UK COLLABORATIVE CENTRE FOR HOUSING EVIDENCE

Heat Pumps and Domestic Heat Decarbonisation in the UK: A Systems Thinking Analysis of Barriers to Adoption

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Acronyms

ASHP Air Source Heat Pump

BUS Boiler Upgrade Scheme

CfD Contracts for Difference

COP Coefficient of Performance

DLUHC Department for Levelling Up, Housing and Communities

DNO District Network Operator

EHS English Housing Survey

EPC Energy Performance Certificate

FHS Future Homes Standard

GSHP Ground Source Heat Pump

HEEPs Home Energy Efficiency Programmes for Scotland

HP Heat Pump

kWh kilowatt-hour

MEES Minimum Energy Efficiency Standards

NIC National Infrastructure Commission

PRS Private Rented Sector

PV Photovoltaics

RHI (Domestic) Renewable Heat Initiative

SAP Standard Assessment Procedure

UK United Kingdom

WSHP Water Source Heat Pump

ZDEH Zero Direct Emissions Heating

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Contents

Executive Summary

Heat pumps are a cornerstone of the government's decarbonisation agenda in the United Kingdom. The electrification of domestic heating, underwritten by the installation of ground-, air-, and water-source heat pumps is expected to reduce the UK's greenhouse gas emissions by around 15 – 17%. In late 2020, the Johnson government announced a target of 600,000 heat pump installations per year by 2028. In mid-2023, despite a grant fund of £450m, data revealed the UK was installing 55,000 heat pumps annually, suggesting the government's goal is unlikely to be met. Consumers of domestic heat pumps in the UK are owner-occupiers, developers, private and social landlords, as well as local councils responsible for social housing (although tenants are the primary beneficiaries in the last three instances).

This report investigates the reasons for this profound gap between government intentions and consumer behaviour. Key actor interviews as well as scrutiny of secondary scientific literature produced data that was interpreted through a systems thinking method of analysis. Systems thinking conceives of outcomes as emergent properties where different aspects and dimensions of the system interact and influence one another[1] . Consequently, this research was interested in identifying relevant negative and positive feedback loops that contribute to the suboptimal uptake of heat pumps[2] . Systems thinking analysis is particularly useful when making policy recommendations since policy interventions are seen as mechanisms necessary to disrupt undesirable feedback loops and, thereby, overcome what are commonly thought of as market failures.

This report has identified the following feedback loops (which differ from traditional linear casual mechanisms) that adversely impact the adoption of heat pumps in the UK:

1. The existing regulatory framework influences the quality of the UK's existing housing stock --> The quality of the UK's existing housing stock suggests heat pumps may not perform to manufacturer's specifications without pre-installation fabric upgrades in many homes -->[3] Without pre-installation fabric upgrades the running cost of a heat pump is higher for many occupants given the relative price of electricity --> The price of electricity relative to gas influences regulatory opportunities in the context of fuel poverty [4]

2. The number of heat pump installers influences developer confidence in designing schemes with large volumes of heat pumps --> Developer schemes determine a degree of heat pump demand --> Heat pump demand influences the heat pump sector --> The heat pump sector determines installer demand --> Installer demand influences the supply of heat pump installers

3. The Boiler Upgrade Scheme (BUS) grant of £7,500 is insufficient to cover additional repair, maintenance, and fabric and heating system upgrades --> The majority of owners are unaware what kinds of upgrades their home may need to permit optimal heat pump performance --> Owners who apply for the BUS grant are informed of required upgrades by a qualified surveyor --> Many owners are unable to afford additional upgrades so they don't apply for the BUS grant --> Modest BUS grant uptake disincentives fund increases

4. The price of electricity relative to gas influences consumer decisions to install heat pumps --> Consumer perspectives on the electricity price suggest shifting levies onto gas --> Shifting electricity levies onto gas may exacerbate social tenant fuel poverty --> The prospect of exacerbating fuel poverty undermines the policy of shifting levies onto gas --> The price of electricity relative to gas influences consumer behaviour

1 Holland, John. 2014. Complexity: A Very Short Introduction. Oxford: Oxford University Press, 25–27; Flood, Robert. 2010. "The Relationship of 'Systems Thinking' to Action Research." Systemic Practice and Action Research 23, no. 1: 269–284. https://doi.org/10.1007/s11213-010-9169-1, 269.
2 Kim, Daniel. 1999. Introduction to Systems Thinking. Cambridge: Pegasus Communications Inc, 5.
3 Symbol indicates directional influence.
4 Symbol indicates that the cycle loops back on itself

This report identifies distinct barriers to adoption for each category of heat pump consumer:

Owner-occupiers
1. A lack of awareness about the suitability of heat pumps for particular situations and a lack of confidence concerning heat pump performance and operation;

2. The upfront costs of heat pump installation in light of additional associated repair, maintenance, and fabric and heating system upgrades (that cannot be deferred or capitalised);

3. The 'hassle factor' of unforeseen fabric and heating system upgrades accompanying heat pump installation; and,

4. The reality that some owners occupy housing types where the installation of individual heat pumps is highly physically challenging.

Social landlords
1. The need to upgrade the fabric of existing housing stock first to ensure heat pumps perform according to manufacturer's specifications;

2. Concern that tenant operation and the relative price of electricity may exacerbate rather than reduce fuel poverty across the sector;

3. The lack of properly qualified installers;

4. The belief that likely future developments in heat pump technology or the prospect of a hydrogen solution warrant a 'wait and see' approach (i.e., an approach intended to offset 'innovation risk' where landlords are locked into investment decisions that are relatively irreversible); and,

5. Competing energy efficiency and decarbonisation priorities within the context of limited financial resources (i.e., fabric first vs. heat pumps now).

Private landlords
1. The Minimum Energy Efficiency Standards (MEES) that exist do not mandate decarbonised heating systems or heat pumps;

2. The considerable upfront costs associated with installation and doubts these will be recouped via higher rental yields;

3. The commercial consequences of a disruptive and prolonged installation; and,

4. Concerns that prospective tenants may look less favourably on homes with heat pumps due to beliefs surrounding running costs, maintenance, and thermal comfort.

Developers
1. The absence of regulatory mandates requiring the electrification of heating and the installation of heat pumps in new homes except in Scotland;

2. The misalignment between an EPC rating model relying on SAP calculations and the decarbonisation agenda (i.e., energy efficiency vs. carbon emission); and,

3. The profit motive governing voluntary design choices for new development schemes.

The report concludes by considering various policy interventions that may have a positive influence on the UK's rate of heat pump adoption. These recommendations take the form of plausible disruptions to the various feedback loops described above and, therefore, can be seen as systemic solutions. Ultimately, however, the fundamental conclusion of this report is that the price of electricity relative to gas is perhaps the single most important aspect of the entire social system. For example:

> If electricity was cheap, abundant, and green it would matter less that heat pump performance is greatly influenced by the quality of the UK's existing housing stock --> If the issue of the UK's housing stock was set aside, the awesome burden of retrofitting millions of homes might be avoided > If retrofitting millions of homes was no longer required, billions of pounds could be saved > The billions of pounds being saved might be directed towards making electricity cheap, abundant, and green 

It is critical to note that this report is underwritten by an appreciation of household and individual expenditure. That is to say, while there are many households in the United Kingdom that would be (or should be) prepared to pay more for carbon-free heating , a far greater number of householders are in no position to do so . Furthermore, even households with capacity weigh their interest in carbon savings against the prospect of upfront and ongoing capital expenditures. Consequently, the airtightness and thermal efficiency of homes matter since these are inextricably linked to heat pump performance and associated running costs. At a minimum, 6.7 million households in fuel poverty across the UK would seem to be in no position to install heat pumps until they can be assured such an installation will not add financial burden .

Introduction

On 18th November 2020, then-Prime Minister Boris Johnson announced the UK would be installing 600,000 heat pumps per year by 2028. Heat pumps were touted as the cornerstone of the government's plans to decarbonise domestic heating – a transformation integral to the net zero target enshrined in law for 2050. Unfortunately, after three years and based on the rate of increase, the data suggests the goal of 600,000 heat pump installations per year will not be reached until around 2225 – i.e., in over 200 years. Clearly, there is a considerable disconnect between the government's ambitions and consumer behaviour. The failure to dramatically increase heat pump uptake represents a genuine social science puzzle given the government's Heat and Building Strategy, £450 million earmarked for grants, and the fact that many of our European neighbours (France, Sweden, Denmark, Lithuania, Estonia, Finland, and Norway in particular) have achieved precisely what appears to frustrate the United Kingdom .[8]

This research project was initiated[9] to understand why the UK lags so far behind when it comes to the adoption of heat pumps, what to do about it, and, consequently, how to advance the decarbonisation of domestic heating. The project is composed of three phases: (1) elite stakeholder interviews and literature review; (2) international expert consultation and cross-country analysis; and, (3) consumer sentiment focus groups. This paper reports on phase one of the project: analysis and interpretation of data obtained from a series of semi-structured interviews conducted in mid-2023 with sectoral leadership directly involved with heat pumps and the decarbonisation agenda, as well as scrutiny of the existing literature dealing with the research problem.

The following research differs from previous investigations into heat pump adoption in the UK because it adopts a 'systems thinking' approach[10] . Systems thinking is a conceptual perspective that considers specific 'outcomes' to be the 'emergent properties' of particular systems[11] . In the present case, therefore, the suboptimal uptake of heat pumps is understood to be an emergent property of the UK's heat pump adoption social system as a whole. Of vital importance is the manner in which the various dimensions of the social system act upon and influence each other to create positive and negative feedback loops, interactions, and reinforcing processes that collectively generate desirable and undesirable, intended and unintended outcomes. Wary of simplistic, reductionist, or deterministic 'X-factor is the cause of Y-outcome explanations,' systems thinking invites the researcher to consider whether factor X may have an influence on Y, which, in turn, has a role to play in Z, where Z itself influences X, reinforcing X's context and/or conditions. In other words, since the UK's regulatory framework influences its built-environment and economic incentives; and, material and economic conditions influence the behaviour of stakeholders; while, stakeholders have a role to play in the formulation of regulations; then, to suggest any one of these factors is the cause of suboptimal heat pump adoption is, necessarily, only a partial answer.

Aside from providing a more comprehensive explanation of the circumstances giving rise to the problem, systems thinking is extremely useful in the context of policy prescription. At a minimum, in the context of significant complexity, policymakers should assume a nuanced and careful approach to intervention. According to the theory, systems are constituted by various feedback loops which reinforce and generate emergent properties. If the emergent property is undesirable then the most effective way of redressing the issue is to 'disrupt' the cycle. Policy interventions can be thought of as mechanisms to disrupt feedback loops generating undesirable outcomes. Consider, for example, the assertion there are presently insufficient skilled heat pump installers to meet increased demand. Developers

8 Vaughan, Adam. 2022. "UK's Slow Heat Pump Efforts Will Take 600 Years to Meet 2050 Target." New Scientist. https://www.newscientist.com/article/2328095-uks-slow-heat-pump-efforts-will-take-600-years-to-meet-2050-target.
9 EPSRC. 2021. "Details of Grant: EP/V042033/1." Engineering and Physical Sciences Research Council. https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/V042033/1; CaCHE. 2021. "Interdisciplinary Retrofit Research Announced." UK Collaborative Centre for Housing Evidence. https://housingevidence.ac.uk/interdisciplinary-retrofit-research-announced.
10 Systems thinking is given a thorough explanation later in the report (pp. 20–25).
11 Gibb, Ken and Alex Marsh. 2019. "Housing and Systems Thinking." UK Collaborative Centre for Housing Evidence. https://housingevidence.ac.uk/wp-content/uploads/2019/07/Housing-and-Systems-briefing-paper_final_170704.pdf.

claim they are hesitant to install large volumes of heat pumps in their schemes given a shortage in qualified labour supply. However, in the absence of increased demand for skilled heat pump installers that would ordinarily be driven by developer schemes placing large orders, there is little to stimulate an increase in the supply of installers. This kind of 'catch-22' implies something of a market failure. It may be that state intervention – whether regulations mandating developer orders, or government-sponsored training of heat pump installers – is required to disrupt the 'installer-dillema' cycle and correct this market failure. Furthermore, these kinds of feedback dilemmas impinge upon hopes that expansion of the heat pump sector will generate economies of scale that ought to bring down the price of heat pump units and installation costs. Put simply, the consumer benefits deriving from economies of scale rely on sector expansion. Therefore, if sector expansion is held back by market failure, so too is the prospect of lower supply costs driven by economies of scale.

This brief example highlights the important relationship between a systems thinking approach to the problem of heat pump adoption and targeted strategic policy prescriptions. Understanding and identifying the interrelationships between various dimensions of the social system is paramount to overcoming market failure and unlocking the benefits of economies of scale.

Through the course of this paper, it will be shown that one of the most significant barriers to the adoption of heat pumps is the physical reality of the UK's existing housing stock. Many homes are insufficiently airtight to permit heat pumps to perform to manufacturer's specifications without first undergoing repair and maintenance, and upgrades to their fabric and heating systems. However, it will also be demonstrated that the low average thermal efficiency of the UK's housing stock is underwritten by decades of specific building, construction, and energy efficiency standards[12]. Heat pump adoption is, therefore, inextricably linked to the fundamental relationship between the UK's build environment and its regulatory framework. Furthermore, there are various economic incentives and disincentives built into the system. For example, the UK has one of the world's most efficient and extensive gas networks with around 74% of homes in England and Wales connected[13] . Gas is three times cheaper than electricity at 10.3p per kWh compared to 34p/kWh. The price of electricity acts, therefore, as an economic disincentive to heat pump adoption, while, conversely, the historic legacy of the UK's gas network incentivises homeowners to retain gas heating. Resolving this imbalance is not without its difficulties, however, given the divergent stakeholder perspectives. If the levies presently imposed upon electricity (estimated to be 27.7% of the p/kWh price[14]) were shifted onto gas, large sections of the population (especially those in social housing) may be pushed into fuel poverty. Here, we encounter another feedback loop: policy-makers influence the price of electricity; and, the electricity price affects the economic condition of various stakeholders; while, the situation of these stakeholders has, in turn, an influence on policy-makers considering their influence on the price of electricity. In the end, heat pump adoption is inextricably linked to the fundamental relationship between the systems economics and the material conditions of various stakeholders.

This report will first describe the background to the research problem – i.e., heat pump uptake in the UK – and then outline the research methodology used to generate its findings.

Research Setting

To meet its statutory net zero obligations by 2050 (2045 for Scotland), the United Kingdom has identified the carbon impact of domestic heating as one of its top priorities[15] . Although there is some disagreement about the precise

12 Baker, William., Acha, Salvador., Jennings, Niel., Markides, Christos and Nilay Shah. 2022. "Decarbonising Buildings: Insights from Across Europe." Grantham Institute. https://doi.org/10.25561/100954.
13 ONS. 2023. "Census 2021: How Homes Are Heated in Your Area." Office for National Statistics. https://www.ons.gov.uk/peoplepopulationandcommunity/housing/articles/census2021howhomesareheatedinyourarea/2023-01-05.
14 Nesta. 2023. "The Electricity-to-Gas Price Ratio Explained – How a 'Green Ratio' Would Make Bills Cheaper and Greener." Nesta. https://www.nesta.org.uk/blog/the-electricity-to-gas-price-ratio-explained-how-a-green-ratio-would-make-bills-cheaper-and-greener.
15 BEIS. 2017. "The Clean Growth Strategy: Leading the Way to a Low Carbon Future." UK Government: Department for Business Energy and Industrial Strategy. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf, 115.

contribution, it is estimated that domestic space and water heating accounts for between 15%[16] and 17%[17] of the UK's total greenhouse gas emissions. Since it is expected that by 2035 electricity will be a 100% 'green' source of energy[18] , if the domestic housing sector can be shifted from gas or oil onto electricity, in time domestic heating will be decarbonised. Starting with the Low Carbon Building Programme in 2006, the UK government has seen heat pumps (both air- and ground-source) as integral to its efforts to decarbonise the domestic sector [19]. Heat pumps are a suitable alternative to gas boilers and oil burners for space and water heating as they are powered by electricity. Despite being considered a relatively new heating technology for the UK, the invention of the heat pump dates back to the mid-19th century and is credited to the Austrian engineer Peter von Rittinger[20] . Heat pumps are, thus, far from 'new.' In fact, in parts of Australia[21] and the United States[22] units known as reverse-cycle air conditioners have been commonplace for many decades. Reverse-cycle air conditioners are air-source heat pumps.

Heat Pumps

As illustrated by Figure 1, the physical and thermodynamic principles underwriting the function of a heat pump are quite straightforward. Chemical refrigerant is pumped in a cycle, passing over a heat source and through a compressor. Because the refrigerant (R410A) has a boiling point of -48.5°C[23] , even during winter, the outside ambient temperature in the UK is sufficient to act as the 'heat source' that boils the refrigerant. In so doing, energy is released from the refrigerant's change of state and pumped into the home as heat. Once the home has received the heat transfer, the refrigerant is compressed back to its liquid state and pumped outside where the cycle continues.

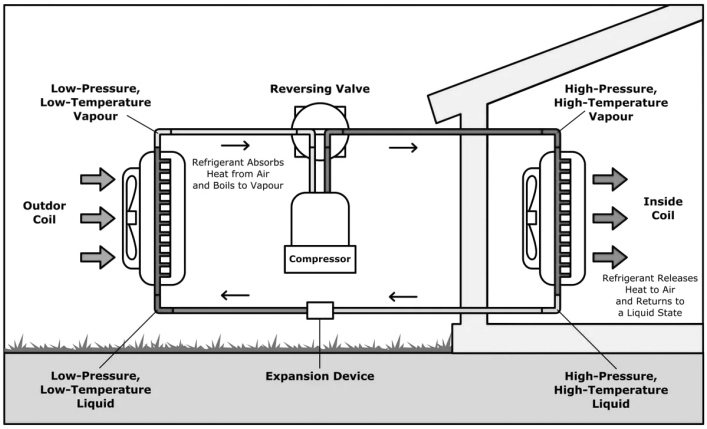

Figure 1. Principles of Air-Source Heat Pump Operation. Source: USDE 2023 [24].

The 'magic' of a heat pump is due to the heat energy released by the refrigerant's change of state is greater than the

16 Bennadji, A., Seddiki, M., Alabid, J., Laing, R. and D. Gray. 2022. "Predicting Energy Savings of the UK Housing Stock under a Step-by-Step Energy Retrofit Scenario towards Net-Zero." Energies 15, no. 3082: 1–18. https://doi.org/10.3390/en15093082, 1.
17 MCS. 2023. "Heat Pump Rollout in France and the UK: A Comparative Analysis." MCS Charitable Foundation, 4.
18 BEIS. 2021. "Plans Unveiled to Decarbonise UK Power System by 2035." UK Government: Department for Business, Energy & Industrial Strategy. https://www.gov.uk/government/news/plans-unveiled-to-decarbonise-uk-power-system-by-2035.
19 DECC. 2011. "Low Carbon Building Programme 2006–2011: Final Report." UK Government: Department for Energy and Climate Change.
20 DETEC. 2008. "History of Heat Pumps: Swiss Contributions and International Milestones." Swiss Government: Department of Environment, Transport, Energy and Communications.
21 DETEC. 2008. "History of Heat Pumps: Swiss Contributions and International Milestones." Swiss Government: Department of Environment, Transport, Energy and Communications. https://www.osti.gov/etdeweb/servlets/purl/21381633, 13.
22 DoE. 2015. "History of Air Conditioning." U.S. Government: Department of Energy. Accessed August 20th 2023. https://www.energy.gov/articles/history-air-conditioning.
23 Miracle. 2023. "What is R410A Refrigerant Gas." Miracle Refrigerant. https://www.miracleref.com/what-is-r410a-refrigerant-gas/.
24 USDE. 2023. "Air-Source Heat Pumps." US Government: Department of Energy. https://www.energy.gov/energysaver/air-source-heat-pumps.

heat one can ordinarily generate from the electricity used to pump the refrigerant around and run the compressor. Most manufacturers specify that (in ideal conditions) their heat pumps generate three to four times more heat than would be expected from standard electric heating [25]. This leveraging of energy efficiency is referred to as the 'coefficient of performance' or COP. In general, heat pumps offer a COP of 3.5, meaning they produce three and a half times more heat than their electricity consumption ordinarily implies[26] . Heat pumps can be used to heat both the 'space' and 'water' of a property – by blowing warm air throughout and progressively heating a water tank, respectively. This means homes that have their space and water heated by a heat pump must be fitted with appropriate radiators and pipework, and have the space for the outdoor unit and a water tank.

There are three types of heat pumps: air-, ground-, and water-source. An air-source heat pump (ASHP) is a heat pump that uses the ambient temperature of the outside air to 'heat' the refrigerant and effect its state change; ground-source heat pumps (GSHP) use the temperature of the ground 75 – 200 metres deep[27] (depending on the local geology and specific heat demand) to heat the refrigerant; and, water-source heat pumps [28] (WSHP) use the temperature of some reliable body of water (e.g., a river, stream, lake, sea water, or aquifer) to effect state change in the refrigerant. The consumer's choice of heat pump depends in large part on the physical realities of their property. Does the home have sufficient outdoor space to bore and install a GSHP? Is the home located adjacent to a suitable body of water? If the answer to either or both these questions is no, the homeowner will likely be recommended an ASHP.

The Research 'Problem'

On 18th November 2020, then Prime Minister Boris Johnson announced a Ten Point Plan that linked his government's Net Zero ambitions with their economic imperative to create and support employment. Point seven – under the heading "Homes and public buildings" – outlined the intention to make

> *"…our homes, schools and hospitals greener, warmer and more energy efficient, whilst creating 50,000 jobs by 2030, and a target to install 600,000 heat pumps every year by 2028[29] ."*

That year, fewer than 50,000 heat pumps had been sold in the United Kingdom, indicating the government's target of 600,000 installations per year implied considerable transformation of both consumer behaviour and the domestic heating sector [30]. This ambitious figure was inspired, in part, by French success – a country that was already installing around 400,000 heat pumps per year in 2020[31] . To help advance their goal, the UK government built upon the pre-existing Renewable Heat Incentive (Domestic RHI), replacing it with the Boiler Upgrade Scheme (BUS). While the domestic RHI (which closed for applications on 31st March 2022) offered quarterly payments over seven years for homeowners who installed a variety of renewable technologies (e.g., biomass boilers and stoves, solar panels, and heat pumps)[32] , the BUS originally provided a one-time grant of £5,000 for homeowners who install air-source heat pumps and £6,000 for those who install ground- or water-source heat pumps[33] . Recently, the Rishi Sunak government announced they would increase the BUS grant to £7,500 to "help households who want to replace their gas boilers

25 MEUK. 2023. "Domestic Air Source Heat Pumps." Mitsubishi Electric: United Kingdom. https://les.mitsubishielectric.co.uk/products/residential-heating/outdoor.
26 GM. 2023. "Air Source Heat Pump Performance." Green Match. https://www.greenmatch.co.uk/blog/2014/06/air-source-heat-pump-performance.
27 EST. 2023. "Ground Source Heat Pumps." Energy Savings Trust. https://energysavingtrust.org.uk/advice/ground-source-heat-pumps.
28 TE. 2023. "Water Source Heat Pumps." Thermal Earth. https://www.thermalearth.co.uk/water-source-heat-pumps.
29 UKGOV. 2020. "PM Outlines His Ten Point Plan for a Green Industrial Revolution for 250,000 Jobs." UK Government: Prime Minister's Office. https://www.gov.uk/government/news/pm-outlines-his-ten-point-plan-for-a-green-industrial-revolution-for-250000-jobs.
30 MCS. 2023. "Heat Pump Rollout in France and the UK: A Comparative Analysis." MCS Charitable Foundation. https://www.mcscharitablefoundation.org/s/MCSCF-Heat-Pump-Report-2023-md38.pdf, 4.
31 MCS 2023, 4.
32 DECC. 2015. "2010 to 2015 Government Policy: Low Carbon Technologies." UK Government: Department of Energy and Climate Change. https://www.gov.uk/government/publications/2010-to-2015-government-policy-low-carbon-technologies.
33 UKGOVT. 2023. "Apply for the Boiler Upgrade Scheme." UK Government. https://www.gov.uk/apply-boiler-upgrade-scheme/what-you-can-get.

with a low-carbon alternative like a heat pump[34] ." Given the cost for the unit and installation of an air-source heat pump is around £12,000, the BUS was designed to almost halve a household's heat pump expenditure[35] .

Two years after Boris Johnson's plan to install 600,000 heat pumps per year, the UK was installing a little over 50,000. Furthermore, although there were 30,000 BUS grants on offer in the scheme's first year (23rd May 2022 – 31st March 2023), the government issued 11,998 vouchers [36].

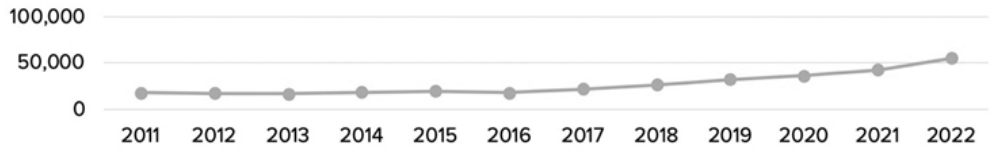

Figure 2. UK Heat Pump Sales (2011 – 2022). Source: MCS 2023.

As illustrated by Figure 2, on the current trajectory, it will take the UK more than 200 years to reach the government's target of 600,000 heat pump installations per year[37] . Clearly, there must be some kind of critical failure somewhere between the government's policy intentions and our measurable real-world outcomes. This, therefore, suggests our research problem:

> *Despite the government's intention to increase heat pump installations from around 50,000 to 600,000 per year, the present rate of increase appears insufficient to meet this goal.*

In summary, the government recognised the decarbonisation of domestic heating as a meaningful objective to help the UK reach its Net Zero target for 2050 and identified heat pumps as a suitable technology for this domestic heating transformation. Unfortunately, despite making a clear policy announcement in 2020, backed by a £450 million grant scheme[38] , there is little evidence consumer behaviour has shifted sufficiently to make the government's target of 600,000 heat pump installations per year likely within the declared time frame. The UK finds itself in the unenviable position of missing a critical mass where increased demand might stimulate supply side investment for manufacturing, infrastructure and training. The nascent heat pump sector lacks mature supply chains and does not presently benefit from economies of scale. A failure to achieve this target not only puts the decarbonisation of domestic heating at risk but, by implication, the UK's Net Zero target as well. It is of considerable importance, therefore, to understand why heat pump installations have fallen short of expectations in the United Kingdom and what can be done to remedy the situation and ensure the decarbonisation of domestic heating.

Research Questions

Given the research problem (i.e., the suboptimal uptake of heat pumps across the UK), the following questions represent an obvious starting point for scientific investigation:

1. What factors contribute to the UK's suboptimal uptake of heat pumps?

34 PMO. 2023. "PM recommits UK to Net Zero by 2050 and pledges a "fairer" path to achieving target to ease the financial burden on British families." UK Government: Prime Minister's Office
35 Green Match suggests ASHP expenses of £8,000 to £18,000; Eco Experts around £10,000; and Evergreen Energy £12,000 to £15,000. https://www.greenmatch.co.uk/blog/2014/08/the-running-costs-of-heat-pumps
36 Ofgem. 2023. "Boiler Upgrade Scheme (BUS) Annual Report - 2022-23." UK Government: Office of Gas and Electricity Markets. https://www.ofgem.gov.uk/publications/boiler-upgrade-scheme-bus-annual-report-2022-23
37 According to the formula P(t)= P_0+r.t
38 BEIS. 2021. "Heat and Buildings Strategy." UK Government: Secretary of State for Business, Energy and Industrial Strategy https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1044598/6.7408_BEIS_Clean_Heat_Heat___Buildings_Strategy_Stage_2_v5_WEB.pdf

However, as this study is underwritten by a systems thinking approach, these questions need to be refined to take account of the social system's hierarchy, elements, and stakeholders. Consequently, this research is guided by the following question:

1. What systemic factors contribute to the UK's suboptimal uptake of heat pumps?

    i. Which built environment; regulatory; economic; and stakeholder factors?

    ii. How do these factors relate to and reinforce one another?

Expanding upon this research agenda generates a further five sub-questions:

1. How does the UK's built environment contribute to suboptimal heat pump adoption?

    a. What is the relationship between the age, condition, and architecture of the UK's housing stock and suboptimal heat pump adoption?

    b. What is the relationship between an efficient and expansive gas network and suboptimal heat pump adoption?

    c. What is the relationship between electricity grid capacity and suboptimal heat pump adoption?

2. How does the UK's regulatory framework contribute to suboptimal heat pump adoption?

    a. What is the relationship between existing housing, building, and energy efficiency standards and suboptimal heat pump adoption?

    b. What is the relationship between existing energy policy and suboptimal heat pump adoption?

3. How do historical or legacy factors contribute to suboptimal heat pump adoption?

    a. What is the relationship between historic housing, building, and energy efficiency standards and suboptimal heat pump adoption?

    b. What is the relationship between historic energy policy and suboptimal heat pump adoption?

4. How do material and economic factors contribute to suboptimal heat pump adoption?

    a. What is the relationship between the unit and installation costs and suboptimal heat pump adoption?

    b. What is the relationship between various supply chains and suboptimal heat pump adoption?

    c. What is the relationship between the price of electricity (relative to gas) and suboptimal heat pump adoption?

    d. What is the relationship between available grants, schemes, and subsidies and suboptimal heat pump adoption?

5. How does the context of various stakeholders contribute to suboptimal heat pump adoption?

    a. What is the relationship between the three dominant housing tenures in the UK (i.e., owner-occupied; social rented; and private rented) and suboptimal heat pump adoption?

b. What is the relationship between the behaviour of new-builders and developers and suboptimal heat pump adoption?

c. What is the relationship between the availability of tradespeople and suboptimal heat pump adoption?

d. What is the relationship between policy-makers' understanding of the problem and suboptimal heat pump adoption?

e. What is the relationship between consumer sentiment and suboptimal heat pump adoption?

Fortunately, the present study builds upon prior work delivered by the UK Collaborative Centre for Housing Evidence (CaCHE). That is to say, this study benefits from extensive research into the "Motivations and Barriers Associated with Adopting Domestic Heat Pumps in the UK," undertaken by Sohail Ahmad in 2022[39] . Ahmad performed a systematic evidence review and literature mapping exercise to capture the existing body of knowledge concerning our research problem. After screening, 24 papers were identified that investigated heat pump adoption in the United Kingdom between 2008 and 2023. In the final analysis, Ahmad reported that the primary factors influencing suboptimal heat pump adoption in the UK were[40] :

1. Household / Consumer Factors:

    a. High capital and installation costs for households;

    b. Consumer scepticism concerning environmental benefits;

    c. Lack of consumer awareness about relative advantages;

    d. Negative consumer perception;

2. Regulatory factors:

    a. The energy tax and levy imbalance between gas and electricity;

3. Built environment factors:

    a. Mistargeting of units. Improper sizing for the home size and heat demand;

    b. Certain homes require retrofit and fabric upgrade prior to unit installation (i.e., a 'fabric first' approach);

4. Stakeholder factors:

    a. Lack of available tradespeople and manufacturers;

    b. Competing interests from different industries (e.g., lobbying, as well as competition over labour and materials);

When we consider this summary of factors in light of our systems thinking-guided research questions, we see there are several research gaps that warrant attention. First and foremost, the UK's built environment has received only superficial treatment. Consider the finding that a primary barrier to the adoption of heat pumps is that the units are being 'mistargeted.' This assumes all homes are 'heat pump' ready provided the correct unit size is selected. This assumption, however, is opposed to the finding that some homes require a 'fabric first' approach. In other words,

39 Ahmad, Sohail. 2022. "Motivations and Barriers Associated with Adopting Domestic Heat Pumps in the UK." UK Collaborative Centre for Housing Evidence. https://housingevidence.ac.uk/wp-content/uploads/2023/04/Heat-pumps-report-final.pdf

40 Ahmad 2022, 5–6; 26

some homes are not heat pump ready and first require fabric upgrades. Clearly, research is needed to resolve this apparent contradiction. Secondly, there is only scant treatment of the UK's regulatory environment. While the existing literature acknowledges heat pumps are suitable for new homes, they don't explain why the overwhelming majority of new homes have been sold over the last decade with gas boilers installed and not heat pumps. Finally, there is little discussion of the research as a problem within the context of the UK's dominant housing tenures. Major emphasis has been on the owner-occupied sector (i.e., household and consumer sentiment), with modest coverage of the social rented sector. Therefore, as Ahmad notes, 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[41] ."

In summary, this study's systems thinking-guided research questions will address many of the gaps and potentially resolve certain contradictions present in the contemporary body of scientific knowledge concerning the suboptimal adoption of heat pumps across the United Kingdom.

41 Ahmad 2022, 26

Methodology

Systems Thinking

Systems thinking is uniquely useful when dealing with outcomes generated by multiple overlapping, interdependent, and hierarchical structures and events [42] [43]. Social systems, therefore, are particularly suited to analysis under such a framework as they exhibit precisely those features and are considered the "most complex class of systems[44] ." In the case of heat pump adoption, we are dealing with a social system constituted of a physical environment (i.e., the built environment and UK housing stock); a variety of actors with varying degrees of interconnection (i.e., social landlords, private landlords, owner-occupiers, developers, tradespeople, advocates, and policy-makers); a regulatory framework that guides and constrains actors (i.e., housing, construction, and energy efficiency standards); and an economic structure that offers various incentives and disincentives (i.e., the price of electricity relative to gas, the cost of labour and materials, and the schemes and subsidies offered by authorities). Since each aspect of this social system contributes to the suboptimal rate of heat pump adoption in the UK – although, critically, it is unclear on the surface in what way and to what extent – "simplification," "linear-thinking" and "reductionism" are unlikely to provide sufficient insight into the problem[45] . That is to say, the system that produces suboptimal heat pump adoption is so complex it cannot be adequately understood thinking merely in terms of cause and effect. Critically, a reductionist approach to the issue would likely "generate as many problems as [it] solve[s] [46]." Given the interrelatedness of the issues surrounding the problem, systems thinking is the appropriate approach.

42 Holland 2014, 59.
43 Anderson, Virginia and Lauren Johnson. 1997. Systems Thinking Basics: From Concepts to Causal Loops. Cambridge: Pegasus Communications Inc, 17
44 Kim, Daniel. 1999. Introduction to Systems Thinking. Cambridge: Pegasus Communications Inc, 4
45 Flood 2010, 269
46 Anderson and Johnson 1997, 19

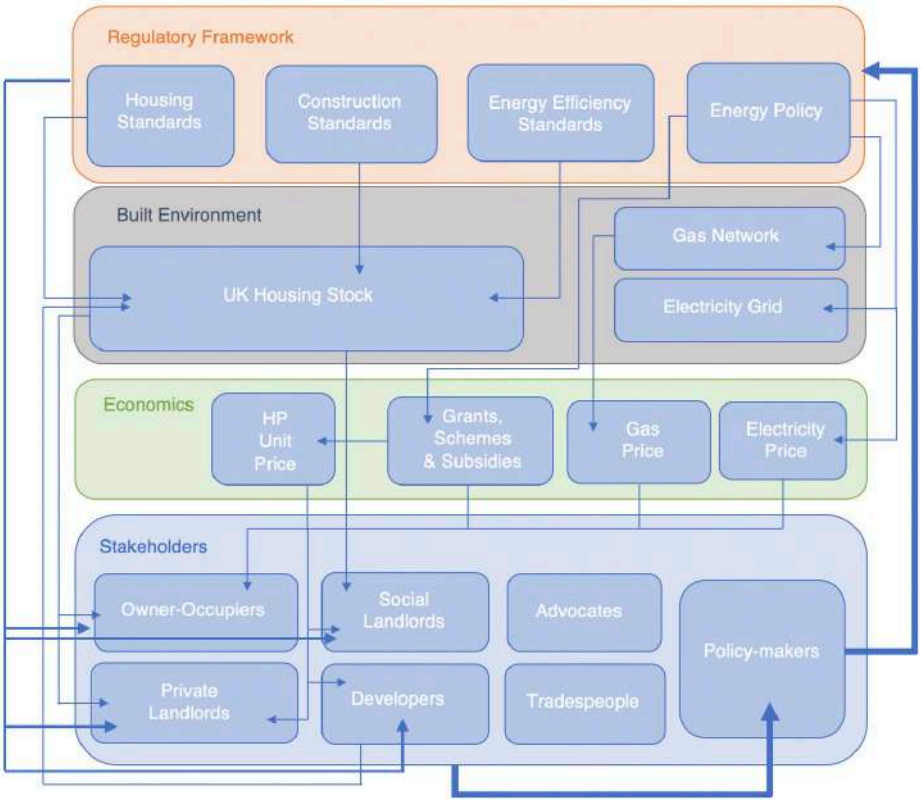

Figure 3. Mental Model of Heat Pump Adoption Social System.

System thinking offers various critical heuristic tools to make sense of our interview data. The first step is to conceive of our 'problem' (i.e., suboptimal heat pump adoption) as the 'outcome' of the system – what systems thinking refers to as an "emergent property." Robert Flood tells us an "emergent property of a whole is said to arise where a phenomenon cannot be fully comprehended in terms only of properties of constituent parts[47] ." In such a way, we can say 'suboptimal heat pump adoption is an emergent property of the social system.' With this concept in mind, systems thinking invites us to construct a "mental model." The mental model is intended to provide a visual-conceptual representation of the system in question. The mental model ought to consist "only [of] those elements whose interaction is capable of self-generating the phenomenon of interest[48] ." Systems thinking posits that hierarchical organisation is the "sine qua non for complexity." The model should, therefore, describe the structural hierarchies of the system. Structural hierarchies help to explain the "interactions of emergent properties at various levels[49] ." Even though we said 'suboptimal heat pump adoption' was an emergent property of our social system, it is by no means the only one. Indeed, suboptimal heat pump adoption is itself an outcome of the interrelation of numerous other emergent properties at different levels of analysis in the system.

Figure 3 represents a mental model illustrating our system's organisational hierarchy and its various emergent properties. The most important features of Figure 3 are: (1) the elements of the system; (2) the aspects of the system's elements (many of which are emergent properties); and, (3) the interrelations between and among the aspects of the system system's elements. Consider, for example, "UK Housing Stock" as an aspect of the system element

47 Flood 2010, 269
48 Richmond, Barry. 2005. An Introduction to Systems Thinking. Lebanon: isee Systems, Inc, 12
49 Holland 2014, 28

termed "Built Environment." According to Figure 3, UK housing stock is an emergent property influenced by the UK's "Energy Efficiency Standards," "Housing Standards," "Construction Standards," and the "Developers." Explained more conventionally, figure 3 illustrates that the nature of the existing housing stock in the United Kingdom is the result of the interaction and interrelation of the rules and regulations that govern how homes are meant to be built, how homes are meant to be maintained, how homes are meant to be improved to meet energy efficiency requirements, and the past and present work of developers and new-builders. In other words, you can't properly understand why the UK's housing stock is what it is without also understanding housing, construction, and energy efficiency standards, as well as the people involved in construction, maintenance, and improvement. But the analysis doesn't end there. The standards as aspects of the Regulatory Framework do not arise from nothing. The UK does not have its housing and construction standards ex nihilo. Instead, as illustrated in Figure 3, we can see that the Regulatory Framework is itself the product of Policy-makers who are in turn influenced by all aspects of the Stakeholder element of the system – stakeholders who are themselves influenced by every other aspect of the system.

Put another way, figure 3 reveals that: (1) the UK's housing stock is an emergent property of the interrelation of the UK's housing, construction, and energy efficiency standards; and, (2) the UK's housing, construction, and energy efficiency standards are emergent properties of the UK's regulatory framework; while, (3) the UK's regulatory framework is influenced by policy-makers who are influenced by all the stakeholders in the system; while, (4) all stakeholders in the system are influenced by the UK's housing stock. In the end, our mental model reveals the co-constitutive nature of many of our system's elements and emergent properties, and leads us to engage in something system thinking calls "loop thinking."

According to Daniel Kim, loop thinking helps us "see the interrelationships among all the variables in the system[50] " and provides a visual description for "closed interdependencies." A closed interdependency describes a situation where "x influences y, y influences z, and z comes back around to influence x[51] ." This brings us to the third stage of our systems thinking approach: a consideration of closed interdependencies such as 'feedback loops.' Feedback loops describe a situation where different elements of the system interact to either reinforce or ameliorate other features of the system[52] . Figure 4 presents one such closed interdependency or feedback loop. Figure 4 describes what we can term the 'installer dilemma.' According to the 'installer dilemma' feedback loop, the lack of qualified installers (x) limits the confidence developers have in designing large schemes with heat pumps (y); which keeps demand for qualified heat pump installers low (z); which, in turn, contributes to the lack of qualified installers (x).

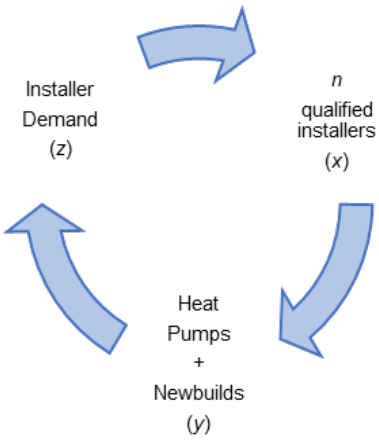

Figure 4. Closed Interdependency A: Installer Dilemma.

50 Kim 1999, 6
51 Anderson and Johnson 1997, 21
52 Kim 1999, 6

Figure 5 presents a further example of a closed interdependency or feedback loop. The feedback loop illustrated by Figure 5 can be called the 'gas price dilemma' where the high cost of electricity relative to gas (x) disincentivises social landlords from installing heat pumps in properties without sufficient airtightness (y); while the government can't shift green tariffs from electricity onto gas because many social tenants would be driven in fuel poverty (z); which, in turn, keeps the cost of electricity high relative to gas (x).

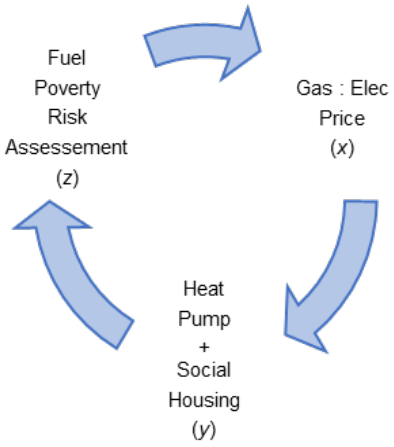

Figure 5. Closed Interdependency B: Gas Price Dilemma.

Identifying such closed interdependencies is vital for research into problems generated by complex systems. In particular, thinking about closed interdependencies is critical when offering policy recommendations. Fundamentally, policy interventions have the function of 'disrupting' feedback loops. Put simply, since the system itself has no way of breaking the loop – and, indeed, reinforces the suboptimal outcome – action from without the system is required to catalyse change. The most suitable policy interventions are, therefore, those which most efficiently disrupt the feedback loop and modify outcomes in the desired direction.

The forerunning section has explained the systems thinking approach that guides this report's research methodology. We began by considering the research problem (i.e., the suboptimal adoption of heat pumps) as an emergent property of our social system. We then constructed a mental model that attempted a hierarchy of elements in the systems, identified the various aspects of the system's elements, and described the interrelations between the elements of the system and the aspects of which they are co-constituted. Finally, we engaged in a process of loop thinking and reflected on two examples of feedback loops relevant to our research problem. This being done, we are now in a position to discuss how the interview data was coded, categorised, and interpreted.

Data Collection

The data for this project was obtained from seventeen (18) semi-structured key actor interviews conducted between 31st May and 4th August 2023. The interviews were between 45 and 50 minutes in duration and took place over Zoom or MS Teams. All interviews were recorded and then professionally transcribed for coding and analysis. The length of transcription ranged between eleven (11) and sixteen (16) pages. The researcher made use of both digital (NVivo) and analogue forms for coding and analysis of the interview data. Each interviewee was asked a series of standardised questions, as well as a number of questions tailored to their sector or specialism (see Appendix p. 68). The researcher asked follow-up questions, probed, and prompted as required to ensure reliable and relevant data.

Key Actors

Those interviewed occupied leadership positions in organisations across various sectors directly implicated in the decarbonisation of domestic heating, including the installation and deployment of heat pumps across the UK. To gather data on the private rented sector, two (2) interviews were undertaken with landlords' associations. Information on the social rented sector was obtained from three (3) interviews with social landlord representatives and a housing association. Insight into the new-build sector derives from two (2) interviews with large property development companies. Understanding of the government sector came from two (2) interviews – one with a national energy and climate change department and another with a metropolitan council. Understanding of the owner-occupied sector came from one (1) interview with a consumer advice association. Data on the existing homes sector was obtained from two (2) interviews with community retrofit organisations. Consumer sentiment data was generated via one (1) interview with a boutique property developer. Information on the heat pump industry came through one (1) interview with an industry lobby. Finally, additional general data was obtained through four (4) interviews with organisations involved in facilitating sustainable development at the local and community level.

Data Analysis & Coding

Given the project's research questions, the interviews were first reviewed to identify all claims relating to issues or phenomena that may influence, had influenced, or were influencing the uptake of heat pumps by consumers or the deployment of heat pumps by stakeholders. This review process revealed an initial taxonomy of influences: (1) cost; (2) regulatory; (3) awareness and misunderstanding; (4) hassle factor; (5) supply chain and labour; and, (6) the constraints imposed by the physical reality of the UK's existing housing stock.

Closer scrutiny of the interview data suggested further ways to categorise claims within this initial taxonomy. For example, influences related to cost were then coded as follows: (i) initial cost of heat pump unit and installation; (ii) cost of heating system upgrades associated with heat pump installation; (iii) cost of fabric upgrades to ensure appropriate heat pump performance; and (iv) running costs (which included claims about the price of electricity relative to gas, as well as costs associated with ongoing maintenance and servicing of the unit). This method of coding was undertaken across the initial taxonomy such that each of the broad classes of influences were appropriately subcategorised recognising and distinguishing their various spatial, agential, and temporal dimensions.

Data Interpretation

Once the interview data had been isolated, coded, and classified according to the principal taxonomy of influences – with its array of concomitant subordinate categories – the researcher made use of the systems thinking approach and considered the social system's hierarchy and its relevant dimensions: the regulatory framework, built-environment, economics, and stakeholders.

First, it became apparent that despite certain commonalities, the social rented, private rented, owner-occupied, and newbuild sectors each face unique barriers and opportunities concerning the adoption and promulgation of heat pumps. These four sectors are not only constituted of distinct stakeholders given variations in tenure but also imply differences in accommodation. The newbuild sector – populated by developers and new-builders – is associated with a vastly different kind of accommodation on average from that generally found in the private rented sector. Furthermore (and of particular note for this project), the social rented sector, despite being populated by residents in the lowest socio-economic tier, is constituted of homes with the highest average energy efficiency (based

on average EPC ratings[53]). These four (4) stakeholder sectors, therefore, ought to be interpreted and considered separately. As always, however, one must tread carefully when considering these kinds of categories analysis. Within the private rented and owner-occupied sectors, for example, we encounter a great deal of socio-economic variation. Additionally, households across the social rented, owner-occupied, and private rented sectors occupy homes of all manner of condition, style, and architecture. Households of economic means might find themselves in older, leakier housing stock, while, equally, those with little disposable income might be domiciled in newer, well-insulated properties. Nevertheless, given the unique barriers to heat pump adoption experienced by these stakeholder sectors, interpreting the interview data according to these categories is a valid approach.

Second, since heat pumps are a piece of physical technology installed into actual existing domiciles – connected to an electrical grid rather than a gas network – built-environment considerations, therefore, represent an important category for analysis. Under this heading, we find: the UK's existing housing stock, the gas network, and the electricity grid.

Third, there is an economic dimension to many of the responses provided by the interviewees: the cost of heat pump units and installation; the cost of fabric and heating system upgrades; government schemes, grants, and subsidies; and, the price of electricity relative to gas. It is, therefore, necessary to consider these factors separately.

Fourth, many of the interview responses referred to a broad regulatory framework constituted by housing, building, and energy efficiency standards, as well as an energy policy that influenced various technological and economic aspects of the heat pump problem. The regulatory dimension, then, represents another relevant means of categorising and interpreting the interview data.

By interpreting the data through the lens of systems thinking, we come to see that these 'system dimensions' influence one another in a cyclical, reinforcing, and co-constitutive manner. In other words – as illustrated by Figure 6 – the regulatory framework influences the kind of built environment and economic incentives we encounter in the system; the built environment, in turn, influences the material reality for the various stakeholders; the economic and material factors influence the behaviour of certain stakeholders; and, the stakeholders collectively contribute to and/or influence the formulation of regulations. Of course, in actuality, the interrelations are far more complicated. This simple sketch nevertheless highlights that seemingly discrete aspects of a research problem impinge upon each other to produce the outcomes we observe.

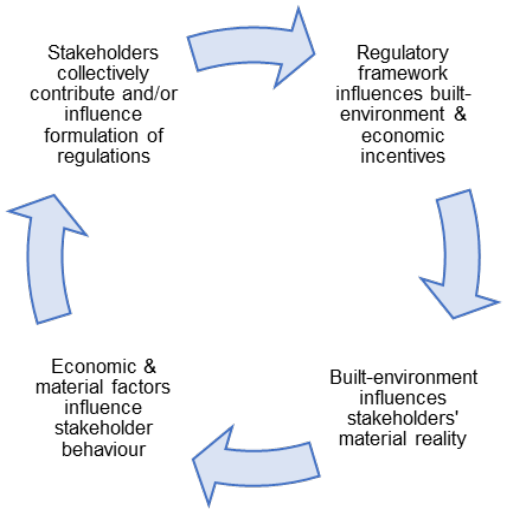

Figure 6. Cyclical Influence of Social System Dimensions.

53 GFI. 2020. "Financing Energy Efficient Buildings: The Path to Retrofit at Scale." Green Finance Institute, Report, May. https://www.greenfinanceinstitute.co.uk/wp-content/uploads/2020/06/Financing-energy-efficient-buildings-the-path-to-retrofit-at-scale.pdf, 30

Findings

Overview

One of the principal barriers to the widespread adoption of heat pumps throughout the United Kingdom over the past decade has been that housing stock across the UK has been treated implicitly as though it were homogeneous and suitably comparable to housing stock in various European nations. The inverse of this situation is that the heterogeneity, age, thermal efficiency, and fabric performance of the existing housing stock have been somewhat set aside as meaningful physical constraints affecting the widespread adoption of heat pumps throughout the United Kingdom. The downstream effect of this neglect is that specific costs as well as certain 'hassle factors' associated with the installation of heat pumps – which present considerable barriers to their adoption – have received precious little attention. In particular, it is rarely acknowledged that a large proportion of existing UK housing stock will require some degree of fabric improvement as well as heating system upgrades to bring the home to a suitable level of airtightness, thermal efficiency, and heating infrastructure such that the heat pump can perform at manufacturers' specifications.

While it is technically true a heat pump will 'work' regardless of a home's thermal efficiency, an occupant in a suboptimal situation will either face higher running costs that might exacerbate fuel poverty, or they may endure a significant reduction in thermal comfort relative to what they would otherwise experience with gas heating. Part of the issue is that the emphasis across the heat pump literature has understandably been the carbon savings. Since electricity is increasingly derived from 'green' sources, even heat pumps that perform below manufacturer's specifications can generate carbon savings. Unfortunately, however, in the United Kingdom, a sizeable portion of the population cannot tolerate increases in their heating bills. Therefore, a heat pump that generates carbon savings at the expense of higher ongoing running costs is oftentimes non-viable. Furthermore, homeowners will little additional capacity in their heating expenses are also those least likely to have capital available for the fabric and heating system upgrades required to bring down the running costs of the heat pump. In summary, perhaps the most significant factor holding back the widespread adoption of heat pumps is the condition of the UK's existing housing stock.

For a variety of regulatory, historical, political, and economic reasons homes in the United Kingdom are considerably leakier than those in comparable European countries. This fact means the majority of homes will require pre-installation improvements that have meaningful financial and convenience implications for homeowners. As a final point, 'repair and maintenance' should always be the first consideration in any retrofit. Put simply, you cannot improve thermal efficiency through fabric upgrades if the property is in disrepair. Consequently, there are many homes in the United Kingdom that, prior to the installation of a heat pump require: (1) repair and maintenance; (2) fabric upgrade; and, (3) heating system upgrades. All of these procedures have their particular demands on time, money, and labour. Installing heat pumps directly into damaged and leaky properties is akin to applying a sticking plaster without first disinfecting and stitching the wound.

Another fundamental barrier to the widespread adoption of heat pumps throughout the United Kingdom over the past decade has been the lack of suitable regulations and policy stipulations. In particular, it is unfortunate that despite almost all homes built in the past two decades offering both the fabric standard and thermal efficiency to permit heat pumps to perform at or above manufacturers' specifications, new-builders and property developers in England, Wales, and Northern Ireland are not mandated to install heat pumps. Recently, however, the Scottish Government updated its New Build Heat Standard, obliging that from 1st April 2024, all new developments and properties to be fit with a "zero direct emissions heating (ZDEH) system i.e. one which produces negligible direct greenhouse gas emissions at the point of use [54]."

It is something of a missed opportunity, therefore, that many of the UK's largest home builders continue to construct

54 SC. 2023. "New Build Heat Standard 2024: Fairer Scotland Duty Assessment." Scottish Government. https://www.gov.scot/publications/new-build-heat-standard-nbhs-2024-fairer-scotland-duty-fsd-assessment

new homes that are fitted with gas heating. Consequently, since March of 2013, something in the order of 1,300,000 new homes were completed that might have had a heat pump installed, but were connected to the gas network instead[55] . Furthermore, the private rented sector (PRS), which is predominantly moved by regulation (given the split-incentive and profit motive), has been under no direct obligation to either electrify heating in general or install heat pumps in particular. In the absence of such regulation of the PRS, an insignificantly small number of the approximately five million privately rented dwellings in the UK shifted off of gas onto heat pumps, when their gas boiler needed a replacement, or they sought to meet EPC standards between tenancies[56] .

A further aspect of the regulatory dimension influencing the lacklustre heat pump adoption is the price of electricity relative to gas. If electricity was considerably cheaper, heat pumps could be readily installed in more homes because the thermal efficiency requirements would be less. Unfortunately, because electricity is around three times as expensive as gas on a /kWh basis, installing heat pumps into a great many UK homes is cost-prohibitive.

If we consider widespread heat pump adoption from a 'carrot' and 'stick' perspective, we observe neither is sufficiently present to incentivise or compel the majority of relevant actors. Heat pumps of all varieties remain more expensive than gas boilers, electricity is a more expensive heating fuel relative to gas (the performance benefits of a properly installed pump notwithstanding), while fabric and heating system upgrades accompany the majority of installations. At present, little financial motivation exists for many consumers to install heat pumps. On the contrary, for many homeowners, the installation of a heat pump would generate considerable unforeseen expenses. Recent research suggests the average heat pump installation costs around "£14,800 including the heat pump unit, additional measures and installation[57] ." Ground source heat pumps are considerably more expensive, at "£47,400 per property on average, including the cost of the ground works[58] ." The government's Boiler Upgrade Scheme (BUS) contribution of £5,000 for air source and £6,000 for ground source heat pumps had, therefore, left the average homeowner with around a £10,000 liability. The recent 50% increase of the BUS to £7,500 does, however, narrow this gap. In the absence of any regulatory mandate, the financial realities militate against whatever environmental and net-zero aspirations the consumer might have. In the final analysis, for the majority of homeowners, the installation of a heat pump is too great an expense, imposing too great an inconvenience, and given there are no legal obligations to do so, they remain content to wait for commercial and regulatory conditions to change before acting.

Stakeholder Factors

Landlords & the Private Rented Sector

The expert testimony concerning the barriers to adoption across the private rented sector was remarkably consistent. The most significant factor was the lack of clear and meaningful regulatory mandates compelling landlords to make the shift away from gas heating systems to electrification and heat pumps. In 2015, Minimum Energy Efficiency Standards (MEES) were promulgated in England and Wales mandating private rented properties to have an EPC rating of E or higher from 1st April 2018[59] . However, if a landlord were to spend £3,500 on energy efficiency improvements and, despite this expenditure, did not achieve the required EPC rating standards, they are eligible to register for an

55 ONS. 2023. "House Building, UK: Permanent Dwellings Started and Completed by Country." Office for National Statistics, dataset
56 ONS. 2023. "Changes in Private Rental Sector Behaviour, England: February 2022 to February 2023." Office for National Statistics, dataset
57 Delta. 2022. "Home Surveys and Install Report." LCP Delta, BEIS Electrification of Heat UK Demonstration Project. https://es.catapult.org.uk/wp-content/uploads/2022/12/BEIS-Electrification-of-Heat-Home-Survey-and-Install-Report.pdf, 6
58 Delta 2022, 6.
59 DESNZ. 2023. "Domestic Private Rented Property: Minimum Energy Efficiency Standard – Landlord Guidance." UK Government: Department for Energy Security and Net Zero. https://www.gov.uk/guidance/domestic-private-rented-property-minimum-energy-efficiency-standard-landlord-guidance

exception[60] . In 2020, the government began a consultation on increasing MEES requirements from a minimum EPC rating of E to C; with a planned enforcement period commencing 1st April 2025 for new tenancies and 1st April 2028 for existing tenancies. In a blow to their own decarbonisation agenda, the Sunak government announced on 20th September 2023 it would delay and weaken these proposals. Prime Minister Rishi Sunak declared he would never "force anyone to rip out their existing boiler and replace it with a heat pump," and that mandated phasing out would not begin until 2035[61] . The Scottish Government, under its devolved powers, has mandated that from 2025, all new tenancies with be required to meet an EPC rating of C. Importantly, however, MEES does not mandate heat pumps or the electrification of domestic heating. The Standard Assessment Procedure (SAP) that determines EPC ratings, instead calculates a property's 'energy performance[62] .' Homes with gas boilers, therefore, can readily achieve an EPC rating of E, while well-insulated homes with photovoltaics (PV) and gas boilers might achieve an EPC rating of C.

One interviewee stated, plainly:

> *"Legislation isn't in place to encourage landlords to be able to, as we would say, do the right thing to meet that net zero target." (TRADE7)*

The general view is that landlords will always take the 'path of least resistance.' That is to say, in the main, landlords only undertake the minimum capital upgrades required to meet regulatory compliance. The issue, at present, is that minimum regulations for the private rented sector do not specify decarbonised heating systems, let alone the installation of heat pumps. An stakeholder confirmed:

> *"Landlords who do want to make sure they're complying with regulations and invest in their home, and many private landlords are very good landlords, but they don't have the information yet to know what it is they're meant to be doing." (THIRD5)*

> *Many private landlords are aware that, moving forward, their properties will have to achieve certain EPC standards to remain in the market, but the connection between the decarbonisation agenda and EPC ratings is often lost on them. One key actor explained that landlords are "not thinking about EPC from a decarbonisation perspective." (THIRD2)*

Worse still, there is some kind of misalignment between the decarbonisation agenda and the outcomes of meeting EPC obligations insofar as the SAP calculations are currently being modelled. The same expert continued:

> *"It's not great for decarbonization, but if you could say replace your electric storage heater with the gas central heating system, and that would get you up to the C. That's what you would have to do, although, of course, that's not great from a decarbonisation point of view." (THIRD2)*

Aside from the lack of awareness that stems from the absence of a regulatory framework mandating decarbonised heating systems and heat pumps across the private rented sector, the issue of cost is an ever-present background concern. The housing stock within the private rented sector is (on average) of a lower quality compared to the owner-occupied or social rented sectors. The additional costs associated with fabric and heating system upgrades required to ensure heat pumps perform to manufacturers' specifications are, therefore, especially pertinent. Compounding the cost issue is the 'split-incentive' mindset whereby landlords are reluctant to invest in upgrade measures for which their tenants may be the beneficiaries, without any clear indication of how or whether the landlords will be suitably remunerated through increased rental yields. One stakeholder noted:

> *"The landlord is not going to benefit from the reduction in heating costs unless they can increase the rent. . .[and]*

60 NRLA. 2022. "EPC Rules for Rented Property: What you Need to Know." National Residential Landlords Association. https://www.nrla.org.uk/news/epc-rules-for-rented-property-what-you-need-to-know
61 UKGOVT. 2023. "PM Ppeech on Net Zero: 20 September 2023." UK Government: Prime Minister's Office. https://www.gov.uk/government/speeches/pm-speech-on-net-zero-20-september-2023
62 DESNZ. 2022. "Standard Assessment Procedure." UK Government: Department for Energy Security and Net Zero. https://www.gov.uk/guidance/standard-assessment-procedure

there's going to be restrictions there about how much rent they can charge, not only because of regulation, but also you know what the market dictates." (THIRD2)

A subset of these costing considerations is the heat pump installation process itself, insofar as the physical disruption to the property may warrant temporary rent discounting by the landlord, or delay reletting of the property between tenancies while works are being completed. In sum, the 'hassle factor' associated with the installation of a heat pump and the associated fabric and heating system upgrades has a commercial dimension as it impacts the liveability of the rental property during the works period. An interviewee commented:

"People are going to be reluctant because it's so disruptive to install… it could take up to a month. If you have fabric upgrades that are also required. You might even have to temporarily rehouse your tenants." (THIRD2)

Finally, given the higher relative cost of electricity and the unfamiliarity the general market has with heat pumps and their particular operation and maintenance, there is a question among landlords about whether letting a property with a heat pump might dissuade prospective tenants worried about ongoing cost and thermal performance. An expert suggested:

"People generally don't really understand heat pumps and how they work. And so, if a property is advertised as having a heat pump, I'm not sure that a tenant looking for a property would really see that as a benefit. They might see it as something that that puts them off because they don't understand how it works, and they might have read scare stories in the paper about how it's going to struggle to heat the property, and that kind of thing." (THIRD2)

In conclusion, the adoption of heat pumps in the Private Rented Sector is held back by: (1) the lack of clear and meaningful regulations mandating decarbonised heating systems and heat pumps in particular; (2) the considerable upfront costs associated with installation and doubts these will be recouped via higher rental yields; (3) the commercial consequences of a disruptive and prolonged installation; and, (4) concerns that prospective tenants may look less favourably on homes with heat pumps due to beliefs surrounding running costs, maintenance, and thermal comfort.

Owner-Occupiers & Existing Housing Stock

The owner-occupied sector is the only one where the actors who invest in the installation of a heat pump are the direct beneficiaries of its performance. This factor presents certain advantages as well as disadvantages. On the one hand, for some owner-occupiers, the installation of a heat pump results in cheaper ongoing heating costs and the satisfaction they are contributing to a net zero future. Provided the purchase and installation of a heat pump is minimally disruptive and economically viable, for this class of owner-occupier a heat pump is something of a 'no brainer.' On the other hand (as emerged across numerous interviews), many owner-occupiers who made enquiries into heat pump installation were then confronted with unforeseen obstacles such as disruptive and expensive fabric and heating system upgrades. Therefore, part of the challenge for owner-occupiers is the knowledge gap surrounding heat pumps as a heating system alternative and the specific requirements of their home. Indeed, many of the key actors interviewed suggested a pervasive sense of confusion surrounding heat pumps was a primary factor limiting their widespread adoption. One expert commented:

"People are totally confused about what to do… it's basically fear of regrets. People are worried about choosing the wrong measure, doing it the wrong way with the wrong contractor, getting the wrong price." (THIRD1)

Heat pumps are a relatively new technology and their technical operation differs markedly from the household heating most UK residents are familiar with. Rather than providing the 'on demand' heating typical of gas, heat pumps provide a constant level of thermal comfort (around 20°C). In other words, occupants with heat pumps won't 'get hot' but they'll always be 'comfortable.' One interviewee noted:

"That kind of control that you lose through having a heat pump is an issue for some people. Some people love it. They love the idea that their house is absolutely a constant temperature and that this thing is ticking away. But a lot of people are alarmed by that because they feel their radiators, they're tepid, and on a cold day there's nothing like coming home and just being able to put your hand on nice hot radiator, and say, oh, the heating's on. Lovely! I'll warm up. So, it's a change in our whole approach to what heat is, if you like. It's about thermal comfort rather than just heat." (TRADE2)

In addition to uncertainty about whether a heat pump is appropriate for their particular domestic situation, how a heat pump works, or how they ought to operate their heat pump, a variety of misconceptions concerning the performance of heat pumps have permeated the discourse over the past decade or so. Another expert suggested:

"There is far too much of the, oh heat pumps are inefficient, oh heat pumps can't keep the house warm, oh heat pumps can't give you hot water, heat pumps can't give you this, heat pumps can't do that, can't do the other." (TRADE1)

In sum, therefore, one of the primary factors limiting the widespread adoption of heat pumps among owner-occupiers is a lack of confidence concerning the technology, whether it is suitable for their particular circumstances, how one might go about installing the unit, what is involved, and how much it will cost. Several stakeholders referred to the lack of a 'one-stop-shop' providing advice and support to homeowners as a fundamental issue. One interviewee explained:

"A one-stop shop…which is part of a number of approaches across Europe… where you can go to some sort of organisation, potentially at local level, potentially regional/national it doesn't really matter. You approach somebody who then works with you to understand what the needs are of your property, and in a realistic way that considers how the property is actually lived in, develops a plan for improving the property so it meets whatever the new regulations are going to be. Identifies what the most affordable way of doing that is, what sort of grant funding, loan funding mechanisms are available to you and then works with you to identify the most appropriate contractors and it's basically a hand-holding service from the beginning to the end." (THIRD5)

Such a 'one-stop-shop' need not be a government of local authority responsibility. Instead (as one expert pointed out), it may be preferable if the point of contact for homeowners seeking advice on heat pumps was a community project or "area-based initiative." This key actor suggested:

"If I knew that there was a team of contractors working on my street, going from house to house offering to install heat pumps. And I know that my neighbours have done it, and it worked well, and these contractors know the properties… I know my neighbours have used them. It's worked well for them, then you know they're not cowboys." (THIRD1)

Beyond the issues of trust, awareness, and confidence, heat pump adoption among owner-occupiers is limited by cost and the 'hassle factor.' It is well-known that heat pumps are more expensive than gas boilers, at present (~£5,000.00 for an air source heat pump[63] versus ~£2,500.00 for a gas boiler[64]). What is less well appreciated are the costs and hassle associated with many typical heat pump installations. Depending on the age, style, and condition of a home, the installation of a heat pump falls somewhere on a spectrum between straightforward to highly challenging. Straightforward installations are generally the most affordable, while highly challenging installations can become cost-prohibitive. If the owner occupies a detached or semi-detached home built after 1990, for example, it is probable little or no fabric upgrades will be required to permit the heat pump to perform to the manufacturer's specifications. That said, such a home is likely to require some upgrades to its heating system: pipework, radiators, and/or controls. Given that heat pumps require 15mm piping (as opposed to the 10mm common for gas heating systems), larger radiators, and water storage (something unnecessary with instant gas water heating), the vast majority of homes – irrespective of age or style – will require additional measures more or less invasive, disruptive, and costly. One expert explained:

63 Elite. 2023. "Air Source Heat Pumps." Elite. https://www.elitesg.co.uk/air-source-heat-pumps
64 EH. 2023. "Boiler Quotation." Eazy Heat. https://eazyheat.co.uk/get-your-boiler-quotation

"There's other challenges in the refurb market. It isn't just a heat pump outside. Let's face it. It isn't just oversizing radiators. If you're on anything other than 15 mil primary pipe work or secondary pipework, then you're into your emitter being changed, your primary secondary pipework, and you're looking at major invasive works to enable a heat pump." (DEV4)

Another stakeholder confirmed:

"So, either they give up and they abandon the change or they end up with a select on price and for the contractor to deliver on that price they have to do half a job and they end up with bad stories." (THIRD1)

On the other hand, if the owner occupies a pre-1919 detached, semi-detached, or bungalow, not only will they require the aforementioned heating system upgrades, but, in addition, the home may require various fabric upgrades to permit the heat pump to perform to the manufacturer's specifications: insulation (loft and/or wall), double or triple glazing, and other air-tightness measures. One expert noted:

"For a heat pump to be effective you need a pretty well controlled building that is, generally, not that leaky in terms of air and that kind of thing. Most old buildings will not provide that… Unless people have either a new build or a custom build or a very specific project that has really been done properly for airtightness and everything else… I hear far too many stories by everybody saying that they're much more expensive than I ever imagined." (THIRD6)

A recent study by Catapult Energy Systems estimated the average cost of installing a heat pump, when the additional fabric and heating system upgrades and been factored in, was in the order of £14,800[65] . In the absence or a regulatory mandate on owner-occupiers, this cost and the 'hassle factor' of installation are considerable barriers to widespread adoption. One interviewee stated:

"One of the biggest barriers is a conservatism with a small 'c' around people being unwilling to invest for something which isn't clear it's got a direct immediate return to them, and it has a significant upfront capital cost." (GOVT1)

There are owner-occupier edge cases that are more challenging still: those living in pre-1919 tenement flats or Victorian-era houses. In the first case, (particularly in England) leaseholder restrictions might mean individual heat pumps are non-viable, and in the second case, conservation orders may complicate matters. Although these issues will be picked up below in the section on the built environment, the comments of one expert bear repeating:

"For private owners as well, it's an inelegant solution to living in buildings with a kind of historic value and the high raised ceilings, detailed cornicing and things like that. These are all very difficult to retain if you are creating insulated boxes within properties. They are very expensive, they're also generally not permitted in terms of within planning conditions around retaining the conservation of the period features of properties… [And then there's the] issue around the common ownership in tenemental properties which is a sticking point given you require others' consent in order for works to be carried out can be a significant barrier for works being undertaken." (GOVT1)

In conclusion, the adoption of heat pumps in the Owner-Occupied Sector is held back by: (1) a lack of awareness about the suitability of heat pumps for particular situations and a lack of confidence concerning heat pump performance and operation; (2) the overall cost of heat pump installation in light of additional associated fabric and heating system upgrades; (3) the 'hassle factor' of unforeseen fabric and heating system upgrades accompanying heat pump installation; and, (4) the reality that some owners occupy housing types where the installation of individual heat pumps is highly physically challenging.

65 Delta 2022, 6

Developers & the New-Build Sector

Developers – i.e., those responsible for the supply of new homes in the UK – were the one actor group where the initially declared barriers to the adoption of heat pumps across their sector differed markedly from the issues that emerged through the course of the interview. That is to say, while the majority of experts in the new build sector suggested immature supply chains and a lack of qualified installers were the primary factors limiting the adoption of heat pumps in the sector, when probed about factors influencing the design stage for new homes, they referred instead to the absence of mandating regulations in England, Wales, and Northern Ireland, as well as the disjuncture between the calculation of EPC ratings and the decarbonisation of heating systems. That is not to say that supply chains and installers are not ancillary limiting factors. It is to say, however, that regulations, building standards, and the EPC system are the primary factors determining chosen heating systems for new-builds in the UK.

It is important to understand there is a considerable time lag between regulations and the kinds of homes that enter the housing market as new supply. One key actor explained:

> *"A scheme that's being built today was probably approved one to two years ago. So, the new regulations wouldn't really come into force in terms of what's built for a good few months because it's always the case that there's a bit of a rush to get schemes approved under the old regulations so you can just get the last ones built." (DEV5)*

Although the Future Homes Standard (FHS) for 2025 specifies a 75-80% reduction in carbon emissions compared to the current building regulations[66] , the vast majority of new homes are being designed with gas heating systems under the old regime. Another interviewee stated:

> *"The regulations in the UK, they don't specify you have to use a heat pump. A lot of builders will use PV today rather than heat pumps, for example." (DEV1)*

In the absence of a clear regulatory mandate, commercial incentives such as the profit motive take precedence. A recent report on a Birmingham demonstrator project of 12 homes built to the Future Homes Standard 2025 found the additional fabric and heating system upgrades constituted a "15% uplift in cost against the project designed to 2013 Building Regulations[67] ." This situation – i.e., the idea that developers would voluntarily forego 15% of their gross profit simply to 'get ahead' of regulations to meet anticipated future standards – explains the slow progress of the sector towards the decarbonisation of domestic heating. An expert explained:

> *"Your typical house builder will be looking to achieve a minimum 20% margin on their development… I think the financial impact is a significant one in their reluctance… Lots of those companies or all of those companies are using the right language, they're saying the right things but actually it's questionable." (DEV2)*

One stakeholder involved in the preparation of Section 106 tenders noted that even when housing associations collaborate and design schemes at a higher level of thermal efficiency and lower carbon emissions, developers remain unmoved. The interviewee stated:

> *"The local housing associations I work with at the moment are regularly in correspondence with the developers as part of their Section 106 bids to see if they can get ahead of the curve and have a bit more Future Homes Standard or have air source heat pumps, for example, or PV or whatever it might be, and I would say 100% of the time the developers say no. So even when they would get paid for it, they don't want to because I guess it affects their time and motion." (DEV2)*

66 MHCLG. 2021. "The Future Homes Standard." UK Government: Ministry for Housing, Communities, and Local Government https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/956094/Government_response_to_Future_Homes_Standard_consultation.pdf, 8
67 MH. 2023. "Project 80 – Eco Drive Handsworth: Future Homes Standard Case Study." Midland Heart. Authored by Monica Mateo-Garcia, Emmanuel Aboagye-Nimo, Franco Cheung, Kui Weng, Mike Leonard, Tony Hopkin, and David Boyd, 3

Coextensive to the issue of 'regulatory absence' is the fact that the current model for determining EPC ratings (i.e., the Standard Assessment Procedure [SAP] calculation) is somewhat at odds with the decarbonisation agenda. Many developers noted that they can achieve a higher EPC rating according to the SAP with a combi boiler and photovoltaics (PV) than they would if they replaced the gas boiler with a heat pump. One expert noted:

> *"If we took heat pumps and put it into a 21 regs compliant fabric, we would have a lower EPC rating than the gas boiler and the PV." (DEV4)*

This situation is reminiscent of the proverb 'There's more than one way to skin a cat.' New-builders and developers have an intimate understanding of how SAP calculations are made and many possess sophisticated computer software that models the energy efficiency of their schemes. If photovoltaics and an efficient combi boiler result in the same EPC rating as installing a heat pump (while being less expensive and easier to execute) developers often take the path of least resistance. The relationship between newbuilds, heat pumps, and EPC ratings is further complicated by the fact that the present means of calculating EPC ratings (i.e., the SAP calculation) emphasises energy consumption rather than carbon emission. This sentiment was expressed by a second expert:

> *"The EPC rating standard is actually problematic because EPCs – obviously if you put a heat pump on, the EPC is directly linked to running costs in the UK. There is the carbon figure behind the scenes, but on the front sheet that you get as they talk about carbon within the England EPCs… And obviously, if you're putting a heat pump on it's going to potentially drag the EPC down." (DEV1)*

Summarising the situation, a third suggested:

> *"The SAP calculator isn't keeping up with the direction of travel." (DEV2)*

Finally, a fourth explained:

> *"EPCs in their current form are pretty detrimental to the calls to be honest because they are not necessarily an indication of energy efficiency or CO2 reduction. They are a cost indicator." (DEV6)*

Although the general attitude across the newbuild sector is to defer the adoption of heat pumps until they are legally required (i.e., FHS 2025), a small number of developers are installing heat pumps in all new homes. One such developer was interviewed for this study: a boutique builder, constructing around 5,000 homes per year for a higher-end clientele. The stakeholder indicated their decision to 'get ahead' of the FHS 2025 was in part a commercial point of difference and in part because they didn't want clients retrofitting their 'new' homes in a few years' time. The interviewee explained:

> *"There was an opportunity here. I think people are interested in new technology. The heat pump, for us, was all part of the sales. How do you sell this product? People are open to new things if you give them the confidence, the support, and help them work with it and understand it." (DEV6)*

> *"This is us 'future proofing' for our customers… we don't want them stuck with gas borders that they've got to replace in 10 years' time." (DEV6)*

Although regulations and building standards are the primary factors influencing design choices that determine heating systems for new homes entering the market, there are secondary factors that also play a role in limiting the confidence the sector has about voluntarily making the shift to heat pumps ahead of regulatory mandates. These secondary factors are electricity grid capacity, supply chain immaturity, and a lack of qualified labour for installation and maintenance.

Sector experts described situations where advice from District Network Operators (DNOs) undermined the commercial viability of development schemes wanting to deploy heat pumps due to additional electricity demand.

That is to say, the DNO advises of surcharges developers face related to the expansion of grid capacity, and developer profit motive takes precedence in the absence of regulatory mandates. One stakeholder explained:

> *"We found this on a few viability schemes, that if we want to put heat pumps on the site, then significant infrastructure upgrades required for the grid… our divisions will be in constant contact with the District Network Operators in link with the grid, and they will say, "Yes, there's enough. It'll cost you this much," and that all ties into the viability. But if there's major upgrades required, it just kills the whole viability and we think like, we can't actually build in that location or look for another solution." (DEV1)*

Another interviewee confirmed:

> *"One of the big ones we struggle with is the electrical infrastructure, you know, because a lot of these guys will have budgeted for sites based on gas infrastructure… potentially, having to pay a fee to the network operators for not having to put a gas infrastructure in… and then also having to pay another fee to the network operators for reinforcing the electrical infrastructure." (DEV6)*

The supply chain issues developers consistently argued limited their adoption of heat pumps is best described as an issue of scale. That is to say, developers suggested unit production volumes were insufficient to meet their demand, in the event they pursued a development scheme where all homes were equipped with heat pumps. One key actor explained:

> *"There is still quite an immature supply chain within the UK. I mean, we deliver around 20,000 homes a year. That's our sort of target. Sort of 15,000 of those will be low rise, and the others will be high rise in London, and a different sort of heating solution. So, for us as a business, we typically need around 15,000 heat pumps when we fully switch over, and what we're finding is the supply chain is quite immature." (DEV1)*

Another expert confirmed:

> *"Probably the main issue at the moment would be concerns about supply chain, about competency within supply chains within the mechanical electrical subcontracting sector." (DEV3)*

Put plainly, developers suggest they can't build new homes with heat pumps because there aren't enough heat pumps being manufactured at the moment. The issue with this claim is that it is something of a catch-22. It stands to reason that if developers – who design their schemes well in advance of construction – gave heat pump manufacturers a large order for units with a two-year delivery date, the manufacturer could generate investment from expansion and fulfil such an order. In the absence, of these orders, however, heat pump manufacturers are presently meeting demand according to market equilibrium. Despite suggestions from developers that the supply chain limited their design choices, no developer could say they had made the kind of order described above and had been denied delivery by the manufacturer. In fact, one boutique developer said they had no supply chain issues and were able to install heat pumps in all their new homes. This expert explained:

> *"We're okay for the time being… Initially we were involved with 3 heat pump manufacturers, and they were all adding additional capacity. I know that Mitsubishi are opening up a new plan in Scotland. I know they have opened up another one in Belgium, and I know that Vaillant are extending their production line in Belper, so all 3 manufacturers are increasing, actively increasing their capacity." (DEV6)*

The situation is somewhat similar with respect to the availability of qualified labour for the installation and service of heat pumps. While, on the one hand, it is true there are presently insufficient qualified technicians to install, let alone service the volume of heat pumps that would exist if developers put them into all new homes, since developers are not designing these kinds of schemes, there is little natural incentive for the labour market to meet these hypothetical demands. One stakeholder noted:

"There is a supply chain issue, there are provider challenges, but I do think that once you've got the rest of the framework in place, to an extent, industry and the private sector will respond to that certainty and clarity in demand that's generated." (THIRD5)

This is not to minimise the challenge presented by critical labour shortages across the retrofit, masonry, building, and heat engineering sectors. It is simply to say that labour market considerations are not one of the primary factors affecting choices at the developer design stage. In other words, the labour market is not a primary factor limiting the adoption of heat pumps in the new build sector. Indeed, there is a strong argument to suggest that developers' design choice will be one of the key drivers for the upskilling and expansion of the labour market for heat pump technicians if regulations were such that all new builds were designed with electrified heating in general and heat pumps in particular.

In conclusion, the adoption of heat pumps in the New Build Sector is held back by: (1) the absence of regulatory mandates requiring the electrification of heating and the installation of heat pumps in new homes except in Scotland; (2) the misalignment between an EPC rating model relying on SAP calculations and the decarbonisation agenda (i.e., energy efficiency vs. carbon emission); and, (3) the profit motive governing voluntary design choices for new development schemes.

Social Landlords & the Social Rented Sector

The question of heat pump adoption in the social rented sector differs from those so far discussed insofar as social landlords have, in the main, already made considerable progress with respect to decarbonisation and domestic energy efficiency. Since balancing fuel poverty and thermal comfort, against the decarbonisation agenda has been a priority for social landlords and local housing associations alike, for many years, the adoption of heat pumps hinges primarily on the parallel issues of cost and performance. Given the financial situation of social tenants, social landlords are not in a position to simply ignore cost implications in favour of lowering carbon emissions. Consequently, social landlords are extremely wary of installing heat pumps into homes that do not provide the level of thermal efficiency and airtightness required to permit heat pumps to perform to manufacturer's specifications. One interviewee stated:

"We must ensure a suitable thermal performance so that the installation of an air source heat pump doesn't create undue financial pressure for the people that live in that home because they're already under significant financial pressure by virtue of living in social housing, and probably the majority of which are in receipt of Housing Benefit and a range of benefits." (DEV2)

Underwriting this strategy is a preference for a 'fabric first' approach to decarbonisation across the social rented sector. That is to say, social landlords opt to undertake fabric upgrades such as repair and maintenance, insulation, and window glazing before consideration of heating system replacement. The expert explained:

"Across the social housing sector, I think what you're seeing is fabric first… So, upgrading the fabric first, and then it's about what comes next. And ideally it would be an air source heat pump, and it would be some PV, and maybe it would be a battery." (DEV2)

As a result of this tendency, the social housing sector has better insulated and more energy efficient homes on average than either the owner-occupied or private rented[68] . On the surface, this ought to make social housing the ideal sector for hat pump addition (since a significant physical constraint limiting adoption in the private sector has been overcome). The expert testimony revealed, however, a degree of scepticism concerning heat pump performance and operation that was frustrating their widespread deployment. One interviewee suggested:

"Social landlords are willing to make that investment where there's confidence, but there isn't that market

68 GFI. 2020. "Financing Energy Efficient Buildings: The Path to Retrofit at Scale." Green Finance Institute, Report, May. https://www.greenfinanceinstitute.co.uk/wp-content/uploads/2020/06/Financing-energy-efficient-buildings-the-path-to-retrofit-at-scale.pdf, 30

confidence in heat pumps yet. So, I don't think it is realistic as yet to see an expansion." (THIRD3)

Social landlords harbour concerns their tenants may operate heat pumps in such a way that energy costs increase rather than decrease, and that – given the higher price of electricity relative to gas – the thermal efficiency of their housing stock is still below that required to justify the claim that heat pumps cost less to run. One stakeholder noted:

"To get optimum performance from an air source heat pump it's running constantly and that's actually an anathema to a lot of the customers that would live in social housing." (DEV2)

Another expert commented:

"What does surprise me? Some of the residents' behaviour. Our residents with heat pumps were, on average, heating their homes to 24 degrees. Because of that difference between 24 degrees and the manufacturer's specification of 19 degrees, there's something like a 20 to 25% increase in energy usage purely due to the difference in temperatures. Some of the residents even wanted their heating at a high temperature 24/7 – even at night time, which just baffles me. That theoretically will triple your energy usage." (THIRD8)

Indeed, one of the key findings from the Birmingham demonstrator project was that "occupant lifestyle is a key factor" in achieving energy efficiency targets, and that consequently, "heat pump operation needs to be explained in an explicit strategy" to social housing occupants[69] .

The housing association expert who was recently involved in the construction of several new homes, all installed with heat pumps, advised that the lack of qualified installers was a serious problem. Despite the appointed installers claiming to have the requisite skills, the key actor reported significant issues. They explained:

"There certainly isn't the supply chain out there when it comes to installers. We went to what was described as a specialist. However, during construction, we had loads of issues. With some of the heat pumps, they hadn't actually connected them to the hot water cylinder. They even put in additional pumps that weren't needed. A lot of the commissioning documents were incorrect, so they hadn't commissioned the units properly, and they hadn't provided the correct documentation. It probably cost us about 2 months on our program. Speaking to the other major house builders, I'd say it's pretty similar. They can't find competent subcontractors in order to install heat pumps." (THIRD8)

Backgrounding uncertainty concerning heat pump technology is a sense that perhaps a 'wait and see' approach is prudent. One expert suggested:

"There's uncertainty, but I think there's also a worry 'what if things change?' so what if we spend a lot of money putting in certain measures and then the measurement changes. There's also a little uncertainty about the technology. So, is it going to improve, is it going to get cheaper as things scale up, should we wait a few years and see what it looks like." (THIRD4)

This wait-and-see attitude has been further exacerbated by the prospect of rival technologies promising greater gains and less disruption, and, therefore, representing a more attractive decarbonisation solution. Specifically, hydrogen has been cited as something 'just around the corner' that might supersede heat pumps as the solution to the decarbonisation of domestic heating. One interviewee stated:

"Some of the decision makers within social landlords are hesitant because they think, well actually are we better hanging back for a hydrogen-based system? There's a lot of muddying of waters potentially as a result of hydrogen." (THIRD5)

The expert testimony described the social rented sector as one characterised by competing priorities under the

69 MH 2023,

auspices of energy efficiency and the decarbonisation agenda, within the context of limited resources and time constraints.

> *"Fundamentally, the challenge the sector's facing is just financial. So, the sector's being asked to build more homes, to invest in heat pumps and other zero carbon heating systems, and keep rent low. Ultimately there is a real tension between these priorities. It's impossible to meet them all at the scale and pace that the government expects." (THIRD3)*

Another stakeholder confirmed:

> *"I know the government are very much pushing heat pumps certainly within new build as an option. But, at the same time you look at the funding that's out there for housing associations to decarbonize their homes. It's overly laborious in order to meet it. There's not enough funding in order to do what you would really have to do in order to meet those requirements." (THIRD8)*

In conclusion, the adoption of heat pumps in the Social Rented Sector is held back by: (1) the need to upgrade the fabric of existing housing stock first to ensure heat pumps perform according to manufacturer's specifications; (2) concern that tenant operation and the relative price of electricity may exacerbate rather than reduce fuel poverty across the sector; (3) the lack of properly qualified installers; (4) The belief that likely future developments in heat pump technology or the prospect of a hydrogen solution warrant a 'wait and see' approach; and, (5) competing energy efficiency and decarbonisation priorities within the context of limited financial resources (i.e., fabric first vs. heat pumps now).

Built Environment Factors

Because a heat pump's technical performance is contingent on the physical environment within which it operates, the quality and condition of the UK's housing stock was a theme that came up in each interview. It is well understood that the UK has older, poorer condition, and less energy-efficient homes than its European neighbours[70] [71] . In fact, around 70% of the UK's housing was constructed before any regulations existed concerning minimum standards for insulation (i.e. prior to the first national building regulations entered into force in 1965) [72]. Because UK homes are, on average, less airtight and less insulated, they lose heat up to three times faster than comparable Western European homes[73] . Consequently, heating systems within the UK are "having to work harder and use significantly more energy to maintain the required temperatures than in comparable countries such as Germany [74]." Given that 13% of households in England, 25% in Scotland, 12% in Wales, and 18% in Northern Ireland are classified as fuel-poor – in the context of a higher relative price for electricity than gas – many experts believed installing heat pumps into homes before they had been retrofit was inappropriate. Commenting on the relationship between heat pump performance and the thermal efficiency of existing UK housing stock, one stakeholder noted:

> *"The energy efficiency point is fundamental. In a lot of cases there will need to be energy efficiency improvements before… I mean a heat pump will work but it will be more expensive to run." (THIRD5)*

70 Kokoni, Sophia and Mathew Leach. 2021. "Policy Mechanisms to Support Heat Pump Deployment: A UK Case Study Based on Techno-Economic Modelling." Renewable and Sustainable Energy Transition 1, no. 1: 1–15. https://doi.org/10.1016/j.rset.2021.100009, 3
71 Bennadji, A., Seddiki, M., Alabid, J., Laing, R. and D. Gray. 2022. "Predicting Energy Savings of the UK Housing Stock under a Step-by-Step Energy Retrofit Scenario towards Net-Zero." Energies 15, no. 3082: 1–18. https://doi.org/10.3390/en15093082, 1
72 Trotta, G., Spangenberg, J. and S. Lorek. 2018. "Energy Efficiency in the Residential Sector: Identification of Promising Policy Instruments and Private Initiatives Among Selected European Counties." Energy Efficiency 11, no. 1: 2111–2135. https://www.hb.fh-muenster.de/opus4/frontdoor/deliver/index/docId/10461/file/Energy_Efficiency.pdf, 2118
73 Tado°. 2020. "UK Homes Losing Heat Up to Three Times Faster than European Neighbours." Tado°. https://www.tado.com/gb-en/press/uk-homes-losing-heat-up-to-three-times-faster-than-european-neighbours
74 Baker, W., Acha, S., Jennings, N., Markides, C. and N. Shah. 2022. "Decarbonising Buildings: Insights from Across Europe." Imperial College: Grantha Institute, Briefing Paper. https://doi.org/10.25561/100954, 4

Another stated:

> *"There is a complete lack of understanding as to the connection between a building's fabric and its particular physical reality and the suitability of a heat pump. For a heat pump to be effective you need a pretty well controlled building that is, generally, not that leaky in terms of air and that kind of thing. Most old buildings will not provide that." (THIRD6)*

A third expert explained:

> *"The majority of our homes are from the 1900s. Not very energy efficient. So, the heat pumps are a challenge for us. Our view at the moment, quite rightly, is that you wouldn't install the heat pump unless your fabric's right." (THIRD8)*

Elaborating, one interviewee suggested the complexity of issues related to the UK's existing housing stock was likely frustrating efforts at achieving widespread heat pump adoption:

> *"I am deeply suspicious that Governments of all shades are potentially seeing heat pumps as a more straightforward solution to the problem than they necessarily are, when you take into account age of building stock, temperature, all sorts of different aspects." (THIRD6)*

It is difficult to determine, precisely, how many homes require fabric upgrades to bring them to a level of airtightness and thermal efficiency to permit a heat pump to perform to manufacturer's specifications. We do, however, have various forms of data (including EPC assessments) from the English Housing Survey (EHS) – i.e., the national survey of housing commissioned by the Department for Levelling Up, Housing and Communities (DLUHC).

Tenure	% of homes with an EPC rating 'D' or lower
Owner-occupied	75.2%
Private rented	72.8%
Social rented	49.4%

Table 1. EPC rating 'D' or less by Tenure.

The (2021–22) EHS reveals around 75% of private housing stock and 80% of social housing stock was built prior to 1990 – with almost 40% of private stock built prior to 1945[75] . The age of the UK's buildings is reflected in their energy efficiency. According to a report by the Green Finance Institute [76] relying on figures for 2016/17, ~75% of owner-occupied homes had been given an EPC rating of 'D' or lower. This figure was slightly lower for the private rented sector, with ~73% of homes having an EPC rating of 'D' or lower. As indicated in Table 1, the social rented sector was the best performing, with only ~50% of homes having an EPC rating of 'D' or lower.

The (2021–22) EHS indicates energy efficiency ratings have improved dramatically over the past decade. Nevertheless, their latest report reveals 53% of all dwellings remain 'band D' or lower under the Standard Assessment Procedure (SAP)[77] . Importantly, although the SAP calculation considers building fabric, thermal insulation, construction materials, and renewable energy technologies – being predominantly a measure of annual unit energy cost for space and water heating – it does not immediately clarify which dwellings are suitable for heat pumps and which are not. Approaching the question from another perspective, Nesta found that 55% of those that "installed into existing home themselves

75 EHS 2022. "English Housing Survey 2021 to 2022: Headline Report." Department for Levelling Up, Housing and Communities (DLUHC). https://www.gov.uk/government/statistics/english-housing-survey-2021-to-2022-headline-report/english-housing-survey-2021-to-2022-headline-report
76 GFI. 2020. "Financing Energy Efficient Buildings: The Path to Retrofit at Scale." Green Finance Institute, Report, May. https://www.greenfinanceinstitute.co.uk/wp-content/uploads/2020/06/Financing-energy-efficient-buildings-the-path-to-retrofit-at-scale.pdf
77 EHS 2022

undertook fabric upgrades[78] ." Furthermore, 53% of heat pump installations "involved replacing the entire heating system [79]."

In general, therefore, it is not unreasonable to suggest that around half of the existing housing stock in the UK (i.e., approximately 14 million homes) will require both heating system and fabric upgrades to permit a heat pump to perform to the manufacturer's specifications. It is worth noting that a 2011 study of air-source heat pump performance found that even when the annual COP of the unit was 2.7 "ASHP running costs were 10% higher than the gas-condensing boiler system[80] ." Furthermore, a 2023 demonstrator project in Birmingham that built homes to the Future Homes Standard (2025) and achieved beyond standard airtightness of (2.5 m3/h/m2), was only able to deliver a "small reduction in bills" due to the offset in electricity usage generated by the photovoltaic panels[81] . These heat pump trials reveal that based on current electricity prices, achieving a running cost saving with a heat pump is challenging even under ideal circumstances. While less than 2% of UK homes have "top energy-efficiency ratings[82] " and, therefore represent ideal heat pumps candidates, as many as 10% may be so challenging to treat that it no longer becomes economically viable. One landlord in the social rented sector suggested ten per cent of their housing stock fell below such a threshold:

> *"The harder to treat properties are very costly. So, significant amounts of money. In some cases, you'd be looking at around £60,000 pounds for a property to retrofit it properly. And the issue is you've got a property, say in the middle of Birmingham from the 1900s. It's worth about £120,000. You can't spend £60,000 on it to get it to where it needs to be in order for it to have a heat pump." (THIRD8)*

With respect to the existing UK housing stock, there are also edge cases to consider. These are properties that fall within housing archetypes that make the installation of heat pumps units either extremely difficult or housing archetypes where individual heat pumps are not the best technological solution. An example of the first kind is homes that fall within a conservation prohibition, while an example of the second kind are multi-story tenements. For tenements, communal or district heating may prove to be more sensible technological and infrastructural choices. These points were raised by several of the interviewees. One noted:

"It doesn't make massive sense to try and encourage owners to undertake individual solutions to properties where they're tightly packed together – when they are three or four storeys up in tenement buildings. We need building solutions, whole block solutions to these issues." (GOVT1)

A second expert suggested:

> *"It seems that people just seem to be ignoring the fact that many people live in tenemental flats… there doesn't seem to be any obvious way of installing heat pumps in a flat other than an ugly unit on the outside of the building, which is going to look really out of place on a beautiful old stone tenement building. Which is, you know, a huge amount of the stock that tends to be rented out." (THIRD2)*

A third observed:

> *"Some cities have an awful lot of pre-1919 flattered tenement buildings and that's a whole different challenge getting the coordination between owners, what does that look like? What kind of insulation? What does that look like in terms of the heat pump? (THIRD4)*

78 Nesta. 2023. "Heat Pumps: A User Survey." Commissioned by Nesta; Research by Eunomia Research and Consulting. https://media.nesta.org.uk/documents/Heat_pump_user_survey_report_May_2023.docx.pdf, 5.
79 Nesta 2023, 5
80 Kelly, N. J. and J. Cockroft. 2011. "Analysis of Retrofit Air Source Heat Pump Performance: Results from Detailed Simulations and Comparison to Field Trial Data." Energy and Buildings 43, no. 1: 239–245. https://doi.org/10.1016/j.enbuild.2010.09.018, 244
81 MH. 2023. "Project 80 – Eco Drive Handsworth: Future Homes Standard Case Study." Midland Heart. Authored by Monica Mateo-Garcia, Emmanuel Aboagye-Nimo, Franco Cheung, Kui Weng, Mike Leonard, Tony Hopkin, and David Boyd, 6; 24
82 Tado° 2020

With respect to conservation concerns, one stakeholder commented:

> *"You may not even get permission. I mean, if it's in the conservation area, or it's a listed building which a lot of these old Victorian buildings will be." (THIRD2)*

A view echoed by another expert:

> *"A heat pump is an inelegant solution when living in buildings with historic value; with high raised ceilings, detailed cornicing and features like that. These are very difficult to retain if you are creating insulated boxes within properties. Upgrades become very expensive. They're also generally not permitted within planning conditions around retaining the conservation of the period features of these kinds of properties." (GOVT1)*

In conclusion, the UK's built environment is, in and of itself, a meaningful barrier to the widespread adoption of heat pumps since approximately 50% of the existing housing stock may require fabric and heating system upgrades to be undertaken prior to unit installation to permit the heat pump to perform to the manufacturer's specifications. Worse still, up to 10% of UK dwellings may be of a kind that bringing them to a suitable level of thermal performance through retrofit is cost-prohibitive. In the final analysis, there are serious cost implications to consider. On the one hand, many owner-occupiers, landlords, and housing associations will face significant additional costs of both time and capital to upgrade their properties prior to the installation of a heat pump. On the other hand, if these actors chose not to bring their homes to the appropriate level of thermal efficiency, they would face considerable fuel costs given the relative price of electricity as compared to gas. While there may be a contingent of homeowners in the owner-occupied sector prepared to make such a choice, it is unlikely those in the social rented and private rented could, given the situation in which this would place their respective tenants. This is to say nothing of the fact that until electricity is 100% green, the decarbonisation agenda can be undermined by heat pumps that do not perform to the manufacturer's specifications.

Structural & Historical Factors

Aside from issues relating to the motivations of particular actors across distinct tenures and the physical limitations imposed by the built environment of the United Kingdom, certain structural and historical factors influence the widespread adoption of heat pumps. In particular, many key actors suggested the historic cost and provision efficiency of the UK's gas network acts to undermine efforts to transition to green energy solutions fuelled by electricity. Put simply, because the UK gas network is so extensive, while, simultaneously, gas is a cheap heating fuel relative to electricity, many homeowners are exposed to a perverse disincentive insofar as installing a heat pump is both a bothersome and persistently more costly alternative form of heating. Given what has been noted above about existing UK housing stock, it is a fact that for approximately 50% of homeowners the ongoing running costs associated with a heat pump are less competitive than remaining on the gas network if they eschew the necessary fabric and heating system upgrades. So long as gas is a cheaper form of heating fuel in the UK, the economic argument in favour of heat pumps is less convincing. One expert noted:

> *"We're addicted to ultracheap gas and successive governments, for the last five decades, that have made it their business to give the population ultracheap gas. It's the reason why no one cares about insulation. The reason our housing stock is so poor and has had so little improvement." (TRADE1)*

Another interviewee suggested:

> *"I think the other barrier to the domestic market for heat pumps, or electric heating in general, is policy. If you break down the 35p – 34p you pay for electricity at the moment, a big portion of that is policy cost… The difficulty the government has is you really need to shift that policy cost from electricity into gas because then that will bring the cost of electricity down and make the heat pumps more attractive all round because then your primary fuel's*

costing less." (DEV4)

A third stakeholder put it plainly:

> *"In terms of electricity versus gas, if we're going to be moving onto a reliance on electricity, then it does need to be affordable." (THIRD4)*

The relative fuel costs are not the only issue, however. Key actors, especially those involved in the newbuild sector or development schemes, noted that the immaturity of electricity infrastructure presents a further challenge to widespread deployment of heat pumps. When consulting with the District Network Operators (DNOs) about grid capacity and substation availability, development schemes were often rendered non-viable based on the additional costs associated with improving existing electricity infrastructure. One interviewee stated:

> *"Because the DNO is a telling us that we don't have the capacity for this… They've got massive capacity issues, really big capacity issues, you know. And that's not just the site. That's the whole district. One of the big ones we struggle with is the electrical infrastructure, you know, because a lot of these guys will have budgeted for sites based on gas infrastructure… potentially, having to pay a fee to the network operators for not having to put a gas infrastructure in… and then also having to pay another fee to the network operators for reinforcing the electrical infrastructure." (DEV6)*

Another expert noted:

> *"We found this on a few viability schemes, that if we want to put heat pumps on the site, then significant infrastructure upgrades required for the grid… our divisions will be in constant contact with the – we call them the DNOs – so the District Network Operators in link with the grid, and they will say, "Yes, there's enough. It'll cost you this much," and that all ties into the viability. But if there's major upgrades required, it just kills the whole viability and we think like, we can't actually build in that location or look for another solution." (DEV1)*

In conclusion, there are historical and structural factors that militate against the widespread adoption of heat pumps in the domestic sector. In particular: (1) the efficiency and coverage of the existing gas network; (2) the relative competitiveness of the price of gas; and (3) the immaturity of existing electricity infrastructure in the face of substantial demand increases all constitute something of a perverse disincentive for certain homes owners and developers in making the voluntary shift to the electrification of heating and the installation of heat pumps.

Cultural Factors

Each key actor was asked if they felt there were any particularly 'British' cultural traits that might play a role in people's willingness or disinclination to decarbonise their domestic heating and install a heat pump in their home or rental property. Remarkably, three cultural themes appeared time and again across the expert testimony. The British cultural traits highlighted by stakeholders were: (a) the conviction that 'my home is my castle'; (b) the tendency to view property as an 'investment' rather than 'common infrastructure'; and, (c) the level of qualification, social esteem, and professionalism associated with the building trades.

The proposition that 'my home is my castle' affected the adoption of heat pumps in two distinct ways. In the first instance, many homeowners were culturally resistant to the prospect of being told 'what to do' in or to their property. Furthermore, because adherence to this credo is sufficiently widespread, policy-makers were conditioned to be wary of imposing strict mandates upon homeowners about what they 'must do' in or to their properties. One interviewee explained:

"One cultural trait is that my house is my castle. It's a very private domain and policymakers are extremely shy about legislating it for anything in the home, and when they do they're really bad at doing it." (THIRD1)

Another expert stated:

"We have that particular British thing of 'your home is your castle' and by 'your' we mean your and, therefore, we won't be intervening in that and we won't be meddling with that. That particular sort of historic use and legislative interaction between owners and building stock I think helped to push us into this quite particular disaster. It's a huge disincentive for policymakers because they don't want to want to meddle in what are seen as people's private affairs, I suppose. It's one of the… yes, the very British way of putting it… It's not an area that makes policymakers feel very comfortable." (THIRD6)

Connected to the idea that British people are particularly sensitive to being told what to do with their property, is the suggestion that one's home is not seen as a meaningful 'part' of a larger 'whole.' That is to say, each property is seen as a discrete and distinct parcel – separate, private, to be individually managed – rather than as a connected component of a larger housing community. This attitude frames decision-making along the lines of 'if I do X' rather than 'if we all did X.' According to certain stakeholders, the issue of decarbonising domestic heating through the installation of heat pumps is considered an individual and personal burden, rather than a social and communal project. Instead of seeing their home as a part of a common infrastructure, British people tend to view their homes as investments – as vehicles for capital accumulation. One interviewee noted:

"The other cultural trait is that in the UK we don't view housing as infrastructure, we view it as a speculative commodity and a substitute for income and a substitute for pensions." (THIRD1)

Another expert stated:

"The meta issue for the UK is that houses or apartments are treated as assets and not treated with a degree of 'stewardship'… The very strong asset nature of property within the UK is a serious issue and, in parallel, is the lack of a duty to maintain. And it's not just that there's a lack of a duty to maintain, but there's also a lack of enforcement around any duty to maintain. If everybody was looking after everything we wouldn't really need any fabric first because, in fact, homes would be lovely wind and watertight, they would be beautifully maintained and interventions would be far, far less necessary." (THIRD6)

The third cultural trait many of the key actors suggested had an influence on the UK's present predicament concerning the decarbonisation of domestic heating and the installation of heat pumps was the British attitude towards the building trades. The leakiness and poor thermal efficiency of many UK homes make the installation of heat pumps a costly and bothersome affair. According to the experts, the leakiness and poor thermal efficiency of many UK homes is a result of suboptimal building practices underwritten by lax accreditation and training, lower standards of professionalism, and how building trades are 'seen' in British society. Generally, the British attitude towards the trades was compared to the way these vocations are perceived and treated in countries such as Germany, Switzerland, and France. One interviewee explained:

"We view trades differently in this country compared to France and Germany. In France and Germany, builders and heat engineers… First of all, you don't use the word 'engineer' in Germany lightly. You could get a vending machine engineer in the UK, but in Germany if you're an engineer, you've been to university for at least four years and you've done a bunch of professional accreditation and you're a member of a professional body and you maintain that accreditation." (THIRD1)

Another expert suggested:

"There's a whole culture thing going on here in the UK. I don't know quite what's going to happen when the New

Home Standard comes in and we're talking about applying the kinds of building standards I just described as happening in Belgium. But, it's going to be a big culture shock for a lot of people because it's going to require them to prove at every stage of the installations that it's fitted, and they've got to prove that it's fitted properly." (TRADE2)

In conclusion, certain British cultural traits are said to have hampered the widespread adoption of heat pumps across the UK. These cultural themes were identified as: (1) the idea that 'my home is my castle'; (2) the tendency to view private property as a personal asset rather than a part of common infrastructure; and, (3) the social, vocational, and professional standing of the building trades.

Key Actor Views on Heat Pumps

As part of each interview, the experts were asked for their views concerning the suggestion that heat pumps are the most suitable solution to the problem of decarbonising domestic heating in the UK. This data is important given that policymakers (at least over the last decade or so) have tended to speak about heat pumps in such terms. Universally, the interviewees considered heat pumps an effective, clever, and impactful technology – and, one that would make a significant contribution to the UK achieving its net zero ambitions. These statements of approval notwithstanding, there was an overwhelming consensus among the stakeholders that heat pumps were not a 'silver bullet' – that heat pumps were not the singular solution to the UK's heating decarbonisation problem.

In general, the interviewees believed that heat pumps had an important role to play – but, given the heterogeneity, age, condition, and leakiness of UK housing stock, heat pumps should be understood as one of several different solutions to the larger problem. For example, no key actor suggested heat pumps were a suitable technology for tenements or large apartment buildings – an archetype representing a significant proportion of housing in large metropolitan centres such as Glasgow, Birmingham, and London.

The expert testimony displayed a degree of pragmatism less evident in the public and political discourse surrounding the deployment of heat pumps across the UK. Instead of holding a dogmatic belief that heat pumps should go into every home as soon as possible, the stakeholders tended to argue for heat pumps in homes that are (in the first place) 'heat pump appropriate,' and (in the second place) 'heat pump ready.' Heat pump appropriate means housing types where the technology has a reasonable likelihood of effective physical installation. Heat pump ready means individual homes where the unit will perform to the manufacturer's specifications without the need for significant fabric and heating system upgrades. In other words, experts did not endorse the installation of heat pumps for housing types where physical installation was highly challenging or impossible. Neither did the key actors endorse the installation of a heat pump before essential fabric and heating system upgrades had been undertaken. One interviewee noted:

"Heat pumps will have a role to play. The extent or the proportion of the role that they can play in terms of decarbonising the UK's energy future, I think that's unclear at present… Air source heat pumps may be a solution, but they're not a single solution for all housing types. In some areas it makes sense. In others, it does not." (GOVT1)

Another stakeholder suggested:

"The heat pump is not the be all and end all for everybody. There are different technologies that will work for different archetypes and certainly that detail will be provided further down the line for people as part of the advice scenarios as to what will work best for that particular property." (GOVT2)

A third expert noted:

"There's kind of been a decade of in our sector of, "Is the heat pump going to be the thing? Is it not going to be the thing?" I would say maybe my mind's in two parts. I think it's the answer now mostly, in most circumstances, I think it's probably the go-to solution… Whether the heat pump is the final best solution in the next five years or so,

I don't know. But I think we're all slightly in the casino and all backing red just now going, "It's heat pump, it's heat pump." And I don't really think there's a plan B, a feasible commercial off-the-shelf Plan B for us just now. So, it's, "let's get the heat pumps in." (DEV5)

A fourth interviewee summarised the situation:

"Heat pumps will play an important part in the decarbonisation picture. But I think it is a simplistic approach from Governments, in particular, to be like 'heat pumps are the answer.'" (THIRD6)

Taking this empirical section as a whole, while the stakeholders interviewed universally praised heat pump technology and acknowledged its likely contribution to the decarbonisation of the UK's domestic heating, they also expressed a consensus position that heat pumps were not suitable for every situation, and, therefore, should not be considered a 'silver bullet' for the government to meet its net zero commitments.

Final Conclusions & Recommendations

Heat pump adoption in the United Kingdom is a systemic issue. The relative failure to increase the number of heat pump installations per year is underwritten by the interrelationships that exist between regulations, the built environment, economic and material conditions, and the behaviour and preferences of implicated stakeholders. The data obtained from the key actor interviews as well as the evidence from heat pump trials and demonstrator projects[83] suggests there is a critical relationship between the condition of the UK's existing housing stock and heat pump performance. Put simply, a heat pump will not perform to the manufacturer's specifications when a home is insufficiently airtight or thermally inefficient due to suboptimal insulation. In the literature, this is referred to as the "disparity between the COP values published by manufacturers and the SPF [i.e., Seasonal Performance Factor] values experienced in real-world testing[84] ." This leaves many homeowners and social landlords with an unpleasant choice. Do they (1) install a heat pump into a suboptimal home and face increased running costs; (2) undertake pre-installation fabric and heating system upgrades and incur considerable additional upfront costs in an effort to avoid higher ongoing running costs; or, (3) remain with their existing heating system saving both upfront and ongoing expenses but contribute considerably more carbon emissions?

The quality of the UK's existing housing stock is the result of decades of housing, building, and energy efficiency standards. The gap between the manufacturer's specifications and real-world heat pump performance in the UK would be considerably narrower today if building standards in the past had been stricter, housing standards more effectively enforced, and if higher energy efficiency standards had been imposed on the residential sector. As it is, however, very few developers install heat pumps into their new homes, private landlords have no obligation to electrify their heating systems, and the Sunak government has recently announced the phase-out of fossil fuel boilers starting in 2026 will be pushed back to 2035. In terms of the relationship between the regulatory framework and the built environment, many mechanisms that reinforce suboptimal outcomes and very few incentives to motivate the shift from gas to electric heating.

From an economic perspective, the decision to install a heat pump is challenging for many homeowners for the reasons listed above. Furthermore, it can be considered prohibitively bothersome if the pre-installation repair and maintenance, and fabric and heating system upgrades are expected to take a considerable period. This work schedule is also impacted by the lack of qualified retrofit and heating system personnel. Private landlords, especially, are wary of commencing voluntary works that may delay their ability to rent their properties.

From a policy perspective, authorities will need to find ways of dealing with the following issues impacting heat pump adoption:

1. The high price of electricity relative to gas;

2. That ~50% of homes in the UK require pre-installation repair, maintenance, fabric, and/or heating systems upgrades;

3. That newbuild regulations in England, Wales, and N. Ireland do not stipulate heat pumps or the electrification of heating;

4. That EPC ratings across the UK emphasise energy efficiency rather than carbon emissions; and,

83 EST. 2013. "The Heat is on: Heat Pump Field Trials Phase 2." Energy Savings Trust. https://www.energysavingtrust.org.uk/sites/default/files/reports/TheHeatisOnweb(1).pdf
84 Staffell, Iain., Brett, Dan., Brandon, Nigel and Adam Hawkes. 2012. "A Review of Domestic Heat Pumps." Energy & Environmental Science 5, no. 1: 9291–9306. https://pubs.rsc.org/en/content/articlelanding/2012/ee/c2ee22653g, 9300

5. The lack of qualified heat pump installers and retrofit tradespeople.

Considering each of these intervention areas from a systems thinking perspective reveals the following insights:

Electricity Price

Around 23% of the high price of electricity relative to gas can be attributed to green levies and tariffs. Does this mean we should shift these costs onto gas? Given that around 35% of the UK's electricity is generated by burning gas[85] , while at least 7.5 million households in the United Kingdom are in fuel poverty[86] while on the gas network, a simple "rebalancing [of] energy levies" may not be entirely feasible[87] . Not only would a higher gas price immediately increase input costs for electricity generation, but millions of households would be thrust deeper into a cost-of-living crisis. Nevertheless, the cost of electricity must come down otherwise the same households that cannot afford increased gas prices are also profoundly disincentivised to be part of the nation's decarbonisation agenda.

Systems thinking suggests the electricity price dilemma reflects an undesirable reinforcing feedback loop. Policy intervention is, therefore, required to disrupt this cycle and overcome what can be interpreted as a form of market failure. Here are two options for addressing the electricity price dilemma without raising gas prices:

1. Electricity subsidy

    The government subsidises electricity such that its consumer price is always lower than the prevailing gas price.

2. National Electricity Production

    The state invests in large-scale renewable electricity generation and sells electricity direct to the public at a price below the prevailing gas price.

Although the UK Government's Contracts for Difference (CfD) scheme goes some way towards facilitating the generation of affordable and green electricity, since it is principally aimed at encouraging private investment, it represents an ongoing public subsidy rather than a prospective source of future revenue[88] .

As a final point concerning electricity, it is worth considering that if electricity was 100% green as well as cheap and abundant, many of the problems confronting the decarbonisation agenda underwritten by the UK's existing housing stock become far less relevant. If electricity was cheap and green it would be far less problematic when heat pumps perform below manufacturer's specifications. Indeed, the overriding issue driving the need to have well-insulated and airtight homes is that heating costs increase significantly under such circumstances. In other words, if electricity was cheap and green we might achieve our decarbonisation objectives without having to expend so much on retrofit, insulation, and upgrades. Perhaps this ideal situation provides an incentive for the state to consider investing in its own renewable energy generation. Such a project could be seen as a genuine win-win-win: (1) the public receives cheap and reliable energy; (2) the state has an ongoing source of revenue; and, (3) the state saves considerable resources that will otherwise need to be spent on repair, maintenance, and retrofit.

85 ESO 2023. "Great Britain's Monthly Electricity Stats." Electricity System Operator https://www.nationalgrideso.com/electricity-explained/electricity-and-me/great-britains-monthly-electricity-stats
86 HC. 2023. "Fuel Poverty." House of Commons Library Research Briefing. Authored by Suzanna Hinson and Paul Bolton. https://researchbriefings.files.parliament.uk/documents/CBP-8730/CBP-8730.pdf
87 Rosenow, Jan and Richard Lowe. 2021. "Rebalancing Energy Levies is a Practical Way to Increase the Electrification of Heat." Inside Track. https://greenallianceblog.org.uk/2021/09/16/rebalancing-energy-levies-is-a-practical-way-to-increase-the-electrification-of-heat
88 DESNZ. 2023. "Contracts for Difference." UK Government: Department for Energy Security and Net Zero. https://www.gov.uk/government/collections/contracts-for-difference

Decarbonisation Schemes and Incentives

The current Boiler Upgrade Scheme (BUS) grant of £7,500 – while a sizable portion of the cost for a heat pump unit and installation in ideal circumstances – remains insufficient to cover the additional costs for repair and maintenance, and fabric and heating system upgrades that accompany around 50% of all other installations. Therefore, it would seem imperative for policy-makers to broaden their conception of what is implicated in a 'boiler upgrade.' Instead of thinking only of the unit and the installation, authorities should understand how common additional repairs, maintenance, and upgrade measures will be. Indeed, the emergent binary discourse describing a retrofit process or a heat pump installation is entirely unhelpful. It is much better to think of home decarbonisation as the objective and heat pumps as one aspect of the treatment required to enable this process. However, the schedule of any home decarbonisation strategy is critical. Step one: repair and maintenance (if required); step two: fabric upgrade (if required); step three: heating system upgrade (if required); and step four: installation of a heat pump (if appropriate).

Furthermore, since there is likely to be a great deal of convergence between households that can least afford these additional works and those occupying homes that require them, some form of means-tested support would seem appropriate. There is little sense in having grants absorbed by households with higher average incomes while those who can least afford to pay are materially ineligible to apply for the scheme because their homes and financial situation are such that they cannot install the heat pump without first expending sums they don't have. Put another way, if the total cost of average heat pump installation is £15,000 while the grant is £7,500, then, ceteris paribus, households with a surplus of £7,500 can gain a £7,500 government-funded advantage while households without such a surplus are excluded from any government support. For this reason, it might make more sense to think about heat pump consumers in three ways: (1) able to pay; (2) able to contribute; or, (3) in need of support. Households in the first category are those that can participate in the decarbonisation agenda without relying on public resources. Households in the second category can participate in the decarbonisation agenda provided their contribution is matched by government. Finally, households in the third category are those that can only participate in the decarbonisation agenda when supported by outside resources. It is worth noting that in October 2023, the National Infrastructure Commission (NIC) proposed the UK government fully subside the cost of heat pump installation for one third of households (based on income) and offer a grant of £7,000 to the remainder[89] .

Skilled Labour

The scale of the work required to decarbonise domestic heating in the United Kingdom is considerable. Across the UK, a little under 30 million homes will require some form of physical attention to align them with the decarbonisation agenda (England: 24.9m; Wales: 1.5m[90] ; Scotland: 2.67m[91] ; N. Ireland: 768,810[92]). Clearly then, a large number of heat pump engineers are required for unit installation and maintenance. Based on the interview data, the lack of these installers and skilled technicians is a factor in the suboptimal rate of adoption. What is unclear, however, is whether we have a supply-side or a demand-side problem. Is the lack of qualified heat pump installers holding back the installation of heat pumps, or is the low demand for heat pump installations holding back the supply of heat pump installers?

89 NIC. 2023. "Long Term Review Sets Out Pressing Need to Modernise Infrastructure to Support Economic Growth and Climate Action." National Infrastructure Commission. https://nic.org.uk/news/long-term-review-sets-out-pressing-need-to-modernise-infrastructure-to-support-economic-growth-and-climate-action
90 ONS. 2023. "Housing in England and Wales: 2021 compared with 2011." Office of National Statistics. https://www.ons.gov.uk/peoplepopulationandcommunity/housing/articles/housinginenglandandwales/2021comparedwith2011
91 NRS. 2022. "Households and Dwellings in Scotland, 2021." National Records of Scotland. https://www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/households/household-estimates/2021
92 NISRA. 2022. "Main Statistics for Northern Ireland Statistical Bulletin Demography and Households." Northern Ireland Statistics and Research Agency. https://www.nisra.gov.uk/system/files/statistics/census-2021-main-statistics-for-northern-ireland-phase-1-statistical-bulletin-demography-and-households.pdf

Although imperfect, the data indicate there are approximately 3,000 heat pump engineers operating in the UK[93] . If these 3,000 engineers are working to capacity, installing 55,000 heat pumps a year – by implication, the UK will require around 32,000 engineers to fulfil the government's annual target of 600,000 installations. This figure is not unreasonable since around 130,000 registered heating engineers serviced the UK's domestic gas network in 2019[94] . On the surface, therefore, the view the heat pump labour market is experiencing a supply-side problem is plausible.

On the other hand, however, if 55,000 heat pumps are presently installed per year, each of these 3,000 engineers installs (on average) 18 heat pumps – or one heat pump every 2-3 weeks. Although this arithmetic does not reveal how much non-heat pump work these engineers perform, since the average air-source heat pump installation takes between 2 and 5 days[95] , the existing pool of heat pump engineers does not appear to be at capacity. Consider the counterfactual: if the data suggested the available heat pump engineers were at capacity in the context of low installation numbers we would expect to find heat pump engineers installing a heat pump every 5 days. Since the installations per engineer are far below this threshold, however, the available data can plausibly be interpreted as suggesting a demand-side rather than a supply-side issue.

Of course, these numbers don't reveal anything about the geographic distribution of these installers. Perhaps the ratio of installations to installers is highly uneven, with some engineers installing 70 heat pumps a year and others installing very few. However, if there was such an uneven distribution, this would necessitate an area in the UK where a small number of installers were overwhelmed by demand. This begs the question: why has such a market not incentivised gas installers to upskill or new engineers to enter the sector? Therefore, regardless of how one parses the data, the relationship between the number of heat pump engineers and the annual volume of heat pump installations is indicative of some form of market failure.

Systems thinking suggests this market failure can be conceptualised as a reinforcing feedback loop where policy intervention is required to disrupt the circuit. Given the uncertainty about whether the relationship between low heat pump installer numbers and suboptimal heat pump adoption represents a supply- or demand-side problem, it makes most sense for policy to address both sides of the equation. Under such a framework, here are two possible options:

1. Mandate & Training

- Mandate all newbuilds as well as any home with an EPC rating of 'A' (or an airtightness measure of 5m3/h/m2 or better) to shift to electrified heating with photovoltaics and heat pumps;
- Provide heat pump training to existing heating engineers as well as a guaranteed contract for work based upon the above mandate.

2. Public works programme

- Establish a department for domestic heat decarbonisation;
- Recruit and train retrofitters and heat pump engineers across the UK;
- Starting with the hardest-to-treat homes in each jurisdiction first – deploy these state or local authority employees to repair, insulate, upgrade, and then install photovoltaics and heat pumps.

93 Nesta. 2022. "How to Scale a Highly Skilled Heat Pump Industry." Nesta. https://media.nesta.org.uk/documents/How_to_scale_a_highly_skilled_heat_pump_industry_v4.pdf
94 UKERC. 2019. "Heating Engineers, Skills and Heat Decarbonization." UK Energy Research Centre. https://ukerc.ac.uk/news/heating-engineers-skills-and-heat-decarbonisation
95 EE. 2023. "Air Source Heat Pump Installation Explained." The Eco Experts. https://www.theecoexperts.co.uk/heat-pumps/air-source-heat-pump-installation

Existing Housing Stock

Since the quality of the UK's existing housing stock is the consequence of decades of inferior housing and construction standards, it makes little sense to spend billions of pounds on repair, maintenance, and retrofit without also future-proofing all new homes. Homes today should not be built to minimum acceptable standards but to the highest possible standard so they are optimally energy efficient and minimally carbon-emitting. It is an unfortunate fact that the majority of new homes will need to retrofit in the coming years.

Given the heterogeneity of the UK's existing housing stock, policy-makers must take a strategic and nuanced approach to the issue of domestic heat decarbonisation. Not all homes require the same level of intervention. Not all homes are 'heat pump ready.' Indeed, some homes are unsuitable for heat pumps, while others cannot be retrofit due to conservation and heritage concerns. The following schematic (figure 7) represents the kind of decision-making framework local authorities might adopt to achieve a more precise and considered approach to domestic heat decarbonisation:

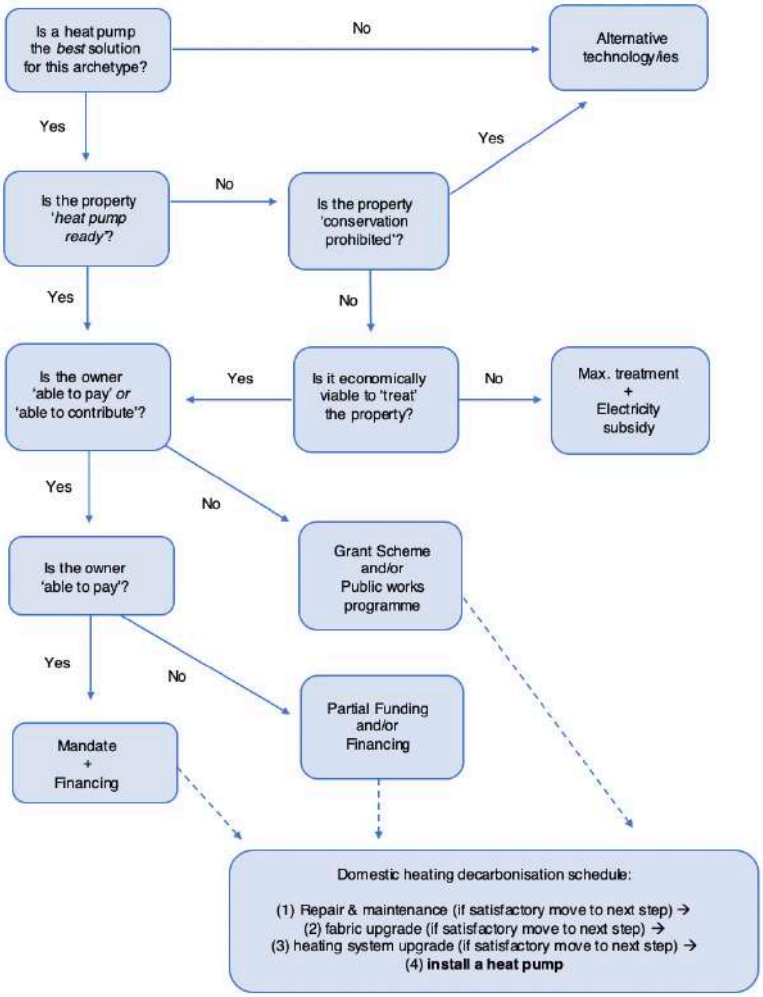

Figure 7. Domestic Heating Decarbonisation Decision-Tree.

Appendix

Standardised semi-structured interview questions (general – all actors)

1. Please tell me a little about yourself and how your present role relates to the decarbonisation of domestic heating.

2. What is your view of heat pumps as THE solution to the issue of decarbonising domestic heating?

3. What, in your opinion, are the most important factors holding back the widespread installation of heat pumps across the UK?

4. To what ext nt do you agree with the claim that a lack of awareness and education about heat pumps among consumers and homeowners influences their widespread adoption?

5. What is your opinion of current government funding arrangements concerning the domestic decarbonisation agenda and the promulgation of heat pumps?

6. What advice would you give to policymakers and industry stakeholders who are looking to promote the adoption of heat pumps in the UK?

7. What is your reaction to the claim that heat pumps need to be the most cost-effective heating system on the market before they will achieve widespread adoption?

8. What role does the price of electricity play in the widespread adoption of heat pumps?

9. How do you feel about the relationship between the current domestic energy efficiency regulations (e.g., EPCs) and the installation of heat pumps?

10. When you think about the existing housing stock in the UK, how do you think issues such as condition and heterogeneity might influence the widespread deployment of heat pumps?

11. Are you familiar with the concept of fabric first, and if so, what do you make of it in relation heat pump installation?

12. What do you make of claims that there are not enough qualified installers?

13. Are there any particular geographic or demographic factors that have affected heat pump adoption in the UK?

14. Can you think of any UK-specific cultural or social barriers that might influence heat pump adoption?

There were additional, sector-specific questions addressed to each expert.