What impact have COVID-19 induced changes in working practice had on greenhouse gas emissions?

A comparative LCA of working from home and working in an office

Appendix to WCEC Report number RR_00031

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Introduction

The goal of this Lifecycle Assessment (LCA) is to assess the environmental impacts of working from home (WFH) compared to working in an office. The reported results could be used to aid policymakers to factor in sustainability considerations when putting together new policies regarding remote working to minimize the environmental burden. The system boundary has been scoped to focus on the energy use and commuting activity of office workers over a 7 day period. Three scenarios have been considered in this study: (1) WFH, (2) commuting to an office via car, and (3) commuting to an office via train. This LCA excludes any production / manufacturing of office equipment such as laptops, desktops and monitors etc. and any inputs that may relate to leisure or personal trips. The functional unit for this study has been determined as a 7 day period of ten individuals working in the UK from either their home or in an office.

Data sources and assumptions

As this work has been undertaken within the Rapid Review it not been possible to use primary data, so all inputs and quantities have been assumed or taken from secondary data available from published reports by the UK government. Due to the scope of the study, the focus is primarily on the energy usage and transport, therefore the lifecycle inventory (LCI) datasets are concise (Table 1). The mass and energy data that has been collected have been paired with the most relevant environmental LCI datasets from Ecoinvent v3.6 (Wernet et al. 2016) using a cut-off approach. The LCI data was then analysed using the ReCiPe 2016 Midpoint (H) impact assessment method.

Table 1: Energy and transport input data, per 10 individuals working in a home / flat over 7 days.

Categories	Input	Unit	Ecoinvent dataset
Materials	Water	M^3	Tap water {Europe without Switzerland} | market for
Energy	Electricity	kWh	Electricity (GB), Market
	Gas boiler (heat)	kWh	Heat, central or small-scale, natural gas {Europe without Switzerland} | heat production, at boiler condensing modulating <100kW
Transport	Car for individual	km	Passenger car (petrol, diesel, and electricity) (RER), Processing
	Train	pkm	Passenger train (AT, BE, DE, FR, IT), Processing

Electricity consumption

The list of individual electrical appliances assessed in this LCA can be found in Table 2, along with their representative wattage (Smarterbusiness, 2019). The figures are based on the average specification and performance that would be used in a standard office role during an 8 hour day over 5 working days. This study does not consider high performance PC equipment which certain roles would use (such as software developers etc.). Regarding lights, Wi-Fi router, and other smaller items (kettle and phone charger), the electricity consumption has been assumed to be the same in all scenarios (full use during an 8 hour period over 5 days). The only variable in terms of office equipment is that the WFH scenario uses a laptop and a monitor display whereas a computer desktop is used in the office scenario.

In the WFH scenario, full operation of the laptop and monitor has assumed to be 7 hours, and 1 hour allocated for these devices to be put on 'standby' mode for a lunch break. In the office scenario, full operation of the computer desktop has assumed to be 6 hours, and 2 hours allocated for this device to be left on ‘standby’ mode representing a lunch break, and periods away from the desk for meetings and other office duties. These figures are then multiplied by 5 to represent electricity consumption over a typical workweek. Electricity for all appliances is assumed to be from the UK grid for which LCI data is well established.

Profiles of working from home and in an office:

Table 2: Inputs considered in the LCA and their quantities of 10 individuals over one week.

Profile of employee	***Aspects considered in the modelling***	**Electricity consumption**	**Unit**
WFH	Use of laptop	17.5	kWh
	Use of computer monitor	3.75	kWh
	Use of lights	24	kWh
	Heating of home	3212.12	kWh
	Other items	9.4	kWh

Profile of employee	***Aspects considered in the modelling***	**Electricity consumption**	**Unit**
Office	Round trip in a car	1609.34	km
	Round trip on a public train	3283.06	person km
	Use of computer desktop	30	kWh
	Use of lights	24	kWh
	Heating of the room (including keeping home warm when not occupied)	2683.08	kWh
	Other items	9.4	kWh

Gas consumption

The gas consumption figures used in this analysis has been collected from published reports by the Department for Business, Energy & Industrial Strategy (BEIS, 2019, 2020) which provide annual gas usage figures per m^2 for *Domestic* and *Non-domestic* building types within the National Energy Efficiency Data work stream. As this analysis does not use site-specific gas consumption, there may be some margin of error to account for. However, data represents the full range of ages of premises, sizes, and occupancy levels, so represents the average of the population as a whole. Within the NEED data for non-domestic premises there is a subset for offices, which was used within this study. The LCI dataset to represent heat from a gas boiler is assumed to be a central or small-scale (<100kW) modulating condensing boiler using natural gas.

Gas consumption in houses and flats

The gas consumption of the average house in England and Wales is 130 kWh per m^2, and 165 kWh per m^2 for the average flat over 2017 (BEIS, 2019).

According to an English Housing Survey Headline Report (2020), 23% of the total dwellings were flats and the remainder houses. Therefore, the WFH gas consumption represents this demographic, assigning 8 of the 10 individuals to gas consumption of a house, and the remaining 2 individuals to gas consumption of a flat. The annual gas consumption per m^2 is broken down to represent a 7 day period. This value was used within the non-WFH scenario as the baseline consumption. The gas consumption values for the 7-day period were then multiplied by the amount of floor space used for 10 individuals’ working space at home (Table 3). The average useable floor area of dwellings in 2020 was 96m^2 (DLUHC, 2021), so for 10 individuals WFH the total floor area has been assumed to be 960m^2.

The domestic annual gas consumption from the BEIS data represents the pre-covid period and was taken as the value for office workers.

To acknowledge an increase in gas use as more people WFH a typical household day was considered. For the office work household, it was assumed gas would be used to heat the house for 3 hours in the morning, then leave for work and heat the house for 4 hours in the evening in a typical working day (total 7 hours), with higher usage reflecting three intervals of gas heating on weekend days (total 10 hours). This gives a weekly usage of 55 hours. For the WFH household, the weekday consumption was increased with a lunchtime interval of 3h gas heating, giving a total of 10 hours, while weekends remained unchanged. Giving a weekly total of 70 hours for WFH. This represents an increase of 27% on the office work scenario. As a result, a factor of 27% was added to the total gas consumption to obtain the WFH values (Table 3).

Table 3: Calculations to heat the home / flat of 10 individuals when working from home.

	Gas consumption (2017) average house (Office scenario)	**Estimated gas consumption post covid (WFH scenario)**	**Unit**
1 year per 1m^2 (house)	*130.0*	*165.1*	kWh
1 week per 1m^2	*2.5*	*3.2*	kWh
1 week per 96m^2 - 10 people	*2400.0*	*3048.0*	kWh
	Gas consumption (2017) average flat	**Estimated gas consumption post covid**	
1 year per 1m2 (flat)	*165.0*	*209.6*	kWh
1 week per 1m^2	*3.2*	*4.0*	kWh
1 week per 960m^2 - 10 people	*3046.2*	*3868.6*	kWh
Total gas consumption of 1 week per 10 people (house and flat)	**2529**	**3212**	kWh

Gas consumption in offices

In terms of the office scenario, the mean gas intensity of offices in England and Wales has been used which is 160 kWh per m^2 over 2018* (BEIS, 2020). This figure is the average gas intensity per m^2 of all offices varying in floor area and business size but has been used in this study as a representative of the average gas usage in an office.

Once more, the annual gas consumption per m^2 is broken down to represent a 7 day period which is then multiplied by the amount of floor space used for 10 individuals' working space within an office (Table 4). This LCA has assumed that the individuals working in an office use standard workstations which typically have an office space of 4 - 6m^2 (Commercial Real Estate, 2019), so for 10 individuals in an office the floor area has been assumed to be 50m^2.

In addition, the pre-covid domestic gas consumption value (Table 3) has been added to the office workers scenario to ensure comparability of the two populations. Use of domestic gas boilers in the morning and evening before and after work was assumed to be unchanged from pre-covid levels.

Table 4: Calculations to heat the office of 10 individuals.

Office		
	Gas intensity (2018)	**Unit**
1 year per $1m^2$	160.0	kWh
1 week per $1m^2$	3.1	kWh
1 week per $50m^2$ - 10 people	**153.8**	kWh

It is understood that different consumers might have different set temperatures within the home or use different numbers of hours of heating etc. However, as the data already contains a gross average of UK heating behaviours the use of a simple percentage value for change in gas usage was deemed most appropriate for this study. Future work could address the same question using primary data for actual user behaviour and actual dwelling types, ages etc. Further studies around the topic of domestic and non-domestic gas consumption would aid this study indefinitely.

Transport

There are two scenarios regarding transport considered in this LCA; commuting to work via car and via train. More specifically the environmental impact of 10 office workers commuting via car, and 10 office workers commuting via train over a 5 day period has been assessed. Regarding the LCI datasets for the transport, these have both been assigned to a corresponding dataset. The assumption was made that the typical car commuting to work is a European passenger car (petrol, diesel and electric) in the classes EURO 3,4 and 5 regarding petrol and diesel vehicles, which is well established in Ecoinvent. The average commuting distance of a round trip in a car was set as 32.19 km, which was taken from the Department for Transport report regarding commuting trends in England (DoT, 2017). The same report was used to gather the average commuting journey of a passenger train which was stated as 65.66 km. LCI datasets for passenger trains in the UK are limited in Ecoinvent, thus an average has been taken from passenger trains in Austria, Belgium, Germany, France, and Italy to represent an average European passenger train.

Results

GHG emissions

Figure 1 displays the total GHG emissions associated with a 7 day period of working in an office via car and train, and a WFH scenario. It is evident that commuting to an office via car is the most environmentally impactful scenario emitting 1256.7 kg CO_2e. This is followed by commuting to an office via train at 892.7 kg CO_2e, and the WFH scenario performing the best, emitting 854.7 kg CO_2e. Thus, the WFH and office via train scenario emit 32% and 29% less CO_2 respectively, compared to the office via car scenario. Although the gas boiler in both locations is the largest contributor overall, the emissions from travelling to work via car is the definitive factor in these results, emitting 535.9 kg CO_2e alone. While these transport emissions are based on average commuting distances respective to the mode of transport, it is clear that commuting via train is much less damaging in terms of GHG emissions than via car, even when travelling greater distances.

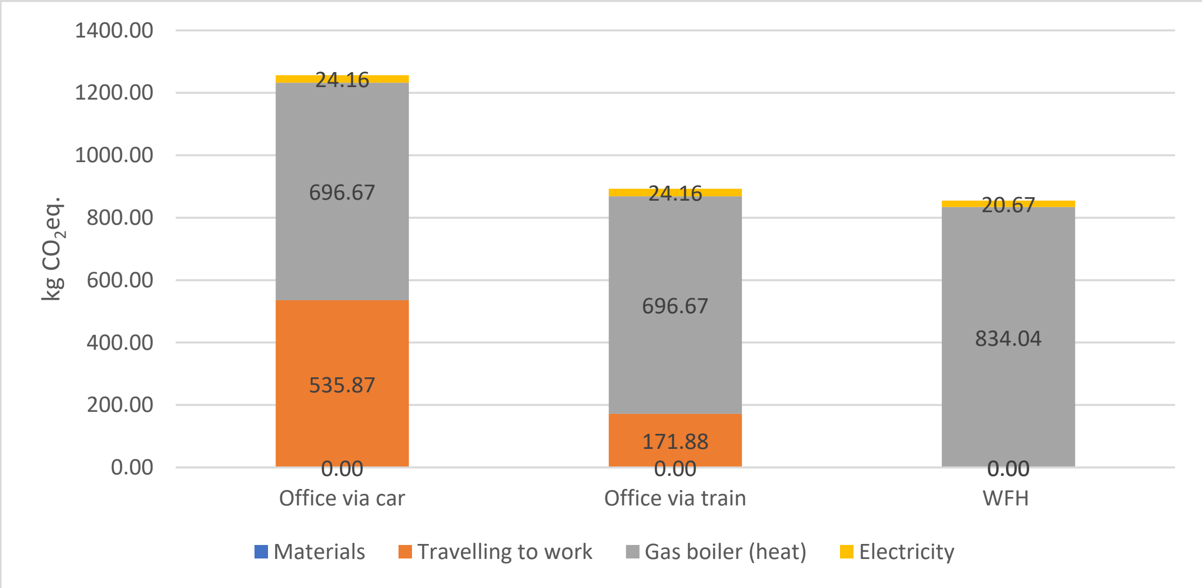

Figure 1: GHG emissions associated with the energy use and commuting activity of office workers over a 7 day period comparing three scenarios.

Figure 2 shows the relative contribution of each input to the overall carbon footprint (GHG emissions) associated with each scenario showing more clearly the environmental hotspots. The gas boiler is the largest contributor in all scenarios, which is especially true in the WFH scenario as it contributes to 98% (834 kg CO_2e) of total emissions with the remaining 2% (20.1 kg CO_2e) coming from electricity. However, this includes all heating and gas usage for a typical dwelling and reflects currently accepted awareness of the impact of space heating on national greenhouse gas emissions. Although the WFH scenario emits less GHG emissions overall, it does perform noticeably worse when comparing emissions directly from space hating, as in both the office scenarios (via car and train) the gas boiler emits 696.7 kg CO_2e, reflecting the economies of scale of heating a single office space for multiple employees.

Despite the electricity emissions having a very small impact overall, it is worth noting that emissions are lower in the WFH scenario. It has been assumed that when working from home a laptop and monitor are used instead of a computer desktop which are often used in an office, and as a computer desktop typically uses more electricity than a laptop, the GHG emissions from electricity in office working reflect this.

Unexpectedly, the working in an office via train scenario and the WFH scenario perform at a similar level. This is due to the added gas consumption in the WFH scenario which is almost cancelled out by the emissions from the train. Due to the system boundary focused to an 8 hour workday over a 7 day period, this LCA does not include the materials needed for the buildings of the workplace nor the equipment used. It only includes materials that may be used during the day such as water, as a result there is an insignificant amount GHG emissions from the materials input.

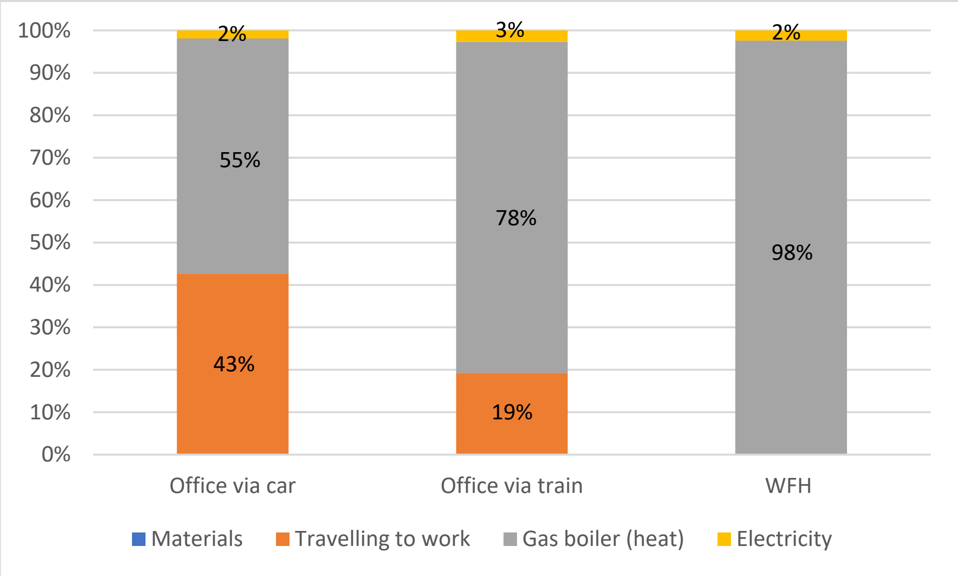

Figure 2: Percentage breakdown of GHG emissions (kg CO_2 eq) associated with the energy use and commuting activity of office workers over a 7 day period comparing three scenarios.

Normalisation

According to the ISO 14044 Standard on LCA, normalisation is defined as "calculating the magnitude of category indicator results relative to reference information", which produces a single numerical score to identify "important" impact categories, interpret and communicate the impact results (ISO, 2006). Using normalisation in LCA is optional but it aids a better understanding of the relative magnitude of each indicator result of the product(s) under study (Pizzol *et al.*, 2017). Through the normalisation treatment, Figure 3 displays the normalised scores of each environmental impact category for the three scenarios in this study.

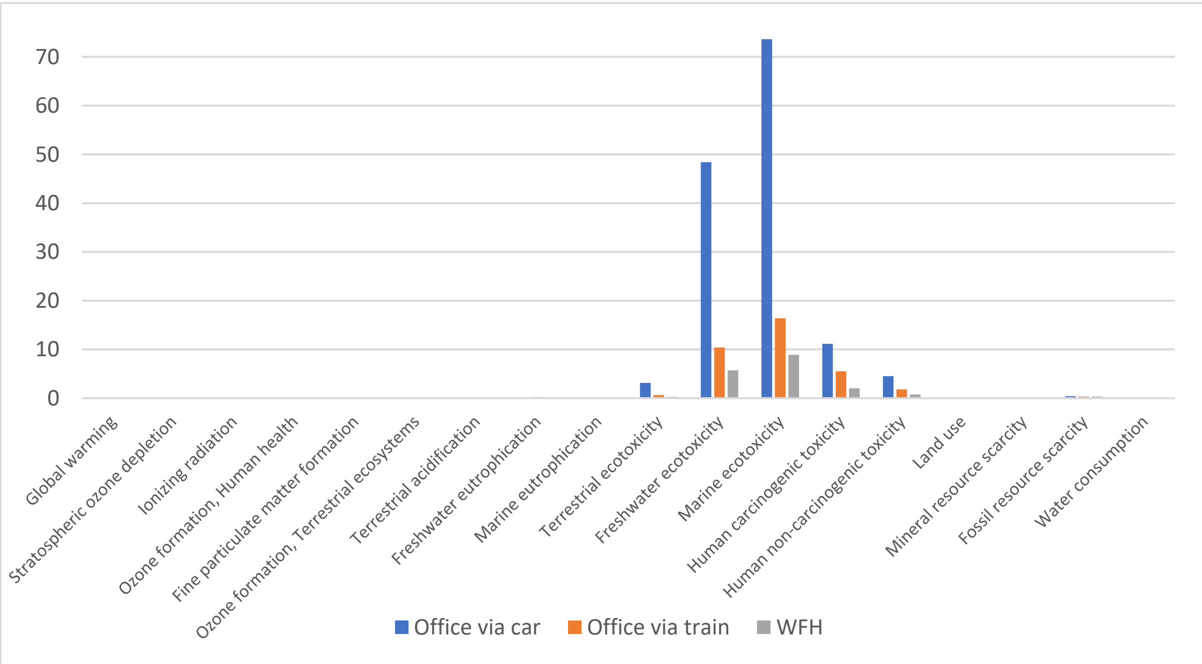

Figure 3: Normalisation results associated with the energy use and commuting activity of office workers over a 7 day period comparing three scenarios.

While the data in Figures 1 and 2 relate to GHG emissions, the normalised data reveals that other environmental indicators may be more significant. The impact categories that are noticeable in Figure 3 are the same across all scenarios, having most of the impact in the toxicity and eco-toxicity categories. However, the office via car scenario scores extremely high in the freshwater and marine ecotoxicity categories which are directly correlated to the environmental impact of the car (Figure 4). This is a similar theme across the remaining visible bars in Figure 3, as Human carcinogenic and non-carcinogenic toxicity, and terrestrial ecotoxicity are still heavily influenced from the car. These normalised results demonstrate that environmental impact categories such as Global Warming Potential (GWP), fine particulate matter formation and eutrophication etc. may not be as relevant to the impacts of office / home working when compared to ecotoxicity and toxicity.

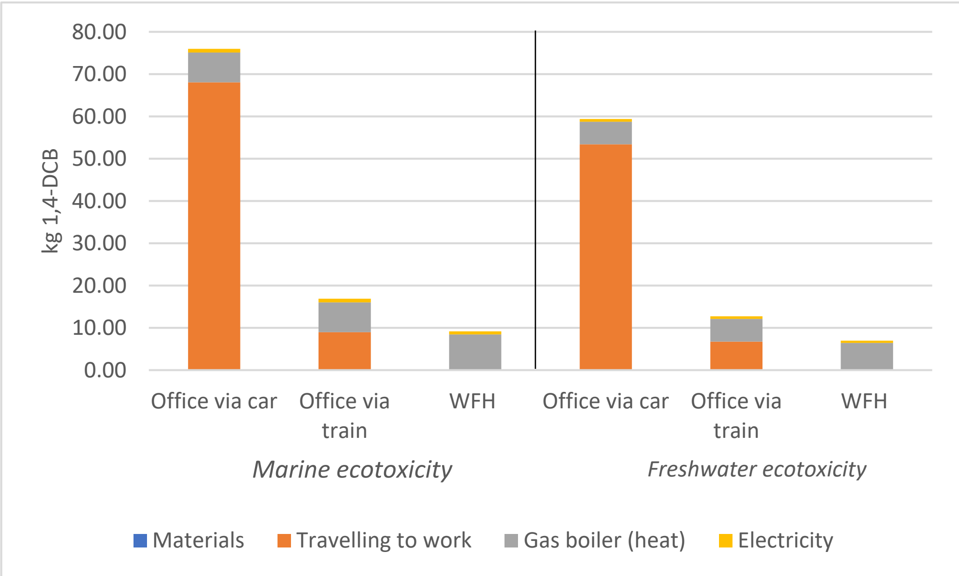

Figure 4: Marine ecotoxicity and freshwater ecotoxicity associated with the energy use and commuting activity of office workers over a 7 day period comparing three scenarios.

The WFH and office via train scenarios performed relatively similarly in terms of GHG emissions (Figure 1) and are far less impactful than the office via car scenario. However, much of the other indicator scores in the WFH scenario are associated with the gas boiler with minimal inputs from electricity, while the impact of the train roughly doubles these scores in the relevant impact categories (Figure 4), and ultimately the results favour a shift towards WFH.

Conclusion and discussion

The main aim of this LCA was to assess and compare the environmental impacts of 10 individuals WFH, and 10 individuals working in an office over a 7 day period. As a result, three scenarios have been depicted: WFH, commuting to an office via car, and commuting to an office via train. As there was no primary data available, this study has used data collected from UK government reports, along with informed assumptions.

In terms of GHG emissions, the least impactful scenario was identified as WFH, which was closely followed by the office via train scenario. By far the most impactful scenario was commuting to an office via car, emitting between 29-32% more GHG emissions than WFH and commuting via train. The major environmental hotspot in all scenarios was recognised as the space heating by gas boiler, which was most damaging in the WFH scenario over working in an office where economies of scale applied.

This related to the larger floor area needed to heat up a typical house / flat rather than a shared office space over the 8 hour period. However, this dynamic could change if the functional unit considered office workers having separate office spaces and thus more floor space per individual, consequently requiring more gas.

Evidently this study has shown that WFH is the least environmentally impactful scenario which is not just apparent from GHG emissions but also, the remaining environmental impact categories shown in the normalisation results. Although the gas boiler is a high emitter in terms of GHG emissions, transport is the crucial issue across many of the other environmental impact categories. This raises the relative impact of transport and more specifically, commuting via car.

The derived conclusion would be for office workers to WFH where possible, but if commuting to an office is necessary, then commuting via train is the least impactful. Yet, rail travel in the UK is imperfect with non-direct routes, limited number of journeys and often delays and / or cancellations. If these are issues and make commuting via train impracticable, then a hybrid work model could be implemented. Effectively splitting the number of days to WFH and commuting via car would lower the overall environmental impact if WFH full-time was not possible. This was not considered in the current study but is supported by promising results from published studies in Europe (Noussan and Jarre 2021, Crowley et al. 2021). The impact of distance on the transport emissions benefits of remote working is considered by Fabiani et al. (2021).

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