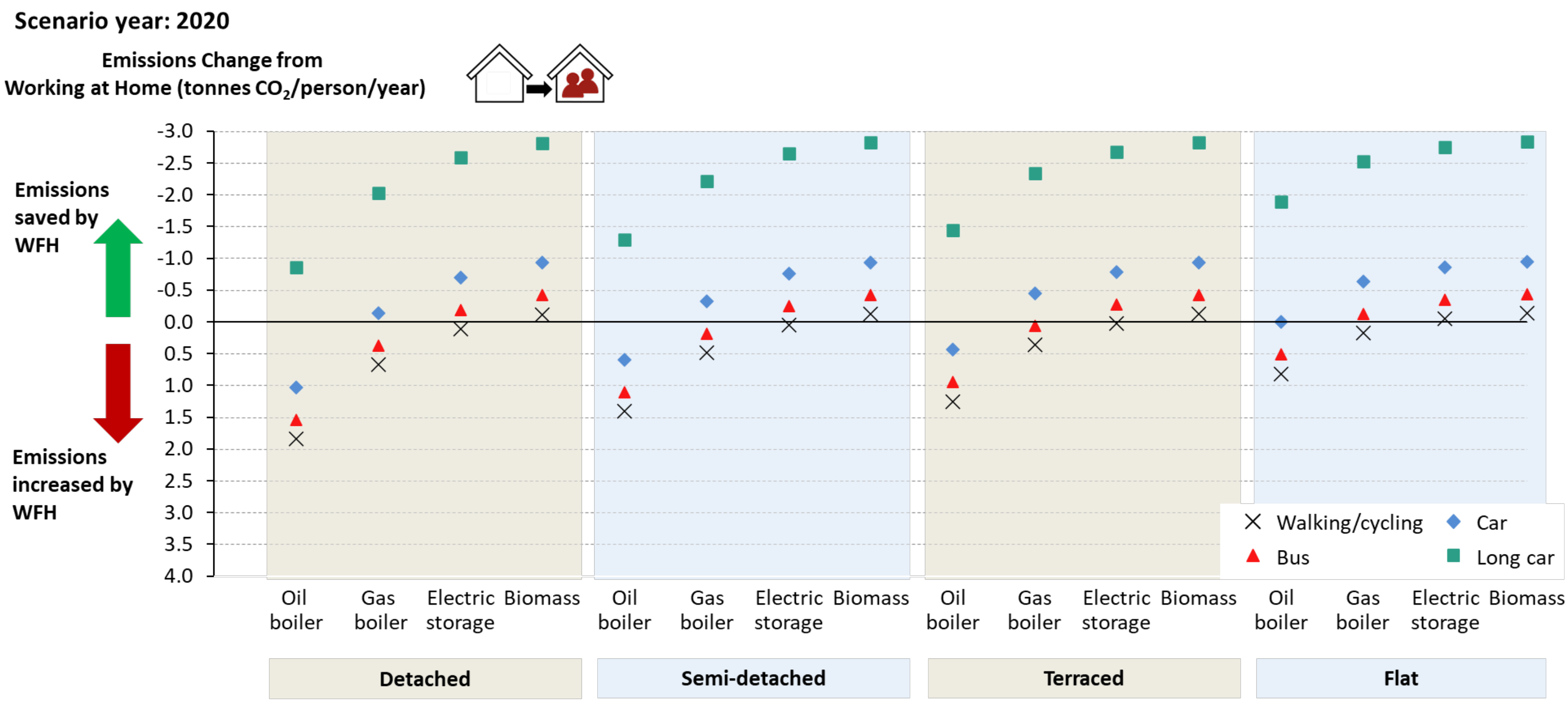


Figure 23: Emissions change due to working from home, for a range of house types, heating systems and travel behaviours, in the case where 2 workers now occupy a house previously unoccupied in the working day

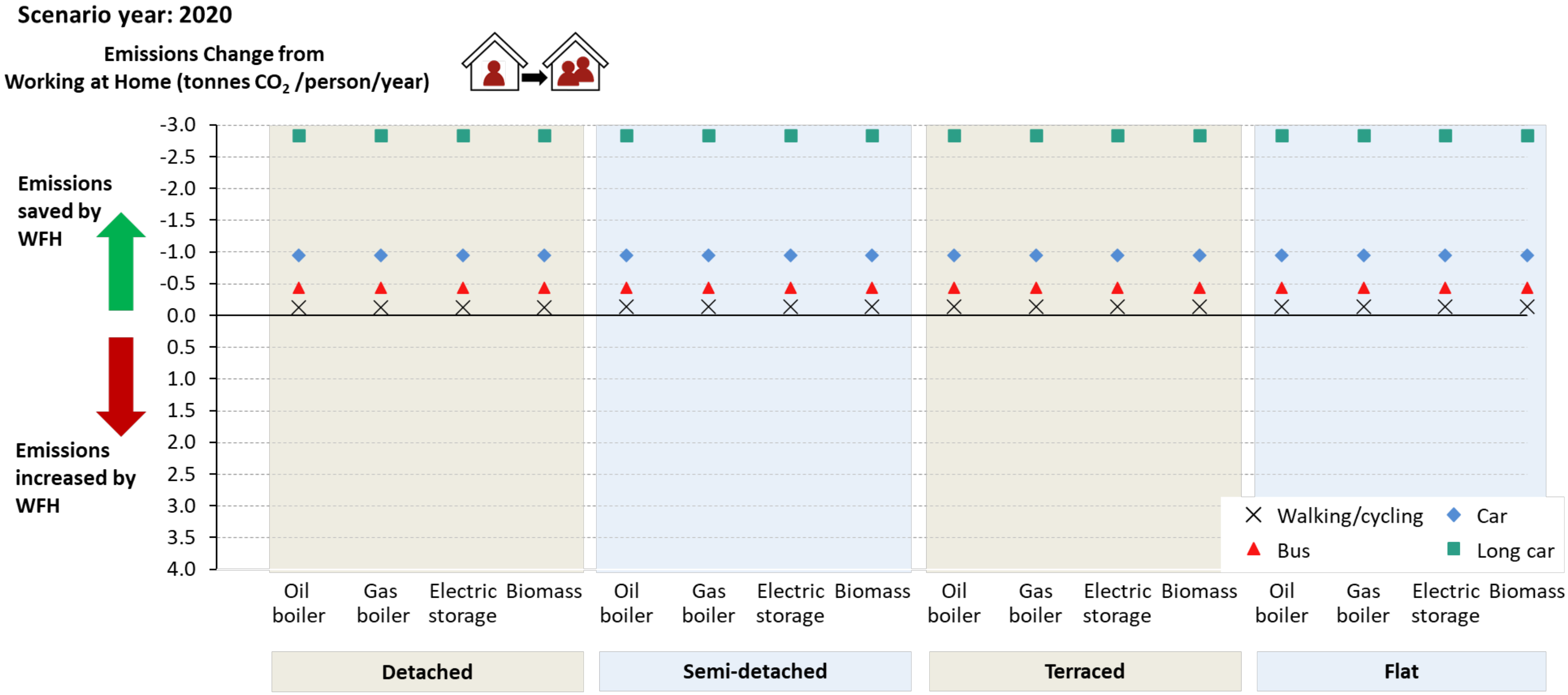
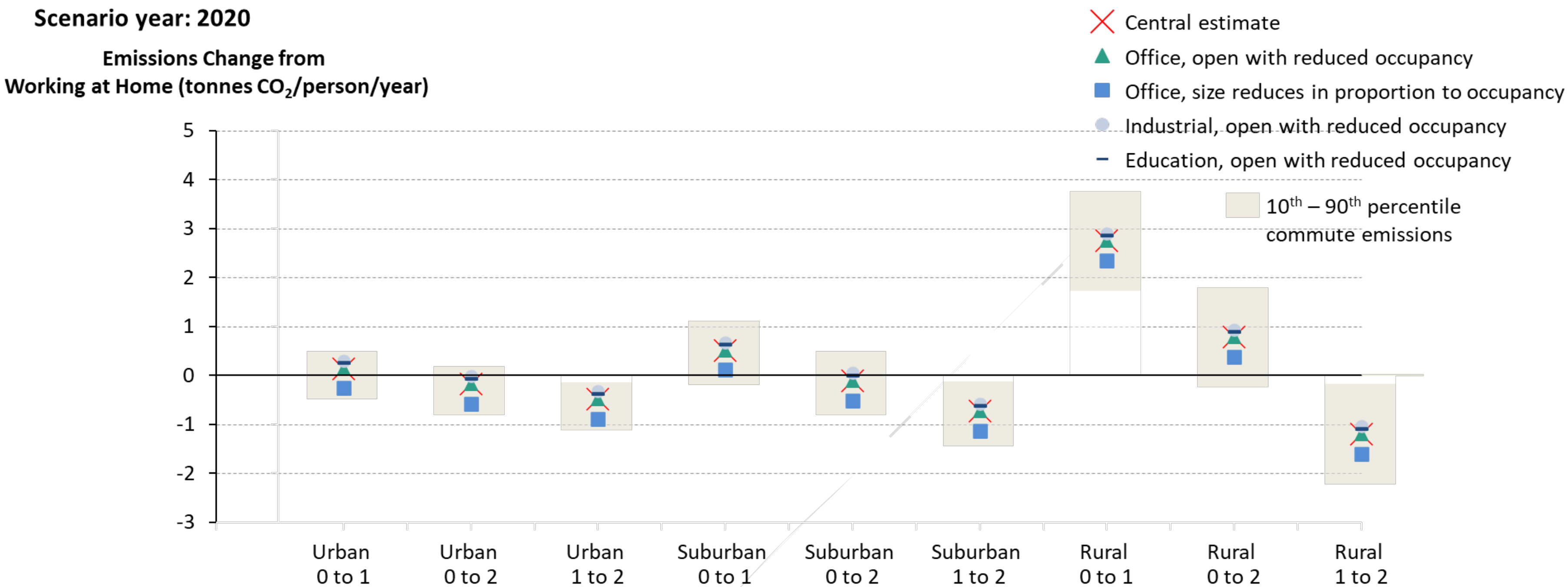


Figure 24: Emissions change due to working from home, for a range of house types, heating systems and travel behaviours, in the case where

6.4 Additional case study: workplace sector and opening assumptions sensitivity



- Where a workplace is open with reduced occupancy, the workplace is heated and lit as before, but energy use of hot water, IT equipment etc. is reduced in proportion to occupancy.
- In the case where the workplace size reduces in proportion to occupancy, the workplace emissions attributed to a remote worker are **zero.**
- The variation in emissions due to different workplace assumptions generally less significant than changing home types and transport modes.

Figure 25: Workplace sector and opening assumptions sensitivity; change in personal carbon emissions when working from home, under a range of assumptions over workplace opening and sector.

6.5 Literature review

Table 21: Summary of key messages taken from the literature reviewed

Source	Key messages

Homeworking: helping businesses cut costs and reduce their carbon footprint – Carbon Trust, 2014	• Factors affecting home energy consumption include:
	  ○ whether the house is normally occupied during the day
	  ○ whether the whole house needs heating or just one room
	  ○ the household's heating system and energy efficiency
	• Office energy consumption is often determined by outlying behaviour – e.g. heating and lighting are on from when the first employees arrive to when the last employees leave.

A systematic review of the energy and climate impacts of teleworking – Environmental Research Letters, 2020	• The paper synthesises the results of 39 studies, 26 of which find that teleworking reduces energy use. • Four categories of impact are distinguished: commuting, non-work travel, home energy use, and office energy use. However, none of the studies included consider all four categories. • UK teleworkers (in one-worker households) have a 10.7 mile longer commute than non-teleworkers and several studies find that teleworkers travel further on days off ○ However, **such studies do not establish the direction of causality**, i.e. it is not known whether people WFH to avoid a long commute or choose to live further from the workplace because they can WFH.
Office vs Home Working: How we can save our carbon footprint – WSP, 2020	• The analysis finds **a strong seasonal effect**; working from home in summer reduces total carbon footprint by 5% due to reduced transport emissions, but in Winter an increase in emissions is found.
Environmental policy implications of working from home: Modelling the impacts of land-use, infrastructure and socio-demographics – Energy policy, 2012	• The analysis considers transport and home energy use changes only (i.e. no office energy changes or wider effects) and finds an overall energy reduction from home working of approx. 3000 kWh per year per worker.

Does home-based telework reduce household total travel? A path analysis using single and two worker British households - Journal of Transport Geography, 2018	• The modelling underlines the **importance of distinguishing between counterfactual occupancy types** – such as the difference between single vs. multiple workers per household. • The study includes summarised data from the National Travel Survey giving various variables (e.g. household income, number of children) by WFH status and occupancy type
Does telecommuting save energy? A critical review of quantitative studies and their research methods - O'Briena et al.	• Few studies have quantified home, office, transportation, and communications energy or GHG emissions implications of telecommuting simultaneously. This paper reviews results and research methods of primarily quantitative studies of any and all four domains that consider operating energy and/or greenhouse gas emissions in order to make progress in answering the question of whether telecommuting results in less energy use and greenhouse gas emissions than conventional centralized office working. • The results show that this problem is complex, and that **current methods are generally inadequate for fully answering the question**. • While most studies indicate some benefit, several suggest teleworking increases energy use – even for the domain that is thought to benefit most: transportation.
Home telework and household commuting patterns in Great Britain - Patrícia C. Melo, João de Abreu e Silva, Available online 24 May 2017, Elsevier	• This study provides new evidence on the relationship between household and intra-household commuting travel and home telework for Great Britain using data from the National Travel Survey for the period between 2005 and 2012. • The results from the empirical models of individual and household commuting travel suggest there is some evidence of longer weekly commuting distances travelled, but shorter total travel times, for more frequent home teleworkers. • The findings also suggest that there is no intra-household compensation effect between partners, that is, the home teleworking status of one of the household's members does not appear to influence his/her partner's commuting travel.
Working at home and elsewhere: daily work location, telework, and travel among United States knowledge workers -	• This paper uses data from the American Time Use Survey to explore the relationship between daily work locations and travel in the United States from 2003 to 2017. • Outcome variables include travel duration and travel during peak periods. Home is by far the most common non-office work location, but

Jonathan Stiles, Michael J. Smart - Springer Nature 2020	working from other people's homes, cafés/libraries, vehicles, and combinations of multiple locations are also measured.
Telework and daily travel: New evidence from Sweden - Erik Elldér - Available online 20 June 2020, Elsevier	• The study examines how telework influences daily travel in Sweden from 2011 to 2016. • Using representative micro-data from the Swedish National Travel Survey, this study also captures travel behaviour during the defined period when the telework was actually practiced, distinguishing different telework arrangements and analysing a range of travel behavioral outcomes. • Telework leads to reduced travel demand, more use of active transport modes, and congestion relief. • Important differences between full- and part-day teleworkers are also highlighted, stressing the importance of understanding telework as a diversified coping strategy for organizing the spatio-temporality of everyday life.
Telework and the transition to lower energy use in transport: On the relevance of rebound effects - Piet Rietveld - 10 March 2011, Elsevier	• Study from 2010 in which telework at that time was proposed as a promising way to reduce energy use in transport. • At the time of that study, quite conservative behavioral response from employees to respect to this opportunity. • Various rebound effects and led to changes in the timing of commuting trips rather than in the changes of numbers of commuting trips. • Interferences between work and private life • Multitasking leads to complex mixtures of activities both during work time and leisure times • (There is other evidence that not everyone who has the option to work remotely does so at all e.g. CIPD (2020) indicates that over 20% of workers who have that option don't use it at all)
The costs of transport on the environment – the role of teleworking in reducing carbon emissions - David Banister, Carey Newson and Matthew Ledbury Transport Studies Unit	• Empirical evidence and literature review on teleworking, mostly between 1995 and 2005 in the UK, using the National Travel Survey, the Labour Force Survey and 2001 Census • Promoting telework has the potential to deliver a substantial reduction in traffic; and has benefits for families, communities and employers • The study included a full costing approach of teleworking that includes both the primary effects of home working in terms of travel, energy and environmental savings, and the potential social impacts.

University of Oxford – 2007	• The authors also carried out a series of targeted interviews with key individuals to explore the main areas of uncertainty for both the energy and environmental aspects of teleworking and the social issues raised

6.6 Overview of TELMoS18/TMfS18

This appendix provides an extended summary of the model's workings and interaction with the transport model.

The full LUTI approach is illustrated in Figure 26. A full model starts from an input base year and forecasts forward over time, alternatively considering land-use/economic and transport changes. The model predicts the detailed outcomes resulting from the interaction of the "top-down" scenarios of overall growth and the "bottom-up" policies of land-use and transport planning. The impacts of interventions, singly or in combination, are calculated by comparing the results of model runs with and without those interventions.

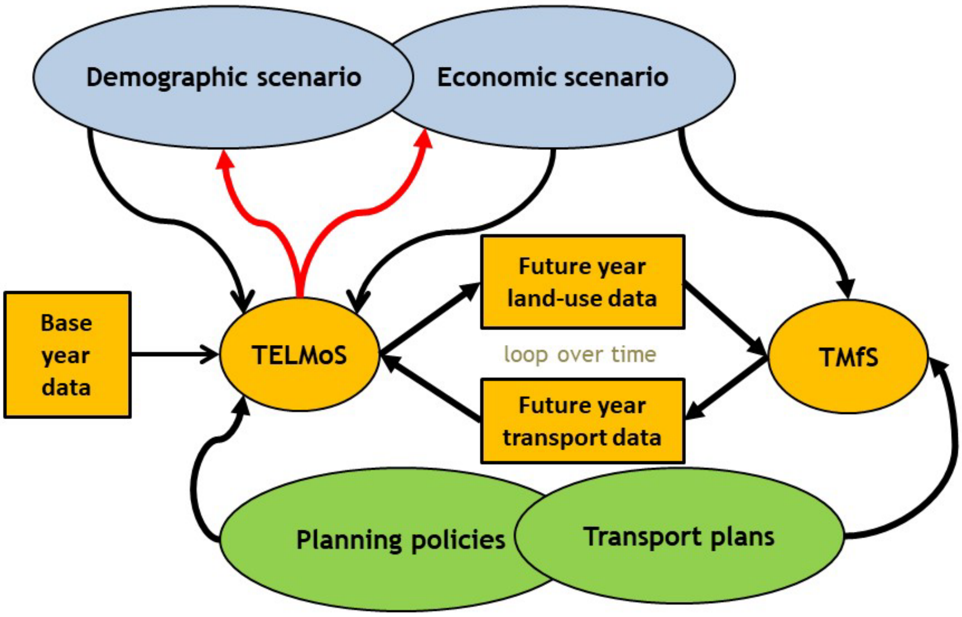


Figure 26: Overall model structure

It is important to keep in mind that the loop between land-use and transport operates over time – this is discussed further below.

One of the key issues in LUTI modelling is whether the scenarios are taken strictly as given, or may be modified by the interventions tested (as indicated the red arrows in Figure 26). The focus of LUTI modelling has generally been on modelling the distribution of fixed totals of population and employment for each forecast year. TELMoS18 can be operated either in that way, as the Fixed Scenario Model or FSM, but also the variable productivity model (VPM) option, in which the consequences of planning and transport interventions can lead to changes in total employment, as indicated by the red link back to the economic scenario in Figure 26. (The demographic scenario is fixed in all present TELMoS18 options.) The employment impacts may be positive or negative – the model does not assume that all plans will have positive consequences. Note that they imply an adjustment of the input scenario in response to particular plans and policies, they do not make the process circular).

Geographical structure – zone system

The TT18 models cover the whole of Scotland, with external zones representing English region. In DELTA terms, the Fully Modelled Area is Scotland.

The zone system within Scotland has been inherited from TELMoS14 with the exception of some disaggregation in a small number of zones, increasing the number of zones in Scotland from 783 to 787. The additional disaggregation was driven by TMfS18 requirements. For most purposes, the number of external zones remains 16 (there are some additional details in the freight modelling interface).

The model also uses higher-level spatial units called macrozones. (These were previously known as Areas; that terminology may persist in places). These are aggregations of sets of zones to functional economic areas (based on Census Travel to Work areas) which the regional economic model (REM) and migration model forecast to. The macrozone definitions have been inherited from TELMoS14, except for a small number of adjustments to some zones which have been allocated into adjacent macrozones because of a poor match to travel to work areas identified during TELMoS14 work. There are 44 macrozones covering the whole of Scotland. The following maps (Figure 27 and Figure 28) show the zone systems in TELMoS18.

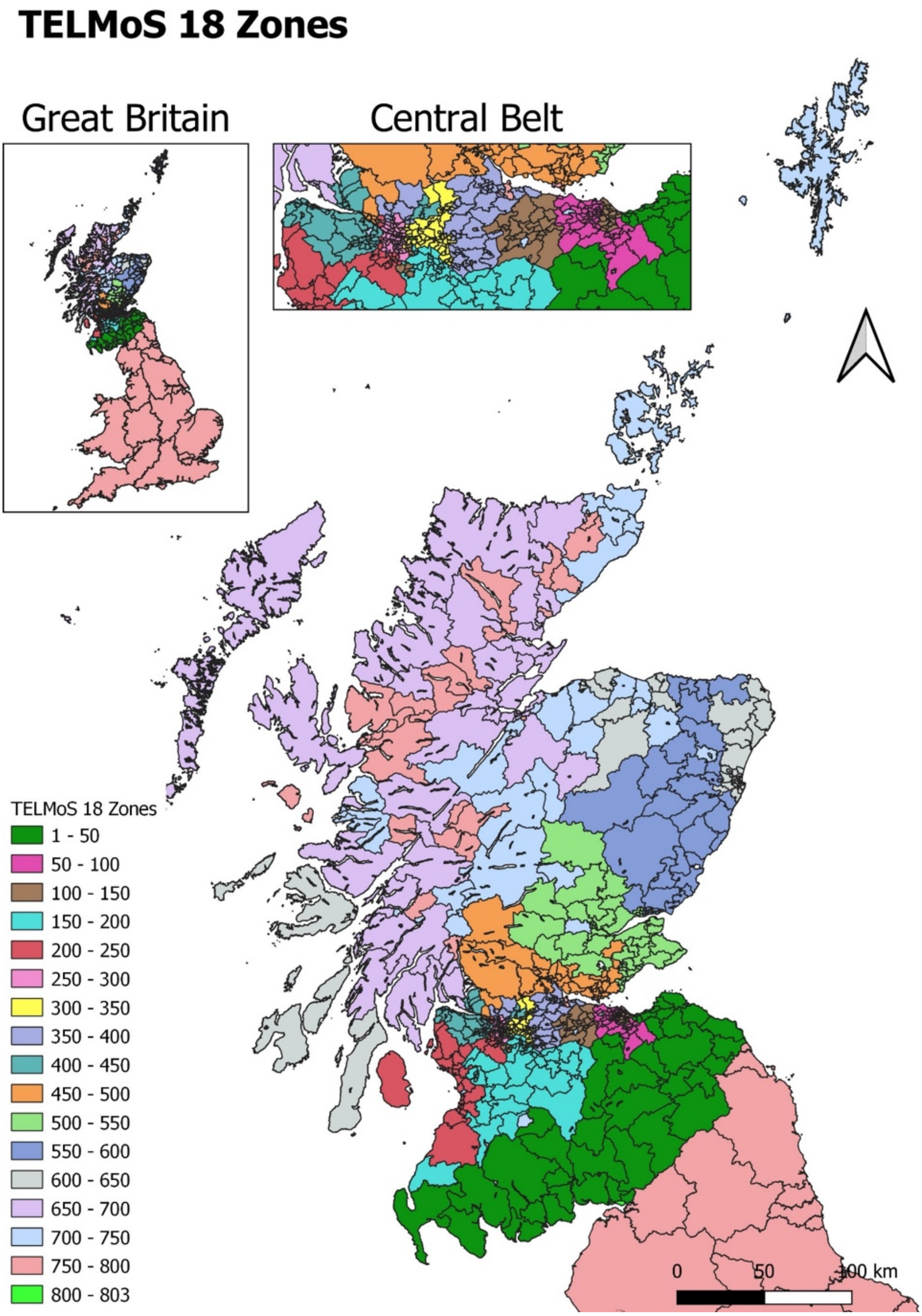


Figure 27: TELMoS18 Zones

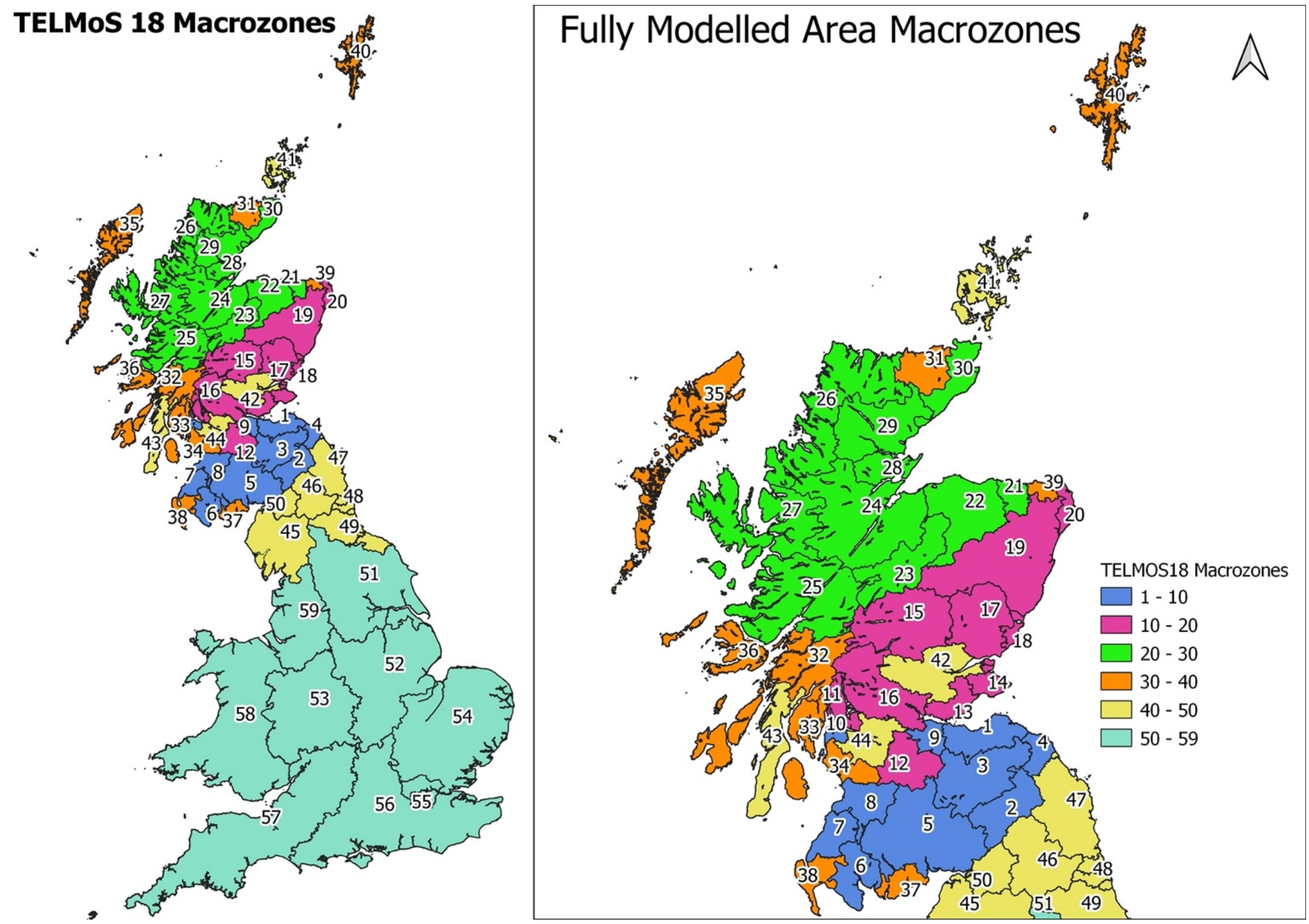


Figure 28: TELMoS18 Macrozones

Base land-use data

The base year for TELMoS18 and TMfS is 2018. The starting land-use databases have been developed in a slightly different method because of the length of time since the last Census. A version of TELMoS14 model was adapted to the slightly different TELMoS18 zone system and used to produce a controlled forecast of change from 2014-2018.

In addition to being the most practical way of estimating the detailed database required for a non-Census year, this approach has the benefit that the time-lagged responses in the early forecast years after 2018 can respond to some of the data about changes over the period 2014-2018. This should give more realistic forecasts than if the model had no information on pre-base-year change.

An important characteristic of the model is that the model reads in the given database for the base year, 2018, and produces a forecast database containing the same variables at the same levels of detail for the first forecast year, 2019. It then repeats the process to forecast for 2020, and so on for as long a forecast as required. **The definitions of variables in the base year database are therefore also the definitions of the forecast output variables**.

Time horizon and modelled years

The DELTA package is used to implement the TELMoS18 model runs in one-year steps, as shown for the first few years in Figure 29. TELMoS18 can currently forecast to 2046. The extension of the forecast period beyond the last transport model year allows the model to capture some (albeit limited) land use impact of that final transport forecast and reflects the types of land-use time lags present in responding to transport changes.

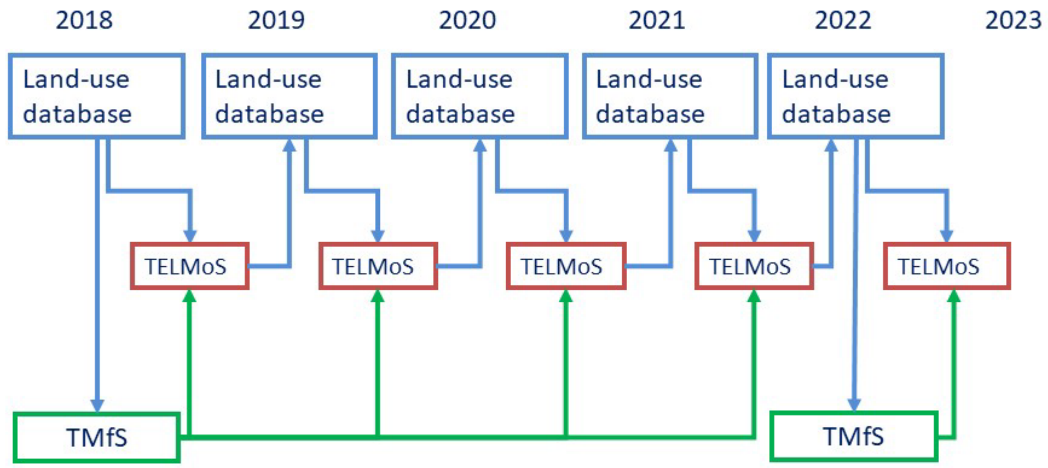


Figure 29: Time-marching sequence

Transport data

The transport data input to TELMoS18 consists of matrices of generalised costs by mode and purpose, for the base year and for all of the transport model forecast years, 2019, 2025, 2030, 2035, and 2040. (NB from the TELMoS18 point of view, the list of transport model years can easily be changed in future work.)

Using the generalised costs data, the model calculates accessibility to housing. Labour and other business. The land use model also passes population, households, and employment data to the transport model in the transport model forecast years using an updated interface. This includes improved treatment of freight which more accurately forecasts volumes of trade and hence freight trips to the different ports of exit.

The generalised costs are used in the accessibility and related calculations described below.

Accessibility calculations

The data obtained from TMfS18 is combined with TELMoS18's own data on land-uses to calculate a range of accessibility measures for each zone and macrozone. These are recalculated in each year of each forecast, in non-transport model years, the most recent generalised costs are used as well as the land-use forecast for the given year. It is worth reinforcing the concept that accessibility in DELTA is opportunity measured, and changes in planning policy and development can affect accessibility and long with changes in generalised costs.

Within a single forecast model run, the other sub-models are sensitive to changes in accessibility over time.

It is the differences between the accessibilities based on Do-Something generalised costs and those based on Do-Minimum generalised costs that give rise to the different forecasts and hence show the impact of any interventions tested.

Business and household processes: choices and responses

Business activity can be measured in terms of employment, output and GVA. National growth in each of these variables is controlled to a given scenario in the base forecast (this is distinct from the do-minimum reference case). They can then vary as a result of the location of employment and subsequent effects on agglomeration or moves to more productive jobs in alternative tests. The net effects depend on whether the Fixed Scenario Model (FSM) or Variable Productivity Model (VPM) is used:

- with the FSM, any increase in household incomes resulting from increased productivity is assumed not to produce any multiplier effects, and therefore not to generate any additional employment;
- with the VPM, multiplier effects are allowed, so improved productivity leading to higher wages, higher incomes and higher demand can generate additional employment (and vice versa – the effects can be negative if the interventions being tested lead to a reduction in productivity).

The modelling work remains largely concerned with how transport and land use interventions will affect the distribution of economic activity within Scotland, whilst the impact of the VPM is usually relatively modest in comparison to underlying overall economic growth controlled by the exogenous scenario. Within each run of the model, the location of employment is determined through processes which represent business choices about:

- where within Scotland to invest;
- where to trade and to produce; and
- at a more local level, about where to locate premises.

Each choice is influenced by accessibility or transport cost terms, as well as by a range of other variables.

The number of households and the size of the population remain constrained to a given national scenario, there is no VPM equivalent for demographics, but the design of the employment model means additional jobs will lead to more people being in work. The location and mix of households and residents changes over time through

- intra-national migration (longer-distance moves, particularly influenced by employment prospects);
- local moves (particularly influenced by housing availability, but also by accessibility to work and services); and
- gaining or losing employment.

Changes in the location of businesses affect households over time, by changing the demand for labour in each location; and changes in the location of households affect businesses over time, by changing the supply of labour and the demand for services.

Developer responses and planning policy inputs

Developer choices are represented by models of how much floorspace to build, and where to build it. Developers' decisions are driven by expected profits, which in turn are driven by occupier demand: development therefore tends to follow businesses and households, whilst also being constrained by the inputs representing planning policy (which control the amount of building which can take place in any location at any time).

Approach to calibration

TELMoS18 is a dynamic model in the sense that it takes a base year (2018) as given and forecasts forward through time. Unlike a conventional static transport model, there is limited calibration (and even less validation) in the base year. Moreover, the focus of the modelling is on the processes of change over time, which cannot be observed in a single year's data. The range of processes and the level of detail is such that a very large-scale, long-term data collection exercise would be needed in order to carry out a "bespoke" calibration entirely on recent, Scottish data. The intention in the development of TELMoS, and of all the other DELTA models, is therefore that the values of the land-use model parameters should be primarily defined by reference to findings from work in urban economics, demography, housing economics, etc.

These ideas about how the model parameters should be defined make a necessity out of what would otherwise be merely a virtue of the design. Until the late 1990s, the literature of urban modelling made much less reference than one might expect to the disciplines of geography, economics, demography and so on, despite the enormous range of relevant research being undertaken in those fields. This was felt to be inefficient, to put it mildly, both in the development of theory and the exploitation of empirical results. The designs of the DELTA models in general, and TELMoS in particular, have therefore tried to devise component sub-models representing processes that would be recognized and perhaps even recommended by researchers in those specific areas of urban studies. Much of the calibration of TELMoS18 therefore relies on the middle or lower levels of the hierarchy shown in the table below.

Table 22: Calibration approaches

Calibration approach		Examples (in TELMoS18)
1	Own analysis of observed data	Some parts of the residential location model
2	Analysis of synthetic data (from microsimulation modelling	Initial values for the household transition models
3	Matching data reported by others	Household mobility rates
4	Direct use of coefficients estimated by others	Car ownership model
5	Reproducing elasticities (etc) reported by others	Effect of accessibility improvement on residential rents
6	Reproducing elasticities (etc) implied by the coefficients reported by others	Effect of changing employment opportunities on rates of migration
7	Matching to “stylized facts”, professional judgement	Choice of variables in migration model, responses in development model

The sources used are of necessity for a wide range of geographical areas, often outwith Scotland, and a variety of time periods. We would argue that this is in many respects an advantage, in that it draws upon evidence from a much wider range of circumstances than if the calibration looked only at recent data for Scotland; this should make the model more robust in representing different circumstances in future. At the same time, the base data, and the given economic and demographic scenarios, ensure that the model is firmly based in Scottish reality.

Base and Alternative Tests

Each full run of the complete TELMoS18 sequence for the forecast period is referred to as a “test”. There is an important distinction between Base and Alternative Tests, which is essential to the way in which the economic scenario is represented. Base and Alternative Tests for model running do not correspond to Base and Alternative for appraisal purposes.

A Base Test is one which is controlled to match the input economic scenario at Scotland level (and is therefore sometimes referred to as a “scenario-matching base test”). This is done on the basis of planning and transport assumptions that match the assumptions underpinning the economic scenario itself. The assumptions are that:

- generalised costs of travel and transport do not change over time (i.e. that neither the SFC nor the Oxford Economics projections are based on a land-use/transport interaction model);
- the supply of the modelled types of floorspace changes in line with the given scenario for each macrozone (neither set of projections considers the land/floorspace market as a constraint).

These conditions effectively assume that a system of “predict and provide” for changes in demand will function in both transport and land development, so that levels of congestion will neither get worse nor better, and shortages or surpluses of floorspace will neither be relieved nor exacerbated.

A new Base Test must be run for each scenario, and any Alternative Test must pivot around one Base Test. In practice, this means that:

- some adjustment factors calculated in the Base Test are reused in each Alternative Test;
- some responses in each Alternative Test are influenced by differences from the Base Test.

Apart from these pivoting effects, the Alternative Tests are free-standing runs of the model using their own planning and transport inputs, i.e. changing the “bottom-up” inputs to the overall modelling process.

In the FSM, this pivoting operates, but the fact that household consumption expenditure is constrained to the Base Test value means that the Alternative Test will not produce any net national change.

In the VPM, the critical result of the pivoting process is that if the planning and transport inputs make the economy more efficient, the outputs of the Alternative Test will show net national gains in GVA and employment compared to the underlying Base Test. Conversely, if the planning and transport inputs lead to less efficiency, the Alternative will show losses relative to the Base Test – there is nothing in the model that assumes that transport investment or particular planning policies are automatically beneficial.

To summarise:

- a Base Test implements the scenario as given, with planning and transport policy inputs appropriate to the assumptions behind the scenario, and does not allow any adjustment to the scenario (i.e. the red links in Figure 26 are absent);
- FSM Alternative Tests forecast local/regional differences depending on the effects of the policy inputs, but will match the Base scenario in total (the red links in Figure 26 are absent);
- VPM Alternative Tests may forecast modifications to the scenario depending on the effects of the policy inputs (the red links in Figure 26 are present - and may be positive or negative for economic growth).

An important consequence is that the Do-Minimum model run forming the base case for appraisal purposes is an Alternative Test which may itself show higher or lower growth than the scenario input to the Base Test, depending on the consequences of the Do-Minimum planning and transport inputs.

Note also that the discussion above is about gains or losses to the economy; the impacts on economic welfare, which is usually the main focus of appraisal, may be different.

Interfaces to and from TMfS18

The interfaces between TELMoS18 and TMfS18 work on quite different data.

The data passed from TELMoS18 to TMfS18 for each zone consists of

- numbers of resident persons in households[21] by size and car ownership
- numbers of jobs by broad employment category
- estimated freight flows, reflecting the changes in the economy and in the location of employment by industry.

Households are recategorised in the TELMoS-TMfS interface, and some further disaggregation of persons (by sex and, for workers, between full-time and part-time work) is applied. There is also the option (not so far in regular use) to segment all the household/person data by income band.

The interface from TMfS18 to TELMoS18 passes matrices of generalised costs for selected purposes and times of day, and formats these as DELTA package files.

6.7 TELMOS/TMfS remote working scenarios

The objective for the scenarios that have been developed for the STPR2 work for Transport Scotland is to create a number of coherent, credible and challenging futures that explore the level of trip making resulting from changes in the contextual environment with a focus on creating significant spatial variation.

The following sections describe the main results from the high traffic and low traffic scenarios.

Remote workers by employment categories

Table 23 represents the proportion of remote workers in 2019 and under the two traffics scenarios of 2025 in both absolute and percentage terms for each employment activities.

The results confirm that under the "high traffic" and "low traffic" scenarios, the office-based jobs, more particularly in business services, have the highest proportions of home workers such as highly concentrated business services with 43% of workers working at home on an average day.

The lowest proportion of workers working at home on an average day is amongst the manual jobs such as for example the agriculture, forestry, and fishing (manual) sectors with respectively 6% and 12% under the high and low traffic scenario.

Table 23: Remote workers by employment activities

	Remote workers (abs)			Remote workers (%)		
Employment activities	2019	2025 High traffic	2025 Low traffic	2019	2025 High traffic	2025 low traffic
Agriculture, forestry and fishing (non_manual)	1434	2336	2682	26%	44%	51%
Agriculture, forestry and fishing (manual)	199	787	1509	2%	6%	12%
Coal and lignite non manual	436	1021	1373	9%	24%	32%

	Remote workers (abs)			Remote workers (%)		
Employment activities	2019	2025 High traffic	2025 Low traffic	2019	2025 High traffic	2025 low traffic
Coal and lignite manual	59	148	212	8%	23%	33%
oil and gas non manual	1903	4048	5221	12%	28%	37%
oil and gas manual	263	866	1473	3%	12%	20%
Other Extraction & Mining (non-manual)	706	1658	2225	11%	29%	40%
Other Extraction & Mining (manual)	97	312	521	4%	13%	22%
Manufacturing (non-manual)	15117	28000	33686	20%	41%	49%
Manufacturing (manual)	2045	7914	14702	2%	7%	13%
Electricity,gas, steam and air conditioning supply	1867	4435	6231	8%	21%	30%
Water supply; sewerage,waste management and remediation activities	1046	3049	4717	5%	15%	23%
Construction	8015	22710	33348	8%	21%	30%
Wholesale and repair of motor vehicles and motorcycles	7161	20185	30642	6%	16%	25%
Retail non Local	3301	9270	14039	6%	16%	25%
Retail Local	10284	28662	43555	6%	16%	25%
Transport	1614	5285	8339	4%	12%	19%
Storage	1987	6520	10295	4%	12%	19%
Accommodation, food service activities and recreation	21147	51488	70989	10%	25%	34%
Information and communication	12329	21483	26424	18%	30%	37%
Very specialized services	216	586	818	9%	26%	36%
Highly concentrated Business Services	8289	17332	21308	18%	35%	43%
Moderately concentrated Business Services	6665	13947	17142	18%	35%	43%

	Remote workers (abs)			Remote workers (%)		
Employment activities	2019	2025 High traffic	2025 Low traffic	2019	2025 High traffic	2025 low traffic
Moderately dispersed Business Services	13200	27394	33646	18%	35%	43%
Highly dispersed Business Services	22359	46941	57714	18%	35%	43%
Monetary intermediation Non local	1792	4889	6823	9%	26%	36%
Monetary intermediation local	1308	3611	4991	9%	25%	34%
Insurance Non Local	556	1561	2191	9%	26%	37%
Insurance Local	309	798	1103	9%	24%	34%
Public administration and defence; compulsory social security Local	4113	13350	20823	6%	19%	29%
Public administration and defence; compulsory social security Non-Local	4113	13350	20823	6%	19%	29%
Higher Education	2976	9414	14224	7%	21%	32%
other Education	10361	32519	49196	7%	21%	32%
Human health and social work activities	24494	73093	107656	8%	23%	34%
Other service activities (22, 23, 24) non manual	3899	10768	15111	10%	28%	40%
Other service activities (22, 23, 24) manual	529	1721	2685	5%	17%	26%

Looking at the proportion of remote workers by work zone in the four main cities in the graph below (see Figure 30), the City of Edinburgh is the city that has the largest proportions of workers working at home with respectively 36% of workers with the “low traffic” scenario and 27% with the “high traffic” scenario. The City of Edinburgh is followed by Aberdeen and Glasgow with similar proportions of remote workers and Dundee.

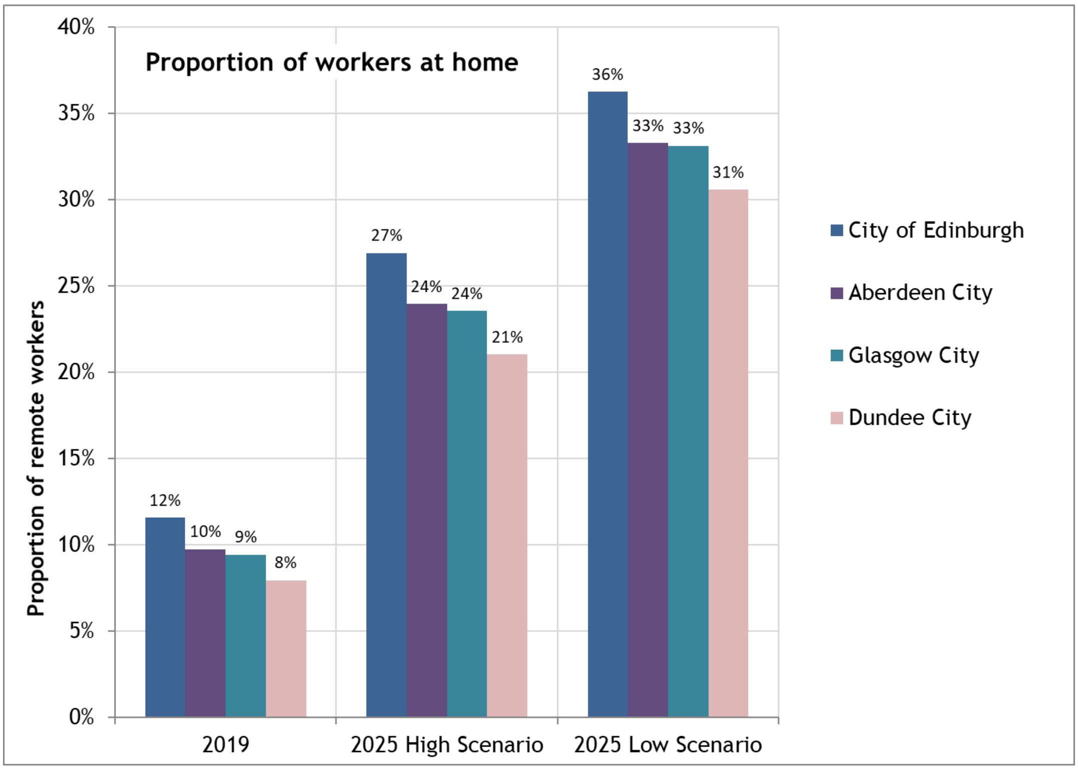


Figure 30: Proportion of workers at home by work zone for the four main cities

Remote workers by household types

The model allows us to compare the level of remote workers by household types for each forecast years.

The graph below (see Figure 31) represents the proportion of workers working remotely on an average day by household types in 2019 and under the two traffic scenarios of 2025.

The proportion of remote workers is as intended higher under the low traffic scenario for all household types. The households type composed of 2+ adults with children has the greatest tendency of working from home. By contrast, the young single households have the lowest proportion of workers working at home.

In addition, the table shows that in each modelled year and for both traffic scenarios, the highest proportion of workers at home on an average day is amongst SEL1.

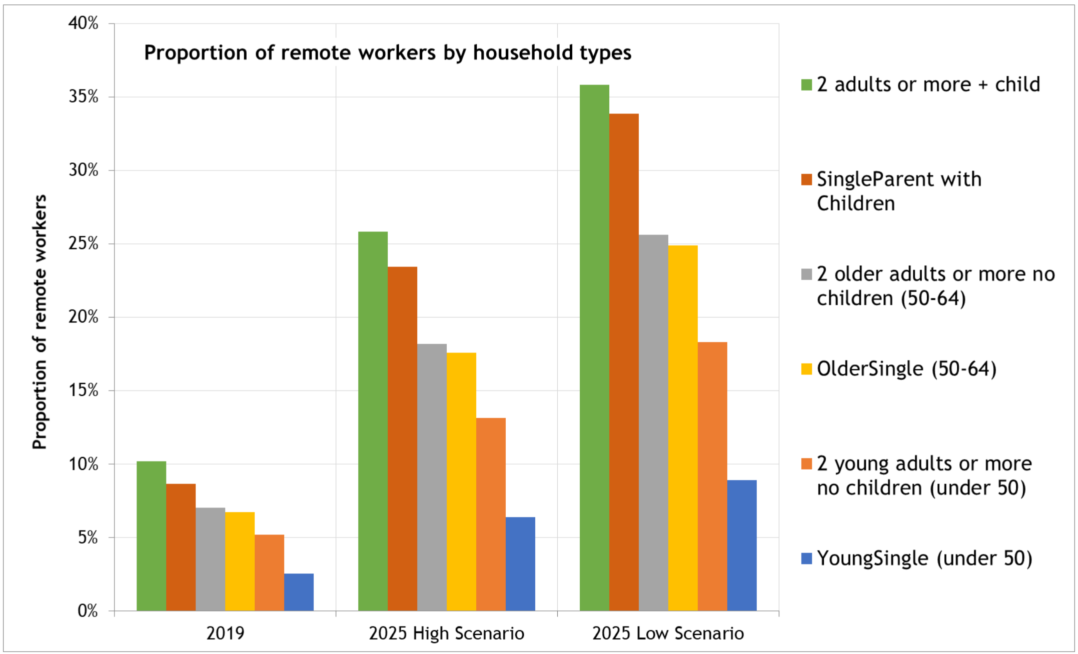


Figure 31: Proportion of remote workers by household types

Table 24: Proportion of remote workers by SEL

Socio Economic Levels	2019	2025 High traffic scenario	2025 Low traffic scenario
SEL1	63%	51%	43%
SEL2	31%	34%	33%
SEL3	0%	6%	13%
SEL4	6%	9%	11%

The maps below (Figure 32 and Figure 33) show the absolute changes in remote workers by home zone between 2019 and 2025 under the "high traffic" and "low traffic" scenario for the 2+ adults with children household type. The biggest differences in the number of remote workers between 2019 and 2025 are mainly concentrated in and around the cities.

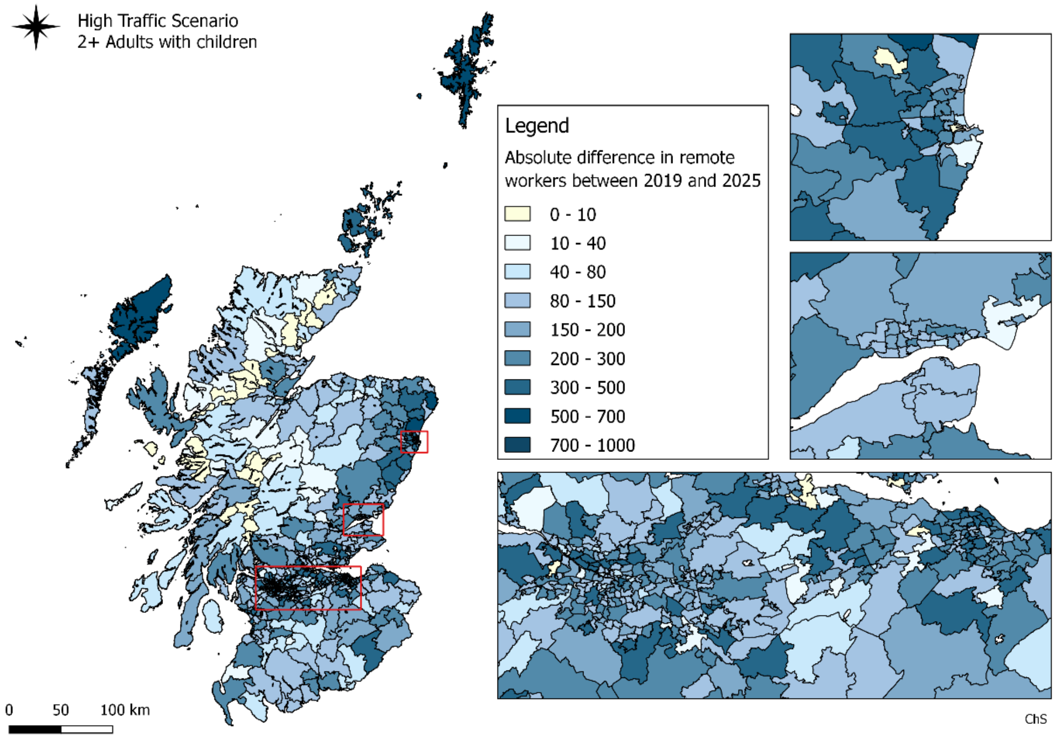


Figure 32: Absolute changes in remote workers (2+ adults with children) 2019-2025 High traffic scenario

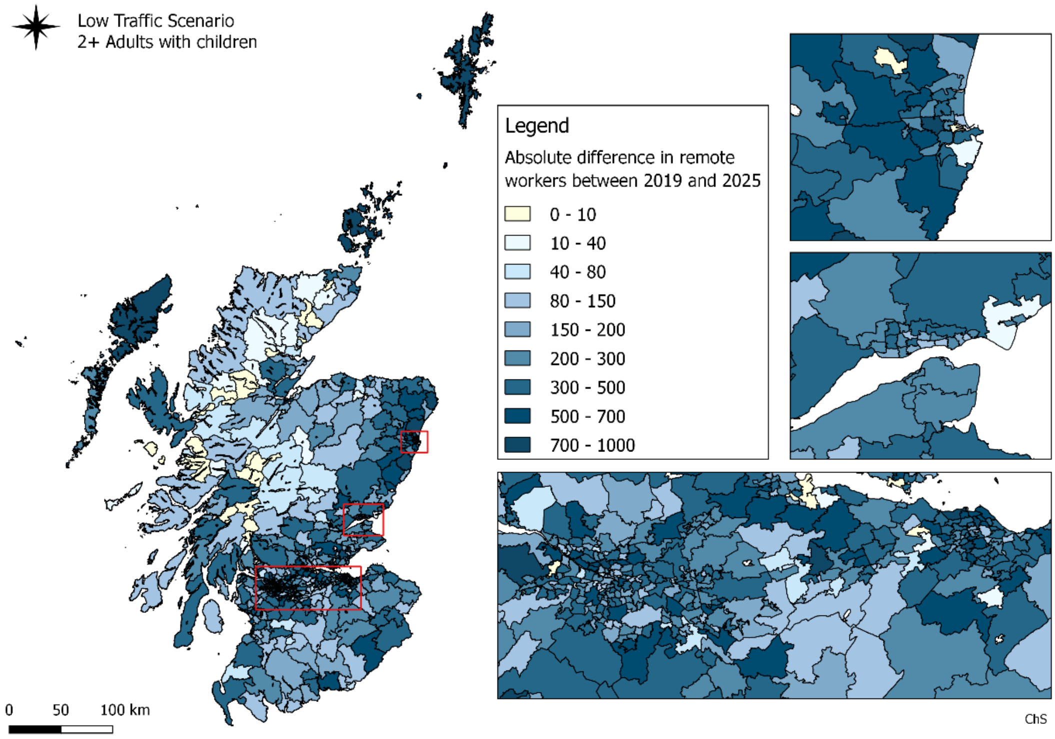


Figure 33: Absolute changes in remote workers (2+ adults with children) 2019-2025 Low traffic scenario

Data from the transport model

The consulting firm doing the transport modelling work for STPR2, AECOM, has provided us with some volume data from their runs of TMfS to allow us to do further analysis on commuting trips.

The volume data they provided is the average neutral weekday for the AM peak period (07:00-10:00am) for one-way trip, from each home zone to each work zone, for both car and public transport modes.

We received this data for 2019 and then for both high and low traffic scenarios in 2025.

The table below shows the overall reduction in the number of commuting trips for all scenarios between 2019 and 2025.

Table 25: Number of commuting trips - car and PT

	Total car trips	Total PT trips	Prop car	Prop PT
2019	747816	197777	79%	21%
2025 high	627271	169325	79%	21%
2025 low	538706	148623	78%	22%

	2019 - 2025 high	2019 - 2025 low
Reduction car trips	-16%	-28%
Reduction PT trips	-14%	-25%

As expected, the number of commuting trips is reducing for both car and public transport, 16% reduction between 2019 and 2025 for car mode and 14% reduction for public transport mode under the high traffic scenario; and 28% and 25% reduction respectively under the low traffic scenario.

We can also note that the proportion of mode share stays quite stable for all scenarios.

The following tables and the corresponding graph below show the number of commuting trips by five kilometres distance bands for car and for all scenarios.

Table 26: Commuting car trips by 5km distance bands

	Car trips		
	2019	2025_high	2025_low
0-5 km	147277.22	118502.65	99866.77
5-10 km	129963.87	106543.82	90548.23
10-15 km	101121.41	84669.88	72314.60
15-20 km	83836.59	69438.28	59426.21
20-25 km	58042.74	48443.77	41676.49
25-30 km	48039.04	39935.60	34480.95
30-35 km	37977.13	31667.33	27434.88
35-40 km	29005.80	24481.86	21180.08
40-45 km	24350.34	21122.70	18407.31
45-50 km	17674.22	15260.02	13310.69

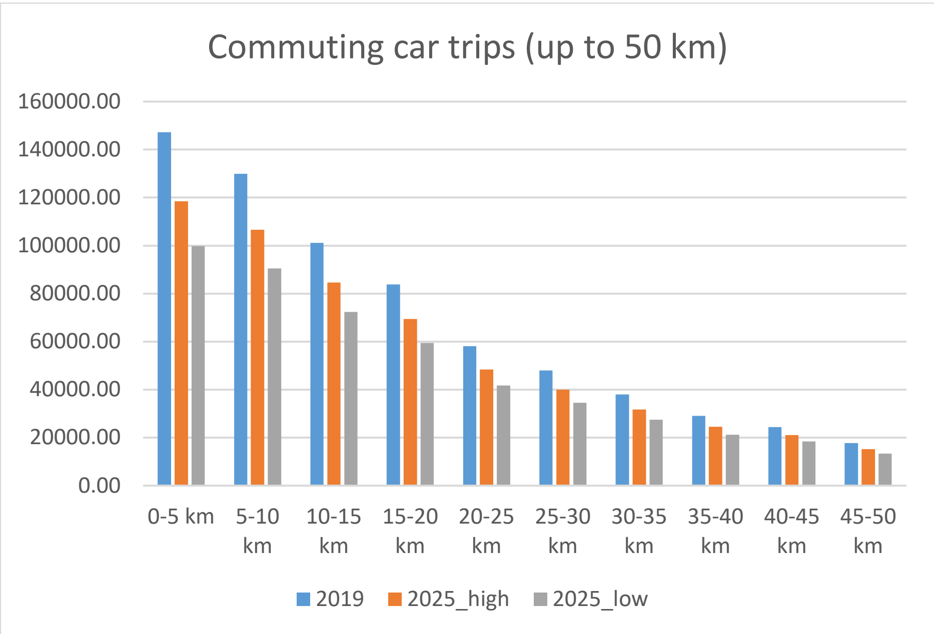


Figure 34: Commuting car trips by 5km distance bands

The following tables and the corresponding graph below show the number of commuting trips by five kilometres distance bands for public transport and for all scenarios.

Table 27: Commuting PT trips by 5km distance bands

	PT trips		
	2019	2025_high	2025_low
0-5 km	44697.49	36555.80	31629.70
5-10 km	44139.79	37810.55	33054.72
10-15 km	28737.75	24835.93	21856.76
15-20 km	17168.50	14440.94	12716.56
20-25 km	13152.77	11121.48	9855.49
25-30 km	9323.84	7859.40	6978.41
30-35 km	6979.75	5876.34	5197.28
35-40 km	6068.76	5327.41	4698.28
40-45 km	5492.67	4821.83	4297.17
45-50 km	3752.92	3287.52	2928.19

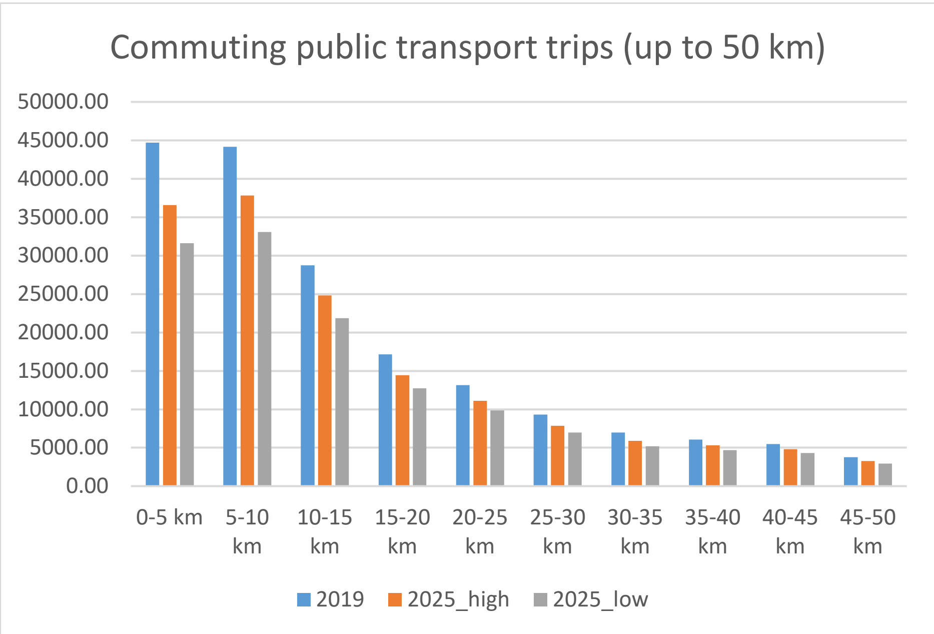


Figure 35: Commuting PT trips by 5km distance bands

For longer distances, the pattern is different. This can be explained as less frequent commuting weakens the relationship between workplace and home, and some households choose to locate further – or more further – from their workplaces. However, they typically still travel to work some days; at long distances, where without remote working there would be little or no commuting, causing an increase in total commuting.

The tables and graphs below show the number of commuting trips for all scenarios by car (Table 28 and Figure 36) and public transport (Table 29 and Figure 37) respectively for distance bands from 50km to more than 500km.

Table 28: Long distance commuting car trips

	Car trips		
	2019	2025_high	2025_low
50-100 km	59515.15	54939.32	48679.17
100-250 km	10505.22	11827.23	10999.80
250-500 km	505.04	436.12	379.24
500+ km	2.67	2.02	1.72

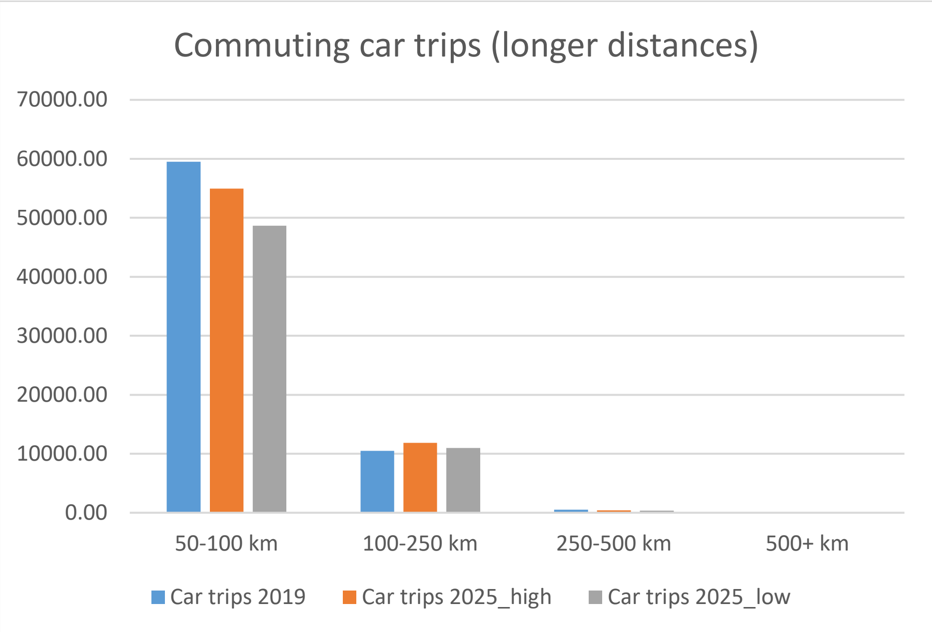


Figure 36: Long distance commuting car trips

Table 29: Long distance commuting PT trips

	PT trips		
	2019	2025_high	2025_low
50-100 km	15867.86	14374.59	12723.57
100-250 km	2326.64	2918.96	2603.52
250-500 km	68.66	94.20	83.64
500+ km	0.10	0.06	0.05

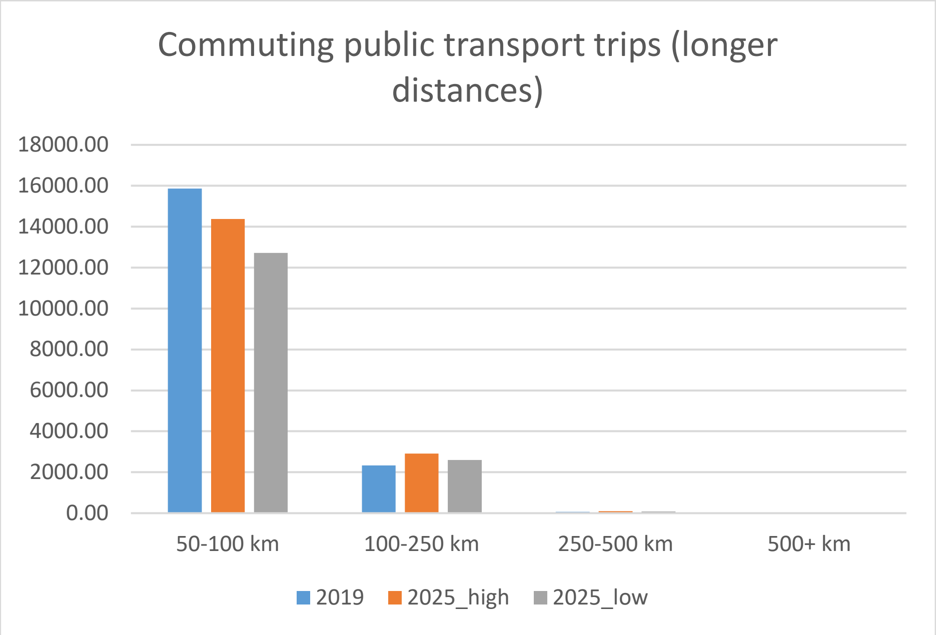


Figure 37: Long distance commuting PT trips

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