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Research Article

Accelerating heat pump diffusion in the UK: emergent tensions and priority areas for change

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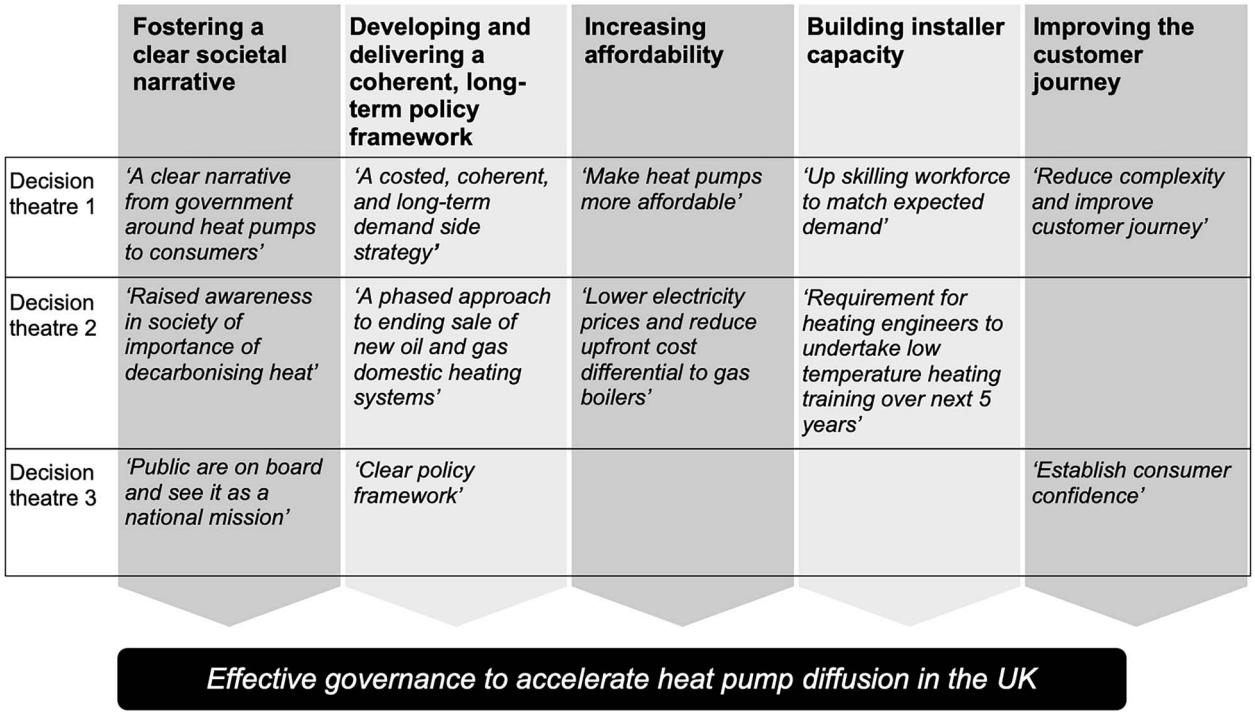
Abstract

Energy efficiency is essential to meeting international carbon reduction ambitions. Shifting how energy services are delivered through the adoption of strategic technologies, like heat pumps for domestic heating, offers one important route to deliver efficiency gains if associated infrastructures, markets, cultures, and practices around broader systems can be transformed as well. Transformative Innovation Policy calls for new, reflexive, multi-actor governance practices capable of guiding such transformative change in particular directions whilst remaining open and responsive to system developments as they unfold. Yet seldom are stakeholders afforded the chance to deliberate on progress towards system transformation and offer insights on what is needed to expediate change. In this paper, we draw on data from three deliberative workshops carried out in 2023 in which experts from across industry, manufacturing, policy and research explored what is required to accelerate the diffusion of heat pumps in the UK. Our findings suggest decision theatres are a promising tool for reflexive evaluation of policy and identify five priority areas for change: (i) fostering a clear narrative, (ii) developing and delivering a coherent, long-term policy, (iii) increasing affordability, (iv) building installer capacity and (v) improving customer journeys. Although individual policies remain important, these priority areas shift the focus from policy instruments to broader considerations about the coherence of policy mixes and strategy for system transformations. Our work affirms how tensions arise in reflexive governance practices and supports the use of decision theatres as a method for exploring their implications in practice.

Graphical Abstract



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Lay summary: Heat pumps can reduce emissions associated with domestic space heating but may require changes to building fabrics, energy markets and user practices to work effectively. Accordingly, their deployment depends on effective policy built on the input of diverse experts. Yet, rarely do experts get to deliberate on what makes policy effective. This research draws on three expert workshops to explore changes required to accelerate heat pump deployment in the United Kingdom. It identifies five priority areas for change—messaging, policy, affordability, installers and customer journeys—and three emergent tensions that require greater consideration in developing effective policy for heat pump diffusion.

Key words: energy efficiency; heat pumps; governance; policy; diffusion

INTRODUCTION

Energy efficiency is described by the International Energy Agency (IEA) as 'the first fuel' because it provides some of the quickest and cheapest options to reduce global emissions. Energy efficiency is therefore expected to play a major contribution to meeting international targets to reduce global warming to 1.5°C by the middle of the century [1–3]. The deployment of heat pumps has previously been identified as a critical technology to reduce emissions [3, 4]. Compared with incumbent technologies, such as gas boilers, the potential of heat pumps rests not in incremental efficiency gains, typically made as technologies mature but in delivering heat in new ways. Their mass adoption subsequently involves changes across the socio-technical systems that currently provide heating [5]. Transforming systems may involve changes to power systems, buildings and energy supply markets, as well as user understanding and cultures, which must all link together in 'seamless webs' for new technologies to work [6].

Because the mass deployment of heat pumps requires the transformation of existing socio-technical systems their deployment is not expected to occur without concerted national support. National governments are expected to play a strong, guiding role [7]. In this research we explore what is required by national governments in concert with others to accelerate the diffusion of heat pumps. Two research questions guide the work: (i) What are the most important changes needed to accelerate the diffusion of residential heat pumps in the UK? (ii) What tensions emerge within proposed changes, and what are the governance implications of these tensions for facilitating system transformation?

Across Europe and North America, a variety of policies have been put in place to support heat pump deployment and system transformation. Most approaches see a variety of policy instruments employed to tackle different parts of incumbent systems [8, 9]. These can be grouped into three pillars consisting of energy pricing instruments, incentives to lower the installation cost and regulation to phase out fossil fuel heating technologies [10]. Energy pricing instruments can lower the cost of operating a heat pump and include carbon pricing, energy taxation and rebalancing levies on energy carriers in line with decarbonization. A range of economic incentives, such as grants, loans and rebates are widely used to reduce the often higher upfront costs associated with purchasing a heat pump. Finally, regulation is used to enforce higher heating system efficiency and lower carbon emissions as well as to phase out existing high carbon heating technologies, such oil or gas boilers. These pillars are often also supported by a coordinating framework including customer protection, technical standards and information. To be effective a variety of policies must be mobilized within a coherent policy package [11] ideally combining one policy from each of the pillars set out above [10, 12]. Nonetheless, questions remain about how to speed up change [13, 14]. Policies need to form part of wider national strategies which build on diverse inputs and draw on the expertise and knowledge from multiple stakeholders. Yet rarely do diverse stakeholders have the opportunity to discuss, critique and shape how new socio-technical systems can be brought about.

In this paper, we draw on data from three deliberative workshops in which experts from across industry, manufacturing, policy and research explored progress in deploying heat pumps in the UK and what it will take to accelerate their deployment. Each workshop followed a decision theatre methodology—a participatory research method used to tackle complex, multi-stakeholder issues, which guides participants towards making decisions about what needs to change whilst eliciting agreement and tensions about issues and potential solutions [15].

The research was carried out with a focus on the UK context. Between 2010 and 2020, ~30 000 heat pumps were installed per year. Since 2020 deployment has slowly increased but remains low compared to other European countries [16]. In 2021, the UK government placed the accelerated deployment of heat pumps at the center of its strategy to decarbonize residential buildings by 2050. The Heat and Buildings Strategy [17] included a target to achieve >600 000 heat pump installations per year by 2028 and set out a package of policies to achieve this. At the time of writing (December 2023), these policies have not yet been fully implemented, and important decisions still need to be made.

The findings—five priority areas for change, and three emergent tensions—we argue, have relevance beyond the UK. Identified priority areas go beyond details of individual UK policy instruments and suggest sweeping changes to the wider policy and strategy. They suggest a narrow focus on discrete system elements and policies to address them can obscure wider and more fundamental issues of technology governance and system transformation that undermine all progress. Accordingly, they point towards the importance of coherent policy mixes and strategies including government commitment and the development of clear, consistent narratives to guide and drive change. Our findings also point to three emergent tensions within efforts to accelerate deployment. The first concerns equity and fairness and emerges in national support for domestic manufacturing. The following two are more practical. The second concerns the relative importance of improving the fabric efficiencies of existing housing stocks before deployment of measures to decarbonize heat, such as the adoption of heat pumps. The third concerns fundamental changes within installer industries, which have been largely overlooked to date yet, have implications for how the industry is supported. Each tension is likely to resonate beyond the UK.

The article proceeds as follows. In following section, we introduce Transformative Innovation Policy and broader work on governing system transformation, on which the research is based. We then detail the methods adopted, followed by our results. The article ends with a discussion of these results and conclusions.

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THEORY: GOVERNING SYSTEM TRANSFORMATION

To transform existing high carbon energy systems to low or zero carbon energy systems will require concerted government intervention over decades [18, 19]. Not only must infrastructures be rebuilt, technologies developed and cultures and practices altered, but existing systems of governance need to be remade [20]. In the following we adopt a socio-technical systems perspective on the diffusion of technologies [5] common within the field of sustainability transitions. Having grown over the last 20 years, the field offers a variety of approaches and insights into governing system transformations.

Early approaches within the field focused on developing niche alternatives to existing technologies and systems. Transition Management and Strategic Niche Management focused on understanding internal processes and activities thought central to success [21, 22]. Later work explored how niches may become empowered to challenge incumbent systems [23]. Throughout this early inquiry experiments and experimentation emerged as a central theme, to the extent they were later formalized into an explicit approach to governing system change [24, 25]. In the last decade, interest in governing system transformation has grown and diversified within the field. Greater attention has been directed towards destabilizing incumbent systems [26], the role of policy and policy mixes in guiding change [27] and towards later stages of transitions including how to accelerate change [13, 28, 29].

Collectively, these approaches argue a plurality of actors, not just governments need to be involved in seeking intentional change. They also demonstrate how existing policy and governance approaches towards innovation and sustainability are inadequate [30, 31]. Recognizing and responding to this, contemporary work on Transformative Innovation Policy [32, 33] draws together insights from the last two decades and sets out a new approach for guiding large-scale transformative change. The approach calls for more tentative, experimental forms of governance, capable of guiding transformative change in particular directions under a coherent strategy and consistent policy mix whilst remaining open and reflexive to events and system developments as they unfold [34]. The approach has in turn resulted in increased recognition of how tensions arise through the mobilization of diverse actors and knowledge [35]. Work in this area remains formative. Although tensions are increasingly recognized in theory, where and how they arise in practice is less clear and requires urgent investigation [34].

Our research responds to the need for more reflexive governance approaches capable of going beyond the development of alternatives to engage with later stages of transition processes. We recognize how different disciplines provide useful insights on different system elements [4]. For example, engineering and technology innovation studies offer insights on current and potential technology advancements and trajectories (e.g. [36]). Techno-economic assessments and economics more broadly can explain the impacts of prices on the relative costs of running heat pumps compared to gas boilers and the implications of market changes [37, 38]. Policy studies, economics and transition studies can provide insights on the range of policy instruments required to drive change and on the processes and dynamics of systems change [39–41]. Whilst work rooted in psychology, sociology and science and technology studies can inform us about individual and societal preferences, how users respond to new technologies and how users embed new technologies within daily practices (e.g. [42, 43]). To be effective, reflexive governance practices must be capable of integrating such diverse disciplinary knowledge. It must also engage and incorporate practice-based knowledge of stakeholders.

The research also responds to increasing recognition by transition researchers and beyond, of the need for engaged, forward-looking approaches and analysis, which applies knowledge generated within the field in a way that is meaningful for policy-makers [44, 45]. In the following we employ decision-theatres as a promising transdisciplinary approach to developing responsive governance for system transformation, explore current progress in deploying heat pumps in the UK and what is required to accelerate their deployment. Informed by the literature reviewed above, we directed particular attention to this method, its capacity to identify emergent tensions and what governance implications this has, if any, for facilitating system transformation.

MATERIALS AND METHODS

Data was collected through three online decision theatre workshops. Decision theatres, first developed by Arizona State University, are a highly discursive, participatory research method used to tackle complex, multi-stakeholder challenges [46]. In decision theatres small groups of stakeholders are guided through a series of exercises designed to draw out a systems level understanding of the challenge, before guiding them towards taking decisions about what changes are required to achieve desired goals. The analysis of written materials and workshop transcripts is subsequently used to understand issues from diverse stakeholder positions, and develop knowledge about common priorities for change whilst building understanding of the tensions and trade-offs required to reach decisions [47–49]. The research was approved by the lead author's departmental research ethics approval process at the University of Oxford.

Stakeholder recruitment

In accordance with the approved ethical process stakeholders were recruited through an open invitation to participate, disseminated through three UK-based research networks and existing researcher contacts. To increase industry participation targeted emails were also used. Prospective participants were presented with a brief explanation of the workshop purpose and format and were invited to express their interest and availability to join across three dates. A total of 33 expressions of interest were received. Each participant was then allocated to one of three workshops, with the aim of achieving a diverse mix of stakeholders and genders within each, all while accommodating their indicated availability. Before each workshop participants were sent information on the project and were required to provide informed consent via an emailed statement before being allowed to participate. A total of 15 people participated across the three workshops. Further details are provided in Supplementary Material 1.

Workshop structure

Workshops were conducted online via MS Teams, with discussions facilitated by the authors using the online collaboration software Miro to share notes. The size of workshops was restricted to facilitate in-depth discussion. Participants were guided through four steps over two and half hours, which included the presentation of new information, periods of individual reflection, and group discussion. Two weeks prior to the workshop, a report, written by the authors detailing how the market for residential

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heat pumps was developing in the UK was shared with participants [50]. The report covered: current technology deployment levels, recent developments in UK policy, and changes to markets arrangements, business models and installer capacity, growth in societal awareness and understanding, and consumer experience to date. The workshops were structured as follows:

Step 1: The report was summarized for participants, who were then prompted invited to reflect on and discuss it. The exercise was designed to foster a systems-mind set and provoke reflections across different system elements.

Step 2: Participants were asked to 'think big', take account of information presented and adopt the role of a powerful 'system architect' to decide what changes they would make to the system to accelerate deployment. Through a period of individual reflection, guided by the question: *what are the changes you would make to support heat pump deployment in the UK?*, participants were asked to create a long list of 'change solutions' comprising both a desired outcome and process. Facilitated discussion followed, leading to the selection, refinement, or creation of six proposed solutions collectively agreed upon as the most important to accelerate heat pump diffusion in the UK.

Step 3: The six change solutions were discussed, refined, and ranked by importance, where possible. Participants were directed towards achieving broad consent rather than consensus. Finally, participants were given time to reflect on and amend the prioritized list of change solutions.

Analysis

The workshops resulted in a range of written outputs (reflections, comments, a long list of change solutions, and a prioritized list change solutions) and audio transcripts. Data analysis proceeded as follows.

To foster understanding about contemporary issues, initial analysis focused on participant reflections and discussion held in Step 1, with written reflections inductively coded into themes [51] and transcripts used to deepen understanding.

Analysis of proposed change solutions was undertaken sequentially. First, long lists of change solutions ($n = 37$, derived in Step 2) were coded thematically into themes and subthemes, with transcripts used to deepen understanding and identify additional change solutions. Summaries of each workshop were written up, focusing on points of agreement and tension and how they evolved through discussion (see Supplementary Material 2). Five priority areas for change (presented below) were then identified by clustering the final change solutions proposed across each workshop. Each area was prioritized (Step 3) in at least two out of three workshops.

Finally, thematic coding of reflections and change solutions were reviewed to identify areas of agreement, disagreement and tension. The analysis followed an iterative, inductive process. Initial points of agreement or tension were identified by individual researchers within each workshop (one per workshop). They were then discussed between the team before further details were identified and compared across workshops.

RESULTS

Our results are presented in two parts.

Points of agreement and tension

Several points of agreement and tension arose during the workshops. Some of these points are well rehearsed across industry, policy and academia. Other points appear more novel, as elaborated in the discussion below.

First, there was significant underlying agreement on the maturity of the technology. There was broad, implicit agreement across workshops that further technology R&D was not a primary concern, though recognition that increased technical performance would support diffusion. Implicit agreement suggested the primary challenge lies in reconfiguring existing societal systems to support adoption and use. Second, the systemic nature of the challenge and potential solutions was widely remarked upon in all discussions. The complexity of the topic and interconnectedness of elements were recognized even as participants stressed individual barriers. Third, the importance of policy in driving change was agreed upon by all. There was unanimous agreement that current UK Government policy lacks detail, pace, and joined-up thinking. Fourth, the UK Government's concern towards fostering domestic manufacturing capacity was widely perceived as misplaced. The manufacturing base was argued as being international and agile, capable of responding to demand as the UK market evolves and grows. Finally, developing an equitable approach to system change emerged through discussion as an important crosscutting issue and area of agreement. Ensuring equitable access was thought to require support for low-income households alongside grants for the 'able to pay' market. Meanwhile, concern for job creation as part of a just transition emerged as a central rationale in the argument for increasing UK manufacturing capacity. Without equitable access, heat pump deployment was widely viewed as regressive.

By comparison there were two initial points of tension and disagreement across workshops.

The first concerned the importance of retrofitting homes to increase energy efficiency and reduce energy demand before installing heat pumps. Fabric first was tacitly accepted as the ideal for a variety of reasons: improving building energy efficiency reduces the size of a required heat pump, lowering unit costs; it reduces running costs as less heat is needed, avoids investment in extra electricity generation assets and potentially avoids costly grid reinforcement costs. However, always tackling fabric efficiencies first can stand in the way of a standalone heat pump install if this was the cheapest or most expedient option. Conservation areas were used as an example, in which fabric upgrades may be costly. They may also not be allowed under planning regulations—in which case a heat pump without fabric upgrades becomes the only viable option. In both instances where this was discussed, deliberation led to agreement that both are important, and prioritization leads to trade-offs. In workshop 1 the need to increase deployment was agreed as being most important and that the design and specification of heating systems was more important than fabric efficiencies and load. In workshop 3 tacit agreement emerged: if deployment was to be decoupled from fabric upgrades, then this should only occur after the price of electricity is reduced, through a rebalancing of levies on electricity and gas, and additional support for those in fuel poverty is provided.

The second area of tension and disagreement concerned installers. All agreed on the important role installer's play as the central point of contact between a householder and the technology and on the need to increase installer capacity. Disagreement turned on whether there was sufficient capacity to meet expected future deployment. Industry sector participants argued there were sufficient trained engineers to meet current and near-term future demand, whilst others disagreed. They suggested gas installers are 'quick to change' if the jobs are there. However, across the workshops a tacit agreement was formed that

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there is already sufficient government and industry provision of re-training opportunities to support a skilled installation workforce.

Nonetheless, deliberation across workshops suggested that confusion arises because the installer industry is often conceived as performing a single role, equivalent to the existing gas boiler industry. Though the skills required installing a heat pump are similar to those required to install a gas boiler, it remains unclear whether the structure of the emerging heat pump installer industry will mirror that of the gas boiler industry, which is dominated by sole traders and SMEs [52]. Industry participants explained how the installer industry performs multiple roles—including surveying, design and specification, installation, and accreditation—and how specialization of roles was occurring. They also pointed to the growth in umbrella schemes—in which multiple, local installation engineers are contracted to a single, accredited company—as diverging from past practice. The importance of high-quality design was repeatedly stressed throughout workshops, frequently leading to the recognition that there is currently a shortage of good quality designers. Acknowledging the disaggregation of the installer industry into multiple roles became an important point across all workshops. Suggestions for more targeted supported followed, recognizing how different aspects of installation industries require different types and amounts of support to grow. Developing a phased approach to scaling up deployment, such that consumer demand can be built up at a pace commensurate with the development of a new installer industry was also viewed as vital, providing justification for a gradual phase out of fossil fuel boilers.

Five priority action areas for accelerating the deployment of heat pumps

Through comparative analysis we identify five priorities for accelerating the deployment of heat pumps in the UK (Fig. 1). Although each priority has clear implications for government, they also contain important messages for industry, research and practice more broadly.

Fostering a clear societal narrative

Creating a clear narrative was seen as critical across all workshops. Continued government indecision about the long-term heat decarbonization pathway, including on the role of hydrogen, was perceived as a principal reason hindering current progress. Accordingly, fostering a clear societal narrative of desired change across the UK housing stock, covering both changes to fabric and heating infrastructure, arose as the most salient issue across all workshops. Any increase in public debate, that developing a clear societal narrative might create was thought beneficial, having the potential to increase societal awareness, counter growing disinformation and create a sense of urgency around a new societal mission. Most participants saw the UK government as being central to a national campaign, important for setting direction and bringing others onboard. Conversely, it was recognized that increasing policy-maker knowledge on heat decarbonization and heat pumps was also required. The importance of narrative work, new and revised, to find improved ways to communicate on previously identified issues, resonated throughout many other priorities identified.

Developing and delivering a clear policy framework

Developing a coherent long-term policy framework was viewed as essential across workshops. There was broad consensus that single policy measures will not suffice. A variety of interconnected yet clearly targeted policies brought together in a coherent policy package and delivered in a timely manner, was widely perceived as necessary to accelerate deployment. Such policies included gas boiler phase out dates; a rebalancing of electricity and gas prices; equivalent protections for consumers of all types of heating; implementation of improved building regulations (the Future Homes and Building Standard (TheFutureHomesandBuildingsStandards:2023 consultation); changes to modeling procedures, namely standard assessment procedures, so that they no longer penalize heat pumps; statutory utility status for community-scale heating infrastructure developers; an increase in grant funding; and mobilization of private sector investment to help subsidize deployment.

Increasing affordability

Traditionally framed as the need to reduce the capital and running costs associated with owning a heat pump, a clear message arising across decision theatres was the need to broaden contemporary thinking about how costs are conceived. Instead of a focus on reducing costs, questions of affordability were raised as a multifaceted issue. Affordability thus reflected a tacit agreement that existing narratives, rooted in 'cost', both upfront and running, do not support change and are unlikely to win arguments soon. Action is required to mobilize private finance and open-up the 'willing to contribute' market through for instance green mortgages or credit loans. A range of approaches each capable of targeting different market segments (e.g. willing to contribute, least able to contribute, on-and-off the gas grid) will be required, supported by government policy and innovation within the market.

Building installer capacity

In recognition of the perceived central role installers play in fostering adoption, building installer capacity was viewed as pivotal to accelerating deployment. Building a skilled workforce, capable of high-quality installations must be undertaken alongside measures to grow the market, without which significant training provision was thought to be wasted. Furthermore, the disaggregation of the installer industry into multiple roles—from design and specification, through to fitting and accreditation—arose within the workshops as an area that requires greater acknowledgement. Increased recognition was thought important in paving the way for targeted support to different parts of the installer industry, particular high-quality design. More broadly, this line of argument pointed towards the need for a revised narrative on the issue (often framed as too few trained installers) and possible solutions (such as increased training provision).

Improving the customer journey

Finally, improving the customer journey emerged as a critical area for accelerating heat pump deployment in the UK. Explicitly discussed as a change solution in decision theatres 1 and 3, increasing societal knowledge about, acceptance of and experience with heat pumps was also widely discussed in decision theatre 2, yet subsumed within proposals on 'raising awareness' and 'lowering costs' within final prioritized solutions. Notably, establishing consumer confidence was perceived as the most important change solution in decision theatre 3. Finding innovative ways to reduce the complexity of installations, potentially via improved design practices and simplified installation processes, were suggested as promising means.

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	Fostering a clear societal narrative	Developing and delivering a coherent, long-term policy framework	Increasing affordability	Building installer capacity	Improving the customer journey
Decision theatre 1	**A clear narrative from government around heat pumps to consumers** including on extent of retrofit required, backed by political will	**A costed, coherent, and long-term demand side strategy** that includes a clear, joined up approach to delivery	**Make heat pumps more affordable** and reduce total cost of ownership potentially via new support for least able to pay, green financing, new business models, including heat as a service and/or reduced cost of electricity	**Up skilling workforce to match expected demand**	**Reduce complexity and improve customer journey.**
Decision theatre 2	**Raised awareness in society of importance of decarbonising heat** including recognition of importance of heat decarbonisation to climate commitments and making heat decarbonisation more salient in the political agenda	**A phased approach to ending sale of new oil and gas domestic heating systems** combined with targeted measures to reduce cost, facilitated by a data-driven and whole system approaches for planning and decision-making	**Lower electricity prices** so that one unit of electricity costs less than three times the price of a unit of gas and **reduce upfront cost differential to gas boilers** through targeted support to high- and low-income households	**Requirement for heating engineers to undertake low temperature heating training over next 5 years**	
Decision theatre 3	**Public are on board and see it as a national mission**, achieved through a well-designed public campaign that reduces disinformation	**Clear policy framework** for the whole housing stock and all its energy use, including heating and cooling, that is long term, doesn't not make the problem worse, supports market growth and unlocks private capital			**Establish consumer confidence** through enhancing consumer protection and fostering knowledge of the technology

Figure 1. Five priorities for accelerating the diffusion of heat pumps. Bold statements indicate change solutions agreed upon within each decision theatre, with additional detail provided in plain text.

DISCUSSION

The research brought together a diverse set of experts to explore progress towards deploying heat pumps in the UK and what can be done to accelerate deployment. Each workshop resulted in a consistent set of clearly articulated ideas about what needs to change, and our analysis subsequently distilled these ideas into five priority areas for action. These priorities cut across conventional problem framings of costs, manufacturing, and installer training, and place a strong, though not exclusive, emphasis on the role of national government in enacting change. In some instances, points of agreement challenge conventional wisdom (e.g. around manufacturing), whilst points of disagreement suggest future investigation is required (e.g. around installer industries) and identify new tensions that must be navigated (e.g. equity and fairness in approach followed). The findings thus have implications for UK heat pump deployment, for our understanding of governing for system transformation and methods for its exploration. Below, we discuss these findings and locate them within the wider literature.

First, the need for coherent, joined-up and comprehensive policy mixes identified by workshop participants is not surprising. Many others have pointed to this before, including the Government's own independent advisors [53]. However, it is worth noting the extent to which coherent policy was perceived as creating a supportive base upon which desired changes in other elements of existing systems can be achieved. That is to say, existing work on policy mixes views coherence as entailing alignment between overall strategy and policy instruments and comprehensiveness of policy mixes as addressing all relevant issues [11]. Our evidence suggests that coherence is key, such that it can mitigate against the absence of policy in other areas. To our workshop participants' consistent government policy was thought capable of building confidence and having the potential to 'iron out' other issues. Conversely, a lack of coherence was thought to undermine individual policies. Our work thus further supports the use of policy mix thinking to achieve long-term transformation change as called for by Kern *et al.* [27] and decision-theatres as a practical method for reflexive policy evaluation.

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Second, our participants viewed establishing a domestic manufacturing base critically. Notwithstanding the possibility of selection bias given the focus of the workshops on heat decarbonization rather than industrial policy, the result is curious and multilayered. Currently about one third of heat pumps sold in the UK are manufactured in the UK [54]. However, many of their components are sourced from all over the world and it seems unlikely that this will change in the future. Participants were adamant scaling up domestic manufacture was immaterial to accelerating deployment in the UK. Yet, they also recognized the political importance of fostering societal support for change and of creating domestic jobs in the process. In our view this latter point is likely to have greater material consequence in a transition to heat pumps than the former. It speaks to an underlying tension around equity and fairness in socio-material change and suggests further research is required to explore how the creation of domestic manufacturing jobs may help foster a 'just transition' [55].

Third, our results suggest moving away from a narrow focus on costs as currently framed within policy [17, 56] towards a focus on making heat pumps affordable. Workshop participants viewed markets and competition, notably the imbalance between electricity and gas prices, as important but argued that continued recourse to this framing is unhelpful. This accords with contemporary research. Recent analysis [57] demonstrates that even after the current subsidy on offer for heat pumps, a heat pump with an average efficiency determined in recent field trials using a standard tariff will cost consumers more money than a gas boiler from a total cost of ownership perspective. Participants recognized and called for policies to address the imbalance between electricity and gas prices, as recognized by research (e.g. [37, 40]). Indeed, participants went beyond existing UK policy aspirations—to rebalance taxes and levies between electricity and gas—to call for wider policy measures to unlock new approaches and service offers that make heat pumps affordable. These results point to the limitations of foregrounding cost-benefit analysis: capital grants and rebalancing costs between electricity and gas were unanimously agreed as important but they were not viewed as sufficient to make upfront and running costs comparable to gas boilers. More broadly, this argument demonstrates the importance of taking a whole system perspective and the utility of decision theatres as a means for exploring different stakeholder positions. It also suggests a potentially fruitful line of inquiry about possible policies capable of fostering new business models and service offers.

Fourth, fabric first has long been held as the gold standard in energy efficiency debates and in national policy. Only recently has this consensus been challenged [58, 59]. Our work further questions the supremacy of fabric first narratives. Crucially, it suggests the biggest impact of continuing 'fabric first' debates is how it inhibits development of clear messaging around residential heat decarbonization and behind heat pumps specifically. This suggests that further exploration of fabric first versus heat decarbonization should focus not only on techno-economic performance, which remains important, but also on the implications for societal understanding and motivation to act.

Fifth, disagreement about the structure and capacity of installer industries suggests an acute need for further research in this area. Whilst the importance of the installer industry is widely recognized ([60–62]) there appears to be a widespread assumption that the future heat pump installer industry will have the equivalent characteristics of the existing gas boiler installer industry. To date there has been no critical inquiry examining on how the structure of the installer industry might evolve and diverge from current practice, or what this means for policy. Future research needs to go beyond evidencing and understanding the installer skills gap to build knowledge about if and how the industry is changing. Particular attention should be directed towards the increased specialization of roles, the shift towards umbrella schemes, and the interaction between these dynamics and what they mean for future policy support.

Sixth, such widespread recognition of the systemic nature of UK heat pump diffusion sits comfortably within our conceptual framing. It sits uncomfortably against most disciplinary research and practice that accentuate attention to singular issues and policy solutions, like reducing costs and increasing the installer base. Attention to particular system elements can be easily justified but often produce narrow policy prescriptions. The structured yet highly deliberative approach adopted proved successful in allowing for a systemic understanding to emerge, drawing out tensions between elements and reaching decisions about what needs to change. Accordingly, our research supports the use of decision-theatres as a promising approach to facilitating systems thinking within decision-making on complex, systemic issues.

Collectively, our work has two implications for understanding governing for system transformations. First, our results clearly demonstrate the importance of employing socio-technical systems thinking in pursuing large-scale technology deployment. Our results suggest that attention to individual elements and policies are likely to miss important interactions and implications at a systems level and how coherence between policies can be more important than individual policies. It is notable how the five priority actions relate to changes in strategy rather than discrete policy instruments despite the work concentrating on a particular country with clearly identifiable policies. Our work thus supports recent arguments made for advancing work on policy mixes for sustainability transitions [27]. It also positions decision theatres as a promising method for reflexive policy evaluation capable of bridging research, policy, and practice and of generating valuable insights for policymaking. Second, our work further affirms how tensions arise in governing for system transformation, tensions which often require trade-offs to be made for progress to be achieved. It reminds us that policy (such as support for domestic manufacturing) can be undertaken for multiple reasons and that unresolved tensions (e.g. between fabric first and heat decarbonization) can result in unintended consequences. Again, decision theatres proved a useful method for exploring tensions and trade-offs in pursuing large-scale technology deployment.

However, decision theatres are not without their limitations, which are apparent in our work too. To be effective decisions theatres demand a concerted engagement by small groups of participants. Our workshops were undertaken online over 2.5 hours, which we viewed as the maximum period we could ask of our participants whilst holding their attention. In practice, we found time was constrained. In-person workshops may be advantageous for maintaining attention over longer periods. Decision theatres are highly deliberative so the number of participants must be limited. Working online again reduced the number of participants (c.f. in person). Whilst we aimed for groups of six to eight participants, we averaged five in practice. Every effort was made to recruit people from different backgrounds. Despite these efforts and due in part to late cancelations, female participants, and participants from industry, and policy backgrounds were underrepresented. The reasons for this are unclear, though participation in a workshop is clearly a significant time commitment. What is clear is that decision-theatres represent a useful yet demanding

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method, for both researchers and participants. Our results, whilst strong, should be read with these limitations in mind: further work to undertake more decision theatres with increased representation from policy and industry would strength the validity of the results.

CONCLUSION

Building on Transformative Innovation Policy and through the application of decision theatres as method we sought to answer two research questions: (i) What are the most important changes needed to accelerate the diffusion of residential heat pumps in the United Kindgom? (ii) What tensions emerge within proposed changes, and what are the governance implications of these tensions for facilitating system transformation?

In answer to the first question, our research identified five priority areas to accelerate the diffusion of heat pumps in the UK. These priority areas have clear relevance to the UK Government. They suggest that the UK government should:

- Raise societal awareness of the technology through developing a clear narrative,
- Demonstrate strong policy commitment at the top of Government and develop a coherent strategy,
- Expedite fuel price rebalancing and facilitate new value propositions that improve affordability,
- Acknowledge the disaggregation of the installer industry into multiple roles and provide targeted support to each, and
- Establish consumer confidence and simplify the customer journey.

In answer to the second question, we identified three tensions in accelerating heat pump deployment in the UK. The first evolves around support for domestic manufacturing but has roots in questions of equity and fairness. Our research contributes to emerging awareness of the need for just transitions by elucidating how questions of equity and fairness manifest in heat pump deployment (manufacturing). The remaining two tensions are more practical. They involve questions about how heat pump deployment could be accelerated and concern the capacity and shape of installer industries and the role of energy efficiency in heat decarbonization. These tensions point towards the importance of developing systemic, reflexive approaches for governing system transformation capable of looking across multiple policy instruments to assess the coherence and consistency of policies. These tensions demonstrate how facilitating system transformation is fraught with difficulty. Interactions between system elements create a variety of tensions, which can be hard to foresee but which require explicit attention and deliberation before decisions about how to proceed can be made. Such decisions are likely to lead to trade-offs with few clear answers. Given the difficulty in foreseeing tensions and their implications, the involvement of multiple stakeholders appears vital to navigating intentional change in particular directions, such as in attempts to accelerate the diffusion of heat pumps.

Our findings have relevance to other countries seeking to deploy heat pumps and other energy efficient technologies. The results direct attention to how system elements interact and coevolve over time, and to the importance of establishing coherent strategies rather than focussing solely on discrete policy instruments. They also highlight how navigating tensions and trade-offs are central to the effective governance of system transformation and how effective, responsive governance practices can be cultured through the increased use of decision theatres.

SUPPLEMENTARY DATA

Supplementary data are available at *Oxford Open Energy* online.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHORS' CONTRIBUTIONS

Jake Barnes (Conceptualization-Equal, Formal analysis-Lead, Funding acquisition-Lead, Investigation-Lead, Methodology-Lead, Project administration-Lead, Supervision-Lead, Validation-Lead, Visualization-Lead, Writing – original draft-Lead, Writing – review & editing-Lead), Taru Silvonen (Conceptualization-Supporting, Formal analysis-Supporting, Funding acquisition-Supporting, Investigation-Equal, Methodology-Supporting, Validation-Equal, Writing – original draft-Supporting), Mike Taylor (Conceptualization-Supporting, Formal analysis-Supporting, Funding acquisition-Supporting, Investigation-Equal, Methodology-Supporting, Validation-Equal, Writing – original draft-Supporting), Jan Rosenow (Writing – review & editing-Supporting)

DATA AVAILABILITY

The data underlying this article—written statements from workshop participants and workshop transcripts—cannot be shared publicly because it is not possible to anonymize whilst providing sufficient information about participants to make sense of the data. The data will be shared on reasonable request to the corresponding author.

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