Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 149 (2018) 354–362

Energy Procedia

www.elsevier.com/locate/procedia

16th International Symposium on District Heating and Cooling, DHC2018, 9–12 September 2018, Hamburg, Germany

Heat pumps with district heating for the UK's domestic heating: individual versus district level

Zhikun Wang[a,*]

[a]University College London, UCL Energy Institute, Central House, 14 Upper Woburn Place, London, London WC1H 0NN, United Kingdom

Abstract

The UK has set ambitious targets to reduce carbon emissions, improve energy efficiency and affordability, encourage renewable energy generation, and reduce dependency on imported fossil fuels. Heating is the most essential component of the UK's current residential energy consumption, and it is mostly supplied through the direct burning of natural gas. With constantly changing market conditions and political regulatory frameworks, technology assessments and cost-effective planning strategies are critical for long-term energy and environmental policy designing. Electric heat pumps with decarbonised electricity are proposed as promising technologies that could replace gas heating and contribute to the UK's future low-carbon heat mix. District heating has been transforming over generations in order to better utilise renewables or resources that otherwise would be wasted. Both technologies have been well developed, with abundant scientific research and industrial experiences in some European countries over the past few decades. However, the market shares of heat pumps and district heating networks are low in the UK. This paper explores empirical heat consumption from smart meter data in different types of dwellings in the UK and the role of heat pumps and district heating for different types of dwellings on different scales. This study investigates heat pumps in individual households versus district heating networks through a levelised cost model, to present their comparative environmental and economic advantages. This study shows that economies of scale arise in the UK's district heating networks with large heat pumps, but the costs of heat are significantly higher than individual gas boilers.

Keywords: heat demand; heat pumps; district heating; levelised cost of heat

* Corresponding author. Tel.: +44 (0)20 7679 8186.
E-mail address: zhikun.wang.10@ucl.ac.uk

10.1016/j.egypro.2018.08.199

1. Introduction and background

The UK has set objectives to deep-decarbonise its economy while improving energy affordability and eliminating fuel poverty, promoting energy efficiency, and reducing dependency on imported fossil fuels, with goals to reduce greenhouse gas emissions by 80% by the year 2050 compared to 1990 levels [1]. To meet these targets, carbon emissions from the building sector will need to be reduced to almost zero [2]. It is possible to achieve deep cuts in carbon emissions from British dwellings with the potential for future improvements in building performance, decarbonising the electricity, and re-engineering the heat supply [3]. Renewable electricity together with high-efficiency, low-carbon heat technologies are expected to play an essential role in meeting the UK's heat demand and energy and environmental targets, while bringing health, wellbeing, and economic benefits. With heat technologies continually upgrading and improving, evaluating technologies' advantages and performance is essential to determine the direction of long-term heat decarbonisation and to develop low-carbon heat infrastructure.

Heat demand is the largest demand in the electricity, heating, and cooling sectors regarding both annual and peak hourly demands in the UK [4]. Currently, nearly half of the final energy demand in the UK is consumed to provide heat across the economy [5]. Gas is the most important energy carrier, and individual gas boilers are the principal way of supplying domestic heat demand in over 85% of British households [6]. Residential heat demand varies in different types of dwellings. There are about 27.5 million dwellings in the UK, including five main dwelling types: terraced (28%), semi-detached (26%), flat (20%), detached (17%), and bungalow (9%), and the estimated domestic gas demand is more than three times higher than domestic electricity demand annually [7].

In recent years, there has been an increasing trend for electricity generation from renewables, and better utilisation of waste energy. This promotes the opportunity for the electrification of the heating sector and a shift away from fossil fuels. Electric heat pumps could play a central role in the UK's future approach to heating, together with the decarbonised electricity grid. Additionally, heat pumps can be integrated into district heating networks, which may provide additional carbon emissions reduction potential. Integrating flexible heat pumps into district heating networks has been recognised as a crucial step in transitioning to a 100% renewable energy system cost-effectively [8]. In the UK, the Building Regulations [9] require new buildings to consider district heating as well as the integration of heat pumps. Recently, the Clean Growth Strategy [10] has set out a series of proposals to phase out fossil fuel heating in buildings off the gas grid during the 2020s, build and extend heat networks across the country, and invest in the development of low-carbon heat technologies and energy efficiency measures.

However, although heat pumps and district heating have been widely deployed in Europe, they are still niche options in the UK. Currently, only about 0.2% of the UK's total heat demand is supplied by electric heat pumps [11]. There are less than 2,000 operating district heating networks across the country, and around three-quarters of them are small networks, which are supplying heat to less than a hundred dwellings [12]. It is suggested that the economic viability of district heating networks in the UK depends on a series of factors, including upfront infrastructure costs, volatility of energy prices, and uncertain energy policies [13]. Moreover, there is a great deal of uncertainty regarding the decarbonisation of the electricity grid, demand variations, and future market shares of heat pumps and heat networks [14]. Currently, due to higher upfront costs and longer payback periods compared to gas boilers, district heating networks integrated with heat pumps are considered risky technology in the UK [15].

There are very few empirical studies regarding the operation of heat pumps in the UK's buildings and heat networks. There is a need for research on potential competing heat technologies and detailed analyses of the comparative advantages of deploying heat pumps and district heating in different types of buildings on different scales. This paper aims to provide an empirical analysis of domestic heat demand in different types of dwellings in the UK and conduct economic and environmental assessments of the application of heat pumps and district heating networks on different scales, from individual buildings to the district level.

2. Methodology

2.1 Empirical data analysis: domestic heat demand

Understanding how much and when heat is consumed is fundamental to evaluating heat supplying technologies and designing cost-effective strategies to meet heat demand. This study analyses empirical residential heat consumption, including space heating and domestic hot water demand, for the five main types of dwellings through smart meter data [7], and investigates hourly heat load profiles over a year to estimate variations in total heat demand as well as peak demand. Due to the low installation rate of heat meters and the predominate gas boiler market share in the UK, natural gas consumption data is analysed as a proxy to evaluate heat demand based on the national average gas boiler efficiency (80.54%) according to [7].

Smart meter data from the Energy Demand Research Project (EDRP) is used for this study. The EDRP was a set of large-scale trials implemented by four major energy suppliers to explore customer responses and individuals' energy consumption with smart meters across Britain from 2007 to 2010 [16]. This study analyses the subset data from EDF Energy, which includes half-hourly electricity and gas smart meter data from 1,879 households in England. This study examines households that used gas boilers as the primary technology for their central space heating and domestic hot water. Half-hourly natural gas consumption data are summed into hourly data, and the annual heat demand from 591 households with different dwelling types is estimated after the data extraction and cleaning processes. Hourly heat load profile is constructed to study peak hourly heat demand over the year of 2009, as winter 2009/2010 was one of the coldest over the last three decades [17].

2.2. Modelling: economic and environmental assessment of heat pumps and district heating

Technology cost assessments are fundamental to inform decision making and policy designing by quantifying and evaluating the trade-offs of how to meet energy demand while mitigating carbon emissions in a cost-effective way. Levelised Cost of Energy (LCOE) is a useful method in modelling to compare the generating costs of energy through alternative technologies, especially for technologies with different operating lifetimes and costing structures. The LCOE method was initially developed for rate-regulated electricity markets. It is sometimes called a life cycle cost as it takes all cost elements into account to generate energy at the plant level through its whole life cycle from planning, installation, and energy generation to site decommissioning and waste management [18]. The LCOE is a form of net present value (NPV) calculation based on the discounted cash flow method under specific technical and economic assumptions [18]. It is the ratio of the NPV of the total costs of a technology over the NPV of the total amount of energy generated by this technology.

Based on the monitored gas consumption data from the EDRP project and the estimated heat demand for individual dwellings and district heating networks, a simple Levelised Cost of Heat (LCOH) model is developed to assess costs and carbon emissions from different individual heating technologies as well as large heat pumps and district heating networks on different scales. Three types of individual heating technologies are considered: a gas boiler, a ground source heat pump, and an air source heat pump. The model is built based on the equation as shown:

$$\mathrm{LCOH} = \frac{\Sigma\left[\frac{\mathrm{Capital_t + O\&M_t + Fuel_t + Carbon_t)}}{(1+\mathrm{r})^{\mathrm{t}}}\right]}{\Sigma\left[\frac{\mathrm{MWh_t}}{(1+\mathrm{r})^{\mathrm{t}}}\right]} \tag{1}$$

Where $\mathrm{Capital}_t$ is the capital expenditures in the year t, $\mathrm{O\&M}_t$ is the operation and maintenance costs. Due to the well-developed gas grid in the UK, this model does not consider the costs to construct the gas networks. This study gathers technology costs and performance data from the government commissioned statistical databases [19 - 21], which are considered to be representative of networks in the UK, in addition to industrial practitioners' databases [22 - 23]. Fuel_t and Carbon_t are the fuel costs and the carbon costs in the year t. This study uses the publicly available annual fuel and carbon prices projected by [5]. $(1+\mathrm{r})^t$ is the discount factor in the year t, with the discount rate r. This study applies 3.5%, corresponding to the 'social cost of capital' [24]. MWh_t is the amount of heat produced in the year t. This study assumes that all heating options start to operate in 2018 to meet households' heat demand, but with different projected future lifetimes. Detailed model input assumptions and cost data are included in the appendix.

Upscaling methods are applied to simulate the aggregated heat demand for district heating networks on different scales that could be supplied through large heat pumps based on the proportions of the five dwelling types in the UK [7]. There are different definitions regarding the size of heat networks in the UK. This study uses the adjusted standards defined by [23] and [25] with five scales:

- Small heat networks (less than 100 residential properties)
- Medium heat networks (between 100 and 500 residential properties)
- Large heat networks (over 500 residential properties)
- Single developments (up to 3,000 homes)
- Medium multi-development scales (up to 20,000 homes)

3. Results and discussions

3.1. Heat demand

Based on monitored gas consumption data and households' metadata, heat demand in the five dwelling types in 2009 was estimated. The average amount of gas consumed in 2009 was approximately 18,900 kWh per household. Figure 1 displays the estimated average annual heat demand from the monitored households. On average, a household consumes approximately 15,200 kWhth of heat a year. As expected, a detached house requires the highest amount of heat among all types of dwellings, with annual heat demand reaching over 18,600 kWhth, while a flat consumes only about 10,400 kWhth. Additionally, this study only considers heat demand supplied by individual gas boilers, and does not consider supplementary heating measures used in those households, such as electric heating or fireplaces due to limited metadata.

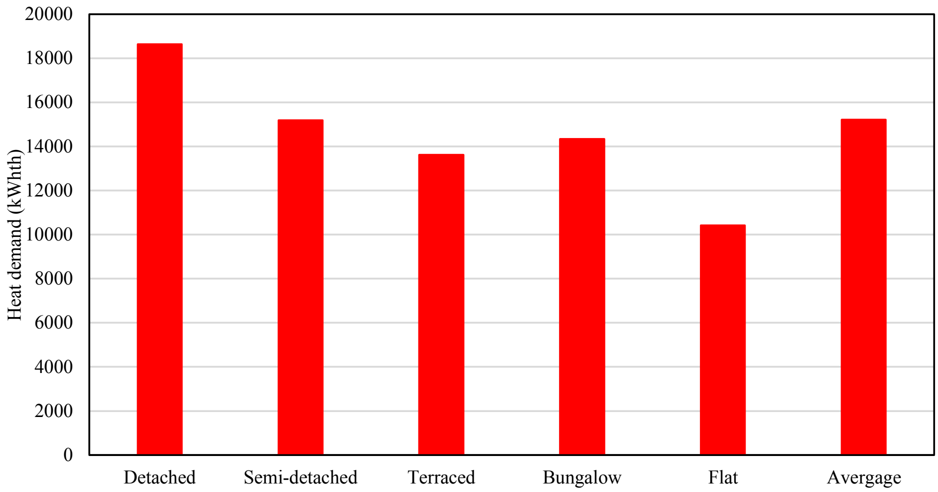

Figure 1. Average annual heat demand in the five main types of residential buildings.

Figure 2 demonstrates the average hourly heat demand profiles per household versus the hourly external temperature over the year of 2009. This figure shows the volatile changes in domestic heat demand over time, with most of the heat demand occurred from November to May. On average, the maximum hourly heat demand reached around 7.5 kWth per household during the coldest periods in the year, which is more than seven times higher than the typical peak hourly heat demand (approximately 1 kWhth) during the summer.

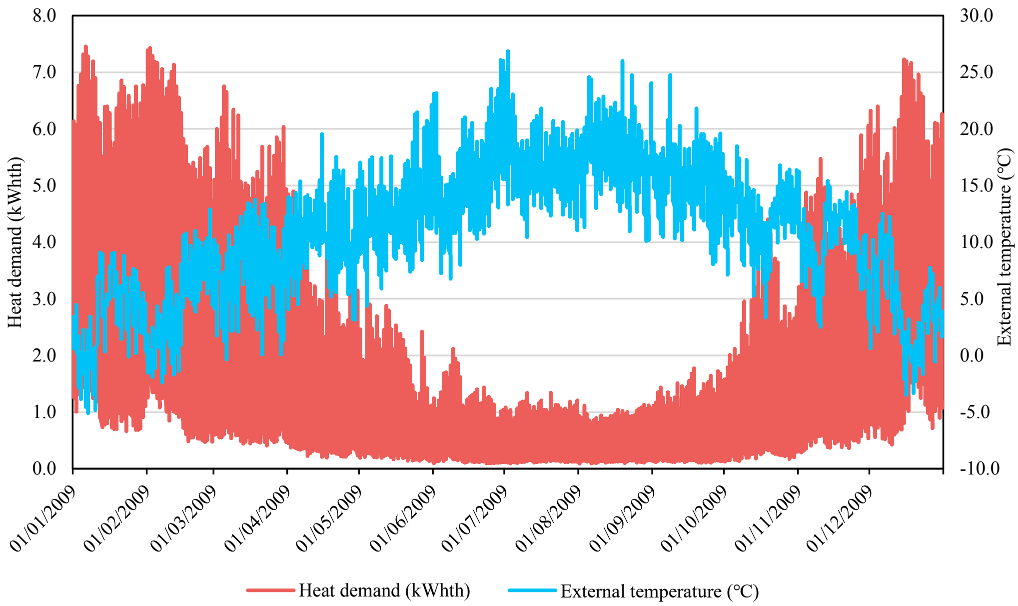

Figure 2. Average hourly heat demand and external temperature in 2009.

3.2. Costs and emissions

3.2.1. Individual heating technologies

The LCOH model is built for different individual heating technologies and district heating networks to meet the heat demand for different types of dwellings. Figure 3 shows the results of the overall LCOH for the five types of individual households, and one household with an averaged heat demand. A 3.5% discount rate is used throughout the technologies' lifetimes. In general, the LCOH is lower in dwellings with a higher annual heat demand, and the difference between the LCOH for a gas boiler and heat pumps becomes larger when heat demand decreases among the five dwelling types. As expected, a gas boiler is the cheapest way to meet heat demand in all individual dwellings, with an overall LCOH of £75/MWhth in a detached house and just over

£90/MWhth in a flat. A ground source heat pump is clearly indicated as the most expensive individual technology for meeting heat demand in all dwelling types. In this study, the LCOH for a flat is indicated as being the highest due to its low annual heat demand, with the LCOH for a ground source heat pump reaching more than £140/MWhth. Meanwhile, based on the average heat demand across all five dwelling types, the LCOH for a gas boiler is just under £80/MWhth, roughly 20% cheaper than an air source heat pump and 30% cheaper than a ground source heat pump.

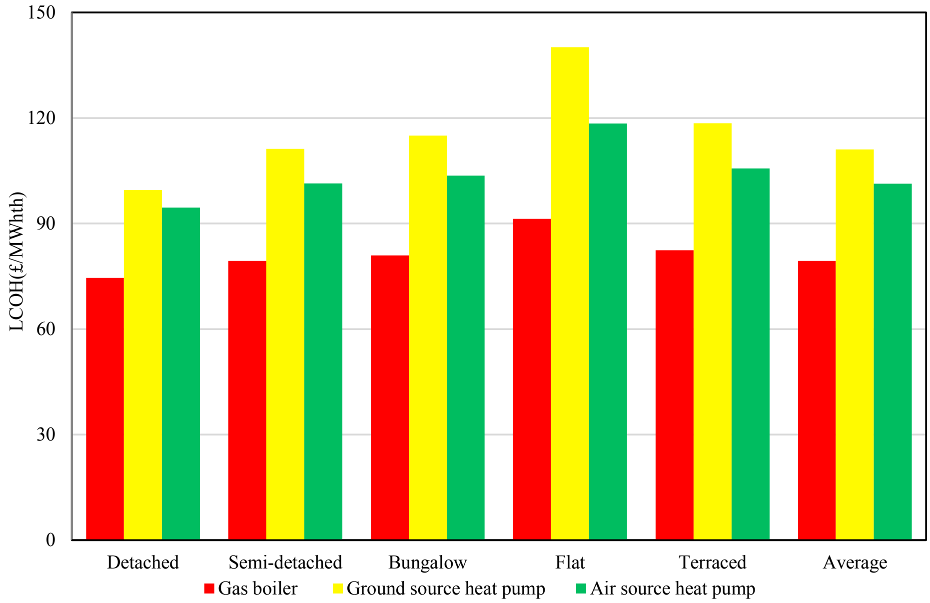

Figure 3. The LCOH for different individual technologies in different dwelling types.

Although heat pumps are more expensive than gas boilers for supplying heat to all individual dwellings, they can significantly reduce carbon emissions from heat for individual households, on the condition that the carbon intensity of the electricity grid in the UK keeps decreasing, as per future projections [5]. Figure 4 indicates the average annual carbon dioxide emissions from different technologies. Based on the carbon content of natural gas and the projected future carbon intensity of electricity in the UK, on average, a gas boiler emits approximately three tonnes of carbon dioxide a year over its technology lifetime. In contrast, a heat pump could reduce more than 80% of carbon emissions while meeting the heat demand, with roughly 0.5 and 0.7 tonnes of annual carbon emissions from a ground source heat pump and an air source heat pump, respectively.

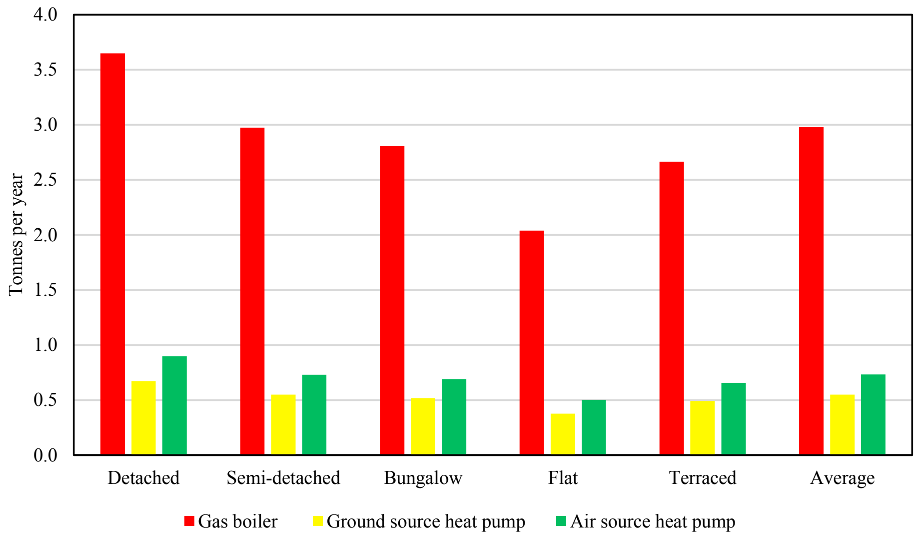

Figure 4. Estimated average annual carbon dioxide emissions from individual heating technologies.

3.2.2. District heating networks integrated with large heat pumps

Based on the five scales of district heating networks defined in section 2.2, the costs of heat are modelled to meet heat demand on the five scales through district heating with large heat pumps, compared to the individual technologies. This study assumes that heat pumps are utilised to generate heat for both space heating and domestic hot water for all dwellings connected to the networks.

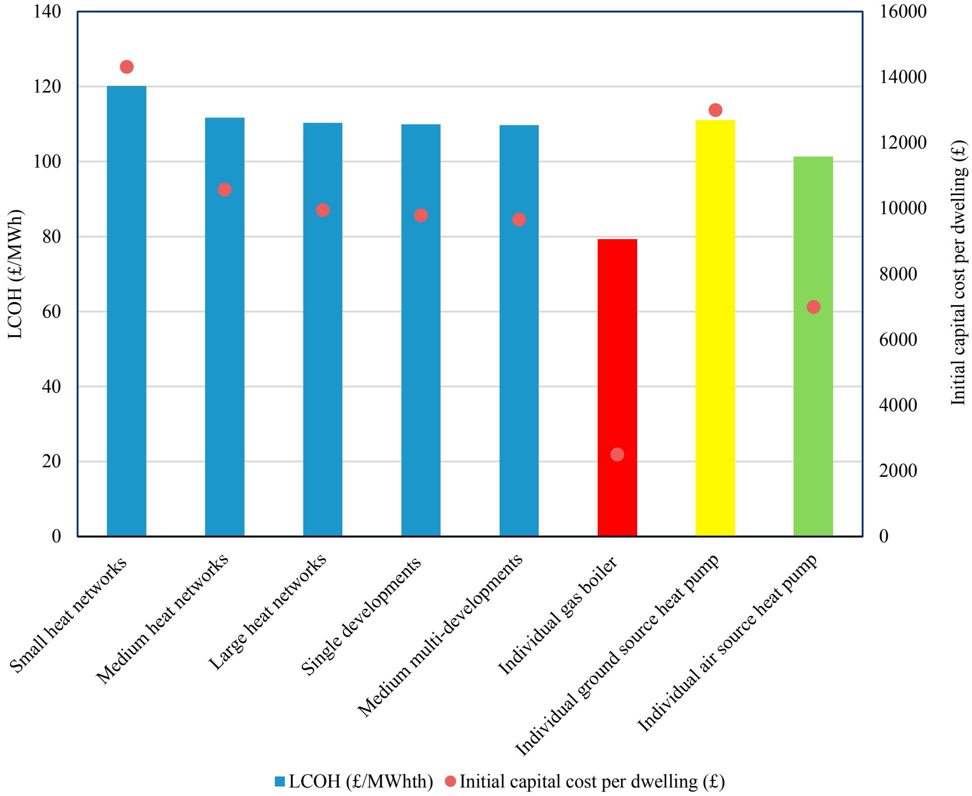

Figure 5. The LCOH and initial capital costs per dwelling for district heating according to five scales, compared to individual heating technologies.

Figure 5 provides an overview of the LCOH (primary vertical axis) and the initial capital costs per dwelling (secondary vertical axis) for district heating networks on the five scales and compared to the three individual technologies. As the figure shows, economies of scale arise in district heating networks, as the overall LCOH decreases steadily from the smallest district heating network to the largest, with the number dropping from over £120/MWhth to under £110/MWhth. However, the results of LCOH for district heating networks are still significantly more expensive than individual gas boilers due to high capital costs.

Figure 5 also compares the initial capital costs for dwellings with different heating options. As the figure indicates, a small district heating network has the highest initial capital cost per dwelling at approximately £14,300 per dwelling on average, while this number is reduced by around one third to roughly £9,600 per dwelling for the largest district heating scale. Although the LCOH for district heating networks becomes similar to the LCOH for individual ground source heat pumps when the network becomes larger, their initial capital costs per dwelling are still higher than installing individual air source heat pumps.

Figure 6 illustrates the compositions of the overall LCOH according to different cost elements, including capital costs, O&M costs, fuel costs, and carbon costs. For an individual gas boiler, capital cost contributes to less than 20% of the overall LCOH, and fuel cost contributes to more than 60%. An individual ground source heat pump has the highest percentage of capital cost (52%) and the smallest percentage of fuel cost (43%). Meanwhile, among district heating networks, the proportion of capital cost becomes gradually smaller when the scale of the network rises. For a small district heating network (with 100 dwellings), capital cost accounts for about 30% of the overall LCOH, whereas for the largest district heating scale (with 20,000 dwellings), capital cost reduces to about 22% of total LCOH. Due to the projected decreasing carbon intensity of electricity and very low future carbon prices [5] in the UK, carbon costs only contribute to very small proportions of the overall LCOH for all heating options, accounting for less than 5% for gas boilers and less than 1% for heat pumps and district heating networks.

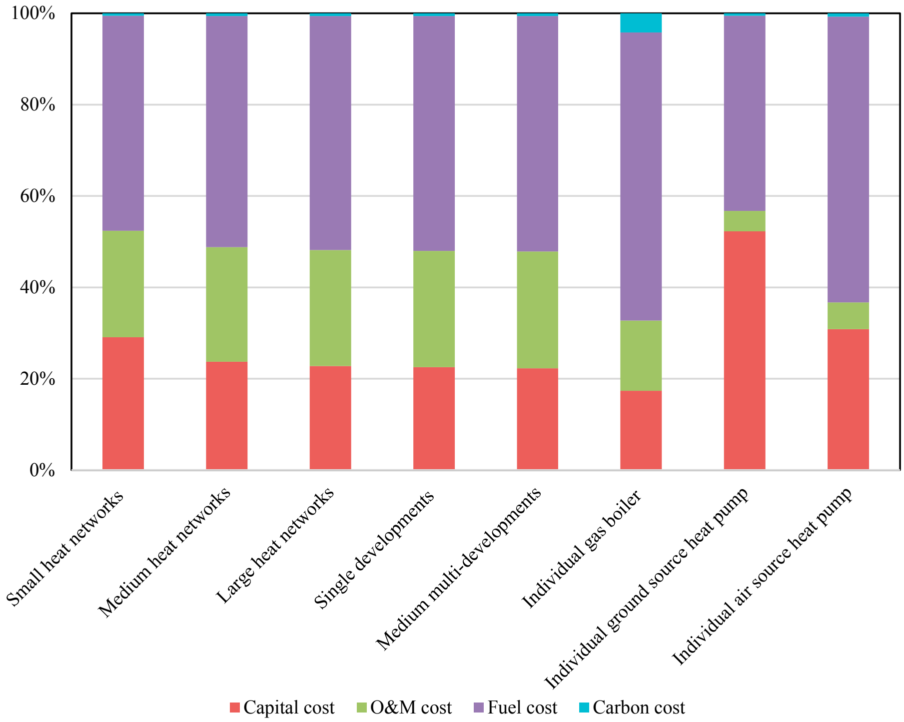

Figure 6: The LCOH cost elements among different heating options.

The levelised cost method is highly sensitive to its assumptions. Sensitivity analysis is conducted to evaluate the correlations between a group of selected independent input factors and the overall LCOH for district heating networks. The LCOH result for a medium scale district heating network is used as a basis, and the selected variables are altered to evaluate their impact on the final LCOH results. Figures 7 and 8 summarise the changes in the overall LCOH when the input assumptions adjusted. Figure 7 displays the percentage changes in the LCOH when the total heat demand, capital cost, and O&M cost are modified by plus or minus up to 50%. The figure shows that LCOH is more sensitive to heat demand changes than cost factors, as it upsurges by roughly 35% when the total heat demand reduces by half, whereas the overall LCOH decreases by 11% when the total heat demand rises by half. Moreover, when capital cost and O&M cost increase or decrease by 50%, the overall LCOH increases or decreases by 15% and 11%, respectively.

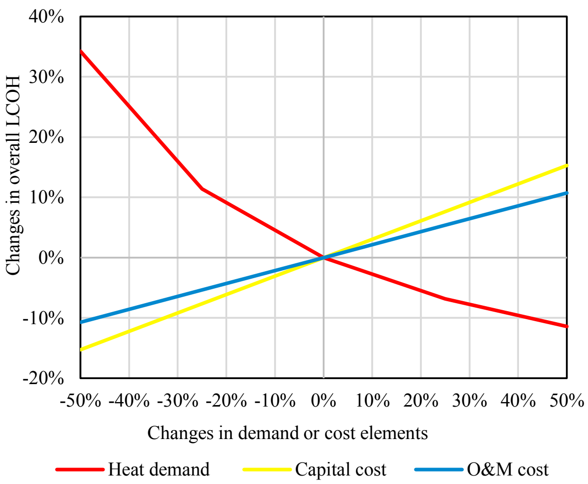

Figure 7: LCOH as the function of heat demand or costs.

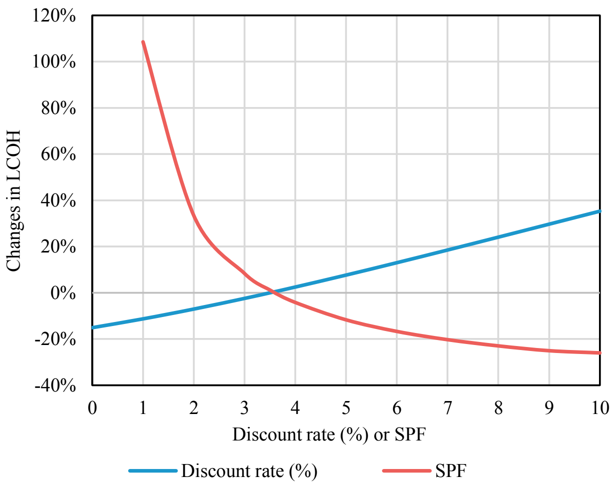

Figure 8: LCOH as the function of discount rate and heat pump efficiency.

The discount rate is crucial, as it determines the net present value and the future costs of technologies over their lifetimes. This study uses 3.5% as a basis, and the number is adjusted from 0% to 10%. As Figure 8 reveals, the overall LCOH drops 15% when the discount rate declines from 3.5% to 0%, and the overall LCOH increases by up to 35% when the discount rate reaches 10%. Moreover, Figure 8 also shows how the overall LCOH changes when the heat pump efficiency (seasonal performance factor, SPF) changes from its initial assumption of 3.6. The LCOH increases significantly, by roughly 110%, when the SPF drops from 3.6 to 1.0, but decreases steadily when the SPF escalates. The overall LCOH could decrease by more than 25%, if the SPF reached 10.

Although the levelised cost method is a useful tool for comparing the costs of different energy generating technologies, some limitations associated with the LCOH are noted. Firstly, the energy costs of the levelised cost method are outputs and assumed to be constant over technologies' lifetimes, and they are not the prices to sell energy. Hence, the levelised cost method does not reflect the short-term or long-term volatilities of energy prices. Secondly, this study modelled the LCOH for the five main dwelling types in the UK. However, the domestic heat demand and technology performance may vary from one dwelling to another, according to numerous features such as building fabrics, ages, designs, sizes, locations and occupants' characteristics. Because of limited metadata, this study does not differentiate heat demand in households regarding their specific features such as floor areas, number of occupants and states of refurbishment.

The results of LCOH are highly sensitive to its assumptions. Accordingly, variations in future heat demand, cost elements or technology performance may considerably influence the results, as the sensitivity analyses have shown. The employed LCOH refers to all costs at the plant level. This study applies secondary technology costs and performance data from different sources, and in reality, these features may vary significantly according to individual dwellings and technologies. Moreover, The LCOH represents a one-time decision that will last for a long period of time. This study uses projected natural gas and electricity prices, carbon taxes and carbon intensities of electricity for the future; however, there are significant uncertainties regarding future taxes, subsidies and renewable shares of electricity generation, and changes in these parameters may cause pronounced impacts on the overall LCOH and carbon emissions. Furthermore, there are substantial uncertainties associated with the UK's future energy and climate policies, especially following the recent Brexit referendum and abrupt changes in exchange rates. Changes in policies may cause significant impacts on many key modelling elements, including technology costs, fuel and carbon prices.

4. Conclusion

To achieve the government's energy and environmental targets, it is imperative to study potential heating options to replace the conventional gas-fired system and reduce carbon emissions. Heat pumps and district heating are established technologies with large-scale deployment in many European countries over the past few decades, but their markets and policy frameworks are immature in the UK, and there are technical, social, and economic barriers for their future deployment. Moreover, the well-developed natural gas networks, the eminently high market share of individual gas boilers and cheap natural gas are the most substantial challenges for the future deployment of electric heat pumps and district heating networks in the UK.

This study quantifies empirical domestic heat consumption through smart meter data from a diverse range of dwellings in the UK. Results show that the domestic heat demand differs in different types of dwellings and changes erratically over time. This study also investigates the cost-competitiveness of heat pumps and district heating compared to individual gas boilers, and demonstrates that economies of scale arise in district heating networks. Although heat pumps with decarbonised electricity could reduce domestic carbon emissions from heat intensively, the levelised costs for heat pumps and district heating are significantly higher than individual gas boilers. The mass electrification of the heating sector and the deployment of the heat networks on large scales will require intensive investment, alterations in supply chain practices, and public acceptance. Further studies are desirable to better understand the role of district heating and heat pumps in the UK's energy system and transform district heating from a strategy into reality.

Acknowledgements

This research was made possible by support from the Engineering and Physical Sciences Research Council (EPSRC) Centre for Doctoral Training in Energy Demand (LoLo), grant numbers EP/L01517X/1 and EP/H009612/1. The author would like to gratefully acknowledge the EDF Energy R&D UK Centre Limited for providing smart meter data and financial support.

Reference

[1] CCC. Building a low-carbon economy – The UK's contribution to tackling climate change. London, UK: the Committee on Climate Change, 2008.
[2] DECC. The future of heating: meeting the challenge. London, UK: the Department of Energy and Climate Change, 2013.
[3] Lowe, R. Technical options and strategies for decarbonizing UK housing. *Building Research & Information,* 2007, Vol. 35, pp. 412-425.
[4] Connolly, D. Heat Roadmap Europe: Quantitative comparison between the electricity, heating, and cooling sectors for different European countries. *Energy,* 2017, Vol. 139, pp. 580-593.
[5] BEIS. Updated energy and emission projections. Department for Business, Energy & Industrial Strategy, 2018.
[6] Delta-ee. IEA HPP Annex 42 Heat Pumps in Smart Grids. Delta Energy and Environment, 2014.

[7] ECUK. Energy consumption in the UK. Department for Business, Energy & Industrial Strategy, 2017.
[8] Connolly, D. & Mathiesen, B. V. A technical and economic analysis of one potential pathway to a 100% renewable energy system. *International Journal of Sustainable Energy Planning and Management,* 2017, Vol. 1, pp. 7-28.
[9] The Building Regulations. The Building Regulations &c. (Amendment) Regulations [Online]. London, UK: Department for Communities and Local Government. Building regulations: divisional circular letters and Building regulation. Available: https://www.gov.uk/government/publications/the-building-c-amendment-regulations-2014 [Accessed 8th May 2018], 2014.
[10] BEIS. The Clean Growth Strategy. Leading the way to a low carbon future. London, UK: Department for Business, Energy and Industrial Strategy, 2017.
[11] Hannon, M. J. Raising the temperature of the UK heat pump market: Learning lessons from Finland. *Energy Policy,* 2015. Vol. 85, pp. 369-375.
[12] IEA. Heat Pumps in Smart Grids: Market overview – Country report for the United Kingdom. The Netherlands: International Energy Agency, 2017.
[13] Kelly, S. & Pollitt, M. An assessment of the present and future opportunities for combined heat and power with district heating (CHP-DH) in the United Kingdom. *Energy Policy,* 2010, Vol. 38, pp. 6936-6945.
[14] Chaudry, M., Abeysekera, M., Hosseini, S. H. R., Jenkins, N. & Wu, J. Uncertainties in decarbonising heat in the UK. *Energy Policy,* 2015, Vol. 87, pp. 623-640.
[15] Hawkey, D., Webb, J. & Winskel, M. Organisation and governance of urban energy systems: district heating and cooling in the UK. *Journal of Cleaner Production,* 2013, Vol. 50, pp. 22-31.
[16] AECOM. Energy Demand Research Project: Final Analysis. Hertfordshire, UK: AECOM and Ofgem, 2011.
[17] Met Office. Met Office Winter 2009/2010. Available: https://www.metoffice.gov.uk/about-us/who/how/case-studies/winter09-10 [Accessed 8th May 2018], 2016.
[18] IEA, NEA & OECD. Projected costs of generating electricity. Paris, France, International Energy Agency, Nuclear Energy Agency and Organisation for Economic Co-operation and Development, 2015.
[19] DECC & AECOM. Assessment of the costs, performance, and characteristics of UK heat networks. London, UK: Department of Energy and Climate Change, 2015.
[20] DECC. Heat pumps in district heating. London, UK: Department of Energy and Climate Change, 2016.
[21] DECC & Sweett Group. Research on the costs and performance of heating and cooling technologies. London, UK: The Department of Energy and Climate Change, 2013.
[22] Pöyry. The potential and costs of district heating networks. A Report to the Department of Energy and Climate Change. Oxford, UK: Pöyry Energy Limited, 2009.
[23] Greater London Authority. District heating manual for London. London, UK: Greater London Authority and Arup, 2013.
[24] HM Treasury. The Green Book: appraisal and evaluation in central government [Online]. Available: https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent [Accessed 8th May 2018], 2018.
[25] DECC. Summary evidence on District Heating Networks in the UK. the Department of Energy & Climate Change, 2013.

Appendix

A.1. Individual heating technology key assumptions

	Gas boiler	Ground source heat pump	Air source heat pump
Capital cost (£)	2500	13000	7000
O&M cost (£/year)	180	75	90
Efficiency (%)	94	400	300
Life time (year)	15	20	20
Carbon intensity (kg/kWh)	0.184	BEIS projection [5]	BEIS projection [5]

A.2. Key modelling assumptions for large heat pumps and district heating networks

District heating	Unit	Value
Large heat pump capital cost	£/kW	1500
Large heat pump O&M cost	£/kW	1
Large heat pump lifetime	Years	25
Large heat pump efficiency (SPF)	%	360
Average length of internal pipework per dwelling	m	13.3
Network parasitic electricity consumption	% of heat demand	1.9%
Network lifetime	year	50
Assumed main network (buried pipes) length	m	1000
Distribution loss	%	20%
Main network (buried pipes)	£/m	468
Network (internal pipes)	£/m	169
Substation cost per kW capacity	£/kW	35
Domestic HIUs per dwelling	£	1075
Heat meter cost per building	£	3343
Heat meter cost per dwelling	£	579
Heat network maintenance	£/MWh	0.6
HIUs maintenance cost	£/MWh	9
Heat meter maintenance	£/MWh	3.4
Labour for metering, billing and revenue	£/MWh	16.9