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UK COLLABORATIVE CENTRE FOR HOUSING EVIDENCE

Motivations and Barriers Associated with Adopting Domestic Heat Pumps in the UK

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UK COLLABORATIVE CENTRE FOR HOUSING EVIDENCE

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Executive Summary

Mitigation within the UK's residential sector will play a crucial role in achieving a net-zero target by 2050, given this sector accounts for 16% of total greenhouse gas emissions. In the residential sector, space and water heating are the predominant sources of energy consumption and greenhouse gas emissions. One key renewable source for space and water heating is the heat pump, however, their deployment is significantly lower in the UK compared to neighbouring countries, despite a reasonable attempt at sector growth in the recent past.

This review attempts to assess the evidence in relation to the underlying factors responsible for or against transitioning to heat pumps (HPs). Employing evidence synthesis based on peer-reviewed published outputs (n=15), and relevant other outputs from snowballing and grey literature (n=9), this study examines key factors across three broad themes – households' socio-technical characteristics, built environment attributes and stakeholders' competing and differing economic and organisational interests – that provide motivations or barriers to scaling up HPs in the UK.

Evidence suggests that saving money, increasing household energy independence and reducing greenhouse gas emissions are the households' principal positive drivers, whereas higher capital and running costs are the major barriers to adopting heat pumps. The current imbalance in energy taxes and levies (environmental levies for electricity and gas bills are 23% and 2% respectively) weakens the economic competitiveness of heat pumps in the UK. Convincing evidence suggests that appropriate knowledge and awareness – choices, technical and financial knowledge – help in the adoption of heat pumps which can be achieved through adopting a bottom-up approach like community-based energy plans.

In the context of the built environment, evidence suggests that the heat pump system is often mistargeted, for example, wrongly sized heat pumps are installed and focus on existing smaller homes (social housing) via retrofits. Contrary findings suggest that current HPs' loads are more suitable for larger and newly built homes. The dominance of the existing housing stock (low stock replacement rates) implies a more nuanced and careful approach should be adopted for this part of the housing system. One of the most important features is to adopt the 'fabric first approach', where heating options should be chosen after achieving building efficiency (and in some cases, energy demand reduction) through appropriate retrofitting.

Furthermore, the stakeholders' competing and differing economic and organisational interests as well as the lack of appropriate skill sets to execute the HPs system are major barriers to upscaling HPs. Existing policies and regulations are not sufficiently aligned to incentivise manufacturers and installers and there is a lack of coherence in policies and regulations. For instance, due to the short-term span of existing programmes, manufacturers and installers are unable to attract and train suitable skill sets for the next generation of workers. These findings have important policy implications:

- Incentives: enhance financial incentives and make an economic case for HPs on the demand-side among consumers by reducing the imbalance in levies on electricity and gas bills.

- Information: increase demonstrator projects (provides real-world data on all forms of benefits, including energy saving). Adopting a bottom-up approach, particularly involving local governments and community-based organisations. Also, targeting the right segments of households who are potential innovators and early adopters.

- Regulation: targeting the right segments, for example, large homes and new buildings initially and then existing buildings after adequate retrofitting. Also, addressing stakeholders' concerns such as manufacturers, traders, and installers in such a way that end-users positively experience the journey of HPs (pre- and post-installations).

Keywords: heat pumps; renewables; consumer attitudes; motivations and barriers

Acronyms

ABS	Area Based Schemes
ASHP	Air Source Heat Pump
BUS	Boiler Upgrade Scheme
ECO	Energy Company Obligation
EESSH	Energy Efficiency Standard for Social Housing (1 & 2)
EPC	Energy Performance Certificate
ETS	Emissions Trading System
EASP	Exhaust Air Source Heat Pumps
FIT	Feed-in Tariffs
GSP	Ground Source Heat Pump
HEEPS	Home Energy Efficiency Programmes for Scotland
HHCRO	Home Heating Cost Reduction Obligation
HP	Heat Pump
HPA	Heat Pump Association
IEA	International Energy Agency
MCS	Microgeneration Certification Scheme
Micro CHP	Micro combined heat and power
PV	Photovoltaics
RHI	Renewable Heat Initiative
TWh	Terawatt-hour
UK	United Kingdom
WHD	Warm Home Discount

Introduction

The UK built environment sector is responsible for almost 30% of total greenhouse gas emissions, where a significant emission reduction via energy-efficiency improvement and low-carbon heating systems, are crucial to achieve the UK's net-zero target by 2050 (Green Finance Institute 2020). In order for the carbon budget to be compliant with the Paris Agreement to keep global warming to well below 2°C, the UK seeks full decarbonisation of energy systems by 2035-40 (Anderson, Broderick, and Stoddard 2020) and the Climate Change Act 2008 targets to reduce greenhouse gas emissions to net zero by 2050 (2045 in Scotland). The residential sector is estimated to have been responsible for 16% of total greenhouse gas emissions in the UK in 2020 where the main source of power for heating and cooking is natural gas (BEIS 2022a).

In the UK, as elsewhere across Europe, heat pumps[1] (HPs) are a key low-carbon technology for space and water heating, which save around 60% carbon dioxide equivalent in comparison to a gas boiler on a basis of per kWh of delivered heat (see Fig 1 below) (HPA 2020). Despite acknowledging this benefit, HPs deployment in the UK is low compared to other European countries (BEIS 2021a). For example, the total number of heat pumps per 1,000 people in the UK is less than 4 whereas it is 114 in France and 261 in Norway (Fig 2 below).

Fig 1: The Carbon Saving from Heat Pumps, Source: HPA (2020)

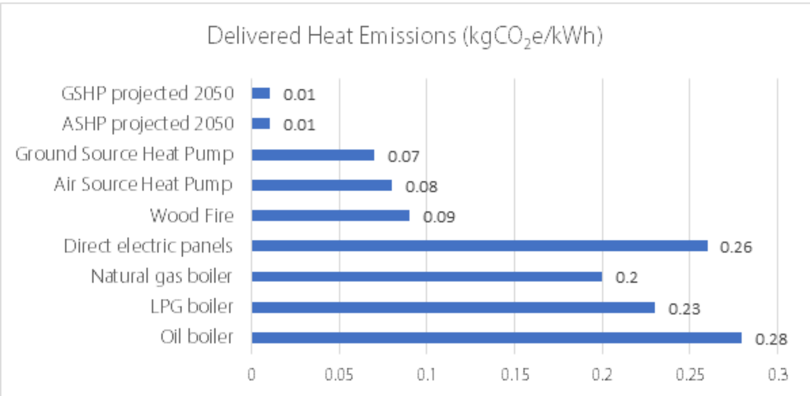
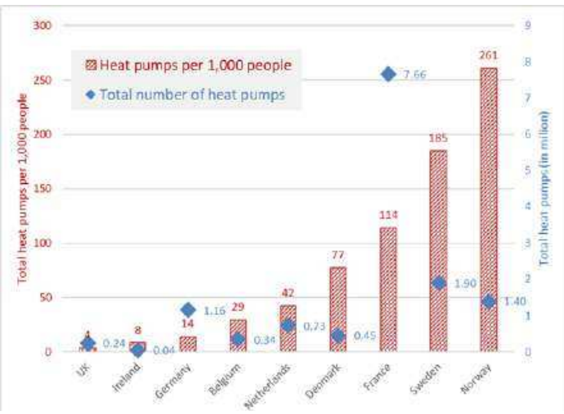


Fig 2: Heat pumps in operation in the UK and neighbouring countries, 2019. Source: Heat Pumps Barometer via Statista



1 "A heat pump uses technology similar to use in an air conditioner or a refrigerator, where it extracts heat from a source such as air, geothermal energy stored in the ground, or nearby source of water or waste heat from a factory" (p.18). HP is more efficient (3-5 times) than conventional heating technologies like gas boilers as most of the heat is transferred rather than generated. HPs are classified based on their source of heat extraction - air source heat pump (ASHP) extracts heat from air whereas ground source heat pump (GSHP) extracts heat from the ground (IEA 2022b).

Currently, space and water heating in the UK are primarily provided by gas (73%), followed by oil (10%) and electricity (9%). In the residential sector, gas is used most (76%), as natural gas boilers are prevalent. In the UK cooling demand is low, about 39 TWh annually compared to with 463 TWh of space and hot water heating, given their geographical and climatic context (BEIS 2021c: 6). About 15% of the UK households (~ 4 million) are off the gas grid, the majority of them use heating oil – the most carbon intensive heating option (Fig 1). For instance, among 1.1 million off-gas grid homes in England, 78% use heating oil, 13% liquified petroleum gas and 9% coal (BEIS 2022d).

In this context, this evidence review aims to identify both the motivations and barriers to scaling up domestic heat pumps in the UK. This is addressed through three interlinked research questions:

- To what extent (and why) are UK households positioned to readily adopt residential heat pumps technologies?
- How can we explain which different built environment attributes shape the uptake of HPs technologies?
- How is HP technology and market roll-out shaped by the stance and interplay of various key stakeholders: business, science, the state, civil society and communities?

The next section discuses recent policies and regulations relevant to the achievement of energy efficiency in the residential sector, followed by a short methods section where I broadly outline the systematic literature search providing evidence for the motivations or otherwise to uptake HPs in the UK. Next, findings are presented across three sub-sections where each subsection addresses a specific research question. The final section presents conclusions.

Recent Policies and Regulations

Recent debates related to scaling up heat pumps in the UK can be found in science and technology studies, environmental psychology, behavioural psychology, and engineering studies. To contextualise the debate, a broad overview of recent policies and regulations is helpful, particularly related to the HPs that are the subject of this review.

In the UK, heat pumps are mainly adopted as a strategy for achieving energy efficiency. Indeed, the deployment of heat pumps is closely linked with building efficiency. A recent International Energy Agency report argues that retrofitting buildings in parallel to heat pump deployment greatly reduces the impact on power systems (IEA 2022b). In this section, some of the UK and Scotland specific policies and regulations will be discussed.

Feed-in Tariffs (FIT) Scheme

The Feed-in Tariffs (FIT) scheme, running between April 2010 to March 2019, was designed by the UK's government to promote the uptake of renewable and low-carbon electricity generation using Solar PV, Wind, Micro CHP, Hydro and Anaerobic digestion[2]. This scheme had two types of participants: FIT generators (the owner of accredited installations) and FIT licensees (licensed electricity suppliers who registered applications and make FIT payments based on electricity produced by installers). In this scheme, households are paid a fixed amount for every unit of energy they generated by approved installations. This scheme was designed in such a way that the household received an annual return on investment of 5% with the payment guaranteed for 20-25 years (Balcombe, Rigby, and Azapagic 2014). Though this scheme is not directly related to the HPs, it can complement it, for example, by accessing renewable electricity through these installations for HPs.

2 Solar PV materials and devices convert sunlight into electrical energy by means of photovoltaics. Wind energy is the process by which wind is used to generate electricity. Micro combined heat and power (Micro CHP) is 'a technology that generates heat and electricity simultaneously, from the same energy source, in the individual's home or building.' This can be more efficient than just burning a fossil fuel for heat therefore it is considered as low carbon technology. Hydropower (in short Hydro) is a low carbon source of renewable energy that uses the power of moving water to generate electricity. Anaerobic digestion is a natural process through which bacteria break down organic matter - such as animal manure, and food waste - into useful product in the absence of oxygen. The process releases biogas which can be used as an energy input such as heat and power.

Green Deal Scheme

The Green Deal, implemented from Jan 2013 to July 2015, facilitated loans for energy-saving improvement in homes. This scheme typically includes insulation (e.g., solid wall, cavity wall or loft insulation), heating, draught-proofing, double glazing, and renewable energy generation (e.g., heat pumps or PV). The main idea for this deal was to support capital costs and then paid-back at a fixed interest rate with their electricity bills. In this scheme, the interest rate was between 7-9% and the repayment term was 10-25 years. The improvement work must be recommended by an accredited home energy assessor and the deal stipulated that the loan is permitted only if the monthly repayment was lower than the predicted saving in the fuel bills. Approximately 1% of households took out loans under this scheme – the Department for Energy and Climate Change (now BEIS) spent £240 million and another £154 million through subsidies for the green deal home improvement fund – however, auditors concluded that it failed to deliver 'meaningful benefit' (Syal 2016).

Energy Company Obligation Scheme

The Energy Company Obligation (ECO) is now in its fourth phase[3] (the Home Heating Cost Reduction Obligation, HHCRO 1 Apr 2022 – 31 Mar 2026), administered via Ofgem. The scheme is a government energy efficiency scheme in Great Britain to help reduce GHG emissions and tackle fuel poverty challenges. Government believes that domestic energy efficiency is the most effective way to tackle fuel poverty[4], thus, this scheme mainly seeks to improve the uptake of energy efficiency measures among low income and vulnerable households (see Table 1). It aims to achieve several complementary goals such as Government's statutory fuel poverty and climate change commitments, reduce energy demand in the residential sector, improving thermal comfort and support jobs and growth. Among the others, it aims to focus support on owner occupied EPC[5] D-G homes (both private rented and social housing), set a minimum requirement to improve EPC D and E homes to EPC C, and EPC F and G homes to at least EPC D (BEIS 2022b). Improvement in EPC promotes significant energy savings and other societal benefits such as health and well-being among the households (Webber, Gouldson, and Kerr 2015; Rosenow and Bayer 2017; Rosenow and Galvin 2013). However, energy-saving policies, including energy suppliers' obligations, have been reduced over the last decade and need to be strengthened to deliver climate goals (Eyre and Oreszczyn 2022: 5; Barrett et al. 2022). Importantly, those who are affected by the current affordability crisis, have experienced reductions in access to energy efficiency retrofit opportunities (Eyre and Oreszczyn 2022: 5). This indicates huge future demand for residential energy efficiency installations.

3 Earlier phases are as follows: ECO1: 1 Jan 2013 - 31 Mar 2015, ECO2: Apr 2015 - 31 Mar 2017, ECO Help-to Heat Apr 2017 - Sep 2018, ECO3: 3 Dec 2018 - 31 Mar 2022.

4 Fuel poverty is a devolved issue in the UK and each nation has its own definition. "England uses the Low Income and High Costs definition to measure fuel poverty. It states that the household is in fuel poverty if their income is below the poverty line (taking into account energy costs) and their energy costs are higher than is typical for their household type." Whereas fuel poverty in Scotland is defined as "if a household spends more than 10% of its income on fuel costs and if the remaining household income is insufficient to maintain an adequate standard of living." Wales and Northern Ireland, similar to Scotland, use a 10% indicator to measure fuel poverty. In principle fuel poverty figures are non-additive in relation to the UK total, but it is estimated that 15% of all households in the UK are fuel poor. Around c.2018, 10.9% English households (2.53 mi), 25% Scottish households (0.62 mi), 12% Welsh households (155,000) and 22% Northern Irish households (160,000) were estimated in fuel poverty. Source: Energy Action Scotland (2020).

5 Energy Performance Certificates (EPCs) provide an indication for energy efficiency in a building and provide advice on how this energy efficiency can be improved. Buildings are rated on a scale of A (very efficient) to G (inefficient). EPC rating is for the property itself and not the way it is used.

Table 1: The context of the UK housing energy efficiency timeline

	2020	2021-25	2026-30	2031-35	2036-40	2041-45	2046-50
Targets, milestones and moment	England & Wales: all private rented homes at least EPC E England: all fuel poor homes at least EPC E	England 2025: all fuel-poor homes at least EPC D Scotland 2022: all private-rented homes at least EPC E; 2025: all social-rented homes at least EPC D (EESSH2)	UK 2030: all rented homes at least EPC C or equivalent (expected) England 2030: all fuel-poor homes at least EPC C Scotland 2028: EPC C private rented housing	UK 2035: EPC C for all rented homes Scotland 2032: EPC B for social rented homes (EESSH2) Scotland 2035: EPC C for owner-occupied private housing	Scotland 2040: at least EPC C for all homes; EPC B for fuel-poor homes	Scotland 2045: net-zero emissions	UK 2050: net-zero emissions
Current policy	Great Britain: Energy Company Obligation for delivering home heating cost reduction measure until 2028						
	England and Wales: new building regulations enter into force	England & Wales: Future Homes Standard enter into force	UK 2030: halve the cost of retrofitting homes to new build standards				
Commitment	UK (2019 manifesto commitment) to 2030: £3.8 bn Social Housing Decarbonisation Fund						
	UK (2019 manifesto commitment) to 2030: £2.5bn Homes Upgraded Grant						
Proposals and other processes		UK 2021: Shared Prosperity Fund to replace EU Structural Funds					

Source: Adopted from Green Finance Institute (2020: 19) and updated based on Scottish Government (2021a) and BEIS (2021a).

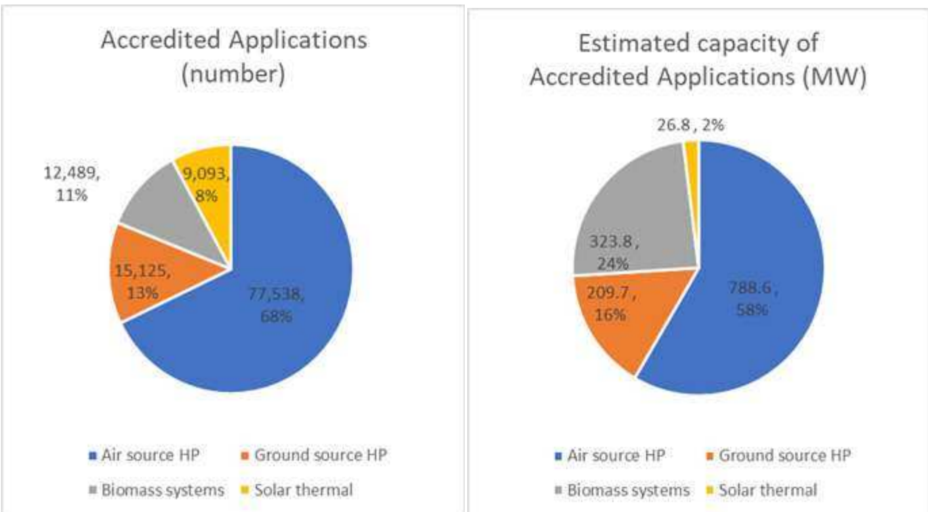
Domestic Renewable Heat Initiative (RHI)

The Domestic RHI is a government financial incentive to promote renewable heat to reduce carbon emissions and meet the UK's renewable energy targets. This scheme opened in November 2011 and closed on 31 March 2022. It helped to partially cover costs in adopting renewable heating systems (e.g., heat pumps, biomass boilers) in place of existing fossil fuel alternatives (e.g., gas boilers).

Between April 2012 to September 2022, in Great Britain through the DRHI programme, 77,538 Air Source Heat Pumps (ASHPs)[6] were accredited: 77% in England, 18% in Scotland and 6% in Wales. During the same time, 15,125 Ground Source Heat Pumps (GSHPs) were accredited: 77% in England, 13% in Scotland and 10% in Wales (see Fig 1) (BEIS 2022c). As per the recent census, the share of households in England, Scotland and Wales was 85.8%, 9.3% and 4.9% respectively. Thus, Scotland and Wales have taken up proportionately higher numbers than England.

This scheme is now replaced by a new three-year Boiler Upgrade Scheme (BUS) that will provide an up-front sum of £5,000 in place of the £7,000 paid quarterly over seven years in the Domestic RHI (see Box 1) to support the installation of heat pumps and biomass boilers in homes and non-domestic buildings in England and Wales. Equivalent to this, Scotland and Northern Ireland have an interest-free loan or a grant scheme. There are two criteria for the BUS: having an Energy Performance Certificate (EPC) of less than 10 years and have adequate loft and/or cavity wall insulation in place. Primarily, this is because EPCs are used to gauge energy-efficiency of the property and impact the payments to the property-owner after approval in the Domestic RHI programme. Moreover, unlike gas boilers, HPs provide lower intensity of heat in homes, therefore, installation in, a property that requires loft and/or cavity wall insulation would not be effective. Currently, 90,000 households (first-come, first-served basis) will be able to claim £5,000 as £450 million has been earmarked.

Fig 3: Number of accreditations by technology type and capacity under Domestic RHI, Great Britain, Apr 2014 to Sep 2022. Source: BEIS (2022c)



Warm Home Discount (WHD)

WHD is a GB wide scheme, a one-off discount for eligible households between September and March. Currently WHD is worth £150 on electricity bills. Eligible households fall under two main groups: either households receive the Guarantee Credit element of Pension Credit, or a 'broader' group on low incomes.

6 A Heat Pump (HP) is an effective way to produce heated water to heat home. They work by absorbing heat from the environment and transferring it to a fluid, which is compressed to increase its temperature. This heat then transferred from the compressed fluid into the central heating system, to use both heating and hot water. The system does not burn any fuel and therefore emits no carbon dioxide. There are two predominant types of HPs: Air Source Heat Pumps (ASHPs) and Ground Source Heat Pumps (GSHPs). As names suggest, ASHPs absorb heat from the air whereas GSHPs absorb heat from the ground. ASHPs are easier and quicker to install than GSHP as they do not require any land to dug up. GSHPs require sufficient land to fit a ground loop, which can be placed vertically or horizontally, however vertical placing cost more. Normally, both types of HPs fall under 'permitted developments' and therefore do not need planning permission with a few exceptions like historical buildings (Energy Saving Trust 2021).

Scotland-specific Relevant Policies

The Home Energy Efficiency Programmes for Scotland (HEEPS)

is the Scottish Government Initiatives to reduce fuel poverty and improving energy efficiency of housing in Scotland, launched in April 2013 (Scottish Government 2021b). HEEPS is a cluster of programmes currently consisting of four Schemes: Area Based Scheme (HEEPS: ABS); Warmer Homes Scotland (HEEPS: WHS); HEEPS: Loans (includes Home Energy Scotland Loan Scheme[7] and Equity Loan Pilot Scheme[8]); and Advice and Support Delivery by Home Energy Scotland[9]. These schemes are designed to work with other energy efficiency programmes by combining funding, such as the ECO programme. This combined approach aims to maximise the opportunities available to households and local authorities and helps delivery of more expensive projects or of higher numbers. HEEPS: ABS is designed and delivered by Local Authorities along with utility companies and local delivery partners, and mainly focused on insulating homes, i.e. through wall insulation. HEEPS: WHS offers fabric measures as well as heating measures to improve energy efficiency in homes and reduce fuel bills. In HEEPS, ABS has the highest share of budget allocation followed by Loans, WHS and advice and support. For instance, out of the total £115.6 million HEEPS' budget in 2018/19, about £49 million (~42%) was used for HEEPS: ABS, £24 million (~21%) was for HEEPS: WHS, £30 million (~26%) for HEEPS: Loans and the remaining £12 million (~10%) used for advice and support.

Local Heat and Energy Efficiency Strategies (LHEES)

is a principal mechanism for a place-based, locally-led and tailored approach to the heat transition with mandate across Scotland. Its responsibility includes support for local planning, coordination, and delivery of heat transition across communities in Scotland and requires close cooperation between Scottish Government and all 32 local authorities. The strategies used underpin the area-based approach to heat and energy efficiency planning and delivering, primarily driven by Scotland's statutory targets of greenhouse emissions reduction (net zero emissions by 2045) and fuel poverty (no household in Scotland to be fuel poor by 2040, as far as reasonably possible). As per the LHEES (Scotland) Order 2022, the local authority will publish its first Local Heat and Energy Efficiency Strategy before 31 Dec 2023 (strategy and delivery plan) and then update within five years.

7 Launched in May 2017 provides interest-free, unsecured loans of up to £32,000 per homes to owner occupiers and registered private sector landlords in Scotland to install energy efficiency measures, including adopting renewable technologies (Energy Action Scotland n.d.).

8 Launched in Jan 2017 to selected local authorities, including Glasgow city, provides equity loans to homeowners on low incomes, and small landlords to achieve energy efficiency in their homes. Loans up to £40,000 available can be used alone or with part with other Scottish Government grants where at least 45% of the funding must be for energy efficiency/works that reduce heat loss (Energy Action Scotland n.d.).

9 A network of local advice centres covering all of Scotland, funded by the Scottish Government and managed by Energy Saving Trust. The network advises about: creating energy efficient homes, reducing energy bills, exploring greener energy options, greener travelling options, and financial support for all of the listed.

Box 1: UK's key policies[10] for the heat and buildings in the Net Zero Strategy

- An ambition that by 2035, no new gas boilers will be sold.
- A new £450 million three-year Boiler Upgrade Scheme will see households offered grants of up to £5,000 for low-carbon heating systems so they cost the same as a gas boiler now.
- A new £60 million Heat Pump Ready programme that will provide funding for pioneering heat pump technologies and will support the government's target of 600,000 installations a year by 2028.
- Delivering cheaper electricity by rebalancing of policy costs from electricity bills to gas bills this decade.
- Further funding for the Social Housing Decarbonisation Scheme and Home Upgrade Grants, investing £1.75 billion. Additional funding of £1.425 billion for Public Sector Decarbonisation, with the aim of reducing emissions from public sector buildings by 75% by 2037.
- Launching a Hydrogen Village trial to inform a strategic decision on the role of hydrogen in the heating system by 2026.

Source: (HM Government (2021: 22-23)

Convincing evidence demonstrates that one quarter of the UK's domestic energy currently used could be cost effectively saved by 2035, for example, through upgrading existing buildings' efficiency and deployment of heat pumps (Rosenow et al. 2018). Simply by improving a property's efficiency by two grades (e.g. from E to C), can reduce heating energy demand by 50% and reduce the size of heat pump needed (IEA 2022b). But government ambition and the current pace of change in the decarbonisation of homes in the UK fall short of achieving the intended net-zero challenge (Green Finance Institute 2020). The Coalition for the Energy Efficiency of Buildings (52 member organisations to date) suggest "to establish a common goal for all homes to achieve EPC C by 2030" around which all stakeholders – the finance industry, supply chain, home owners and tenants – come together to achieve the goal (Green Finance Institute 2020: 56). European countries, including the UK, have provided significant energy subsidy in the context of Russia-Ukraine war as energy bills increased very rapidly. In this background, domestic energy and building efficiency related regulations and economic incentives even become more critical to addressing current and future challenges. Green Finance Institution's study demonstrates that UK's business-as-usual approach is not enough to tackle the situation as a huge gap exists between government ambitions for decarbonising homes and pace of change in the sector due to various reasons, including limited financial flows (ibid). Therefore, far greater efforts are required to decarbonise homes to achieve net-zero.

Methods

This evidence review is based on peer-reviewed publications as well as other relevant publications (i.e. research reports) accessed through snowballing and grey literature related to motivations and barriers to the adoption of heat pumps, primarily focused on the UK. This research employs a literature mapping exercise developed by colleagues at the UK Collaborative Centre for Housing Evidence (CaCHE) (Soaita, Serin, and Preece 2020; Serin 2018). This exercise aims to find evidence in relation to the above three research questions (see introduction section), focusing on the UK.

10 Scotland has higher ambitions for the heat and buildings strategy, for instance, transition to net zero by 2045 (75% reduction by 2030 and 90% by 2040). Scotland has statutory requirement of no more than 5% of households are fuel poor, no more than 1% are in extreme fuel poverty and the fuel poverty gap is no more than £250 (in 2015 prices) by 2040.

Thematic focus and scope: Key inclusion-exclusion criteria were developed before the review began based on the thematic focus of the exercise (domestic heat pumps), timeframe (last 15 years, January 2008 until now 2023), and geographical focus (UK). This study has focussed on the last one and a half decades because this period witnessed major progress relevant to the focus of this review, for example, the Climate Change Act 2008 evolved approaches to tackling and responding to climate change. Further, this review has focused on studies published in the UK as these outputs are relevant to understand contextual motivations for or against heat pumps. The review specifically excludes studies focusing on purely technical aspects such as the efficiency of Heat Pumps.

Search media: Scopus is used as the main search media due to its wide coverage in this area. The review focus on scholarly outputs (journal articles, reviews and indexed book chapter). Further, literature is identified through snowballing of the identified outputs, including grey literature (e.g., policy documents, reports and briefs). This study searched "(TITLE-ABS-KEY (heat AND pumps) AND TITLE-ABS-KEY (domestic) AND TITLE-ABS-KEY (UK)) AND PUBYEAR > 2008 AND PUBYEAR < 2023".

Review steps: Our search of the database yielded 117 studies. I screened all titles and abstracts, of which 21 were identified as being potentially relevant. I assessed the eligibility of these by accessing and screening the full texts of the studies and included 15 studies and excluded 6. Further, 9 studies were added using snowballing and grey literature. A total of 24 outputs became key sources for this study. Appendix A1 presents the steps followed for this exercise.

Findings: Motivations for or Against the Uptake of Heat Pumps

This section presents findings in three parts: each part addresses a specific research question. The first discusses motivations/barriers relating to the uptake of HPs, the second presents a review of built environment attributes influencing the uptake of HPs and the third part looks at the stakeholders' competing and differing economic and organisational interests that enable or inhibit the uptake of HPs. These three classifications, partly deviate from the existing approaches to the study of heat pumps or energy efficiency. IEA (2022b), for instance, classified barriers between the demand side (i.e. cost and non-cost barriers to consumer adoption) and supply side (i.e. manufacturing constraints and supply chain vulnerability, and shortage of skilled installers). In the energy efficiency context, this could be potentially classified into regulation, information and incentives (IEA 2022a).

Socio-technical factors at the household level

Table 2 outlines households' motivation and barriers to adopting domestic heat pumps in the UK, mainly grouped into four parts: financial, environmental, knowledge and awareness, and miscellaneous. Each section is discussed in detail below.

Table 2: Motivations for and barriers to adopting domestic heat pumps

	Motivation	Barrier
Financial	- Earning money from installations - Reducing fuel bills - Protecting against future high energy costs	- Capital costs and running costs (and losing money if moved home) - Other alternative energy sources are more suitable
Environmental	- Desire to reduce carbon emissions	- Environmental benefits too small
Knowledge and awareness	- Community-based renewable energy plan and champions [bottom-up approach that includes generation, coordination and communication the necessary local knowledge resources and trust to promote community-based renewable energy]	- Lack of trustworthy information related to microgeneration - Perceived complexity of the technology
Miscellaneous	- Increasing household energy independence	- HP is too loud and poor value for money - Visual impact, particularly ASHPs - Disruption from ASHPs installation

Source: Adopted from various sources, including Balcombe et al. (2013).

Financial

Evidence suggests that high capital and installation costs are important barriers to adopting heat pumps in the UK (Balcombe, Rigby, and Azapagic 2014; Barnes and Bhagavathy 2020; Roy, Caird, and Abelman 2008). Further, in the current tax regime, the balance of taxes and levies negatively impacts the economic competitiveness of HPs. (Barnes and Bhagavathy 2020).

Balcombe et al. (2014) identified the importance of consumer motivations and barriers associated with the adoption decision and identified relative differences between adopters, considerers and rejectors across UK population segments for microgeneration (GSHP, ASHP along with Solar PV, Wind, Biomass, Combined Heat and Power, and Hydro) based on a questionnaire (best-worst scaling survey method) with 291 valid respondents. Balcombe et al. findings are not limited to HPs but provide a reasonable estimate for them. They identified three important motivations for the uptake of microgeneration: saving or earning money from the installation, increasing household independence, and protecting against future energy costs. Conversely, the survey reveals the three most important barriers as high capital costs, not earning and saving enough money and the risks of losing money if moving home. Other barriers were hard to find trustworthy information, system performance reliability and unsuitable home/location. Staffell, Brett, Brandon, & Hawkes (2012) also evidenced that some of the users reveal that earning money from installation (via saving energy use, especially as a result of Feed-in Tariffs) as well as protection from future energy costs motivated adopting HPs.

The current imbalance in energy taxes and levies weakens the economic competitiveness of HPs in the UK. Currently, taxes and levies make up a significant portion of electricity and gas prices and, therefore household energy bills. These taxes and levies are intended to support measures such as the deployment of low-carbon renewable sources and the installation of energy efficiency measures. In the UK environmental levies accounts for 23% of electricity bills while the same charge makes up to 2% of gas bills (Lowes et al. 2022: 35-36). This is comparable to Europe where these instruments are approximately ten times higher for electricity than natural gas on a per unit of energy basis (ibid). Barnes and Bhagavathy (2020) analysis demonstrated that economic competitiveness of HPs is largely dependent upon seasonal performance factor (SPF)[11] achievement. In terms of annual fuel costs, HPs with higher SPF are more competitive compared to gas boilers. Therefore, studies suggest that reducing taxes and levies on electricity and imposing appropriate taxes on fossil fuels can reduce the total cost of ownership over the lifetime of HPs (Lowes et al. 2022; Barnes and Bhagavathy 2020). In the current regime, governments can impose a tax on environmental pollutants based on an estimate of their environmental impacts. An Emissions Trading System (ETS) is one example, that follows a 'cap and trade' approach, where an allowable quantity of emissions is set, and companies need to have emission allowance for every tonne of CO_2 they emit within a calendar year.

In the Scottish context, Boorman et al. (2021) identify that applied levy costs on electricity bills may exacerbate the problem of fuel poverty and are unlikely to offer running cost savings in HP compared to gas boilers since the electricity demand is attached to running an HP. They suggest alternative options for energy levy recovery, for instance, applying levy cost recovery on a non-volumetric basis such as a flat charge per household or splitting the recovery of levy costs between gas and electricity tariffs. UK government has recognised that the current taxes and levies mechanism on energy does not incentivise consumers to make green choices such as a shift from gas boilers to electric HPs and intends to reduce electricity costs via shift or rebalance energy levies or obligations away from electricity over this decade (BEIS 2021b: 8).

Environmental

Evidence reveals that users choose renewable sources for heat technologies because they wish to help the environment. A relatively old survey (2008), conducted by the Open University and Energy Saving Trust project based on responses from over 900 households[12] who were considering or adopting microgeneration heat technologies (covering four technologies: solar thermal hot water, GSHPs, wood-fuelled boilers, and automatic pellet-fed biomass room heaters and stoves) indicated that reducing their carbon emissions was one of the motivations (Roy, Caird, and Abelman 2008). Respondents feel high levels of satisfaction from using low or zero-carbon energy. Among 859 respondents, 75% of them stated that they wished to reduce carbon dioxide emissions and 61% stated that they get pleasure from using low-carbon energy. Other studies also support environmental motivations for adopting low-carbon technologies for space and water heating (Claudy et al. 2010). Balcombe et al. (2014)'s survey also reveal the fourth top motivation desire to help improve the environment as a motivation for installing microgeneration HPs along with others. In a slightly different context, based on a consumer survey among 2,047 Dutch households, findings reveal that environmental concerns are the most important driver of a household's intention to generate their own power (Leenheer, De Nooij, and Sheikh 2011).

Knowledge and awareness

Community-based renewable energy plans and champions led to a bottom-up approach that includes generation, coordination and communication of the necessary local knowledge and trust required to promote community-based renewable energy (Allen, Sheate, and Diaz-Chavez 2012).

Numerous field trial studies suggest the lack of trustworthy information related to microgeneration as a reason inhibiting the adoption of HPs technology (Balcombe, Rigby, and Azapagic 2014). In addition, the perceived complexity of the technology leads to barriers to adopting HPs technology (Burley and Pan 2010). Specific technology, building form and user characteristics interact with each other. Thus, operating complexity significantly vary if one variable changes in the system. For instance, older householders face more difficulty in dealing with maintenance requirements for new technology, which may in turn influence the efficiency of the system.

11 SPF is the average Coefficient of Performance (CoP) of a heat pump over the full heating system, where CoP is the ratio of heat outputs (in kilowatts) over the electrical inputs (in kilowatts) at any one time. SPF presents an assessment of the overall efficiency of a HP in use in a given operating period

12 34% were considerers, 59% adopters (via Low Carbon Building Programme grant) and 7% non-adopters.

Miscellaneous

A few studies suggest that increasing household energy independence is a motivation for opting for renewable heating sources, including HPs. Some of the households who opted for HPs complain about noise, and visual impact, particularly from ASHPs (Sweetnam et al. 2019). Studies also reveal usability challenges, particularly with the control interface and hardware, though this is not a direct indicator of a barrier but a potential challenge to the acceptability of such systems in future (Sweetnam et al. 2019). Others suggest disruption of household routines from HPs installation and their demand side management (Wang, Wang, and He 2022; Gupta and Morey 2022). For instance, in a recent demand-side response trial in social housing dwellings (Barnsley, England), households experience disruption but to an acceptable level (Gupta & Morey, 2022).

Built environment attributes

Built environment attributes, such as the nature of the housing stock, age, location and type, influence motivations for or against the uptake of HPs. Studies have suggested that HPs will be more adopted in those homes that are off-grid to gas networks and are not connected already to a heat network (Owen, Mitchell, and Unsworth 2013). About 17% of the UK's population live in rural areas, often not connected to the gas grid, where oil is used predominantly for the heating purpose (Qureshi 2022). A significant share of the rural population – 10% in England, 27% in Scotland and 14% in Wales – live in fuel poverty (Free 2022). For them, low-carbon options, such as heat pumps, would be cheaper in the long run but upfront costs cause unaffordability (Qureshi 2022). Moreover, off-grid properties in rural areas tend to be older buildings and are energy inefficient and, therefore, require a fabric first approach before exploring low-carbon heating options (ibid).

Housing size: Wrongly sized Heat Pumps load for the properties

HPs are suitable for large homes as they are mainly manufactured for a large load. Boait, Fan, and Stafford (2011) using a system model show that the heat pump performance in the UK is on average worse than in continental Europe on account of a mismatch between the size of the dwelling and corresponding heat load. For instance, the average HP system installed in Germany can produce an extra 1.2 kW of heat per kW of electricity than a similar system operating in the UK (Staffell et al. 2012). The Energy Saving Trust's trial study suggests that wrongly sized HPs for the properties along with incorrectly set up and operation in sub-optimal modes are some of the reasons for inefficient systems (Roy, Caird, and Potter 2010) Currently, HPs designed for UK's market are for 5kW which is much more than required to meet the need of winter load of a small (60-80 m_2) well-insulated home needing 100 W/°C (Staffell et al. 2012).

Housing type

Housing type also influences selecting HPs technology for space and water heating. In this regard, most of the studies discuss either private housing or social housing. Based on HPs field trial, Caird, Roy, and Potter (2012) show that private households generally have a higher level of satisfaction and fewer problems than social housing residents with their HP systems, where the former choose their energy efficient systems and the latter are provided with a system by social landlords. This should be read in the context of social landlords as innovators or early adopters as they are obliged to decarbonise. In this context, social housing providers go furthest and fastest to achieve decarbonising standards. In this process, they may face risks associated with innovation by opting for technologies that potentially turn out to be inefficient solutions. This might be a reason for lower satisfaction amongst social housing residents. Based on the lessons derived from the innovators or early adopters such as the social housing sector, later improved approaches might be opted by others, including private households, resulting in a higher level of satisfaction. Empirically, the system efficiency of HPs installed at the private housing sites were significantly higher than social housing sites. Authors conclude that private dwellings' larger average size and relatively newly built units with underfloor heating are positively associated with system efficiency, whereas social housing's mainly retrofit projects with conventional radiators are negatively associated with efficiency. Also, private households had greater knowledge and understanding of systems and frequently use continuous heating patterns than their counterparts in social housing residents. However, approximately 19% of private renters (65% of all housing in the UK was owned and occupied and renters made up 35%, including 19% private renters) are almost not covered by any specific policy interventions to adopt renewable energy sources though they require to achieve a minimum efficiency requirement within a time limit (Table 1).

Area-based approach: Misaligned targeted group

Using an innovation diffusion perspective[13], Owen et al. (2013) conducted 12 interviews: six households who had adopted ASHPs, two programme managers who had designed area-based programmes, and four surveyors who had specified and installed the ASHP systems in the East Riding of Yorkshire. Their research suggests that current adopters would be innovators interested in the technology itself or early adopters willing to take risks. Adopting ASHPs as a mode to tackle fuel poverty is difficult given these users are likely to be 'late adopters' or even 'laggards' by preference. Current technology design, installation and maintenance processes are not yet developed by considering individual users, instead sought to adopt an area-based approach[14] focusing on vulnerable users and their technology design needs as well as consideration of installation and commissioning procedures that need attention. Further, spatial analysis based on the UK-wide datasets suggests that heat pumps, indeed, would reduce emissions but are predicted to increase fuel costs (Savage et al. 2022). Here, it is also notable that the current unit cost of gas (used in boilers) is much cheaper than electricity, as electricity cost includes social and environmental obligation costs such as schemes to support energy efficiency measures. Savage et al.'s analysis reveal both local and regional areas of high fuel poverty (e.g., Northern Great Britain and rural areas) would experience some of the largest increases in fuel costs if they transitioned to HPs. In this context, transition to sustainable heating (e.g., from gas boilers to heat pumps) would exacerbate social inequality in the UK, therefore a tension exists between social and environmental goals. Local policy interventions are required to balance outcomes. Among others, place-based attributes such as those homes that are not connected to the main gas grid could be preferred for the uptake of HPs given, they fulfil other conditions including building efficiency. They conclude that every household, even when with similar demographics, location and economic characteristics requires a unique approach to the adoption of HPs.

Fabric first approach

A 'fabric first' approach is crucial to achieving affordable heating and thermal comfort, irrespective of technologies. Fabric first is a concept for focusing on insulation, adopting double or triple glazing, reducing draughts and optimising orientation and design to capture as much solar heat as possible. A fabric-first approach means working on improving measures that improve the building fabric (e.g., walls/lofts) before making a change in the heating system. The majority but not all of them can be considered in retrofits. The overall idea is that irrespective of the use of heating technology, energy use should be minimised for space and water heating. For example, using a cost-benefit analysis of a traditional tenement retrofit to EnerPHit[15] standards (107 Niddrie Road, Glasgow) demonstrates that retrofitting is a better social investment than demolition and new building due to the larger capital costs and embodied carbon costs (Higney and Gibb, 2022). This EnerPHit standards retrofit project is expected to deliver net zero and a 80-90% reduction in fuel costs. In another example, using a modelling approach, Millar et al. (2019) show that in Scottish traditional tenement buildings improving building conditions alone could offer a 30% reduction in energy consumption for space heating and therefore dwellings should be improved as far as is economical before adopting technology in order to maximise carbon and energy savings. Based on a modelling study, Jenkins et al

13 Diffusion of innovation theory, developed by E.M. Rogers in 1962, aims to explain how, over time an idea or product gains momentum and spread through a specific population. A new product does not happen simultaneously in a social system, rather it is a process where some people adopt quickly than others. He states five established adopter categories: innovators (roughly first 2.5%), early adopters (13.5%), early majority (34%), late majority (34%) and laggards (last 16%). There are five main factors that influence adoption of innovation: relative advantage, compatibility, complexity, triability, and observability (LaMorte 2019).

14 Area-based approaches adopt a geographical area rather than a sector or target group, as a primary intervention/entry point. This has been used to tackle problem associated with urban deprivation.

15 EnerPHit is a Passive House standard intended for refurbishment projects, can be achieved either based on the requirement for heating demand (for the UK - max heating demand 25kWh/m2) or on the requirements for individual building components (see https://passipedia.org/certification/enerphit)

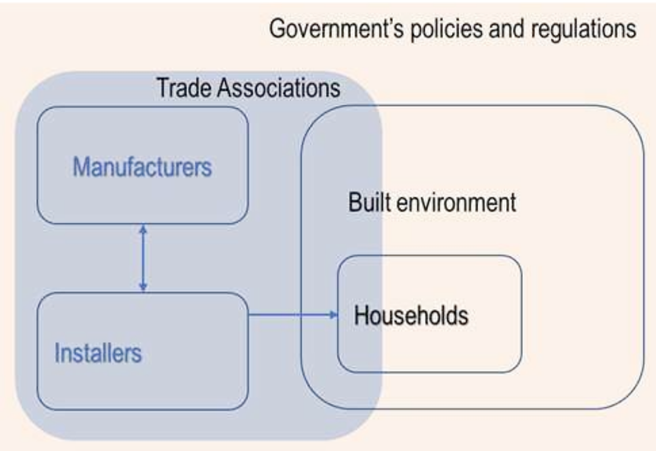
(2009) conclude that GSHPs should be aimed towards a new build-market due to their reliance on surface area and low-temperature distribution system.

The stakeholders' competing and differing economic and organisational interests

In the roll-out of HP technologies, various technological and non-technological aspects interact, along with key actors like HP manufacturers, installers, and end-users within the overarching policies and programmes such as Renewable Heat Initiative (RHI) and Microgeneration Certification Scheme (MCS) (Fig 4). Several studies evidenced that competing and differing economic and organisational interests, priorities, time constraints etc with various stakeholders have inhibited scaling up HPs in the UK (Calver, Mander, and Abi Ghanem 2022; Barnes and Bhagavathy 2020).

Moreover, development in a sectoral context (i.e., heating system), where one option competes with others, influences the uptake of a specific option like HPs (Kieft, Harmsen, and Hekkert 2021). For example, in the Netherlands, there are two dominant types of pumps: stand-alone heat pumps and hybrid heat pumps. This study distinguishes between them via systematic analysis of available all technologies for heating homes (and their target towards zero on the meter bill). Authors suggest that the identified barriers are related to sectoral context and not to the relative Technology Innovation Systems such as the performance of heat pumps.

Fig 4: Interplay amongst stakeholders in the adoption, use and impact of heat pumps in the UK.



Misaligned technology with end-users

Using an energy justice framework, Calver et al. (2022) provide evidence of a mismatch between new technology and end-users. While adopting low-carbon system innovation, such as HPs, appropriate choice, consent, cost, comfort, disruption, and control should be considered. In practice, less attention to these aspects has resulted in poor diffusion of HPs technology. It requires partnership with the end-users to optimise the benefits for the households and the electricity system. In a similar line, for instance, Caird et al. (2012) have argued that private households enjoyed more efficient HPs systems than social housing residents on account of better alignment with their needs (autonomy to choose the system) rather than an imposed system.

Lack of skilled workers

Another aspect here, partially related to the previous theme, is the lack of required skilled workers for production, installation and maintenance of HPs in the UK. This has been widely discussed in several reports, including in Grant Thornton's Glasgow city region home energy retrofit feasibility study (Thornton 2021). This feasibility study was commissioned by Glasgow City Council as a part of the Glasgow City region's Covid Recovery Plan which is sought through 'green' job creation. They also sought to deliver from the existing programmes such as HEEPS' Area Based Schemes and Warmer Homes Scotland. Notably, the report sought to establish an academy, similar to the Retrofit Academy in England, to train Retrofit Coordinators. Further, Littlewood & Smallwood (2019) identify the underperformance of exhaust air source heat pumps (EASHP)[16] heating systems, as they measured the performance gap between the original design-intent and delivered as-built in-use dwellings based on a one-year post-occupancy study in 13 homes in Wales. The reasons were incorrect installation, commissioning and maintenance of installed HP systems. Indeed, they also highlight the lack of necessary knowledge and understanding within design, construction and commissioning projects among all stakeholders. The government report also acknowledges that not only supply chains but also the skills of installers are crucial for 'scaling up' low-carbon technologies (Parliament. House of Commons 2022). The same study suggests the government should work with industry and trade unions to support a low-carbon apprenticeship programme to ensure that they deal with the challenges of the implementation. Evidence also suggests there is a need for engineers who know how to install low-carbon heating systems in every community across the country.

Conclusions

In this evidence review, we asked three specific questions related to scaling up heat pumps (HPs) technologies in the UK: a) to what extent (and why) are UK households positioned to readily adopt residential heat pumps technologies?; b) how can we explain which different built environment attributes shape the uptake of HPs technologies?; and c) how is HP technology and market roll-out shaped by the stance and interplay of various key stakeholders: business, science, the state, civil society and communities?

In the context of households' motivations, we identified four broad factors for or against heat pumps: financial, environmental, knowledge and awareness, and others, termed as miscellaneous. Evidence suggests that earning money from the installations and reducing (future) bills are the major motivations for adopting HPs technologies. Still, higher capital and installation costs are the major barriers to adopting HPs technologies. Perhaps, this challenge is partly addressed in the form of the Domestic RHI scheme – Clean Heat Grant (also known as Boiler Upgrade Scheme) – where an upfront sum of £5,000 is provided. It is also evidenced that a large share of households wants to choose HPs to reduce carbon emissions, but a few households have questioned the magnitude of environmental benefits. This, possibly, could be minimised by providing real-world data on saving energy consumption and reducing carbon emissions. Further, evidence suggests knowledge and awareness about the HPs, including their comparative (dis)advantage, compared to other available technologies, helped in selecting appropriate low-carbon heating options. Here, a bottom-up approach, including community-based plans and champions, would be more effective in increasing relevant knowledge and awareness and therefore helpful in scaling up HPs technologies. Some of the studies also provide evidence that users do not like HPs technologies because of their noise, appearance and the disruption caused during installation, particularly in relation to ASHPs. Also, increasing household energy independence is listed as a motivation to opt into HPs.

In the context of the second theme, built environment attributes, evidence suggests that HPs are suitable for large homes, newly built (rather than retrofit) and more generally where there is a careful match between dwelling size and required heating loads. In contrast to these attributes, HPs installation tends to be targeted at smaller homes

16 EASHP is another type of HPs that transfers heat from exhaust system to warm air and then used for heating and hot water. The EASHP combines ventilation, heating and hot water in a single unit and available in smaller capacity (e.g., loads < 5kW).

(particularly from the social housing sector) and retrofit projects leading to a mismatch with required heating loads. Further, the current approach of adopting HPs to address fuel poverty is problematic in that HP technologies are misplaced, given that the majority of these households would match the profile of 'late adopters' or even 'laggards' of HP technologies. Some of these challenges could be addressed through a contextual design approach, including, suitable-sized HPs technologies development and targeting the right groups. Further, related to the built environment, none of the studies is related to private renters, including any specific incentives despite regulatory mechanisms being placed. Therefore, we need more studies focused on solutions for private rented properties and the specific barriers to the adoption of low-carbon heat sources that exist there. Also, the focus should be on those households who have the potential to be innovators/early adopters of new technology, as well as spatially compatible households including those who are not connected to the main gas grid. Studies also provide clear evidence that before considering HPs, the fabric first approach should be considered. Indeed, this is the reason Domestic RHI seeks to fulfill certain aspects of fabric first options for providing grants.

In relation to the interplay of stakeholders, several studies have evidenced that competing and differing economic and organisational interests among stakeholders – manufacturers, installers, and households – with HPs relevant policies and regulations influence the uptake. While scaling up, as stated earlier, choice, consent, cost, comfort, disruption and control system should be adequately assessed by the end-users. To do so, appropriate skill sets, including those of engineers and installers should be improved, perhaps through the support of low-carbon internship programmes.

References

Allen, Joshua, William R Sheate, and Rocio Diaz-Chavez. 2012. 'Community-based renewable energy in the Lake District National Park–local drivers, enablers, barriers and solutions', Local Environment, 17: 261-80.

Anderson, Kevin, John F. Broderick, and Isak Stoddard. 2020. 'A factor of two: how the mitigation plans of 'climate progressive' nations fall far short of Paris-compliant pathways', Climate Policy, 20: 1290-304.

Balcombe, P., D. Rigby, and A. Azapagic. 2014. 'Investigating the importance of motivations and barriers related to microgeneration uptake in the UK', Applied Energy, 130: 403-18.

Balcombe, Paul, Dan Rigby, and Adisa Azapagic. 2013. 'Motivations and barriers associated with adopting microgeneration energy technologies in the UK', Renewable and Sustainable Energy Reviews, 22: 655-66.

Barnes, J., and S. M. Bhagavathy. 2020. 'The economics of heat pumps and the (un)intended consequences of government policy', Energy Policy, 138.

Barrett, John, Steve Pye, Sam Betts-Davies, Oliver Broad, James Price, Nick Eyre, Jillian Anable, Christian Brand, George Bennett, Rachel Carr-Whitworth, Alice Garvey, Jannik Giesekam, Greg

Marsden, Jonathan Norman, Tadj Oreszczyn, Paul Ruyssevelt, and Kate Scott. 2022. 'Energy demand reduction options for meeting national zero-emission targets in the United Kingdom', Nature Energy, 7: 726-35.

BEIS. 2021a. "Heat and Building Strategy." In. London: HM Government.
———. 2021b. "Heat pump ready programme: Engagement events and one-to-one sessions Q&A responses." In, 58. London: BEIS.
———. 2021c. "Opportunity areas for district heating networks in the UK: National Comprehensive Assessment of the potential for efficient heating and cooling." In.
———. 2022a. '2020 UK Greenhouse Gas Emissions, Final Figures'.
———. 2022b. "Final stage Impact Assessment ECO4." In, 63. London: Department of Business, Energy and Industrial Strategy.
———. 2022c. "Non-Domestic and Domestic Renewable Heat Incentive (RHI) monthly deployment data (Great Britain): September 2022." In RHI monthly deployment data: September 2022 (Quarterly edition), edited by Energy & Industrial Strategy Department for Business.
———. 2022d. "Phasing out the installation of fossile fuel heating in homes of the gas grid." In.: BEIS.

Boait, P. J., D. Fan, and A. Stafford. 2011. 'Performance and control of domestic ground-source heat pumps in retrofit installations', Energy and Buildings, 43: 1968-76.

Boorman, Adam, Craig Lowrey, and Tom Goswell. 2021. "Review of gas and electricity levies and their impact on low carbon heating uptake." In, 62. Edinburgh.

Burley, J., and W. Pan. 2010. "Adoption of air source heat pumps for low carbon homes." In Association of Researchers in Construction Management, ARCOM 2010 - Proceedings of the 26th Annual Conference, 1361-70.

Caird, S., R. Roy, and S. Potter. 2012. 'Domestic heat pumps in the UK: User behaviour, satisfaction and performance', Energy Efficiency, 5: 283-301.

Calver, P., S. Mander, and D. Abi Ghanem. 2022. 'Low carbon system innovation through an energy justice lens: Exploring domestic heat pump adoption with direct load control in the United Kingdom', Energy Research and Social Science, 83.

Claudy, Marius C, Claus Michelsen, Aidan O'Driscoll, and Michael R Mullen. 2010. 'Consumer awareness in the adoption of microgeneration technologies: An empirical investigation in the Republic of Ireland', Renewable and Sustainable Energy Reviews, 14: 2154-60.

Energy Action Scotland. 2020. 'Fuel Poverty across the UK', Energy Action Scotland, Accessed 02 December. https://www.eas.org.uk/fuel-poverty-across-the-uk.
———. n.d. 'Home Energy Efficiency Programmes for Scotland (HEEPS)', Energy Action Scotland.

Energy Saving Trust. 2021. "Air source heat pumps vs ground source heat pumps." In.: Energy Saving Trust.

Eyre, Nick , and Tadj Oreszczyn. 2022. "The energy price crisis – issues for energy use (CREDS Policy brief - 023)." In.

Free. 2022. 'United Kingdom Rural Energy Data', Free (Future of Rural Energy in Europe), Accessed 12 December. https://www.rural-energy.eu/country-data/united-kingdom/.

Green Finance Institute. 2020. "Financing energy efficient buildings: the path to retrofit at scale." In.

Gupta, Rajat, and Johanna Morey. 2022. 'Empirical evaluation of demand side response trials in UK dwellings with smart low carbon technologies', Renewable Energy, 199: 993-1004.

Higney, Anthony , and Kenneth Gibb. 2022. "A cost-benefit analysis of a traditional Glasgow tenement net zero retrofit - 107 Niddrie Road." In, 29. Glasgow: UK Collaborative Centre for Housing Evidence.

HM Government. 2021. Net Zero Strategy: Build Back Greener (Controller Her Majesty's Stationery Office).

HPA. 2020. 'Written evidence submitted by the Heat Pump Association (HPA) (DHH0080)'.

IEA. 2022a. "Energy Efficiency 2022." In, 128.
———. 2022b. The Future of Heat Pumps: World Energy Outlook Special Report.

Jenkins, D. P., R. Tucker, and R. Rawlings. 2009. 'Modelling the carbon-saving performance of domestic ground-source heat pumps', Energy and Buildings, 41: 587-95.

Kieft, A., R. Harmsen, and M. P. Hekkert. 2021. 'Heat pumps in the existing Dutch housing stock: An assessment of its Technological Innovation System', Sustainable Energy Technologies and Assessments, 44.

LaMorte, Wayne 2019. 'Diffusion of Innovation Theory', Boston University School of Public Health, Accessed 19 October. https://sphweb.bumc.bu.edu/otlt/mph-modules/sb/behavioralchangetheories/behavioralchangetheories4.html.

Leenheer, Jorna, Michiel De Nooij, and Omer Sheikh. 2011. 'Own power: Motives of having electricity without the energy company', Energy Policy, 39: 5621-29.

Littlewood, J. R., and I. Smallwood. 2019. "Occupant interaction with as-designed smart heating: Impacts upon energy use & thermal comfort." In Smart Innovation, Systems and Technologies, 403-12.

Lowes, R. , D. Gibb, J. Rosenow, S. Thomas, M. Malinowski, A. Ross, and P. Graham. 2022. "A policy toolkit for global mass heat pump deployment " In.: Regulatory Assistance Project, CLASP, Global Buildings Performance Network.

Millar, M. A., N. Burnside, and Z. Yu. 2019. 'An investigation into the limitations of low temperature district heating on traditional tenement buildings in Scotland', Energies, 12.

Owen, A., G. Mitchell, and R. Unsworth. 2013. 'Reducing carbon, tackling fuel poverty: adoption and performance of air-source heat pumps in East Yorkshire, UK', Local Environment, 18: 817-33.
Page, Matthew J, Joanne E McKenzie, Patrick M Bossuyt, Isabelle Boutron, Tammy C Hoffmann, Cynthia D Mulrow, Larissa Shamseer, Jennifer M Tetzlaff, Elie A Akl, and Sue E Brennan. 2021. 'The

PRISMA 2020 statement: an updated guideline for reporting systematic reviews', International Journal of Surgery, 88: 105906.

Parliament. House of Commons. 2022. "Decarbonising heat in homes." In, edited by BEIS Committee. London: House of Common.

Qureshi, Zoyn. 2022. "Reaching rural properties: Off-grid heating in the transition to net zero." In, 48. London: Localis.

Rosenow, Jan, and Edith Bayer. 2017. 'Costs and benefits of Energy Efficiency Obligations: A review of European programmes', Energy Policy, 107: 53-62.

Rosenow, Jan, and Ray Galvin. 2013. 'Evaluating the evaluations: Evidence from energy efficiency programmes in Germany and the UK', Energy and Buildings, 62: 450-58.

Rosenow, Jan, Pedro Guertler, Steven Sorrell, and Nick Eyre. 2018. 'The remaining potential for energy savings in UK households', Energy Policy, 121: 542-52.

Roy, Robin, Sally Caird, and Jennie Abelman. 2008. 'YIMBY Generation–yes in my back yard! UK householders pioneering microgeneration heat'.

Roy, Robin, Sally Caird, and Stephen Potter. 2010. "Getting warmer: a field trial of heat pumps." In. London, UK: The Energy Saving Trust.

Savage, Thomas, Jethro Akroyd, Sebastian Mosbach, Michael Hillman, Franziska Sielker, and Markus Kraft. 2022. 'Universal digital twin–the impact of heat pumps on social inequality', Advances in Applied Energy, 5: 100079.

Scottish Government. 2021a. "Heat in Building Strategy: Achieving Net Zero Emissions in Scotland's Buildings." In. Edinburgh: The Scottish Government.
———. 2021b. "Home Energy Efficiency Programmes: Energy Efficient Scotland Delivery Report 2018/19." In. Edinburgh.

Serin, Bilge. 2018. "Cross disciplinary review of placemaking literature." In.

Soaita, Adriana Mihaela, Bilge Serin, and Jenny Preece. 2020. 'A methodological quest for systematic literature mapping', International Journal of Housing Policy, 20: 320-43.

Staffell, I., D. Brett, N. Brandon, and A. Hawkes. 2012. 'A review of domestic heat pumps', Energy and Environmental Science, 5: 9291-306.

Sweetnam, T., M. Fell, E. Oikonomou, and T. Oreszczyn. 2019. 'Domestic demand-side response with heat pumps: controls and tariffs', Building Research and Information, 47: 344-61.

Syal, Rajeev. 2016. 'Green deal scheme did not deliver energy savings, audit finds', The Guardian.

Thornton, G. 2021. "Glasgow City Region Home Energy Retrofit Feasibility Study – Final Report." In. Glasgow: Grant Thornton.

Wang, Y., J. Wang, and W. He. 2022. 'Development of efficient, flexible and affordable heat pumps for supporting heat and power decarbonisation in the UK and beyond: Review and perspectives', Renewable and Sustainable Energy Reviews, 154: 111747.

Webber, Phil, Andy Gouldson, and Niall Kerr. 2015. 'The impacts of household retrofit and domestic energy efficiency schemes: A large scale, ex post evaluation', Energy Policy, 84: 35-43.