Air Sourcing Net Zero?

1 Introduction

Many European Union countries are promoting electrical heat for domestic usage over the use of hydrocarbon-based heating systems and are subsidising the installation of heat pumps. The UK national strategy is to deploy heat pump technology in the majority of homes across the UK to progress decarbonisation of the domestic sector. Legislation is already set to exclude gas from all new build homes from 2025 (> 200,000 new homes are built each year). The most significant challenge is to reduce or remove gas from more than 20 million existing domestic UK properties.

This paper examines financial and carbon-emission simulation results for the replacement of gas-based systems with electric heating and heat pumps. The study is based on actual gas volumes consumed (at 30min resolution) over the last 12 months in a sample of target properties[1]. No other report has analysed this volume of properties to this level of resolution. The consumption profile for each property is individually re-modelled from existing gas-based to an air source heat pump. The actual carbon generated from the profiles is then calculated together with the financial cost using real world tariffs and the historic carbon content of the electricity grid. The study represents the virtual installation of air source heat pumps into 401 properties across the UK from late 2020 and predicts the resulting energy and carbon costs.

The analysis specifically focuses on gas consumption and the transition to heat pumps and the associated energy and carbon changes as part of this process. Other energy uses (such as other domestic electrical appliances) are not considered in this paper. The energy prices used are detailed in 7.3 and have been taken as a typical price from the market in February 2022.

To provide a starting point, all properties in the target set used gas central heating as their primary heating source, for both hot water and space heating, which resulted in the following absolute impact as a whole for the 400 residential properties:

Period:	12 months (November 2020 – November 2021)
Total Energy consumed:	5,832 MWh
Total Carbon generated:	1,225 tonnes
Total Energy bill (est):	£626,101
Total m2 of living space:	44,759

2 Carbon Content

The results of the simulation and analysis are as follows, specific focus has been given to the headline figures of carbon content and cost however further analysis will be performed in subsequent papers using the same or extended data set.

2.1 Total Carbon Generation

Across the target community the average carbon reduction achieved was 54 % versus gas. This is driven primarily from the Coefficient of Performance (COP)

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[1] A random selection from across all regions of the UK

factor of a heat pump and largely not related to the carbon content of the energy use for heating. Over the sample period the carbon content of electricity (per kWh) used during the modelled heat pump operating times were broadly similar with natural gas[2].

The table below shows the average carbon content of both utilities across all homes in the sample, one using its original gas and the other using the virtual air source heat pump modelled from the gas behaviour.

kg of carbon	Gas	Heat pump (COP = 2)
Per m2	28.4	13.1
Per property	3053	1413
Per kWh	0.210	0.097

Table 1 Average carbon output for the gas and heat pump scenario across households.

2.2 kWh Carbon Generation

The carbon content of electricity[3] varies throughout the day and year (intermittency in the use of solar, wind and coal) whereas the carbon content of gas[4] remains stable. The chart below shows the average carbon content of electricity can vary significantly through the day and even greater variations throughout the year.

10th percentiles and 90th percentiles within the chart shows the typical carbon content of electricity during the best and worst month (~35 days, non-contiguous) during the period monitored.

Note also that this chart shows carbon intensity per kWh. After factoring in the heat pump efficiency performance (COP=2), the heat pump always outperforms gas.

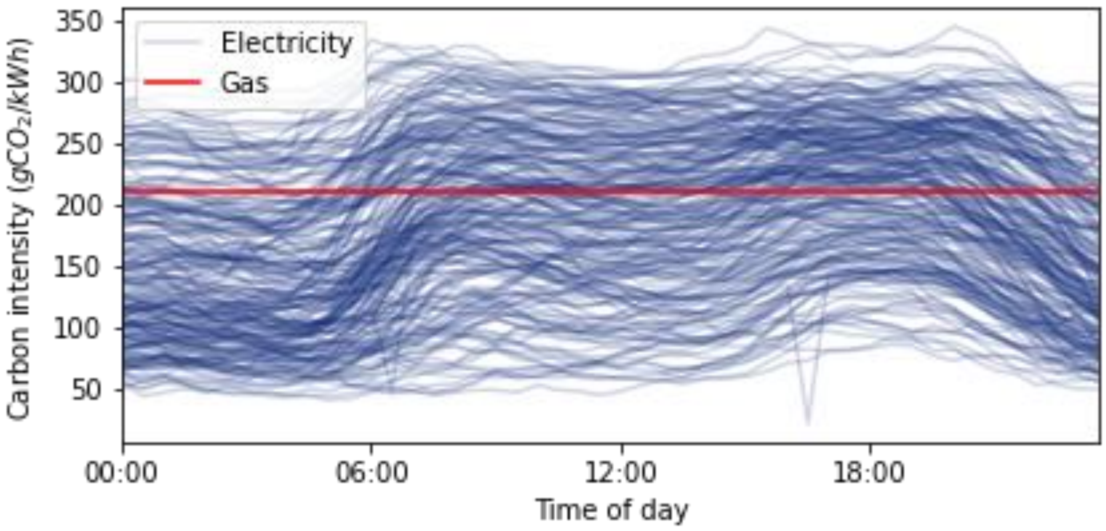

Figure 1 Carbon intensity of mains gas (SAP v10.2) vs electricity grid (https://carbonintensity.org.uk/)

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[2] Although the carbon content of electricity is expected to reduce over time
[3] Carbon content of electricity according to https://carbonintensity.org.uk/
[4] Carbon content of gas according to Standard Assessment Procedure v10.2

Scenario 1: Saving Carbon through better control

Heat pump technology is significantly cleaner than gas due to its inherently better Coefficient of Performance (COP). Although overall carbon content of grid energy will reduce overtime, it is highly likely that fluctuations will continue to be present throughout the day and year for many years to come which will coincide with typical heat pump operation.

To maximise savings, it is essential to combine heat pump deployment with price and carbon aware control technology to automatically avoid operation during peak periods. This could be achieved by minimising energy use via zonal heating, or the early storage of energy used for heating (as heat or electrical energy) for later use during the peak times.

3 Cost of Energy

Across the target community the average cost of energy used to heat the home via a heat pump increased by 42 % using today's energy tariffs. The UK government has announced a strategic plan to align green taxes to carbon emissions however it is unclear on how or when this may happen. For the purpose of this analysis, we have not considered the movement of green taxes.

Note, this increase in energy cost is based on like for like tariffs and does not consider the general cost increase of energy over the period on in the future (which will bring further significant costs).

3.1 Energy Tariffing

Two common energy tariffs were considered for the analysis. The traditional flat rate tariff (same cost throughout the day/year); and the Economy 7 tariff which introduces a low-cost off-peak period but increases the rate for all other times. The calculated costs in the table below include standing charge and cost for the prime energy considering a COP of 2.0 for the heat pump.

Flat rate Tariff	Gas	Heat pump	Increase
Per kWh (average)	11.2p	37.2p[5]	
Per m2	£ 14.60	£ 25.16	
Per property	£ 1561.35	£ 2710.52	42%
Total sample	401	401	

Table 2 Energy costs including standing charge for heating with Gas vs. Heat pump using a fixed tariff.

Economy 7 Tariff	Gas	Heat pump	Increase
Per kWh (average)	11.2p	29.2 p	
Per m2	£ 14.60	£ 19.79	
Per property	£ 1561.35	£ 2134.54	27%
Total sample	401	401	

Table 3 Energy costs including standing charge for heating with Gas vs. Heat pump using an Economy 7 tariff.

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[5] Based on retail tariff of 34p per kWh combined with the heat pump COP of 2.0

Our initial observation on tariffs (regardless of energy consumed) is that all electricity tariffs are triple the cost of natural gas. Therefore electricity, regardless of tariff, even with a heat pump COP of 2, will be more expensive. Heat pumps are not economically viable under these tariff conditions. The figure below demonstrates the current pricing structure.

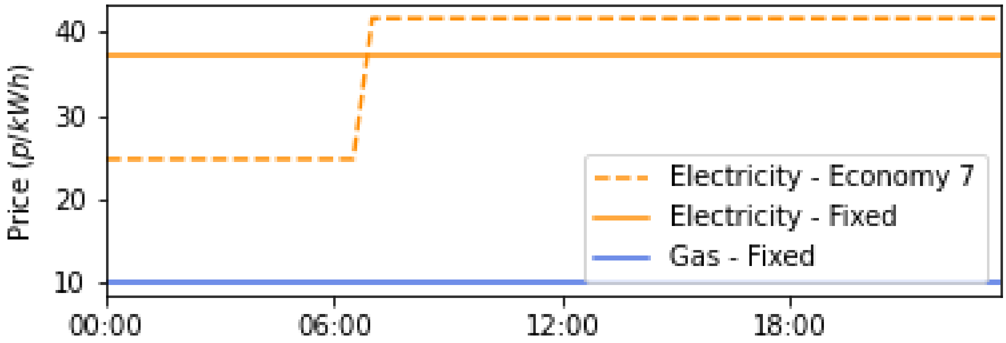

Figure 2 Electricity and gas tariff prices throughout the day.

Scenario 2a: Increasing Cost through electrification

The deployment of air-air heat pump technology is more expensive than natural gas. Significant improvement to building fabric will reduce this difference in cost but will equally reduce both cost and carbon of a property without deployment of heat pump technology.

4 Complication

Scenario 2a, assumes that improved building efficiency can significantly improve costs, and therefore carbon emissions from an individual property. However, the following charts plot the EPC predicted gas consumption with the meter energy consumption (gas) per m2 for each property aligned to their energy efficiency rating (EPC[6]) from our wider dataset (1178 properties).

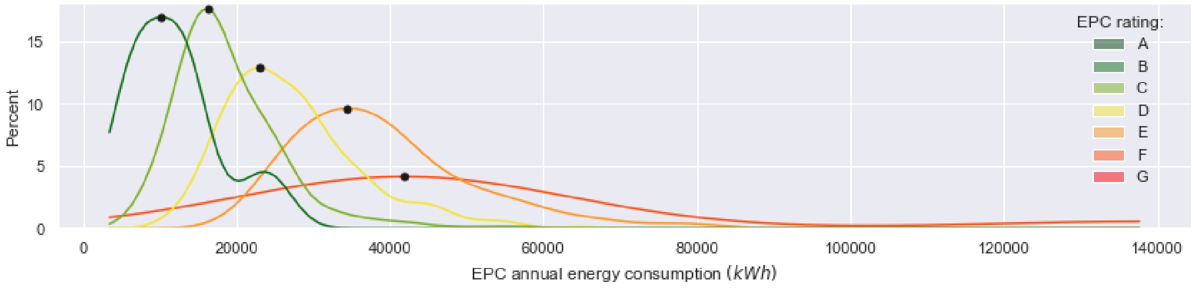

Figure 3 Probability density function and maxima of the EPC estimated energy consumption for each EPC rating group. EPC ratings A and G were excluded due to low sample size.

The EPC predicted consumption above shows a relatively equal spacing of consumption between each EPC rating band with each improved band demonstrating markedly improve efficiency.

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[6] Energy Performance Certificate, a document that sets out the expected energy efficiency performance of a property independently of occupant behaviour.

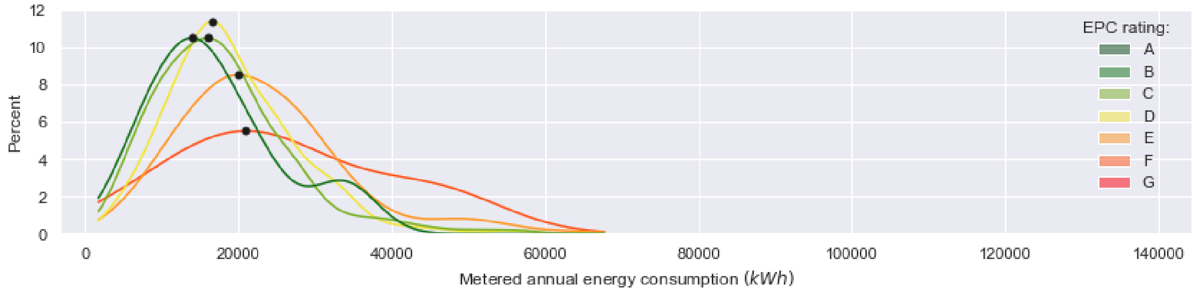

Figure 4 Probability density function and maxima of the metered energy consumption for each EPC rating group. EPC ratings A and G were excluded due to low sample size.

However, the actual meter consumption shows only minor improvements on absolute energy consumption (and therefore cost and carbon emissions) between EPC bands within a significantly lower variation of performance within each rating range. EPC ratings clearly have only a marginal effect on actual energy consumption for the vast majority of properties within each rating category, therefore other factors outside of physical property construction (and the energy assets installed) have a far larger effect on total energy consumption.

This suggests that scenario 2a misses some other factor which strongly indicates occupant behaviour has a far more significant impact on energy and carbon costs than any other metric, improved EPC ratings only up to band D having the most significant influence from a property perspective.

Scenario 2b [REVISED]: Reducing Cost and Carbon through behaviour automation

The deployment of heat pump technology is more expensive than natural gas without being combined with significant improvements to occupant behaviours, supported by basic improvements property materials (addressing the lowest performing properties). Without both elements being addressed, high consumption will continue to be for the key issue in achieving limited carbon reduction. It is also noted that this approach will achieve significant cost and carbon reductions independent of electrification.

It is noteworthy that some companies propose education programmes in an effort to improve consumer behaviours.

5 Conclusion

Primary method of reducing energy costs and carbon is by changed user behaviour. Further education on energy use and how to lower consumption will improve both costs and carbon generation in the near term. For these improvements to be sustained, control automation for optimisation is fundamental to carbon reduction. Acceptance by consumers, continued incentives and support is needed to become and continue to be energy aware while going about our daily lives.

Investing in actions that can enable carbon and cost reductions together with continued support to enable changes in daily behaviour will enable significant savings for all energy users.

6 About Carbon Laces

Carbon Laces uses data science in the energy and financial markets to ensure accountable auditable outcomes allowing both funders and end-users to benefit from decarbonising through the financed emissions value chain. This is done by

- Monitoring: Transparent monitoring to lock new emergent improvements
- Automation: Capture data elements which lie hidden or lost
- Education: Enable the end customers a proactive stance
- Incentives: Suggests incentives where needed through evidence-based impact
- New financing: Unlocks new forms for all to benefit and particularly those who are most vulnerable.

7 Methodology

7.1 Translating gas heating to air source heat pump

Due to the characteristics of a Heat pump the amount and times of energy consumption by a heat pump is significantly different from a gas boiler. To achieve the same (or similar) customer experience of heat as actually experienced by the occupants of the target community we will assume to deliver the same volume of energy as heat to the property through the output of the heat pump as compared to the input of the gas boiler (although it is acknowledged that some minor variables will remain unknown, such as the efficiency of each gas boiler).

There are two factors considered in this scenario,

- The amount of energy consumed by the heat pump or COP factor
- When that energy is consumed over each 24 hour period

For the first consideration, for the purpose of this simulation, we chose a COP factor of 2.0.

For the second consideration, we normalised the output of each heat pump using the observation found with the report[7] and then applied the selected COP factor. This model was then applied to each 24 hour period of each property within the target community resulting in a parallel set of consumption figures. The graph below shows an example of this translation

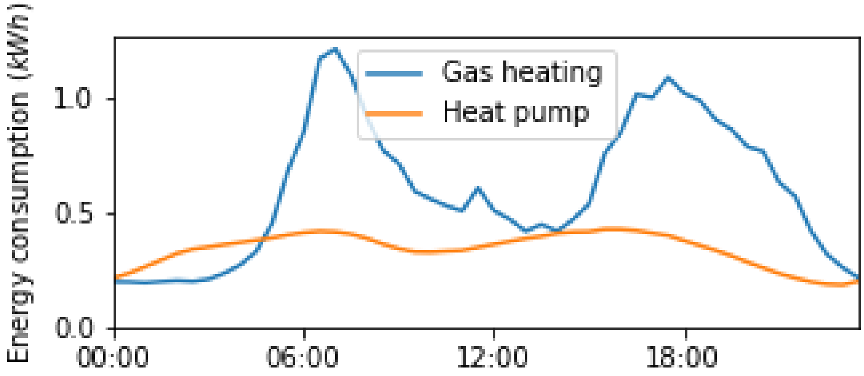

Figure 5 Energy profiles of median gas consumption and the generated electricity profile for the heat pump (COP=2).

7.2 Calculating Carbon footprint

Although regional variations in the carbon intensity of grid provided energy exists, these are minor as compared with the time variations and therefore only time dependant variations were applied to the resulting energy profile. The carbon intensity figures used for the electricity grid can be found at: https://carbonintensity.org.uk/. The gas carbon intensity was taken from the latest version of the SAP v10.2.

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[7] Love, J., Smith, A. Z. P., Watson, S., Oikonomou, E., Summerfield, A., Gleeson, C., Biddulph, P., Chiu, L. F., Wingfield, J., Martin, C., Stone, A., & Lowe, R. (2017). The addition of heat pump electricity load profiles to GB electricity demand: Evidence from a heat pump field trial. *Applied Energy*, *204*, 332–342.

7.3 Cost Calculations

We have standardised on two relevant tariffs from January 2022 in order to determine the household costs. Specifically, we considered a flat rate tariff and an Economy 7 tariff which were priced as specified in the able below. The household costs per kWh that were reported above account for the energy cost and the standing charges that each household incurs.

		Electricity		**Gas**	
	Time of day	Unit rate (p/kWh)	Standing charge (p/day)	Unit rate (p/kWh)	Standing charge (p/day)
Flat rate	-	37.23	24.11	10.08	26.1
Economy 7	Night (12am to 7am)	24.79	24.19	10.08	26.1
	Day (7am to 12am)	41.6	24.19	10.08	26.1

Table 4 Energy pricing details for the Flat rate and Economy 7 tariff.