IOR.org.uk
REFRIGERATION AIR CONDITIONING HEAT PUMPS

The knowledge hub for refrigeration, air conditioning and heat pumps

The Challenges of Heat Pumps for Domestic Heating

Christopher Parker AMInstR

What you will learn

- The paper summarises the results of an investigation and modelling of the cost and energy supply and carbon emission consequences from electrification of domestic heating using electric heat pumps to meet the UK 2050 net zero target.
- A key component of the government strategy for the transition to heat pumps is the thermal insulation upgrade of legacy housing to current standards.
- The modelling predicts a total cost of £306bn to switch domestic heating to electric heat pumps by 2050 and will require around a 2.4x increase in electricity generation capacity and a large deployment of carbon capture storage at power stations if an increase in UK carbon emissions is to be avoided.
- A key challenge for the industry is the number of domestic heat pump installations that will have to be delivered to meet the 2050 target. The modelling shows a rapid ramp up in annual installation numbers, rising to around 1 million in 2030 and around 2 million a year by the mid 2030's.

Abstract

The financial and electricity burden caused by the electrification of domestic heating has been investigated and presented in this paper. The overall cost to achieve legacy housing improvement and widespread ASHP adoption is approximately £309 billion pounds between 2023 and 2050. The financial burden will vary for each household, but most of the burden falls on legacy housing from pre-1919 and gradually reduces as property age reduces to 1981-1990 period. Multiple fund schemes financed by UK Government and local authorities will ease the burden, but they are targeting low-income housing representing 21% of the domestic market and are only scheduled to operate until 2026. Further and clear financial support is required to encourage insulation refits and heat pump adoption.

The increased electricity demand requires an installed plant capacity of 248 GW by 2050 with the generation split of 39% renewables, 32% CCCT with carbon capture storage and 29% nuclear, a 137% increase from the existing capacity. Despite no demonstrable case study for the scale needed, a cornerstone of the UK Government strategy is the deployment of carbon capture storage (CCS) technology as a reliance on natural gas is retained for secure grid flexibility while fulfilling the definition of 'Net Zero' (1). Without CCS, the total consumption of natural gas increases in an electrified society compared to retaining domestic natural gas boilers by 2.9%, thereby increasing annual emissions. If a completely renewable UK society was targeted by 2050 an installed capacity of 435 GW would be required, an increase of ten times the current renewable capacity.

Introduction

The UK Government is currently committed to reducing the net carbon account in 2050 to 100% lower than the 1990 baseline (2). To achieve this goal, every sector must seek methods to reduce their carbon emissions. Heating domestic properties accounted for 17% (77.3 $MtCO_2e$) of the UK's territorial carbon emissions in 2019 (3). Current strategies proposed by policy makers and industry experts is to move domestic heating technology from natural gas boilers to a mixture of heat pumps, hydrogen boilers and communal/district heating systems, depending on the unique property challenges (4). This paper proposes the challenge of nationwide conversion of 28,679,806 (as of 2022) domestic properties (5), aspired to increase to 28,802,646 by 2025 and 34,020,553 by 2050, to an electrified heat pump solution. The challenges focus on the financial burden to prepare the substantial legacy housing stock for heat pump technology and the growing impact on the UK's electricity supply in line with current Government strategy, ambitions and timelines.

How Heat Pumps Work in A Home

A heat pump is a mechanical device that transfers heat from a cool sink to a warm sink using the refrigeration cycle. The type of cool sink often describes the type of heat pump. Air source heat pumps transfer heat from mechanically motivated air external to the control space. Ground source heat pumps transfer heat from the soil or ground water and water source heat pumps transfer heat from an open body of water. There are other types of heat pumps available, but the three mentioned are the most accessible in the UK domestic market.

A heat pump system requires a hot water storage cylinder as the technology is not efficient at generating direct hot water but rather maintain a provision of instant hot water (4). Since central heating became mandatory for newly constructed housing in 1970, most domestic properties have a refurbished central heating system from within the past 20 years. The original systems were open vented with hot water cylinder storage but have gradually been replaced with combination boilers, eliminating the need for water storage space.

As of 2021, there were 15 million combination boiler systems and 9 million boiler systems with a hot water storage component. The original mounting space for the 15 million storage cylinders made redundant by past refurbishments have likely been repurposed for alternative use (4).

The installation of heat pumps will require reinstallation of a water storage cylinder which may necessitate sacrificial dwelling space to accommodate the vessel as original mountings may have been re-purposed, and dwellings constructed over the past two decades do not have accommodation for a storage vessel (4). Recent guidance has suggested a combined approach is required to make a property ‘low-carbon’ ready by ensuring the building fabric is of suitable insulation level, the heat emitters and pipework are of appropriate size and a hot water storage space is made available (4). These, combined with the change of technology from boiler to heat pump increases the financial burden of the heat pump installation. As of 2022, 97% of domestic heating demand was supplied by a fossil fuel energy source and approximately 83% was supplied by natural gas fired boilers (6).

UK Housing

The UK has the oldest housing stock in Europe and most likely the world (6), consequently, the energy efficiency

Table 1 - Number of properties in the UK by age, 2017 data (6). (1,000s)

Dwelling Period	Nation				UK Total
	England	Scotland	Wales	Northern Ireland	
Pre 1919	4,972	467	351	82	5,871
1919-1944	3,793	291	133	68	4,284
1945-1964	4,582	544	219	126	5,472
1965-1980	4,689	515	304	189	5,698
1981-1990	1,895	194	99	99	2,287
Post 1990	4,019	452	235	216	4,923

of UK housing is amongst the worst in Europe (7). There are several historical events that have led to a relatively even split of dwelling periods in the UK as listed in Table 1.

The presence of properties from various periods introduces unique challenges to replace fossil fuel heating with electrified heat pumps across the country. The Government’s current strategy is to improve the thermal energy efficiency of the existing housing stock in preparation for heat pump central heating (3).

Modern properties constructed with the latest standards and guidelines require little modification to reduce energy consumption whereas, the further back in time the property was constructed, typically more work is required. Prior to 1919, most housing was of solid wall construction, with cavity walls being introduced during the inter-war period before becoming standard after The Second World War. While cavity wall construction became normal practice, installing insulation within the cavity wall was not introduced until the 1970s and was not a compulsory requirement until 1990 (8).

This timeline leads to the worst-case scenario of 23,612,000 dwellings with no wall insulation, however, Government grants since the 1990s has made retrofitting cavity wall insulations a cost effective and common energy efficiency measure (6). Solid wall insulation is available but not widely undertaken due to a mixture of higher installation costs from constructing either an internal or external cavity wall prior to insulation and difficulty in properly detailing the most appropriate design for construction without introducing condensation

Table 2 – Number of UK Dwellings with and without wall insulation (6) (1,000s).

Dwelling Wall Construction	Nation				UK Total
	England	Scotland	Wales	N. Ireland	
Cavity insulated	11,157	1,363	636	570	13,726
Cavity uninsulated	5,242	457	298	66	6,063
All cavity walls	16,399	1,820	934	636	19,789
Solid with insulation	694	115	71	11	891
Solid uninsulated	6,301	529	307	107	7,244
All solid walls	6,996	644	378	118	8,136

(8). Table 2 lists the volume of homes with wall insulation by construction type in 2017 (6).

Using the data and knowledge of the construction timeline, an estimation of the volume of insulated walls and uninsulated walls by dwelling age can be made. Table 3 list the approximate split of wall insulation.

Table 3 - Approximate number of households with wall insulation by construction type and dwelling period (1,000s).

Dwelling Period	Solid Walls	Cavity Walls	Estimate With Insulation	Estimate Solid Walls Without Insulation	Estimate Cavity Walls Without Insulation
Pre 1919	5,871	-	696	5,175	-
1919-1944	2,265	2,019	1,457	1,996	830
1945-1964	-	5,472	3,222	-	2,250
1965-1980	-	5,698	3,355	-	2,343
1981-1990	-	2,287	1,347	-	940
Post 1990	-	5,678	5,678	-	-
Totals	8,136	21,154	15,755	7,171	6,363

There are approximately 13.5 million homes in the UK without wall insulation. Further incentives have delivered approximately 17 million insulated loft space across all property types according to the latest standards (270mm thick insulation) up to December 2022 (9).

Table 4 - ECO+ consultation estimated insulation cost (10).

Property Type	Loft insulation	High-cost cavity wall	Solid wall insulation
Terraced	£890	£8,708	£22,167
Semi-detached	£950	£9,533	£24,267
Detached	£1,300	£12,742	£32,433
Bungalow	£970	£8,617	£21,933
Flat	£890	£7,333	£18,667
Annual Thermal Energy Reduction kWh (11)	550	1,683	4,107

Current UK Government consultation has further extended insulation grants for low income and low EPC rated housing between 2023 and 2026 through the ECO+ scheme and provides an estimate cost and scale to install insulation initiatives across various properties (10), see Table 4.

Based on the UK Government's estimated figures in Table 4 and the published housing statistics from the last National Housing Survey listed in Table 3 (6), the following Figure 1 illustrates the capital investment required insulate the remaining UK housing stock to the current building standards.

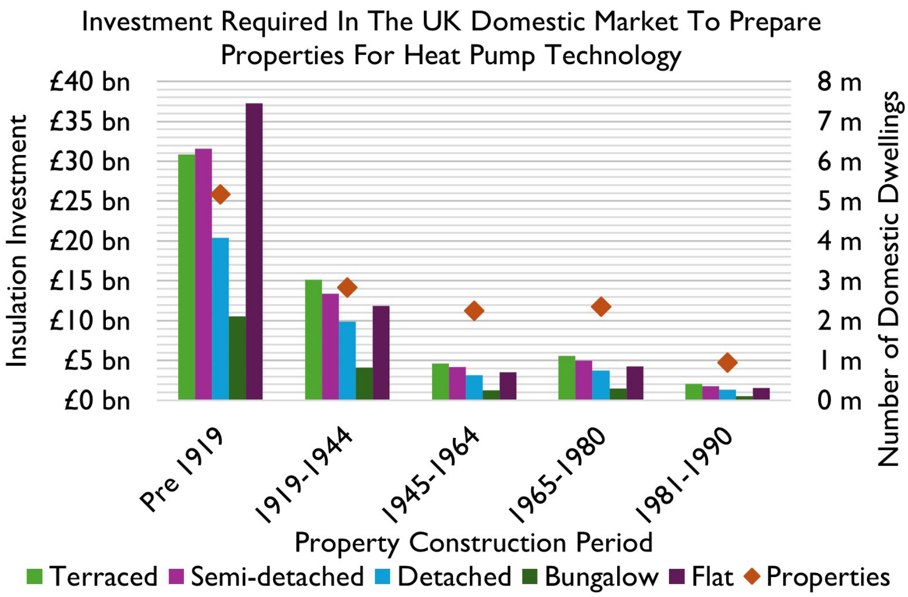

Figure 1 - Insulation investment required to prepare the UK housing stock for efficient heat pump installations by property type and period.

The approximate total capital investment required is £229 billion pounds to modernise the remaining legacy housing stock thermal efficiency levels to current building standards. Of the total cost, 57% is for pre-1919, 24% for 1919-1944, 7% for 1945-1964, 9% for 1965-1980 and 3% for 1981-1990 housing.

Over the years to 2050, the number of old housing stock will likely remain the same as it currently stands due to low replacement rates in the UK and the continuing desirability for older homes (6). Therefore, it is reasonable to expect the modernisation investment to be spread over the period.

The UK Government's Heat Strategy includes seven key ambitions related to heat pumps on the journey to 2050 (3).

- By 2025, there is an ambition for heat pumps cost to reduce 25% to 50% of 2021 prices (£7,000 to £14,000).
- By 2025, natural gas boilers cannot be installed in new UK housing.
- By 2028, 600,000 heat pumps should be installed annually, 50% of which are manufactured in the UK.
- By 2030, 1,000,000 heat pumps should be installed annually.
- By 2030, heat pump costs should reach parity with natural gas boilers.
- By 2035, natural gas boilers cannot be installed in legacy UK housing.
- By 2050, the UK should achieve Net Zero.

Assuming the ambitions are achieved and the following expectations are made, a model of domestic heat pump growth, investment and fossil fuel decline to 2050 can be made.

- UK population growth continues at a rate equal to the average growth rate between 2011 and 2020 (+0.67%) (5)
- Natural gas boiler cost £2,000.

- ASHP initially cost £10,000.
- Annual new housing growth ensures an average of 2.4 persons per household is maintained.
- All new housing from 2023 have Air Source Heat Pumps (ASHPs) installed during construction.
- ASHPs installed annually between 2023 (200,000), 2028 (600,000), 2030 (1,000,000) and 2035 (replacement gas boiler ban) increase linearly.
- Natural Gas boilers have a life expectancy of 15 years.
- ASHPs have a life expectancy of 20 years.
- Heat pump retrofit installations include the cost to insulate legacy housing to modern standards.
- Annual retrofit installations are equally split between dwelling type and period construction.

Figure 2 illustrates the modelled change of installed system types and the investment fluctuations between 2023 and 2050 for the idealised Government strategy.

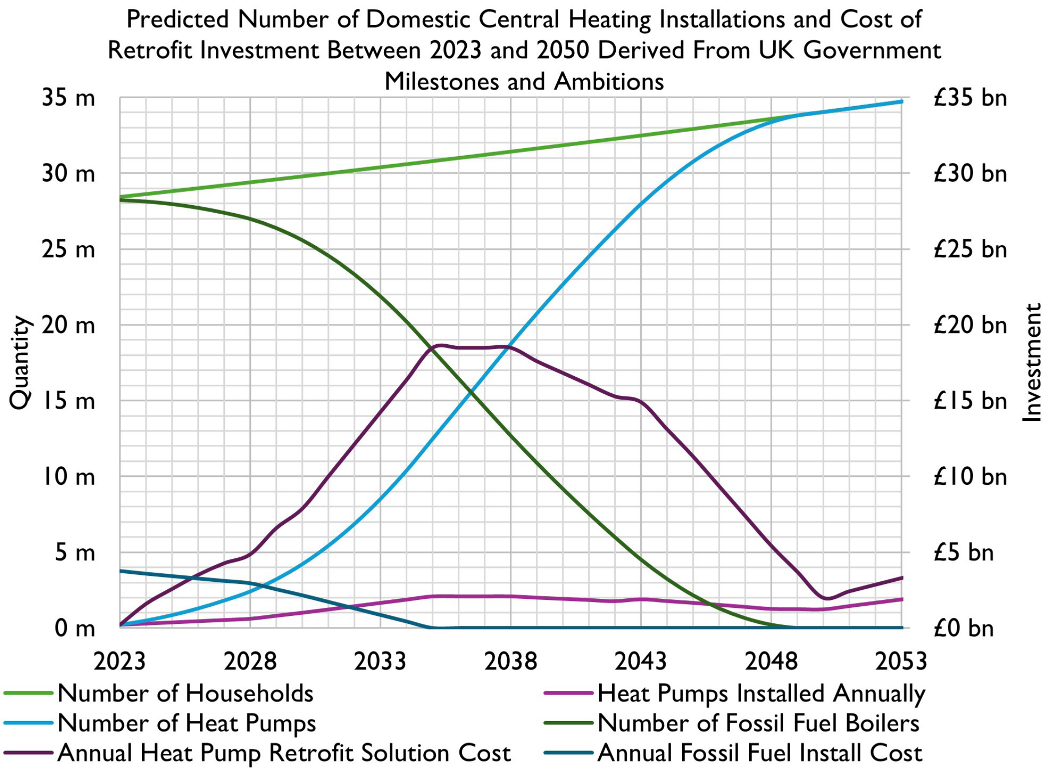

Figure 2 - Predicted growth of domestic heat pump installations and decline of natural gas boiler central heating.

The number of heat pumps installed increases sinusoidally to equal the total housing stock by 2050 while natural gas boilers reduce inversely to 0 by 2050. A total of £85.7 billion pounds is required to install heat pumps into every household between 2023 and 2050 after the insulation modification. The annual heat pump retrofit investment increases sharply from approximately £1.6 billion to a peak of £18.5 billion in 2035 before gradually decreasing to £2 billion in 2050. The cause of the increase is the targeted heat pump installations of the Government ambitions increasing the annual number of targeted legacy housing which are further invested in to increase thermal efficiency. The gradual decline of annual investment after 2038 is due to the reduced number of boiler retrofits as the 2023 installations reach their end of life, and the volume installed is reduced by the heat pumps installed that year.

The decline is continuous until 2043 where the first-generation heat pumps installed in 2023 come to their end of life and require replacement, but the insulation works remain intact. The annual investment continues to decrease until 2050 when all legacy housing energy efficiency has been improved to current building standards and thereafter, heat pump installations are the gradual end of life replacements from 20-year previous retrofits or new build construction.

This model does have limitations, mainly:

- The assumption that all domestic heating will be supplied by ASHP in 2050 is highly unlikely due to continuing research and funding into alternative forms such as ground source heat pumps, district heating and hydrogen boilers likely splitting the percentage of solutions by 2050. Although, no definitive strategy has been outlined.
- Individual flats have been considered to receive their own ASHP solution when communal heating systems would be more likely for a flat block. However, there is limited data available to determine the spread of flats across block sizes in the UK housing survey, restricting the model to assume a flat-by-flat solution.
- Insulation upgrade figures are fixed according to the Government ECO+ assumptions for each housing type whereas the cost would vary by building size, planning limitations and competition; as a highly valuable market, more installers and manufacturers would likely establish themselves to supply a demanding market.
- Value changes in the sterling pound have not been considered as there is no viable method to predict currency change.
- An even split of dwelling types and period has been considered for the annual retrofit as it is unknown whether certain demographics would respond to heat pump installations quicker than others.

While the limitations are stated, the modelled Government strategy clearly illustrates a strong financial burden on the domestic market, over five times greater than the natural gas boiler replacement by 2035. Further Government proposals suggest providing financial grants for low-income housing through various schemes (3) but, as low-income is generally classified as an annual income below 60% of the median income of the UK population (12) this represents approximately 6 million or 21% of all UK households (13) leaving the remainder to finance the insulation modification themselves with potential support from local authority grants.

UK Energy Market Since 1970

The UK's electricity generators have changed significantly since 1970. In 1970 coal was the prominent source of heat to generate electricity by the Rankine Cycle. Following coal, the next significant fuel sources were oil, nuclear, hydro and natural gas. Alternative fuels such as biofuels and renewable generators were available but did not generate electricity in significant numbers (14). This split of significant fuel sources remained consistent throughout the 1970s and 1980s despite the declining coal mining industry in the UK. It was not until 1992 that generation from coal was gradually replaced with Natural Gas following the sudden expansion of gas fired generation in what was known as the 'Dash for Gas' (15). Combined Cycle Gas Turbines (CCCT) continued to be rapidly expanded to dominate the energy generation market until 2013 where they held their peak split of the power capacity make-up and have since maintained a consistent capacity value (14). Renewable energy generators had also been gradually expanding alongside the 'Dash for Gas' although not at the same magnitude. It was not until 2010 that renewable generation started rapidly expanding to the portion seen in 2022 while coal plant capacity has receded to less than hydro capacity.

As of the 2022 data, renewable generators are continuing to expand and are not showing signs of plateauing (1). The following Figure 3 illustrates the electricity generator split by energy source in 1970 and 2022.

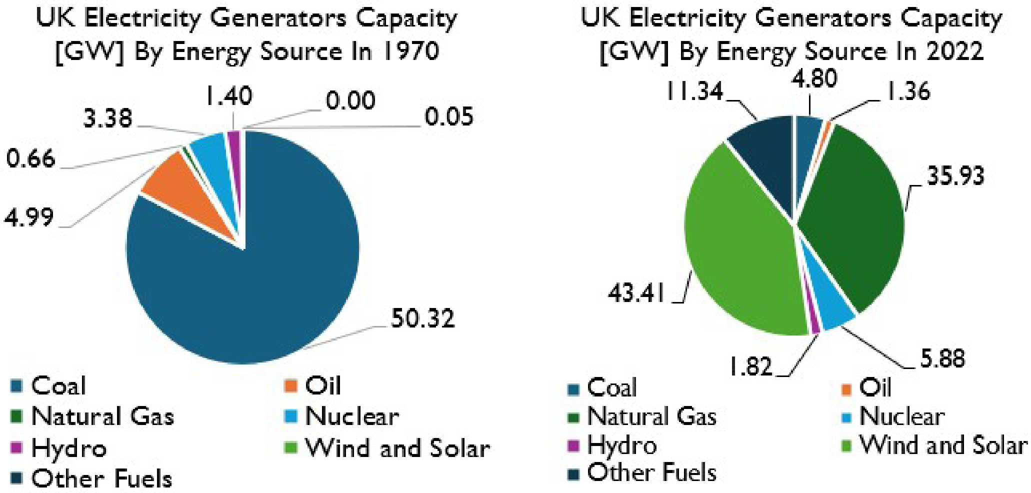

Figure 3 - UK electricity generators installed capacity [GW] by energy source in 1970 and 2022 (14)

Several other features of the UK electricity supply have changed since 1970 and have been listed in the following Table 5.

Table 5 - Electricity generation changes between 1970 and 2022.

Year	1970	2022
Installed Capacity	61.56 GW	104.55 GW
Load Factor	43.2%	33.9%
Domestic Use	33%	34%
Carbon Factor	879 gCO_{2e}/kWh	207 gCO_{2e}/kWh

The installed capacity represents the sum power generation of all energy sources and has increased over the period due to population growth. The load factor represents the percentage total of energy supplied from the potential installation capacity and had reduced due to the increased reliance on renewable resources that have a limited operating period compared to fuel source generators. Domestic use is the percentage of total electricity supply that is used by domestic households and has remained relatively consistent by only increasing from 33% to 34%. The carbon factor is the representative greenhouse gas (GHG) emissions released by the total electricity generation for the year from the fuel input supplied. The carbon factor has decreased due to a reduced reliance on coal, which is the most polluting fuel source in terms of direct GHG emissions and further increasing reliance on renewable resources (14) (16) (17).

The data available shows how electricity generation has changed over 50 years from 1970 to 2022 but also emphasises the challenge to achieve a net zero electricity supply by 2050. Using the heat pump installation model developed against the UK Government's own timeline and ambitions, the future impact on the UK's energy supply can be predicted and used to target increased installation capacity.

A current unknown is how the UK power generator capacity will be split by energy source in 2050. There is no defined strategy or ambition agreed for 2050 and the UK Government are consulting experts in various committees to learn what options are available.

One committee paper delivered to the BEIS Select Committee on 9 January 2023 suggests a split between 39% renewables, 32% CCCT with carbon capture storage and 29% nuclear (18) which closely corresponds with the current published Government material (1).

Several assumptions must be made in addition to those listed for the heat pump installation model:

- Annual domestic energy use for a society that retains natural gas for domestic heating reduces from an initial values of 11,309 kWh natural gas and 4,053 kWh electricity per household in line with insulation installation following the ASHP installation model. (14) (17)
- The split of domestic natural gas use for a society that retains natural gas for domestic heating remains 36% of the total UK supply each year, representing a proportional growth in commercial and industrial markets. (14) (17)
- The split of domestic electricity use for a society that retains natural gas for domestic heating remains 34% of the total UK supply each year, continuing the represented proportional growth in commercial and industrial markets. (14) (17)
- The transition of power generator split from the 2022 values 43%/34%/6% for renewables, CCCT and nuclear is linear to the select committee paper proposal values. (18)
- CCCT thermal efficiency remain fixed at 46%. (14) (17)
- The load factor of renewables, CCCTs and nuclear remain fixed at 24%, 37% and 71% respectively. (14) (17)
- For the electrified future society where, electrified transport is achieved by 2050, the travel miles per household is 11,290 per year (19).
- Electric vehicles are capable of 0.33 miles per kWh.
- The ASHP installed maintain a seasonal coefficient of performance of 2.5.

The following Figure 4 illustrates the changes in energy consumption for three development strategies. The first is a UK society that does not electrify domestic heating but rather retains the use of natural gas boilers. While this is contradictory to the UK's net zero ambitions, it establishes a baseline trajectory. The second considers the gradual installation of ASHP in all domestic properties following the model previously described and discussed. The third considers the ASHP installation and the gradual transition of domestic transport from internal combustion engines to electric vehicles, illustrating the impact of a completely electrified UK domestic market from 2022 to 2060.

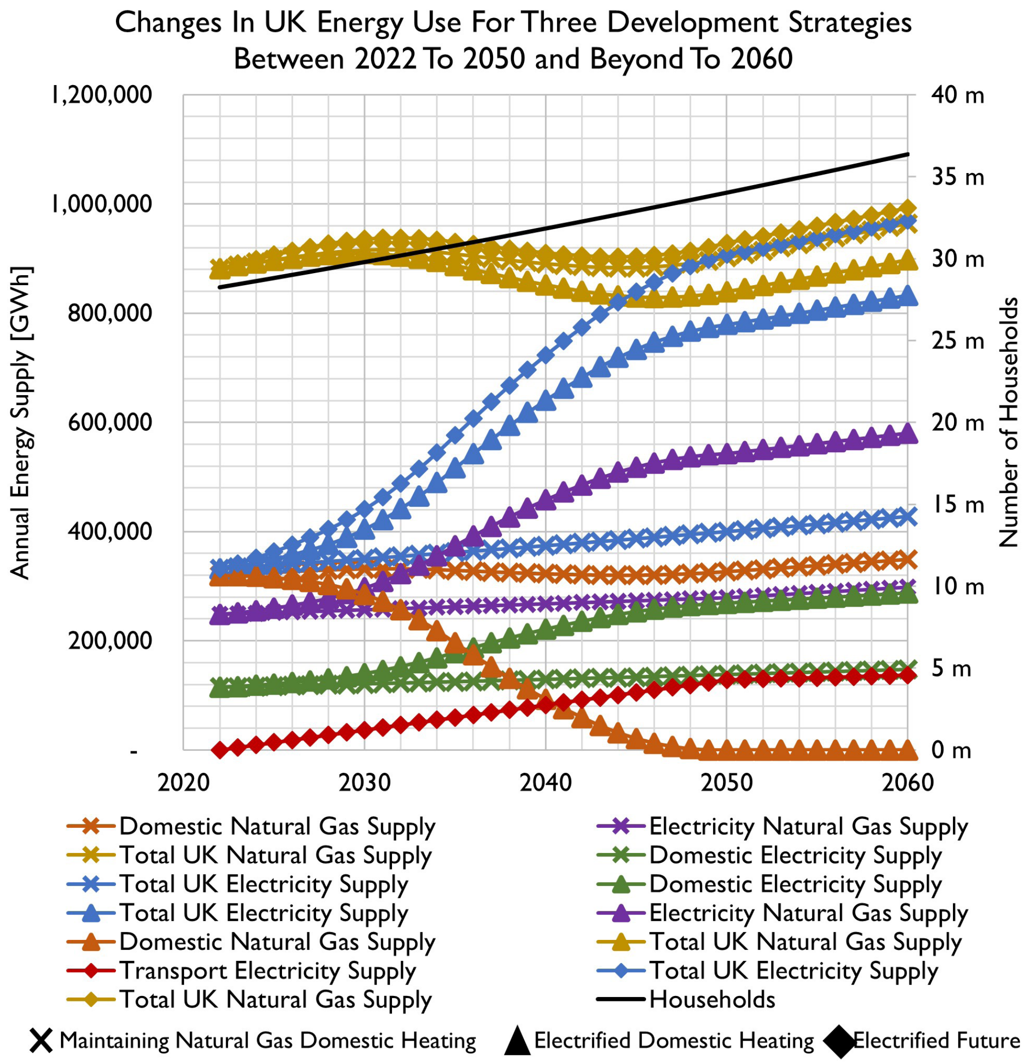

Figure 4 - Changes in UK Energy Use For Three Development Strategies Between 2022 To 2050 and Beyond To 2060

The initial strategy where natural gas is not removed from homes demonstrates a gradual increase in natural gas and electricity consumption proportional to household growth. An expected trend but establishes a benchmark for alternative strategies to measure from. By 2050, the UK electricity supply has increased by 68,058 GWh (20%) from 2022 requiring an installed plant capacity of 109 GW. To accommodate domestic heating and electricity generation, natural gas consumption is 902 TWh by 2050.

The second strategy that only considers the deployment of ASHP in the timeframe of the model discussed previously illustrates the reduction of domestic natural gas to zero and increase of electricity consumption until 2050 when the last natural gas boilers are decommissioned. After 2050 the electricity consumption follows a linear growth proportional to increasing households. Following the BEIS committee power generation split proposal, natural gas is retained in the UK for power generation and alternative uses beyond the domestic market. By 2050, the UK electricity supply has increased by 447,185 GWh (135%) from 2022 and 379,127 GWh (95%) from the benchmark 2050, requiring an installed plant capacity of 213 GW. To accommodate electricity generation, natural gas consumption is 839,386 TWh by 2050, a decrease of 4.8% from the benchmark and 6.9% from 2022.

The third strategy considers the deployment of ASHP like the second and the electrification of transport, illustrating the total impact of a completely electrified domestic market. The energy trends are like the second strategy; however, the magnitudes are larger. By 2050, the UK electricity supply has increased by 575,218 GWh (173%) from 2022 and 507,160 GWh (127%) from the benchmark 2050, requiring an installed plant capacity of 248 GW. To accommodate electricity generation and other uses, natural gas consumption is 928,572 TWh by 2050, an increase of 2.9% from the benchmark and 5.3% from 2022.

This model does have limitations in addition to those stated previously. The model assumes natural gas and electricity use outside of the domestic market remains consistent with assumed population growth representing no initiatives to increase energy efficiency or reduce natural gas beyond domestic dwellings. In the model, the thermal efficiency of CCGT remains fixed at 46% on the journey to 2050 but will likely increase due to improved technical and control advancements.

The additional demand on the UK electricity generation during the journey to 2050 is a challenge introduced by the electrification of domestic dwellings. Even if the current expectations for plant capacity and generation split can be met, the increased total consumption of natural gas cannot be ignored but acknowledged as a direct cause of increased electricity demand and energy security.

If a completely renewable energy society was possible by 2050, modifications to the model provide an expectation of an installed capacity requirement of 435 GW, a 187 GW increase from the third strategy. The large capacity requirement is directly caused by the relatively low load factor associated with renewable technology, representing the limitations of extracting wind power and solar power when the sources are available.

Conclusion

The domestic financial and electricity burden caused by the electrification of domestic heating has been investigated and presented in this paper. The cost of electricity generator and grid upgrades and workforce recruitment and training needed to deliver electrification of domestic heating were not considered by the modelling and are outside the scope of this paper.

The transition of domestic heating to heat pump technology is a key strategy to reduce the UK's annual emissions by removing the natural gas combustion in households and relying on a 'low carbon' electricity supply with the ambition to achieve a net zero by 2050. The current approach is to ensure legacy housing is modernised to existing insulation standards and improve domestic building energy efficiency. The overall cost to achieve legacy housing improvement and widespread ASHP adoption is approximately £309 billion pounds between 2023 and 2050. The financial burden will vary for each household, but most of the burden falls on legacy housing from pre-1919 and gradually reduces as property age reduces to 1981-1990 period. Multiple fund schemes financed by UK Government and local authorities will ease the burden, but they are targeting low-income housing representing 21% of the domestic market and are only scheduled to operate until 2026. Further and clear financial support is required to encourage insulation refits and heat pump adoption.

The additional demand on the electricity supply has been demonstrated for a growing UK population transitioning domestic heating to electricity as well as the parallel transition from internal combustion engines to electric vehicles, both of which are key strategies to achieve net zero by 2050. The demand requires an installed plant capacity of 248 GW with the generation split of 39% renewables, 32% CCCT with carbon capture storage and 29% nuclear, a 137% increase from the existing capacity. A limitation of the current grid expansion strategy is the lack of clear direction and ambition.

The UK Government are in the process of consulting select committees for advice and guidance with various proposals for future energy demand, the proposed split of generators being taken from one of the committees. This paper provides a value for the burden caused by electrifying the domestic market. Despite no demonstrable case study for the scale needed, a cornerstone of the UK Government strategy is the deployment of carbon capture storage (CCS) technology as a reliance on natural gas is retained for secure grid flexibility while fulfilling the definition of 'Net Zero' (1). Without CCS, the total consumption of natural gas increases in an electrified society compared to retaining domestic natural gas boilers by 2.9%, thereby increasing annual emissions. If a completely renewable UK society was targeted by 2050, an installed capacity of 435 GW would be required, an increase of ten times the current renewable capacity.

About the author

Chris Parker graduated from Liverpool John Moores University with a first-class honours degree in mechanical engineering, and early experience working as an engineering consultant. After two years of advancing his career, Chris achieved Chartered Engineer status at the age of 26. Using his knowledge and experience, Chris has supported several projects that require an in depth understanding of the thermodynamic and fluid mechanic phenomena that occur in complex mechanical systems. Chris maintains a strong comprehension of the wider landscape, seeking to learn the wider issues compound existing challenges, influence decision factors and impact engineering solutions. To this end, Chris has delved into research regarding the UK's challenges to decarbonise the national energy demands. Several opportunities are available, and many hurdles stand in the way of widespread alternative technology adoption. Chris currently works for WAVE.

Presented before the IOR on 7 March 2024 and amended by the author on 23 April 2024

References

1. His Majesty's Government. Powering Up Britain Energy Security Plan. london : His Majesty's Stationary Office, 2023. ISBN 978-1-5286-4018-3.

2. Climate Change Act 2008. Climate Change Act 2008. London : Her Majesty's Stationary Office, 2019.

3. Kwarteng, Kwasi. Heat and Buildings Strategy. London : Her Majesty's Stationary Office, 2021.

4. Heating and Hot Water Industry Council. Heating Up to Net Zero. Kenilworth : Heating and Hot Water Industry Council, 2021.

5. Department for Business, Energy & Industrial Strategy. Energy Consumption in the UK (ECUK): Energy Intensity Tables. Digest of United Kingdom Energy Statistics (DUKES). Westminster, Greater London, United Kingdom of Great Britain and Northern Ireland : Department for Business, Energy & Industrial Strategy, 29 July 2022.

6. Piddington, Justine, et al. The Housing Stock of The United Kingdom. Watford : BRE Trust, 2020.

7. Harris, Ben and Walker, Alan. UK Parliament Post Heat Pumps. London : His Majesty's Stationary Office, 2023.

8. Glew, David, et al. Demonstration of Energy Efficiency Potential. London : Department for Business, Energy & Industrial Strategy, 2021.

9. Department for Energy Security & Net Zero. Household Energy Efficiency Data to December 2022. London : His Majesty's Stationary Office, 2023.

10. Department for Business, Energy & Industrial Strategy. Energy Company Obligation ECO+: 2023 - 2026. London : His Majesty's Stationary Office, 2022.

11. Department for Energy Security & Net Zero. Household Energy Efficiency Statistics. London : Department for Energy Security & Net Zero, 2023.

12. Citizens Advice. Briefing: Local Citizens Advice Income Profile. London : Citizens Advice, 2015.

13. Office for National Statistics. National Statistics. The effects of taxes and benefits on household income: financial year ending 2021. Newport : Office for National Statistics, 2022.

14. Department for Business, Energy and Industrial Strategy. Estimated electricity capacity and generation timeseries between 1920 and 2022. Estimated electricity capacity and generation timeseries between 1920 and 2022. London : His Majesty's Stationary Office, 2023.

15. Mc Garry, Toby. UK Electricity capacity and generation by fuel between 1920 and 2020. London : His Majesty's Stationary Office, 2023.

16. 2022 UK greenhouse gas emissions, provisional figures. 2022 UK greenhouse gas emissions, provisional figures. London : His Majesty's Stationary Office, 2023.

17. Department for Energy Security and Net Zero. Electricity since 1920. ondon : His Majesty's Stationary Office, 2023.

18. Ambler, Tim, Edwards, Peter and Clanmorris, Simon. UK Electricity Strategy: Capacity, Demand and Pricing. London : BEIS Select Committee, 2023.

19. Department for Transport. Road Traffic Statistics. A Department for Transport Web site. [Online] Department for Transport, 2023. [Cited: 1 December 2023.] https://roadtraffic.dft.gov.uk/summary#:~:text=Motor%20vehicle%20traffic%20on%20Great,to%20323.8%20billion%20vehicle%20miles.