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EVALUATING THE GREENHOUSE GAS EMISSIONS REDUCTION POTENTIAL DUE TO THE USE OF HEAT PUMPS

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1. ABSTRACT

This study investigates the deployment of heat pumps to decarbonise domestic space heating in the United Kingdom. This study develops a novel modelling tool that includes hourly ambient temperature, dwelling characteristics at a local authority-level, and electricity grid carbon intensity data. This is to evaluate the potential reduction in greenhouse gas emissions associated with the adoption of air source heat pumps compared to conventionally used natural gas boilers. Key factors influencing the reduction in the greenhouse gas emissions included electricity grid carbon emissions, split of houses (between detached, semi-detached and terraced), and the total number of houses in the local authorities.

2. INTRODUCTION

To reduce dependence on fossil fuels for heating, heat pumps are widely seen as a viable alternative [1]. Heat pumps use electricity to power a vapour compression cycle that absorbs low-grade ambient heat from the ground, water, or air, and then amplifies and transfer it inside a building. The environmental case for heat pumps is focused on the decarbonisation potential that they offer by reducing greenhouse gas emissions from conventionally used heating systems (e.g. natural gas boilers), because of the higher efficiencies of heat pumps compared to boilers. This is important if the electricity to power the heat pumps also has a lower overall carbon intensity.

This study focuses on estimating the greenhouse gas emissions reduction potential by using air source heat pumps (ASHPs) for domestic space heating in the UK. Specifically, this work was undertaken at a local authority scale and all calculations were performed for 2022 as a reference year, as this was the most recent complete year for undertaking a detailed analysis.

3. METHDOLOGY

3.1 Local authority and housing characteristics

The selection of specific local authorities for this study was based on following factors aimed at ensuring the representativeness and comparability of the chosen regions. In West Midlands, Birmingham, Warwick, and Shropshire were selected to provide a range of land-use classifications, from urban to rural, while also enabling local analysis relative to the University of Birmingham. The selection of local authorities spanning from urban

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to rural environments ensures a diverse range of housing categories. Similarly, in the Northwest region, Manchester, Oldham, and West Lancashire were chosen.

Additionally, three primary housing categories were considered: terraced, semi-detached, and detached houses (number of dwellings [2]), with constant size and age of houses. Flats and apartments, which constitute a significant portion of the UK's housing stock, have been excluded because ASHPs require sufficient outdoor space for installation and may necessitate permission from the apartment building's landlord.

3.2 Efficiency of air source heat pumps and boiler

Coefficient of performance for ASHPs has been previously derived from the industry average data, which is also used in this study (Eq. 1 and 2). Average boiler efficiency was considered as 84%.

$$\begin{gathered} for\ 15℃ \leq \Delta T_{lift} \leq 60℃ \\ COP_{ASHP} = 6.81 - 0.121\Delta T_{lift} + 0.000630\Delta T_{lift}^2 \end{gathered} \tag{1}$$

$$\Delta T_{lift} = T_{outside} - T_{sink} \tag{2}$$

$T_{outside}$ represents the outside or ambient temperature (sourced from [3]). T_{sink} is dependent on both the space heating temperature T_{SH} and the domestic hot water temperature T_{DHW}.

3.3 Heat demand modelling

The inside air temperature (T_i) distribution was modelled iteratively in 10-minute intervals for houses (Eq. 3). Bimodal heating pattern was considered for both types of heating systems. The daily heating periods applied were 0700-0900 and 1600-2300 for each housing type. Furthermore, an additional condition which was introduced to the heating model was that if the average outside temperature for the past 24 hours was 14°C or greater, the heating in the following 10-minute window would not activate.

$$T_{i+1} = T_i + \frac{Q_{in} - Q_{loss}}{m_{air} C_{p,air}} \tag{3}$$

T_0 was set at 20°C, which is the average comfort temperature in a house, whilst 1 kJ kg^{-1} K^{-1} was used for $C_{p,air}$ (isobaric specific heat capacity of air) and m_{air} (mass of air) was estimated for each housing model by multiplying the volume of the house by the density of air at 20°C, 1.204 kg m^{-3}.

4. RESULTS

This study demonstrated that in six different local authorities, following factors influence the potential of greenhouse gas reduction and heat demand. While both regions incorporate a significant amount of wind energy into their energy mix, renewable energy has a more dominant presence in the North West, as evident in the ESO national grid dataset. For example, average electricity grid emissions in North West was 72 gCO_2/kWh compared to West Midlands as 188 gCO_2/kWh). This results in a higher GHG reduction potential by using heat pumps for replacing gas boilers. In addition, **housing characteristics** determine the extent of yearly heating demand and power consumption, particularly concerning the ratio of detached houses to terraced ones. This is evident in the comparison between Manchester and Shropshire, where despite Manchester boasting a higher total number of residences, Shropshire demonstrates greater yearly heating demand and power consumption across all scenarios. Lastly, the annual heating demand and power consumptions is interlinked with the **number of houses** in a local authority.

Table 1. Heat demand and % reduction in CO_2 equivalent emissions at a local authority scale.

	Local authority	Birmingham	Manchester	Oldham	Shropshire	Warwick	West Lancashire
100% boilers	SPF	1.8	1.9	1.8	1.8	1.8	1.9
	Heating demand	717.0	305.6	183.8	353.6	125.7	113.0
	Natural gas	853.6	378.7	241.1	433.1	145.5	123.8
	CO_2e emissions	155.5	69.0	43.9	78.9	26.5	22.6
95% boilers, 5% ASHPs	Energy demand	830.5	368.4	234.5	421.4	141.6	120.3
	CO_2e emissions	151.8	66.2	42.1	77.0	25.9	21.6
	% reduction (GWh)	2.71%	2.73%	2.71%	2.72%	2.71%	2.80%
	% reduction CO_2e emissions	2.37%	4.05%	4.04%	2.39%	2.36%	4.08%
80% boilers, 20% ASHPs	Energy demand	761.1	337.3	215.0	386.1	129.8	110.0
	CO_{2e} emissions	140.8	57.8	36.8	71.4	24.0	18.9
	% reduction (GWh)	10.84%	10.92%	10.82%	10.86%	10.83%	11.19%
	% reduction CO_2e emissions	9.48%	16.19%	16.15%	9.55%	9.43%	16.30%
60% boilers, 40% ASHPs	Energy demand (GWh)	669	296	189	339	114	96
	CO_{2e} emissions	126	47	30	64	22	15
	% reduction (GWh)	21.67%	21.85%	21.64%	21.73%	21.66%	22.38%
	% reduction CO_2e emissions	18.95%	32.38%	32.29%	19.10%	18.86%	32.61%

*CO_{2e} equivalent refers to CO_2 equivalent emissions in kilo tonnes, energy demand refers to natural gas and electricity demand (in GWh), SPF = Seasonal performance factor. Units for heating demand and natural gas demand are GWh.

4. CONCLUSIONS

This study undertakes a data-based modelling in six different local authorities in the West Midlands and Northwest regions of England to predict heat demand and potential reduction in greenhouse gas emissions due to the use of heat pumps. Future studies would benefit from extending this work to all the local authorities in the UK and considering marginal carbon emissions of the grid and age of housing stock.

5. ACKNOWLEDGEMENTS

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