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RESEARCH ARTICLE

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Going backwards? A temporal perspective of what constitutes improvement in domestic heating transitions

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ABSTRACT

To meet UK government targets and support the transition to net zero, the energy system will need to decarbonize. In particular, buildings, as one of the largest sources of UK emissions, will need to transition to clean heat. This will involve changes to the material infrastructure of homes, which may have implications for people's everyday lives and relationships, with public acceptability critical to processes of energy-system transformation. Alongside decarbonization, UK energy-system transformation has been positioned as potentially able to deliver significant benefits to households. In this article, we present qualitative data from deliberative workshops with members of the public concerning perceptions of heat decarbonization. We explore how low-carbon heating is not necessarily seen as an improvement where changes to heating systems may result in perceived compromises to comfort and convenience. We contend that a temporally sensitive approach, which explores past energy-system transitions and experiences of current heating systems as well as anticipated future technologies, can offer important insights into the transition to low-carbon heating.

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Introduction

To meet the UK government's carbon-reduction targets and support the transition to net zero, the country's energy system will need to shift away from fossil fuels, including transitioning buildings to clean heat (BEIS 2021a). In the UK, buildings account for 23% of total carbon emissions, with 77% of the overall building emissions from residential buildings (CCC 2020). Decarbonizing heat, which remains the largest single end-use energy service worldwide, is recognized as both imperative and difficult (Sovacool, Demski, and Noel 2021). Given the prevalence of the gas grid in UK domestic heating, ensuring this transition toward low-carbon heating is as smooth as possible represents a major national challenge (BEIS 2018). Research has indicated that while the decarbonization target is set in law, and is an explicit policy focus, the perceived benefit and importance of heat decarbonization to policy makers is limited (Lowes and Woodman 2020), and there is little public knowledge of sustainable heat policy and how this would affect individual households or neighborhoods (Jansma, Gosselt, and de Jong 2020; Smith et al. 2024).

Insights into energy-system change can be gleaned from historical experience, including previous transition in the UK from coal gas to methane or natural gas (1967–1977). Arapostathis, Laczay, and Pearson (2019) explored this prior transition, highlighting how the particular governance arrangements of the then state-owned gas industry helped to steer this national project to convert 35 million appliances, and the authors suggest that such governance arrangements may be hard to achieve in the UK's current socioeconomic and political conditions. While this prior transition was achieved at pace partly due to the advantages of a "technical and economically superior fuel, in terms of cost, thermal capacity and toxicity," the transition to low-carbon heating arguably does not offer significant improvement in cost, performance, or service delivery (Kerr and Winskel 2022, 4). This highlights a significant challenge in achieving sufficient scale and pace of change in the domestic heating sector to meet current government targets.

Various routes are available for heat decarbonization in the UK (Becker et al. 2023), with anticipated low-carbon technologies including heat pumps, heat

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networks, and hydrogen (CCC 2016; BEIS 2018; BEIS 2021a). Questions have been raised, for example by Rosenow (2022), about the feasibility, efficiency, and cost of hydrogen for home heating. However, hydrogen is still discussed as a possible solution to the decarbonization of domestic heat (Lowes, Woodman, and Speirs 2020), with a government decision on the role of hydrogen due in 2026 (Gordon, Balta-Ozkan, and Nabavi 2023a).

Technologies are likely to vary for different housing types, with older buildings of solid wall construction posing a particular problem due to their lower thermal efficiency and the lower operating temperatures of heat pumps compared to gas boilers (Gordon, Balta-Ozkan, and Nabavi 2023b). There is also potential variance in how low-carbon heating may be rolled out across the UK. For example, Scott and Powells (2020) suggest a specific economic and social geography of hydrogen is emerging focused on the north of England, meaning development and deployment may be highly place specific. Subsequently, sensitivity to local place is important in introducing low carbon-heating options, with action delivered at a fine spatial scale if it is to be appropriate for specific contexts (e.g., Owen, Mitchell, and Unsworth 2013).

With the transition to low-carbon heating, "suitable upgrades" (ETI 2018, 15) to energy-efficiency measures in homes – such as greater levels of insulation – are also likely to be required. Purported benefits of more efficient, low-carbon buildings include smarter, better performing buildings, reduced energy bills, and healthier, more comfortable environments (BEIS 2021b). However, the transition will result in "significant change for consumers" with some options necessitating "considerable up-front costs" (BEIS 2018, 65), as well as disruption from material changes at household level, such as installation of new appliances, energy technologies, and insulation (Beauchampet and Walsh 2021). While decarbonization could potentially help financially vulnerable householders to access basic energy services, it also risks potential exclusion (Crowther, Petrova, and Evans 2023) and harm through further disadvantage, such as worsening energy and transport poverty (Sovacool et al. 2023) or exacerbating existing inequalities through unequal cost burdens (Sandri et al 2021). Therefore, work is required to ensure that the benefits of new technologies reach all members of society (ETI 2018), which necessitates understanding people's views and experiences of energy-system change.

In this article, we take a temporally sensitive approach to explore public perceptions of future heat-decarbonization technologies in the context of past and current heating experiences in order to elucidate views of different low carbon-heating options. We introduce some existing research concerning public awareness of the need for heat decarbonization, and the related UK policy context and identified barriers to change. We then detail the methodological approach of our study, before exploring the data in relation to three main themes.

Public awareness of heat decarbonization

Public awareness in the UK of the need to decarbonize heat, and the potential impacts of doing so, remains low (BEIS 2018; Demski, Cherry, and Verfuerth 2022), with 90% of people installing new gas boilers when replacing their heating systems, rather than low-carbon alternatives (ETI 2018). Alongside low awareness, existing research has highlighted critical media coverage of heat pumps (Barnes, Taylor, and Silvonen 2023), modest savings associated with their installation (Rosenow 2023), and unfamiliarity with the technology (Gordon, Balta-Ozkan, and Nabavi 2023b) as reasons for lack of uptake. Comparing heat-decarbonization pathways across three countries, Hanna and Gross (2021) note how in Denmark and Germany, promotion and information dissemination has helped to lower consumer uncertainties, leading to increased deployment of heat pumps and district heating, while in contrast public awareness remains low in the UK. They also note the less developed supply chain for heat pumps and public confidence in their performance, which have constrained UK uptake.

Central to anticipating responses to low carbon-heating transition is understanding people's experiences and views of current systems (Parkhill et al. 2013; Sovacool, Demski, and Noel 2021). Research has indicated high levels of satisfaction with existing fossil fuel-based heating systems, which suggests people are not currently considering switching to alternative technologies (Sovacool, Demski, and Noel 2021). Cost also plays a crucial role in influencing public perceptions of low-carbon heating (Becker et al. 2023), with the 2021 Heat and Buildings Strategy noting "current pricing of electricity and gas does not incentivise consumers to make green choices" (BEIS 2021b, 21). While research over the last decade indicates cost as a concern (e.g., Parkhill et al. 2013), financial pressures have been exacerbated by both the COVID-19 pandemic, and ongoing gas crisis (Gordon, Balta-Ozkan, and Nabavi 2023b), making this a pertinent current issue. The Energy Technologies Institute (ETI 2018) associates lack of progress toward heating transition with technologies not appealing to consumers, indicating that public support for heating transition will falter unless

people can get the experiences that they value from low-carbon alternatives. Such valued experiences go beyond energy efficiency or economic utility to improving comfort and health (Bolton et al. 2023), recognizing that people use heat in different ways, including to care for others (CCC 2016). This highlights the challenge of reducing energy demand while also maintaining quality of life (Demski et al. 2015).

Despite low public awareness, public acceptability has been described as critical in processes of energy system transformation (Spence and Pidgeon 2009; Demski et al. 2015; Beauchampet and Walsh 2021; Sovacool, Demski, and Noel 2021; Sovacool et al. 2023). Previous work has identified several core values held by the public in relation to energy-system change (Parkhill et al. 2013). One value is that of improvement and quality, which includes long-term trajectories (Butler et al. 2015), incorporating improvement both in terms of socio-technological advances and quality of life, also connecting with the value placed on comfort, convenience, control, and freedom (Parkhill et al. 2013). Such values are interwoven with biographical experiences and relationships, attentiveness to which can elucidate energy consumption and its transformation over time (Butler et al. 2014). Where technology is regarded as not addressing this value of improvement and quality (for example, continued reliance on fossil fuels) this may be considered a non-transition; not representing real change (Butler et al. 2015; Demski et al. 2015). Thomas, Demski, and Pidgeon (2019) highlight a similar recurring theme in their work on public acceptability of energy storage, with participants expressing concerns about technology perceived to be old-fashioned and failing to address underlying environmental problems.

In the remainder of this introductory section, we explore the UK policy context for heating decarbonization in order to situate current efforts to incentivize changes to domestic heating and consider some potential barriers to change.

History and policies for heating upgrade

Policy documents related to energy-system transition refer to network upgrades (e.g., BEIS 2021a), generally the way that energy providers will need to upgrade network lines and transformers to accommodate the increase in electricity demand under accelerated electrification (CCC 2019). Similarly, financial incentives offered in the UK such as the Home Upgrade Grant[1] and the Boiler Upgrade Scheme[2] aim to support the decarbonization of heat in buildings, reduce bills through energy-efficiency upgrades, and subsequently address fuel poverty (BEIS 2021b). Use of the term "upgrade" carries connotations of improvement, with heating-system transitions also described as able to "improve the consumer proposition" (BEIS 2018, 66), or "improve outcomes" for consumers, for example, through smart control systems offering cost savings as well as greater levels of comfort and control (BEIS 2021a, 26). However, such transitions are also recognized in UK policy and academic literature as disruptive and as bringing extensive change for consumers (BEIS 2018), with concerns about costs and convenience (Jansma, Gosselt, and de Jong 2020; Kerr and Winskel 2022), representing an immediate barrier to change (CCC 2016). The level of disruption will vary according to the technology installed and the extent of accompanying work required. However, change may be less extensive with hybrid systems (BEIS 2018), or hydrogen boilers, which may be why some public preferences research has identified these as favored options (Demski, Cherry, and Verfuerth 2022).

One likely change is the need for hot water storage, as most currently available low carbon-heating solutions require a hot water cylinder (Hot Water Association 2021). While relatively little is known about the need for hot water storage in UK households, the number of homes without hot water tanks has risen substantially with the introduction of combi-boilers (BEIS 2018).[3] The reintroduction of hot water tanks raises potential issues with internal space requirements for hot water storage (NEA 2017), while research indicates that 80% of consumers would want the convenience of immediate hot water in their next heating system (ETI 2018), given demand for hot water is linked to meeting conventions of cleanliness (Shove 2003).

Policies use incentives to persuade households to decarbonize their heating (ETI 2018; CCC 2016), yet existing work has critiqued the framing of people as behaving solely as rational actors responding in a simplistic way to price (e.g., Cherry et al. 2022). Instead, understanding the lived experiences of households, which considers rhythms and relationships with people and objects (Ransan-Cooper et al. 2020), may lead to a better-informed approach (Maller, Horne, and Dalton 2012). Existing research concerning low carbon-heating technologies has largely focused on those who have self-funded renovations and are broadly able to pay for retrofit (Bolton et al. 2023), and we know very little about the readiness of other people to embrace new low carbon-heating technologies (Sovacool, Demski, and Noel 2021). While people may express awareness and concern about the environment, it has been suggested that "this concern washes up on the

shoreline of routines and standards of daily living" (Maller and Horne 2011, 70), where shifting household practices relating to comfort, cleanliness, and convenience (Shove 2003) can result in increased resource consumption and hamper efforts to change, despite green intent. This observation echoes findings by Sovacool, Demski, and Noel (2021) indicating that respondents profess to highly value environmental protection for future heating systems but that this does not yet meaningfully translate into readiness to adopt low carbon-heating systems. It has been argued that the incorporation of energy or environmental interventions to reduce consumption ultimately depends on their compatibility with frequently performed or daily practices such as caring for family, socializing, maintaining thermal comfort, and other aspects of ordinary routines (Judson and Maller 2014). Supportive of this argument are studies such as Energy Biographies (Henwood, Groves, and Shirani 2016), which make the case for a relational approach as part of a broader relational turn (Bolton et al. 2023) involving in-depth qualitative methods, that pays attention to how people's social relations, including relational aspects of home (Maller, Horne, and Dalton 2012), influence their energy use.

Changes to homes and technologies are an important aspect of energy research, yet Küpers and Batel (2023) suggest that insufficient attention has been given to historical energy transitions and argue for deeper engagement with time in research concerning the social acceptance of renewable energy technologies. There are some notable exceptions to Küpers and Batel's (2023) claim, for example, the previously mentioned study by Arapostathis, Laczay, and Pearson (2019) and work by Hanna and Gross (2021) exploring the relevance of historical insights for achieving heat decarbonization. Sarah Darby's (2017) interviews in a mining community have also highlighted the relevance of past experience of energy transition, echoed in our own work in a former mining community (Shirani et al. 2021). We have also explored experiences of major historical shifts in technological infrastructure, considering how participants narrated the meanings of these transformations partly through their relationships to others (Henwood, Groves, and Shirani 2016). Recently, Ambrose (2023), has drawn on oral history interviews, highlighting how the transition to gas-central heating was experienced as a labor-saving innovation that meant heating could fade into the background of consciousness. Ambrose highlights the continuing cultural value of some past modes of heating – such as open fires – which have associations of comfort, homeliness, and control, despite lacking the convenience of gas-central heating. This recognition of valued aspects of past ways of doing things highlights the complexity of understanding how people interpret notions of improvement and progress. Our research seeks to build on this temporal understanding through detailed discussions of low-carbon heating with diverse UK groups in different geographical contexts. In particular, we explore how both past and future transitions are viewed in relation to the value of improvement and progress, and consider the implications of this for low carbon-heating transitions.

Methods

This article presents qualitative data from six deliberative workshops, each lasting seven hours, involving 49 members of the public between 2022 and 2023. The study aimed to capture perceptions of heat decarbonization, including heat pumps, hydrogen, heat networks, and hybrid-heating systems as well as the infrastructure-network upgrades and changes to homes that might be required to support them (Thomas, Henwood, and Pidgeon 2023). We provided participants with written information about what taking part would involve and they had an opportunity to ask questions of the research team before consenting to participate. The study was granted ethical approval by the Cardiff University School of Psychology ethics committee (EC.22.07.12.6588GRA).

Where topics may be unfamiliar, and existing public knowledge limited, deliberative workshops have been identified as an appropriate method to understand public perceptions of complex, technical, or emerging areas of science, technology, and policy (Roelich and Litman-Roventa 2020). Given this unfamiliarity, participants are provided with balanced information about the topic of deliberation to enable their discussions to be technically informed (Pidgeon 2021), alongside their own emplaced concerns (O'Sullivan et al. 2023). In asking participants to think about future energy-system change therefore, they bring together this new information and personal knowledge and views to "situate themselves in relation to [future] infrastructure change while maintaining a firm grounding in local context" (Cherry et al. 2022, 3). Affective-deliberative studies in which wide-ranging ethical considerations merge with more localized concerns have a growing track record in eliciting informed consideration of alternate pathways for decarbonization (Cherry et al. 2022; Demski et al. 2015) with the potential to inform future developments (O'Sullivan et al. 2023).

Each workshop group comprised 7–9 participants, recruited by a professional market-research company and offered a £150 honorarium to ensure a diversity of sociodemographic perspectives. Participants ranged in age from early 20s to 70s and had a variety of living arrangements, including single-person households, family groups, and shared housing. A total of 27 participants were women and 22 were men. The sample was not intended to be nationally representative but to represent a range of perspectives from the local areas, and included groups in Wales and Scotland, addressing an identified need for representation in these locations (Gordon, Balta-Ozkan, and Nabavi 2023b). Participants in each group lived in similar housing types and geographical areas (Table 1), providing a focal point of shared experience around which detailed discussions could emerge (Thomas et al., 2024).

Workshops took place in local hotels and community centers central to the communities under study. The study was designed to include a range of housing types that would be differently suited to various low carbon-heating options, with locations also selected to reflect geographical variation in potential low carbon-heating technology. Participants were informed of the reason for their location's inclusion in the study. For example, at the time of the workshops there were plans for a trial hydrogen village in Ellesmere Port, close to the Liverpool sites where participants lived in older housing, whereas the newer built well-insulated detached homes reflected in the Gloucester group may have been more suited to heat pumps. Cardiff represented typical UK housing, with groups divided by occupancy type. Finally, the Scottish Borders group lived in homes not connected to the gas grid; an important perspective given suggestions that off-grid homes are a "low regrets" option, and therefore a priority for low carbon-heating transition (BEIS 2018; CCC 2016; Lowes and Woodman 2020). Scotland also has higher rates of fuel poverty; in 2019, 24.6% of Scottish households were classed as in fuel poverty, compared to 14% in Wales in 2021 and 13.4% in England in 2022 (DESNZ 2023), relevant to discussions of the potential impacts of decarbonization (Sovacool et al. 2023).

Workshops included activities designed to familiarize participants with heat decarbonization and frame this in the context of their homes, communities, and local environment. Participants were informed of the aim to cease new gas installations by the mid-2030s, and of total heat decarbonization by 2050. Early tasks included participant drawings of their homes followed by discussion of current heating systems and energy prices. Participants were then shown a short presentation on heat decarbonization and asked to discuss factsheets depicting the broad array of costs, in-home and distribution-network disruptions associated with heat pumps, hydrogen-ready boilers, hybrid-heat pumps, and heat networks, alongside fossil-fuel boilers as a point of comparison. Participants were shown a video, obtained from the History of Advertising Trust, and information materials concerning the aforementioned 1960s transition to North Sea gas, which framed discussion of the organization of energy-system transition and provided opportunity for temporal reflection on a past transition. Afternoon activities included responding to posters concerning different modes of governing heat decarbonization, and a personas task; a way of exploring scenarios for energy-system change through developing characters (see Cherry et al. 2022 for detailed methodological discussion of personas), to consider how heat decarbonization might impact the everyday lives of others, before a final overarching discussion. The combination of tasks was designed to elicit informed deliberations over heating disruptions, while maintaining focus on the everyday lives and concerns of participants (Thomas, Henwood, and Pidgeon 2023). Workshops were recorded and subsequently transcribed, anonymized, and coded using NVivo software. Coding followed an iterative process involving multiple readings and interpretation of the dataset and constant cross comparison between themes. In the following analysis, participants are referred to by pseudonyms and the researchers are referred to as "moderator" alongside their first name initial.

Table 1. Group Descriptions.

Group name	No. participants	Housing type	Current heating
Cardiff OO (owner occupiers)	8	1930s semi-detached	All GCH
Cardiff SPR (social and private rental tenants)	7	1930s semi-detached	1 electric radiators, 6 GCH
Gloucester	8	1990s onwards detached	All GCH
Scottish Borders (a region with limited access to the gas network)	8	Mixed including 1970s flats, bungalows, older and modern detached	1 electric radiators, 3 storage heaters, 3 oil, 1 wood burner
Liverpool T (Toxteth area)	9	Victorian, small terraced	All GCH
Liverpool C (Crosby area)	9	Victorian, large terraced and semi-detached	1 electric radiators, 8 GCH

Data analysis

We identified relevant data through careful reading of the transcripts for discussion of energy-system transition, particularly focused on consideration of improvement and upgrading. We begin with discussion of existing and past heating systems before exploring responses to proposed future heating options. Finally, we consider how participants responded to the language of "upgrade" and how this related to their experiences with current heating systems. In presenting our analysis in this way, we highlight the value of a temporally sensitive approach to understanding how lived experiences play a role in perceptions of past, current, and future energy-system change.

Existing and past heating systems

Of the 49 participants, 39 lived in homes with gas-central heating (GCH). The biggest issue in relation to heating expressed by the majority of these participants was concern about cost. In contrast, heating-system decarbonization seemed a distant and unfamiliar problem (Thomas, Henwood, and Pidgeon 2023; see also Beauchampet and Walsh 2021) and a less pressing concern; "bank over emissions" as one participant put it. Some suggested that recent energy-price rises made it a challenging environment in which to discuss energy-system change: "If you'd asked us a few years ago, our decisions would have been made more emissions based, but in the current climate, it's down to cost" (Clare, Cardiff OO). However, given the prominence of cost in the previous research discussed above, it is likely that participants would have raised this point regardless. Recent energy-price increases meant that many participants spoke of changing the way that they used their GCH, for example, reducing heating times or temperatures, heating only specific rooms of the house, and wearing additional layers. Some were avoiding switching their GCH on altogether and instead spoke of using electric heaters for localized heat. Despite pressing concerns about cost, participants appeared largely satisfied with their GCH systems for the comfort and convenience they offered through responsive heating and "instant" hot water. This reflects expected standards of performance from GCH systems, around which habits and routines have developed (Owen, Mitchell, and Unsworth 2013).

Of those without GCH, several expressed dissatisfaction with their current heating systems. For example, oil and some electric heating was described as costly, while storage heaters were discussed as unresponsive and ineffective as well as expensive, with the three participants in homes with storage heaters opting to turn their heating off altogether. One tenant with electric radiators described her heating as comfortable but "not convenient at all." (Megan, Cardiff SPR). In this instance, the small electric radiators provided adequate heating but were unsuitable for drying laundry, which led to greater reliance on the tumble dryer, illustrating how changes to heating had consequences for other related domestic tasks and energy use. Conversely, a number of participants with GCH spoke of how they had reduced their use of tumble dryers in light of concerns about energy prices and had instead purchased or utilized washing (or clothes) lines:

> George: I've…put washing lines, you know, just across –
> Neil: Washing lines. Wow.
> George: And then hang, you hang the clothes up even on a day like this, I'll get home, my clothes are gonna be dry.
> Neil: My mum and dad had washing lines.
> George: Seriously.
> Marie: I've got a washing line, I love.
> Lucy: We've got a washing line, not had one for 15 years.
> Neil: Yeah, something like that.
> Lucy: And bought a washing line and an airer.
> Liam: I think, I think, I think with the airers –
> Lucy: Yeah, just a washing line – in the summer actually we quite enjoy it.
> Becky: Yeah. I did, in weird kind of way, yeah. (Gloucester)

Washing practices have been associated with wider environmental issues regarding energy demand, given entanglement with other domestic practices such as space heating for clothes drying (Matschoss et al. 2021) and with the energy intensity of tumble drying. UK weather conditions mean there are times when line drying is not possible, yet with only 58% of UK households having a tumble dryer (ONS 2019), other forms of indoor drying – such as via radiators, as discussed above – are adopted. Interesting here is the discussion among those who have tumble dryers choosing not to use them in favor of line drying, depicted as an older practice to which some have gone back. While potentially more inconvenient and time-consuming than tumble drying, the use of washing lines provided enjoyment, as well as energy and cost savings. This enjoyment of outdoor drying may relate to the olfactory and visual experience of pegging out (or hanging) laundry, for some participants also associated this activity with memories of past experience (Pink 2005).

While some participants could not remember anything other than GCH, the 1960s video shown in the workshop about the transition to North Sea gas

prompted discussion about how this transition might have been viewed at the time. Participants largely saw this as a positive change, "bringing something new in" (Holly, Liverpool T) that participants described as "exciting and positive for the general public" (Doug, Cardiff OO). In contrast, most participants suggested that the context for transition now was "very different," with the benefits for consumers less clear:

> Katie: I think back then it was very different, wasn't it?
> Vicky: Yeah.
> Katie: They were all using the one thing, coal, and you could clearly see that that wasn't good from pollution, health issues, all of that. So, when this came along, yeah, you would think, okay, that is the better option. But I think now it's very different.
> Moderator (G): So, do you think the problem is less visible with natural gas? Is that what you're, you're saying people could see the, the effects of coal.
> Katie: I mean I'll be honest, it sounds selfish, but I know that there's climate change and all of that, I understand all of that. But does it affect me per –, does it affect my health personally? No. So, that sounds awful, doesn't it? But I just mean like I'm not desperate to change to something tomorrow because my health is currently affected by the way I heat my home now.
> Jason: Do you, do you see it though as the benefit for your children?
> Katie: Yeah, I mean I understand long term, I really do, and I understand climate change and all of that, and I understand we need to stop using this. But I think it's very different from then to now.
> Moderator (G): You don't, you don't think it's the same pressing issue as –
> Katie: No.
> (Liverpool C)

In this extract, the group indicates broader awareness of climate-change discourses, but this is for some participants a "long term," less visible, or pressing concern than the need to transition away from coal was perceived as being in the 1960s. The "very different" present context also relates to people's level of trust in the transition. Several participants spoke of the public as now more skeptical about what they were told than they perceived 1960s consumers to have been, related to greater availability of multiple information sources. Others related this skepticism to the privatization of energy, in contrast to the nationalized service in the 1960s, and a view of energy companies as untrustworthy. Further, Tom (Cardiff, OO) suggested that it would now be more difficult to convince people to change their heating systems "because it's not new innovation anymore, is it? They're gonna think, well, why am I going to replace something that's currently working for me?" Such sentiments indicate satisfaction with existing heating systems and the expectation that new heating systems should offer an improvement to convince people to change. One anticipated improvement was through addressing costs:

> Moderator (G): Does it need to be cheaper for this to be?
> Holly: Well it needs to be better than what it is now.
> Pat: Of course.
> Ciara: Definitely, it's got some sort of –
> Holly: I mean why would you change?
> Ciara: Exactly, there's no point, all that upheaval for nothing.
> Yasmine: For nothing, yeah.
> Andrew: I don't think it needs to be as much –
> Claude: They've got to, definitely got to give some kind of incentive.
> Yasmine: Incentive, yeah.
> (Liverpool T)

The above extract illustrates the expectation that a new system should not just be cheaper but be "better" to function as an "incentive" to change. Therefore, while affordability was pressing, it was not the only concern. In the following section we look beyond cost to consider what participants understood a better future heating system to be.

Future low-carbon heating

Participants were presented with information about four low carbon-heating options, as well as fossil-fuel boilers as a comparison, and asked to work in pairs to rank the options in order of preference. This activity indicated a preference among most participants for heat pumps and heat networks, while fossil-fuel and hydrogen systems generally received low rankings. While cost was a significant factor in participants' decision-making, some described how it was considered alongside anticipated lifespan of the technology and emissions as a broader evaluation of "value." Therefore, for many participants, low cost alone was not sufficient reason to opt for a technology if it did not also meet other goals, including innovation.

> And then obviously, the fossil fuels…we can't sustain that anymore, and it's obviously caused, the situation that we're in now with the planet, etc. so we need to make this extinct. (Holly, Liverpool T)

As Holly's quote indicates, technology that continued to rely on gas was viewed by some participants as outdated, even "extinct," and insufficiently progressive. Others in the group raised similar concerns that "the technology has been and gone and we now need to move forward" (Ben, Liverpool T). Given general satisfaction with GCH, and the rationale for changing

domestic heating systems in order to meet net zero carbon-emissions targets, some viewed options that were not seen as adequately addressing carbon emissions as "a bit pointless" (Becky, Gloucester) due to "still relying on the old system" (Alistair, Scottish Borders). Therefore, an innovative, progressive system that addresses emissions reduction was seen as important. Hot water tanks were described as particularly problematic, with participants across the groups explicitly reflecting on this as "going backwards."

> You just used to just turn your shower on and have a shower or a bath, you know what I mean, now we've got to wait for water, buy gadgets to heat your water, oh my God, it's scary to think like we should be evolving, we're just going backwards. (Ciara, Liverpool T)

Participants gave several reasons as to why hot water tanks were viewed as a backwards step, including houses being too small or unsuitable to accommodate a tank – a particular issue for Liverpool residents in small, terraced homes – or concerns around convenience. Having responsive heating and readily available hot water was something that people were used to and would find difficult to change because "We've evolved…got too busy lives" (Linda, Liverpool C). Time pressures on family households in particular were seen as necessitating convenient and responsive systems, which made some low-carbon alternatives unappealing. As Ben (Liverpool T) put it: "But in this world of convenience and instant access to things, why would I want a heat pump?"

While many participants viewed hot water tanks negatively, some of the older participants in one group of post-1930s semi-detached homeowners had a more nuanced discussion of what "going backwards" might mean in this context:

> Gill: We're going back to the heat pumps, you're going backwards rather than forwards because we got a combi-boiler years ago, we used to have the, the water tank and the heaters. So it seems to be going backwards. But for that one, it wouldn't disturb me having that one installed, because we've got plenty of room for it in the property we've got.
> Moderator (G): Could you say a little bit more about that? About going, the going backwards thing. What, what did you mean by that?
> Gill: Well, before the combi-boilers I recall we had a water tank up in the cupboard…as kids growing up, there used to be a water tank and a heating tank, or the back boiler of a fire. You know, where you had the coal fires and used to heat up all the house.
> Moderator (G): Well, I guess, when you say going backwards, that suggests to me that that's, that that was a bad thing, and what –
> Jean: But these did away with the, with the tanks, didn't they, and the immersion tanks, and then on, on one of them then, they're talking about.
> Gill: Reintroducing them again. That's not a bad thing. But it's going forward with things, isn't it? You know, there's, there's new things coming out, obviously saving energy, because the planet. So, it's, it's not a bad thing. Not to say they, everything refreshes and gets, you know, cheaper to run and better for the environment, isn't it? You know, so that one, to me, would be going backwards in a more positive way, if that makes sense?
> (Cardiff, OO)

Gill draws on her experience of past heating systems to position heat pumps as both going backwards because of the reintroduction of hot water tanks and going forwards because of "saving energy" and "the planet." In concluding that heat pumps would be "going backwards in a more positive way," Gill indicates that the cost, energy, and environmental benefits make heat pumps a positive option overall, representing some beneficial aspects of past ways of doing things, despite water tanks being potentially problematic (albeit not for Gill's household). This shows some similarities to the discussion of laundry drying being an older way of doing things, but one which has potential benefits to current consumers. These past and present experiences were intertwined in views of whether energy-system transition could be considered an upgrade, as we consider in the final data section.

Understanding what constitutes an upgrade

The language of "network upgrades" was used in workshop materials, reflecting policy and technical literature (e.g., NAO 2020), which carries connotations of improvement, as discussed earlier. However, some participants queried the terminology:

> Neil: Is it an upgrade or is it a switch? How is this being positioned overall? Which word would be more suitable?
> Moderator (N): That's a good question. I'm not sure…Is it an upgrade?
> Neil: It is, isn't it? We're saving the planet. We're reducing our reliance on Russia or whoever else.
> (Gloucester)

Here, despite earlier concerns about cost, Neil interprets the transition to low-carbon heating as an upgrade because it is addressing energy security as well as "saving the planet." This illustrates how participants' understandings of improvement went beyond their own households to wider societal concerns. The term "upgrade" was also used in the workshops in relation to changes to homes to increase energy efficiency. While houses are frequently remodeled or remade to reflect homeowner aspirations, enhancing the environmental performance of a home is not necessarily seen as an improvement in the same way (Maller and Horne

2011). However, an alternative discourse was how these changes could enhance and add value to homes:

> Moderator (N): Alistair, you said, oh it's just an upgrade, just earlier, what, what was going through your mind when you were thinking about that?
> Alistair: The amount of work I had to do [laughter]. That is, is, in theory is, it's nothing great, just putting insulation in and change the pipes…improving the property as well.
> (Scottish Borders)

Across the groups, participants indicated that uncertainty over low carbon-heating options and whether these may be superseded by an alternative in the future, meant uncertainty as to whether a low carbon-heating system would add value to their properties, which might have implications for resale value for homeowners, or potential rent increases for tenants.

Crucial to perceptions of improvement were experiences with current heating systems and what potential future options might be available. For example, a group of homeowners in Liverpool with GCH viewed the proposed low carbon-heating options quite negatively. The following discussion occurred during the personas task in a scenario where gas boilers were no longer available, and participants were asked how their created personas might feel about hydrogen, heat pumps, or hybrid boilers.

> Lee: I think that, like, if it's something new, you'd be expecting it to be something better.
> Gordon: Yeah, yeah
> Lee: Do you know what I mean? Like to say we're going to do all this work, and it's going to cost you a little bit more, or we're gonna do it all this work, and it's gonna stay the same, it's like, what's the point? Like you've had all this, you've had these like, since 1969, you've had natural gas, so you've had all these years to be considering this, and you're telling me it's just going to be the same, or it's not going to be the same, but it's going to cost you a little bit more.
> Jason: I think, the other side of it though, if they're your only options, then that's it, isnt it?
> Moderator (G): Katie, you were shaking your head and saying you wouldn't be happy if those were the choices?
> Katie: No. No, I wouldn't be happy with those choices.
> Gordon: What gets me though.
> Moderator (G): Is it the same thing, it doesn't feel like an improvement?
> Katie: No, it doesn't.
> (Liverpool C)

Participants expressed a view that low-carbon heating options do not represent an upgrade or improvement, with Lee indicating frustration with lack of progress over time. Participants were made aware of plans for a trial hydrogen village in nearby Ellesmere Port and this negative reaction appeared to partly be influenced by the potential for hydrogen to be introduced in the area. Several participants were concerned about hydrogen due to potential costs, safety concerns, and perceived lack of innovation or progress in relation to decarbonization. Instead, several in this group expressed a preference for heat networks but thought this was unlikely to be a feasible option for their own homes. In contrast, tenants in the Scottish Borders group, who had expressed dissatisfaction with their current storage heaters, did see low-carbon heating as an upgrade:

> Moderator (G): Are we enthusiastic about these options or not?
> Suzi: Compared to what I've got now, hell yeah.
> Sophie: Yeah.
> Callum: Yeah.
> Sophie: I'd agree with that.
> Moderator (N): Is that because of the costs and the, the environmental impact?
> Suzi: The rubbish storage heaters that, you know, we have at the moment.
> Sophie: Yeah.
> Moderator (N): Yeah.
> Moderator (G): So, for you it does actually sound like an upgrade, cos we've, we've…
> Suzi: Oh totally, yeah.
> Moderator (G): …we've been describing this stuff as a, as a heating upgrade, yeah, does it actually feel like an upgrade when you, when you hear about it?
> Callum: It would be for us, yeah.
> (Scottish Borders)

These participants were not using their storage heaters due to concerns about cost, as well as finding the advance planning required by the system inconvenient. In such cases, low carbon-heating options – particularly heat pumps as the most likely option for their homes – were therefore seen as offering an improvement. The geographical context is relevant here, given Scotland's high proportion of off-gas households and higher proportion of fuel-poor households (DESNZ 2023), which may mean low-carbon options are more appealing than to those with GCH. However, others in this group with different current heating sources were more wary about transitioning to low-carbon options – such as heat pumps – due to perceptions that they were ineffective from hearing of others' experience. This reflects how technologies may enter the public consciousness by word of mouth, while remaining largely unfamiliar (Gordon, Balta-Ozkan, and Nabavi 2023b).

Discussion

Our analysis has shown how cost was a primary concern for participants, yet lower cost heating options were not always favored if they were not also perceived to represent improvement or progress. Participants showed awareness of the need to transition away from fossil fuel-heating systems, therefore technologies that involved continued reliance on fossil fuels were viewed by some as insufficiently progressive, evident in the language some used in terms of extinction and evolution. This supports existing research highlighting the value of improvement, with some technological interventions viewed as a non-transition (Butler et al. 2015).

Our research adds detail to this prior discussion, indicating that costs and emissions are relevant considerations to understandings of improvement, while notions of convenience are more complexly intertwined with perceptions of progress. For example, some participants spoke of their preparedness to hang washing out on lines, which was less convenient than the use of tumble dryers but saved on costs and energy use. Conversely, hot water appeared to be an area where many participants were unwilling to compromise on convenience. Water tanks were therefore perceived by several to be incompatible with daily practices and ordinary routines (Judson and Maller 2014), which could hamper their adoption. This may be partly influenced by perceived in/ability to time shift particular aspects of everyday routines (Friis and Christensen 2016), which is often intertwined with family routines and relationships. Understandings of comfort and convenience were frequently discussed in terms of relations to others, with waiting for hot water viewed as particularly unsuited to the time pressures of modern family life (Bolton et al. 2023). This highlights the relevance of the relational context of heating for understanding what may constitute an inconvenience or unacceptable disruption (Thomas et al., 2024). These findings highlight how there is scope for further work to consider the distinction between valued aspects of past practice and that which is regarded as outdated or regressive.

We suggest that a temporal perspective can illuminate new insights in relation to low-carbon heating, given our research indicates that perceptions of improvement were fundamentally related to participants' experiences with past and current heating systems. Our data suggest that meeting or improving on the experience of GCH is challenging given participants' experience of these as convenient and responsive systems. In contrast, those with expensive, inefficient, or inconvenient heating systems, such as storage heaters, were more positive about the prospect of low-carbon heating offering an improvement to their everyday lives. While participants indicated current awareness of climate change and recognized the need to address emissions from fossil fuels in future energy-system transition, other temporally immediate demands – such as the ability to pay high energy bills – often took priority. Recognition of these competing temporal pressures is important in understanding people's ability and willingness to adopt low carbon-heating options.

Conclusion

Given the recognized importance of public acceptability regarding energy-system transitions, our work makes a relevant contribution, going beyond a sample who have opted for or may be able to pay for low carbon-heating retrofit to elicit a range of concerns about the transition to low-carbon heating. Our temporally sensitive approach highlights the value of contextualizing participants' views on future energy-system change in relation to past and present experiences to understand how they perceive improvement in relation to domestic heating systems. While past transition from coal to GCH was described in terms of clear and visible progress that addressed a pressing need and improved everyday life, participants did not view the transition to low-carbon heating in the same way, expressing uncertainty regarding the timescale over which this was required. With the motivation to change to low-carbon heating framed primarily in terms of addressing decarbonization, participants were therefore often critical of proposed technologies that did not appear to adequately address these concerns, which potentially diluted the perceived urgency of the problem. Our findings suggest that policy must be sensitive to shifting social contexts and indicate how, over a clearly articulated timescale, low carbon-heating technologies can represent improvement by going beyond decarbonization to address other pressing concerns to avoid this incongruence.

Given acknowledged low public awareness and lack of familiarity with low carbon-heat technologies, there are methodological challenges for researching public preferences (Becker et al. 2023). While our study addresses an identified need for deliberative methods in this area (Scott and Powells 2020), the way in which information is presented to participants has implications for their responses (Thomas et al., 2024). Our qualitative research provides detailed insights into participants' views of different low carbon-heating options and how this relates to their past and current experiences, housing, and locations.

We have indicated geographical variation in how participants viewed low-carbon heating, related to housing type and current heating systems, as well as likely options for their own situations. Future research could usefully expand this work to other geographical areas, housing types, and demographic groups as efforts to decarbonize domestic heating continue.

Notes

1. The Home Upgrade Grant is available to homeowners in England who do not have a gas boiler to make energy-efficiency improvements. See https://www.gov.uk/apply-home-upgrade-grant.
2. The Boiler Upgrade Scheme covers partial costs to support UK homeowners to replace fossil-fuel boilers with a heat pump or biomass boiler. See https://www.gov.uk/apply-boiler-upgrade-scheme.
3. A combi-, or combination, boiler provides central heating and hot water from one unit. Over 80% of UK boilers are combi-boilers. https://www.uswitch.com/energy/boiler-statistics.

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Data-availability statement

The data are not publicly available as they contain information that could compromise research participants' privacy and consent.

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