Assessing the Greenhouse Gases Emissions of Home Working versus Commuting to an Office

CENTRE FOR ENERGY AND THE ENVIRONMENT

Internal Document 999

September 2021

Report Name:	Assessing the Greenhouse Gases Emissions of Home Working versus Commuting to an Office
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Report Number:	Internal Document 999
Publication Date:	September 2021

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Rev. No.	*Comments*	*Approved By*	*Date*
1	First Draft	T. A. Mitchell	21/07/21
2	First Release to DCC		21/07/21
3	Amended following DCC feedback		8/09/21

Management Summary

Devon County Council commissioned the Centre for Energy and the Environment to undertake a high level assessment to establish the potential climate change impacts of home working against traditional office working. A simple analysis of home working versus office working has been undertaken, that considered commuting modes and distances, vehicle ownership, and energy consumed both at home and in the office. The results of the analysis show that with the assumptions made home working will typically result in savings in greenhouse gases when compared to office working. Whilst the conclusion depends on the assumptions, sensitivity analysis has demonstrated that under a range of likely circumstances, home working should still result in savings. The average savings (based on the base case) are in the region of 2 t CO_2e per year. The most significant variable at present is the commuting mode and distance, though as transport shifts to electric vehicles powered by a low carbon electricity network, these emissions will decrease.

1. Background

As a result of the Covid-19 pandemic, there has been a significant upturn in the number of office workers undertaking their work from home. Looking beyond current restrictions imposed by the pandemic, organisations will face choices about future working practices. This will be set against other contextual factors, including the impact of work on climate change.

Devon County Council (DCC) commissioned the Centre for Energy and the Environment (CEE) at the University of Exeter through the South West Energy and Environment Group (SWEEG) to undertake a high level assessment to establish the potential climate change impacts of home working (HW) against traditional office working (OW).

2. Approach and Scope

The impact of an activity on climate change is usually expressed in terms of the amount of greenhouse gases (GHG) emitted. In order to establish the relative benefits of HW versus OW, emissions from both regimes were estimated. An initial high level assessment was required, and the approach adopted was to set a baseline scenario for each method of working, and to express the impact as the difference in daily emissions between the two. There are many different factors that impact on both scenarios, and these were explored in a sensitivity analysis by making sequential changes to the baseline assumptions. Given the limited resource available, the cumulative impact of different variables was not tested.

The following potential factors were taken to be in scope of the assessment and are discussed in greater detail in the next section:

- Transport related impacts:
    - Commuting mode
    - Commuting distance
    - Vehicle ownership
- Domestic energy related impacts:
    - External temperature
    - Home fabric efficiency
    - Heating system
    - Heating strategy

    - Hot water consumption
- Office building related impacts:
    - External temperature
    - Office space occupancy density
    - Space strategy

The following potential factors were taken to be out of scope of the assessment:

- Impact on public transport: A structural shift from OW to HW would have an impact on the demand from public transport and this could result in reduced services with an associated GHG emission reduction. However, this is hard to quantify, and there are counter arguments that reducing public transport services (e.g. frequency) could undermine wider usage and could have negative impacts. In addition, over time there is the intention to further decarbonise public transport (e.g. hydrogen-fuelled buses), and so this impact has been excluded. As a best estimate, it is felt that its inclusion would improve savings associated with HW.
- Congestion: Increased HW would reduce traffic and congestion, especially at peak times, and this may result in an overall reduction in wider emissions from transport. However this was difficult to quantify and so was not included.
- Catering (food): Office workers will typically eat one main meal (lunch) during their working hours, as well as additional snacks and drinks. The emissions associated with the main meal will depend on what it is and how it is prepared. For example, a packed lunch prepared at home will have no emissions allocated to the office, preparing food in the office will use energy within the office, and purchasing food from catering outlets might result in emissions from that scenario, though not from the office itself. Conversely, HW might result in similar emissions to the OW scenario if a simple packed lunch type meal is prepared in the same way, or it could result in increased emissions if more involved cooking is undertaken. In short, it is hard to account for all these different options but it is expected that the overall impact of this factor is likely to be relatively small and neutral.
- Hot Drinks: In simple terms, if a person drinks a similar number of hot beverages under the HW and OW scenarios then there should be little difference between the two scenarios. The matter is complicated by the way hot water is boiled with kettles dominating at home whereas hot water heaters are common in offices (though kettles are used in many offices as well). These have the advantage of users drawing off only the amount of water needed, though also suffer from constant standing losses whereas a kettle does not. In addition, if kettles are "over-filled" then the additional energy consumed is not necessarily purely "wasted" (a common criticism), for example that energy might simply displace space heating energy in the winter. A study commissioned by *Zip* who produce water heaters reported energy consumption for standby and draw-off for a range of water heaters, and a kettle, for a typical five-day week in a scenario where 120 cups of hot water each 167 ml are boiled each day [1,2]. Assuming a person typically consumes 4 cups a day (though some might not drink any), then this would serve 30 people. A poor (high energy) system could use approximately 10 kWh/week on standby, whilst a better system (e.g. with time and other controls) might use half of this. Using current grid electricity factors this results in an effective range of approximately 0.018 to 0.024 kgCO_2e/person per day from a hot water heater or 0.021 kgCO_2e/person per day for a kettle. These values will reduce over time as the grid decarbonises. In the context of the total daily emissions associated with the HW and OW scenarios discussed below, these are very marginal and so have not been included.

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[1] https://www.tlc-direct.co.uk/Technical/DataSheets/Zip/Zip_HB_Plus.pdf
[2] https://usermanual.wiki/Document/ZipHydroBoilPlusEnergySheet.1613412013.pdf

- Lighting and power: It is assumed that only simple IT equipment and lighting is used in the HW scenario, and no other home energy usage arises from HW (e.g. increased use of white goods or other equipment). Lighting and power consumption in the OW scenario is assumed to be included in the general energy benchmarks of the building.
- Office fabric efficiency: There was insufficient data available to investigate the impact of the building fabric on the OW scenario. It is noted that for the office energy benchmarks used, fossil fuel consumption (which can mostly be attributed to space heating, though some will be used for hot water and potentially other uses) is 56% of total energy use, and so well under half of office energy use will be impacted by the fabric efficiency (space heating demand will be impacted by both fabric efficiency, and air exchange e.g. from ventilation).
- Cooling: It is assumed that there is no cooling demand in homes and that therefore home working in the summer does not result in additional energy demand from cooling. For offices energy from cooling will be included in the general benchmarks used, though no additional analysis or separation of cooling from general energy use was included.
- Embodied emissions savings from change of use: HW could lead to the freeing up of office space which can be converted to other uses (e.g. residences) that would otherwise have had to be constructed from new. This would result in reduced emissions from the materials used in the construction of those buildings. This impact has not been modelled.

The next section outlines the data sources, assumptions, and calculation approaches for each of the impacts that have been taken to be in scope.

3. Method

3.1 General Assumptions

The approach taken has been to calculate daily emissions arising from the HW and OW base case scenarios based on typical values for each variable. The sensitivity of the results to each of these variables was then tested by adjusting them individually (though not in combination) to explore higher and lower bounds. The range chosen for the testing was not intended to encompass extremes, but rather to be a pragmatic range to highlight the sensitivity of each variable.

It was assumed that a working day consisted of 8 hours, and that there are 232 working days in the year. This results in approximately 63% of all days in a year being working days, and it was assumed that these were apportioned evenly between the months (though in practice there will be a greater proportion of leave taken in the summer).

3.2 Transport Emissions

Emissions from a range of different modes of transport (petrol/diesel cars, hybrid cars, electric cars [both now and in 2030], motorbikes, taxi, bus, coach, rail, and walking/cycling [taken as zero emissions]) were tested by taking the emission factors [1] in kg CO_2e/km[3] published annually by the government and multiplying them by the return distance from home to work. The average commuting distance in the UK was stated by the RAC [2] to be 10 miles (16.1 km) and the baseline scenario assumed this distance in an average diesel/petrol car. The sensitivity scenarios explored varying the range between 5 and 50 km, and the mode to either an electric car (with current electricity carbon intensity factors) or a large diesel/petrol car. As commuting emissions were

[3] Note: The emission factors were taken as the sum of factors from combustion and any associated Well to Tank (WTT) emissions

found to have the greatest impact of all scenarios, additional combinations of mode and distance were also explored. Emissions from commuting were applied only to the OW scenario and it was assumed that HW resulted in no transport emissions.

There are currently 29.4 million privately owned cars and a further 2.2 million privately owned vans in the UK [2]. This averages to 1.1 privately owned vehicles per household, though if the 24% of households without access to a vehicle are excluded, this rises to 1.5 vehicles. If a significant reason for owning multiple vehicles is to enable commuting, then there is the potential with HW for a reduction in vehicle ownership, though the impact of this would be indirect as the demand for vehicles drops over time. For the baseline scenario it was assumed that HW did not have any additional impact on car ownership, but the sensitivity testing assumed that working at home enabled a household to relinquish a single vehicle. For simplicity, this was quantified as the average daily embodied carbon of a car. It was inferred from a paper by Messagie [3] that a car has embodied emissions of 3 t CO_2e. It should be noted that this value would be very sensitive to the size of the vehicle, and other sources report significantly different values, though these were not considered here. It is assumed that the average age of a car at the time of scrappage is 13.9 years [4] and that given 232 working days in a year, this results in 0.9 kg CO_2e/day.

3.3 Domestic Emissions

In order to estimate the additional carbon emissions at home under HW, a simple building physics model was constructed. This assumed that the heating system will have to make up all the heat lost during the working hours, and that this heat is the additional energy arising from HW. This is an over-estimation as in practice if the home is unoccupied during the OW scenario then when occupants return home some of that energy will still need to be put into the dwelling to achieve comfort temperatures. This is further complicated as we transition towards heat sources like heat pumps which work more efficiently at lower circuit temperatures which would require longer running times. The values calculated here are therefore expected to be over-estimates of the increase in emissions from dwellings under the HW scenario.

The model assumed an 85 m^2 semi-detached two-storey house with 30% glazing on the front and rear facades oriented East-West and a ventilation rate of 0.5 air changes per hour. It was assumed that the fabric was of “average” standard in terms of heat loss, though sensitivity testing was applied for “bad” and “Passivhaus” specifications as follows:

- Average: Insulated cavity wall (U-value 0.6 $W/m^2.K$), standard double glazing (2.0 $W/m^2.K$), 100 mm insulated loft (0.4 $W/m^2.K$), uninsulated suspended ground floor (0.5 $W/m^2.K$)
- Bad: Solid wall (U-value 2.0 $W/m^2.K$), single glazing (5.0 $W/m^2.K$), uninsulated loft (2.3 $W/m^2.K$), uninsulated suspended ground floor (1.0 $W/m^2.K$)
- Passivhaus: Super-insulated opaque elements (0.15 $W/m^2.K$) and certified triple-glazed windows (0.8 $W/m^2.K$)

The baseline scenario assumed that a central heating system with no zone controls was used that therefore heated up the whole house. Sensitivity testing was undertaken whereby only a single room (16.3 m^2) was heated up using a plug-in direct electric heater. The heat losses for these different combinations were as follows:

- House: Fabric 397 W/K bad, 125 W/K average, 40 W/K Passivhaus; Ventilation 39 W/K
- Room: Fabric 69 W/K bad, 25 W/K average, 8 W/K Passivhaus; Ventilation 7 W/K

Heat loss calculations were performed for each month using average temperature data for Exeter (average 10.8^{o}C, July 17.1^{o}C, December 5.8^{o}C). It was assumed heating systems were turned off between May and September inclusive.

Solar heat gains assumed average daily irradiation (all of which was assumed to occur within the 8 working hours) from Table 2.12g (London) of CIBSE Guide A [5] applied to windows with a g-value of 0.72 and a frame factor of 0.7, both from SAP [6]. Internal gains were assumed to come from 2 litres of hot water generated from a gas combi-boiler (which was sensitivity tested between zero and 10 litres), metabolic gains of 60 W (for one person from SAP), 50 W for a laptop and 10 W for lighting. Additional gains from cooking and other appliances were excluded but are likely to be minimal.

A number of different heating systems and fuels were tested, with the base case assuming a gas boiler with 80% efficiency. The heating systems tested were gas, oil and LPG at 70%, 80% and 95% efficiency, and electric heating systems (direct electric, and air source heat pumps with efficiency of either 200% [now] or 300% [2030]) both now and in 2030. All carbon conversion factors were taken from the Government factors [1] with the exception of electricity where current and 2030 factors were taken from the Climate Change Committee's 6th carbon budget report [7].

3.4 Office Based Emissions

A simplified approach was taken to offices whereby the energy demand was taken from typical benchmark data for "general office" buildings from CIBSE TM46 [8] to be 95 kWh/m^2 of electricity and 120 kWh/m^2 of fossil fuel. As previously stated, no adjustments were made for the fabric efficiency of the building. Occupancy density was taken from a report by JLL [9]. This segmented office buildings by density expressed as rentable square meterage per person (which was converted to gross square meterage using a factor of 1.25 from CIBSE TM46) as under 11 m^2 (taken here to be very high density), 12 to 15 m^2 (high density), 16 to 19 m^2 (average – as used in the baseline scenario), 20 to 25 m^2 (low density) and over 25 m^2 (very low density). The midpoint of these values was taken to establish a building square meterage per occupant to which the energy benchmarks could be applied. The benchmark energy consumption was taken to be the same regardless of occupancy density (in practice electricity use from equipment and cooling will be higher at higher densities, though heating energy may be lower).

It was assumed that the office is heated using gas at 80% efficiency, though the sensitivity of switching to a heat pump with 300% efficiency was tested. The base case scenario assumed that under the HW scenario, office space can be immediately disposed of (e.g. sold, converted to other uses etc.) as staff work from home, though the sensitivity of not being able to do this was also tested (although not including the impact of fewer people in the office: i.e. the office is assumed to consume the same amount of energy which is likely to penalise the home working scenario under this sensitivity test). In practice, the ability to dispose of office space is likely to occur over time and at trigger points (e.g. as enough people in an office work from home to enable some kind of wider rationalisation).

4. Results

The overall results for the base scenarios are shown in Figure 1. It can be seen that on average the daily savings from home working are 9.3 kg CO_2e which over a year result in savings of 2.1 t CO_2e per person. It can be seen that emissions from commuting are the most significant impact (based here on a 10 mile commute) with savings from potential office disposal the second largest potential saving. The magnitude of these space savings more than offset the added energy use in the home. Vehicle ownership in the base scenario is neutral as it is assumed that there is no change in car ownership.

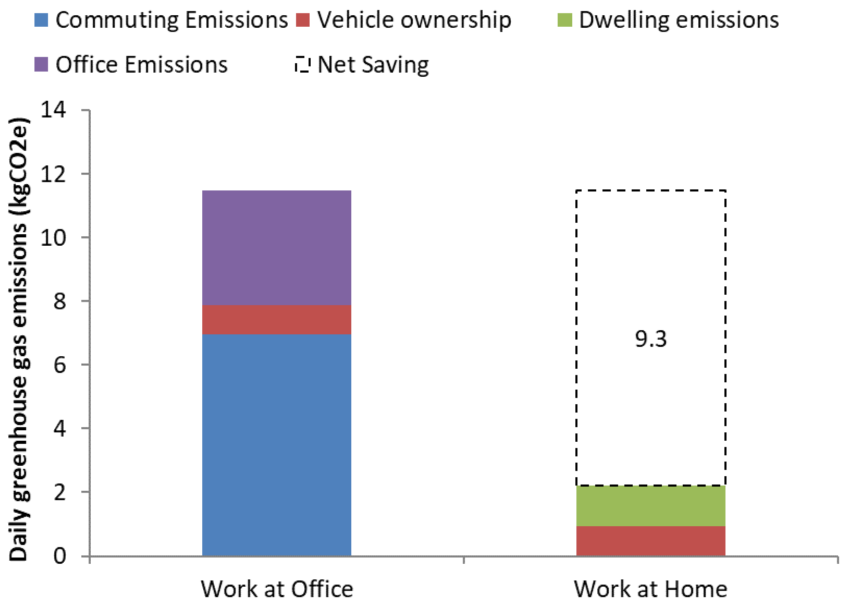

Figure 1: Emissions from the baseline scenario from the OW and HW scenarios for each of the transport and building categories. The net saving is denoted by the area bound by a dotted line.

The base scenario results in commuting emissions of 7.0 kg CO_2e/day in an average car travelling 16.1 km each way. The combined impacts of various selected modes and commute distances are shown in Figure 2. This reveals the very large range in impact from commuting. For example, commuting from Exeter to Plymouth in a large car could result in over 40 kg CO_2e/day, whereas the same journey (assuming walking at either end) by train would result in only about 6 kg CO_2e/day. It can also be seen that over time the impact of commuting will reduce as there is a move to electrification and other decarbonisation of the transport sector. For example, currently the emission factor for an electric vehicle is 68% lower than that of an average car, and by 2030 as the grid decarbonises it will be 92% lower. It should be stated that even though grid intensity is lower, there are still significant benefits to reducing the demand for energy from commuting, as this will mean that upstream less low carbon energy will need to be delivered. It is also important to note that there was a total net saving under HW even without commuting (e.g. if someone walked to work) from the base scenario.

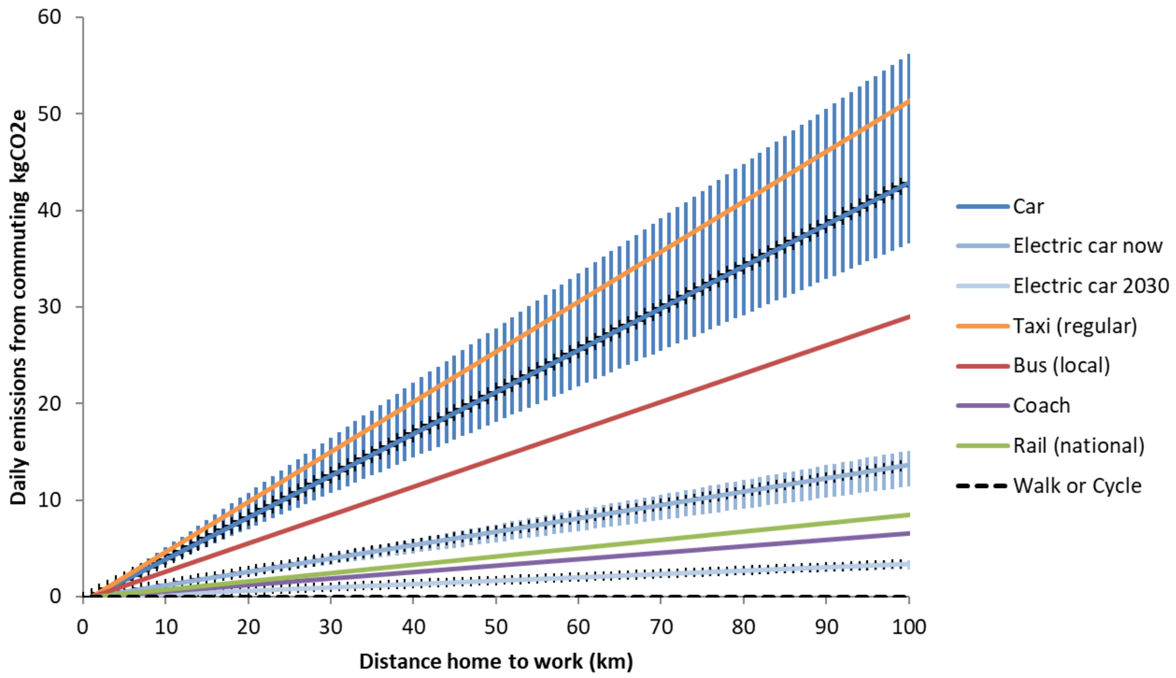

Figure 2: Range of daily emissions for different modes and distances between home and the workplace. For the cars, a range between small and large cars compared to an average car is shown by the shaded zone

The sensitivity analysis results compared to the net savings under HW of 9.3 kg CO_2e/day from the base case is shown in Figure 3. The ranges explored are not intended to represent the extremes, rather a demonstration of likely potential impacts of different factors. This highlights the likely significance of each individual impact.

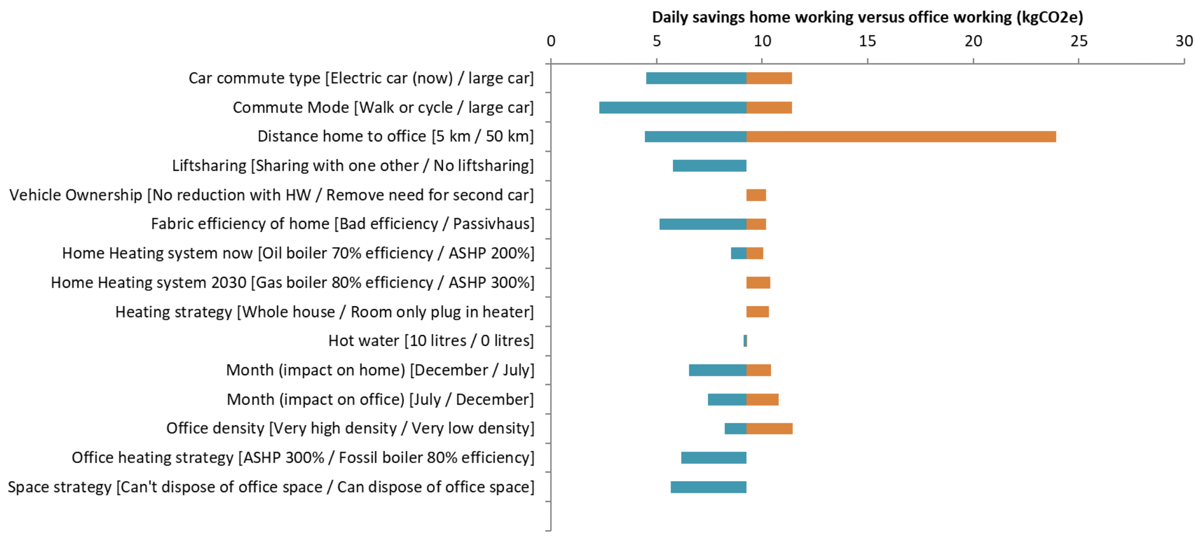

Figure 3: Change in daily saving compared to the baseline scenario from HW with lower range (blue) and upper range (orange) for each variable as described. The baseline scenario results in average daily savings of 9.3 kg CO_2e.

The following observations are made:

- No individual factor modelled was in itself sufficient to result in emissions from HW being higher than OW. Whilst this does not mean HW will always result in savings – for example if those that worked in the office walked or cycled and the office remained open consuming energy in parallel to the added home energy use – it does suggest that in aggregate terms a shift to HW would result in an overall net saving.
- The assumptions around commuting are likely to have the biggest impact on the analysis, with long distance commuting having the greatest potential to result in large potential savings.
- The reduction in vehicle ownership could have a modest benefit if households require fewer cars. This would also have positive impacts on congestion, and would reduce running costs for households.
- The baseline scenario only resulted in 1.3 kg CO_2e/day of carbon emissions from dwelling energy use, within a context of a net saving of 9.3 kg CO_2e/day of savings from HW. Therefore, the potential impact of different factors on this category are comparatively low though it is shown that savings from HW are improved if the home is well insulated, if only one room is heated, and if a lower carbon heating system is used. The amount of hot water used at home for hand washing (but not showering which was assumed to be the same under both scenarios) was shown to have a negligible impact.
- The time of year impacts daily emissions, with home heating emissions being significantly higher in the winter. This is to some extent balanced out by lower winter heating emissions from the office, if that space can be disposed of. Home heating strategies of heating one room only become more significant in the winter.
- Regarding emissions from the office, if it is heated using a low carbon heat source, then the net benefit of HW will be reduced, though is still likely to be positive. If the office is low density then disposing of it will result in higher savings than if it is densely occupied. The baseline scenario assumes that office space can be disposed of – if it cannot and needs to be retained in parallel to HW and is not rationalised as part of a wider estate strategy, then the potential for savings will be reduced (though it should still be positive at given typical current commuting behaviour).

5. Conclusions

A simple analysis of home working versus office working has been undertaken, and has shown that with the assumptions made homeworking will typically result in savings in greenhouse gases when compared to office working. Whilst this conclusion depends on the assumptions, sensitivity analysis has demonstrated that under a range of likely circumstances, homeworking should still result in savings. The average savings (based on the base case) are in the region of 2 t CO_2e per year. The most significant variables at present are the commuting mode and distance, though as transport shifts to electric vehicles powered by a low carbon electricity network, these absolute emissions will decrease.

Following from this simple exercise, it may be possible to usefully expand on the findings by developing a calculator to enable a user to undertake a personal calculation that is suited to their own circumstances. The findings here could also be built on further by establishing typical inputs for the variables tested, in terms of both range and frequency distribution, in order to undertake a more in-depth analysis that is able to provide results as a range of carbon savings (or increases) across a population (e.g. DCC corporately, Devon geographically etc.) in a probabilistic manner.

References

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