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Feeling the heat: Understanding stakeholders' perceptions of residential-sector heating decarbonisation options in the UK

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ABSTRACT

The reliance on natural gas for residential sector heating in the United Kingdom (UK) presently accounts for around a fifth of national greenhouse gas emissions. Phasing out this reliance is considered important as the UK's 'Net-Zero' ambitions. Alternatives to a reliance on natural gas, include the use of hydrogen boilers and electrification using heat pump technologies. The acceptance of these technologies among different societal actors (including publics) will play a significant role in which are backed, available, and used.

The aim of this study was to consider the perceptions of key stakeholders in the UK residential heat decarbonisation sector about: (a) policies pertaining to this sector; (b) the factors likely to shape public acceptance of hydrogen and heat-pump technologies; and (c) the prospect of repurposing the gas pipeline network to support heat decarbonisation. Interviews were held with 12 stakeholders from the UK's residential heating sector. Interviews were supported using bespoke 'flash cards' to convey core details about each of the options under consideration.

Interview principally considered the relative strengths and drawbacks of hydrogen versus 'standard' heat pump options, with discussions centring on four primary themes: Relative risks and benefits; Public choice and control over residential heating options; Engaging with the public throughout the energy transition; and Envisioning future energy transition scenarios for residential home heating.

The findings confirm that the factors and actors feeding into the relative 'acceptability' of each option are manifold, and that the 'acceptance' of each option is tied to factors, such as: (a) the consistency of policy signals from government; (b) the relative affordability of the technology; and (c) both the physical infrastructure and social aspects of the local development context. The concept of repurposing the gas pipeline network was considered to be a good idea in principle, although enthusiasm was heavily caveated with reference to the practicalities of achieving this goal.

1. Introduction

In 2022, the UK's residential sector is estimated to have been responsible for about 17% of all national carbon dioxide emissions (Committee on Climate Change, 2022; Department for Energy Security and Net Zero, 2024). This makes the decarbonisation of the residential sector a crucial step in meeting the UK's aspirations of becoming a 'Net Zero' economy by 2050 (UK Committee on Climate Change, 2020; Department for Business, Energy and Industrial Strategy, 2021). With around 85% of UK households currently using natural gas (methane) for space and water heating (Department for Business, Energy and Industrial Strategy, 2018), phasing out a reliance on gas for these purposes is considered a key part of the equation (BEIS, 2022; Committee on Climate Change, 2019; Eyre & Baruah, 2015; Salite et al., 2024; Slorach & Stamford, 2021).

Set against the back-drop of the UK's transition to low-carbon

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residential heating, this qualitative, semi-structured interview study considers the perspectives of 12 residential-heating sector experts (i.e. 'practitioners') about: (a) UK policies for residential heat decarbonisation; (b) the factors shaping public (intentions to) uptake and use hydrogen and heat-pump technologies; and (c) the repurposing of the natural gas pipeline network to support the use of hydrogen and augmented heat pump technologies (aligned with the *GasNetNew* project).

1.1. UK residential sector decarbonisation

The last 20 years has seen successive UK governments set out a range of policy interventions, communication strategies and financing measures, designed to transform and decarbonise the residential sector (e.g., Daruwada et al., 2022; Royapoor et al., 2023; Cotton et al., 2024). This has included, among other initiatives (e.g., the decarbonisation of electricity networks), public outreach campaigns focused on demand reduction and household energy retrofit schemes.

Due to their ability to conserve energy and alleviate fuel poverty, as well as support other social and economic policy objectives, there is a clear justification for investing in programmes of household energy retrofit (Kerr et al., 2017). Over the past two decades, UK government-backed schemes (including public incentivisation schemes) have been introduced to encourage the uptake and installation of energy efficiency measures (e.g., insulation), micro-generation technologies, and low-carbon heating options (e.g., heat pumps) in people's homes (Kerr & Winskel, 2020; Carter & Pearson, 2024; Salite et al.2024). These include the Feed in Tariffs Scheme, the Green Deal, the Community Energy Saving Programme, and the Boiler Upgrade Scheme, to name but a few (see Brown et al., 2024, for a summary of the UK policy context). However, uptake and delivery of some of these public incentivisation schemes and home energy retrofit initiatives has remained low for various reasons, including 'eligibility-readiness gap' (i.e., the difference between the number of households deemed to be eligible for support compared to the number that are actually ready to receive the technology), a scarcity of skilled and qualified installers, and low levels of public awareness of and motivation to engage with such schemes (Castaneda et al., 2020; Elsharkawy & Rutherford, 2018; Jenner et al., 2013; Lamb & Elmes, 2024). Ongoing (and future) attempts to decarbonise the residential sector will thus require more efforts to better understand the mix of factors (e.g., funding availability, infrastructural readiness) and actors (e.g., installers, publics) that drive or inhibit the uptake of innovation in this sector (Selvakkumaran & Ahlgren, 2019; Royapoor et al., 2023).

A significant part of the UK's 'issue' around residential sector decarbonisation is the continuing heavy reliance on natural gas for water and space heating. Two of the primary alternatives to natural gas being considered in the UK are: (1) the electrification of heating via an expanded use of heat pumps; and (2) the use of hydrogen as either a partial (i.e. blended) or complete substitute for natural gas in domestic boilers. Heat pumps are used to extract energy principally from air, ground or water-sources, allowing for it to be used for the purposes of space and water heating (Gaur et al. 2022). Heat pumps sit alongside other forms of electrification, including the use of electric resistance heaters and electric storage heaters.

Previous research has provided insight into the relative advantages and disadvantages of these two low-carbon alternatives for residential heating with regard to their practical viability, output quality, safety, and performance (Fernández-Dacosta et al., 2019; Acar et al., 2019; Gaur et al. 2022; Bartela et al., 2022). As in -depth review is beyond the scope of this article, we have instead provided a summary of the key advantages and disadvantages of each option is provided in Table 1.

In the face of ongoing policy and technological innovation in the sector (e.g., solar assisted thermochemical heat pump technologies) and in the wake of some failed large-scale demonstration hydrogen projects (e.g., Whitby 'Hydrogen Village'), there remain questions about the relative social acceptability of these technologies. Blue hydrogen, for instance, is hydrogen produced by fossil fuels and refers to the combination of brown/grey hydrogen and carbon capture and storage (CCS; Lagoia et al., 2023). Although viewed by some as an important energy carrier in a future decarbonized world, sometimes promoted as producing low carbon dioxide emissions, controversy remains around blue hydrogen with many (e.g., Hannan et al., 2025; Howarth & Jacobson, 2021; Noussan et al., 2021; Pingkuo & Junqing, 2024) questioning how green it truly is. Furthermore, there remains a high number of unsolved issues relating to blue hydrogen, including technical challenges, economic and geopolitical implications which can influence people's social acceptance of this alternative technology (Gordon et al., 2022, 2024). Nonetheless, like all alternative technologies (e.g., heat pumps) aimed towards achieving residential decarbonisation there is a greater need to have a clearer vision on ways societies can transition to low-carbon residential technologies (e.g., hydrogen, and heat pumps) which are based on a broader global perspective (Noussan et al., 2021).

The current study forms part of the *GasNetNew* project, an interdisciplinary research programme designed to help support residential decarbonisation in the UK. In addition to modelling residential heating demand, *GasNetNew* project *is* developing thermochemical and water-

Table 1
Advantages and disadvantages of the use of hydrogen and heat pumps as alternatives to natural gas for residential sector heating.

Option	Advantages	Disadvantages
Hydrogen	● Potential of repurposing the natural gas grid. ● With further investment and economies of scale, costs of producing and supplying hydrogen energy can be brought down, with green hydrogen potentially becoming cost-competitive with natural gas by 2030. ● There are potential other markets for hydrogen, e.g. within the industry sector. ● It allows the 'disused underground salt caverns may be used for seasonal storage of the hydrogen. ● With the growth in renewable sources (for H2 generation) and with more storage capacity, payback times for investment in hydrogen technologies will reduce. ● Once installed in people's homes, boiler units should operate 'like-for-like' with natural gas boilers.	● Within a closed environment (like a house) there is a slightly higher risk of leaks with hydrogen than natural gas at present. ● More research is needed to understand the benefits and risks of using hydrogen in certain types of industrial processes, domestic properties and buildings. ● Carbon dioxide emissions are a by-product of some forms of hydrogen production. For example, when using steam reformation to produce hydrogen from fossil fuels. ● Hydrogen has a wider range of flammable concentrations in air and lower ignition energy than gasoline or natural gas, which means it can ignite more easily, posing a risk.
Heat pumps	● Heat pumps are relatively safe, assuming good design and proper installation. They do not heat water to near-boiling temperatures. ● Air and ground-source heat pumps will reduce carbon emissions depending on the source of electricity used to power them. ● Upfront capital and installation costs to the consumer are offset by lower running costs compared with traditional gas-heating systems.	● The electricity grid upgrades required to support the installation in an individual house can take 4 weeks to complete. ● Payback periods can vary, but on average they start from 10 years plus. ● More research is needed to understand the safe use of chemical source heat pumps in certain types of domestic properties and buildings.

*All information is collated from Fernández-Dacosta et al. (2019); Acar et al. (2019); Gaur et al. (2022); Bartela et al. (2022); Scovell (2022); Gordon et al. (2022); Sadeghi et al. (2022).

source heat exchangers to support residential heat pump technologies (Famigliett et al., 2023). Associated with this, the project is examining how the legacy natural gas pipeline network in the UK could be used to either extract hydrated thermochemical solutions from households (supporting thermo-chemically assisted heat pumps); or transport non-potable water to households (supporting water-source heat pumps). Another branch of *GasNetNew* project is researching the potential for parts of the gas pipeline network to be used for adiabatic compressed air energy storage (CAES) (see Bartela et al., 2022). The remainder of this introduction outlines the importance of considering the social acceptance of innovations in residential heat decarbonisation (another key facet of the *GasNetNew* project) before outlining the specific focus on the current study in this regard.

1.2. The importance of assessing social acceptance

A key determinant of the success of technology and policy interventions is whether they are deemed to be 'acceptable' and are thus 'accepted' by societal actors. Studies into the social acceptance of emerging energy technologies have thus increasingly become a part of the research and development cycle (Boudet, 2019; Ingeborgrud et al., 2020; Jones et al., 2017). Understanding about the concept of social acceptance continues to develop (Windemer, 2023), however, prominent theoretical frameworks tend to agree that it should be treated as multi-actor and multi-level (Devine-Wright et al., 2017; Upham et al., 2015). Several frameworks, for instance, delineate between acceptance at the macro (e.g. societal, national), meso (e.g. community, regional) and micro (e.g. household) scale and among key actor groups, including policy actors, publics and 'other' stakeholders (Gordon et al., 2022). The 'other' stakeholders tend to include business and industry, academic, NGOs, and charitable organisations, among others. It is the attitudes, actions and interactions among these different actor groups at different scales, which can ultimately determine the acceptability and societal readiness for the introduction of a new technology (Gordon et al., 2022).

There is a growing literature that speaks to the nature and determinants of the social acceptance of residential sector heating innovations, including the uptake and use of heat pumps and hydrogen. This has included studies focused on perspectives at the macro level (i.e. acceptance 'in principle'), as well as at the meso- and micro-levels relating to their community and household-scale deployment (Gordon et al., 2022; Scovell, 2022; Thomas et al., 2024).

The extant research in this space has begun to identify some of the key barriers to engagement in demand response initiatives relevant to heat pumps and the uptake of low-carbon energy options among UK households. Demand response is a program that encourages households to use less electricity during peak hours by adjusting their heat pump usage, thus reducing strain on the power grid (Barani et al., 2024; Chantzis et al., 2023; Crawley et al., 2021). For instance, Parrish et al. (2020) in a systematic review of consumer engagement with residential demand response initiatives, identified a range of important factors. Positive drivers for enrolment included the anticipated environment and (more importantly) financial benefits, and barriers included a lack of familiarity with the concept of demand response and mistrust in the motivations of the organisers of schemes. Other factors included the beliefs about the extent to which demand response would facilitate (rather than disrupt) existing household routines, the perceived complexity and effort required to engage with the schemes, and the anticipated risks (e.g. less predictable pricing, technical issues) and reduced control by users (Barani et al., 2024).

The importance of the concepts of trust and financial consequences were also evident in work by Gordon et al. (2024) in relation to the use of hydrogen for residential heating. In a series of 10 online focus groups with members of the public, they explored the acceptability of the UK hydrogen transition at the macro-, meso, and micro levels. This study highlighted a trust deficit in government and energy suppliers and the associated need to ensure fairness and equity across different communities in the pursuit of heat decarbonisation and Net Zero (see also Dillman & Heinonen, 2022). It also demonstrated that there was an openness to switching to hydrogen, this was contingent on there being a 'price pledge' on energy bills to assist with the transition (e.g. to assist with appliance purchases).

While studies into the opinions of publics towards the low-carbon residential energy transition (e.g. in their role as householders and/or prospective recipients or consumers or technology) have grown rapidly, there has been comparatively less focus on eliciting the opinions of other social stakeholders. This is in spite of their potential to offer informed and/or different perspectives on energy transitions, including in relation to how publics might think and behave in relation to new technologies (Ercan et al., 2024). For example, in relation to residential heating, Lowes and Woodman (2020) following semi-structured interviews with experts in UK heat policy (including a politician, political advisors, industry-based policy experts, and civil servants), concluded that policy makers view heat decarbonisation as fundamentally disruptive, particularly for consumers, with little up-side. Among the policy implications stemming from their study, they highlight how the prospects of disruption and increasing energy costs for consumers might limit the political will to deliver on heat decarbonisation policy, particularly among politicians seeking re-election. Relatedly they advocate for the pursuit of further, low-risk trials (e.g., in off-grid communities) to help reduce uncertainty around technologies and approaches while also affording opportunities to learn about how best to limit consumer disruption.

In another study, based upon 58 semi-structured interviews with 'practitioners' (e.g., industry professionals, policy experts, civil servants, etc.), householders with a shared loop ground-source heat pump, and householders without a heat pump; Brown et al. (2024) reflect upon public attitudes towards GSHPs (and associated financial support mechanisms), as well as the wider policy, governance and financing requirements required to expand the implementation of this technology. In their conclusions they champion the need for stronger policies around heat decarbonisation (e.g. to give greater certainty to developers) and highlight the key role that local authorities should play in delivering projects - as trusted and empowered intermediaries (provided they are given appropriate funding and capacity to deliver). They also highlight the need for a government backed training and testing centre to upskill qualified fitters to deliver on the ambitious heat decarbonisation programmes. An interesting finding from this study was the apparent discrepancy in concerns over disruption to consumers. While the practitioners perceived this to be a significant barrier to deployment (akin to Lowes & Woodman, 2020), the householders were found to be fairly accepting of such disruption, considering it akin to other forms of infrastructure disruption.

These and other studies (Gordon et al., 2022; Thomas et al., 2024) not only begin to highlight emerging trends in the drivers of the social acceptance (or rejection) of residential decarbonisation options (e.g., the need to ensure appropriate financing for schemes and assurances for consumers, the need to employ trusted intermediaries to deliver schemes), but also attest the value of assessing the viewpoints of a range of stakeholders, including 'practitioners' when seeking to more fully understand the motivations, enablers and barriers to residential sector decarbonisation.

1.3. Aim of the current study

The aim of this study was to consider the perceptions of key stakeholders ('practitioners') in the UK residential heat decarbonisation sector about: (a) policies pertaining to this sector; (b) the factors likely to shape public acceptance of hydrogen and heat-pump technologies; and (c) the prospect of repurposing the gas pipeline network to support heat decarbonisation. The contribution of this study thus lies in developing an understanding of how key stakeholders perceive the prospect of repurposing the gas pipeline network to support heat decarbonisation within a UK context. This study's findings are therefore considered novel in that they could stimulate design transformations that are derived bottom-up and may be engage in in-depth discussions and interrogations of the technologies offered.

The current study employed 12 semi-structured interviews to explore 'practitioner' perspectives on the viability of different technologies for decarbonising household heating in the UK. Our interview schedule focused on eliciting interviewees' perspectives on the use of hydrogen and 'regular' heat pumps, as well as the 'augmented' heat pump options and CAES being considered within the *XXXX* project. Specifically, interview discussions centred around four primary themes: (1) Relative risks and benefits; (2) Public choice and control over residential heating options; (3) Engaging with the public throughout the energy transition; and (4) Envisioning future energy transition scenarios for residential home heating. Qualitative interviewing is a common method for exploring stakeholder perceptions of innovative energy technologies, and has been used successfully in other recent studies pertaining to the decarbonisation of energy systems (Hoseinpoori et al., 2023; Thomas et al., 2024). It can provide a rich and nuanced picture of interviewees' opinions that can otherwise be lost with a reliance on more quantitative or economic tools (e.g. cost-benefit analysis and modelling techniques).

2. Methodology

2.1. Population sample and recruitment process

Interviewees were recruited using a selection criterion to ensure the population sample represented a diverse range of stakeholder views. Interviewees were selected to represent from six target groups with an interest or involvement in residential sector heating UK ('practitioners'): grid operators, policy advisors, energy providers, industry professionals, energy-focused consumer bodies, and academics. Prospective interviewees that met this selection criteria ($n = 41$) were identified via desktop research (e.g., via Google search and contacts within project team) and subsequently approached via email with an invitation to participate in an interview, as part of the initial selection process. Of the 41 people approached, 12 agreed to being interviewed (29.2% response rate). The interviewees interviewed represented the following six target groups: grid operators ($n = 1$), policy advisors providing decarbonised energy advice to UK businesses ($n = 3$), energy providers ($n = 2$), industry professional in a strategic advisory role ($n = 1$), energy-focused consumer bodies ($n = 3$), and academics researching decarbonised energy options ($n = 2$). All interviews were conducted online (via Zoom) between July and October 2023. Interviews ranged in length between 35 and 90 min (Mean duration: 51 min) and were conducted with one interviewee at a time. All interviews were audio-recorded and subsequently transcribed prior to analysis.

2.2. Materials and procedure

The project was subject to appropriate ethical review at the University of XXXX (Ref: SHFEC 2023-062). Before commencing the interview, participants were provided with an information sheet about the study and asked to sign a consent form. The interview schedule was developed with reference to themes prominent within the literature pertaining to social acceptance of residential sector decarbonisation. The full list of questions can be found in the Supplementary Materials.

The interview was broadly structured as follows:

1. *Preliminary questions:* Interviewees were asked about their organisation and their role within the organisation, and their familiarity with the UK residential heating sector. Interviewees were also asked to reflect on their opinion of the current trends towards residential sector decarbonisation through the replacement of gas boilers with heat-pumps, and the trials using hydrogen as a full or partial replacement for natural gas.
2. *Discussion of the technology options:* All interviewees were then invited to think about the future, where natural gas had been phased out and was no longer used in residential heating. In this context, they were invited to consider the relative costs, risks, benefits and overall social acceptability of six technology options: (i) hydrogen; (ii) air-source heat pumps; (iii) ground-source heat pumps; (iv) heat pumps supported by a water-source heat exchanger; (v) heat pumps supported by a thermochemical heat exchanger; and (vi) compressed air energy storage (CAES). The study did not include heat networks as a further alternative technology option as the existing gas network pipes are not entirely well suited for conversion into district heat as they are not well insulated (e.g., the soil temperature will be lower than the heat network). Instead, we selected those alternative technology options where the gas network with as little change as possible. To assist interviewees in the process of making comparisons, they were each provided with a series of 'flash cards' to look through (outlined below). Each card provided a brief description of one of the six options alongside expert-evaluations of that option in terms of its performance against seven criteria (e.g., investment payback time, carbon abatement potential).
3. *Recommendations for the future:* Interviewees were finally asked to outline their personal recommendations for the future of decarbonising UK residential heating. In doing so, they were invited to consider the utility of the options provided within the interview, as well as making any more general recommendations or comments. All interviewees were then thanked for their time and dismissed.

2.2.1. Flash cards

Information cards ('flash cards') containing brief details about each technology option to be considered within the interview were prepared and provided to interviewees. The use of flash cards (or 'cue cards') has a long history within qualitative research, helping to challenge existing ways of thinking and open-up conversations by overcoming shyness or reticence, and by giving participants greater control over aspects of the research process (Harada & Waitt, 2024). The flash cards were developed in association with the diverse group of chemical, mechanical and design engineers that make up the project team. Fig. 1 provides an example of one of the flash cards (i.e. the Hydrogen flash card). All the flash cards developed and used in the study available in the Supplementary Materials. The flash cards had a dual purpose within the interview: (1) to ensure that interviewees were more familiar with the technologies under discussion, so as to elicit more informed opinions; and (2) to be provocative, such that interviewees would actively weigh-up and critique the options. As such, we were open to dispute about the information on the cards, to the extent that this provided an opportunity to more fully explore interviewee perspectives on the comparative strengths and weaknesses of the different options.

The flash cards took a comparative 'Top Trumps' style format. 'Top Trumps' is a card game where objects (e.g., animals) are rated against a common set of criteria (e.g., speed or strength). 'The higher the score the object receives for each criterion, the better the object is judged to be for that purpose; an overall judgement can also be made based on the combined scores. This 'Top Trumps' style approach has been utilised successfully in prior research designed to gain informed perspectives on emerging energy technologies, including carbon dioxide utilisation (Jones et al., 2014) and heat decarbonisation (Thomas et al., 2024). In the current context, the six technology options were introduced and evaluated against seven criteria: (i) investment payback time; (ii) market potential; (iii) carbon reduction or abatement potential; (iv) safety; (v) cost benefit to the consumer; (vi) date to commercial viability; and (vii) ability to promote 'business as usual' operations. Outline descriptions of these seven criteria are provided in Table 2. Each criterion (except for commercial availability, which was estimated in years) was provided with an 'expert rating' on a scale of 0–10, with higher scores equivalent to a better assessment on that criterion (e.g., greater strength,

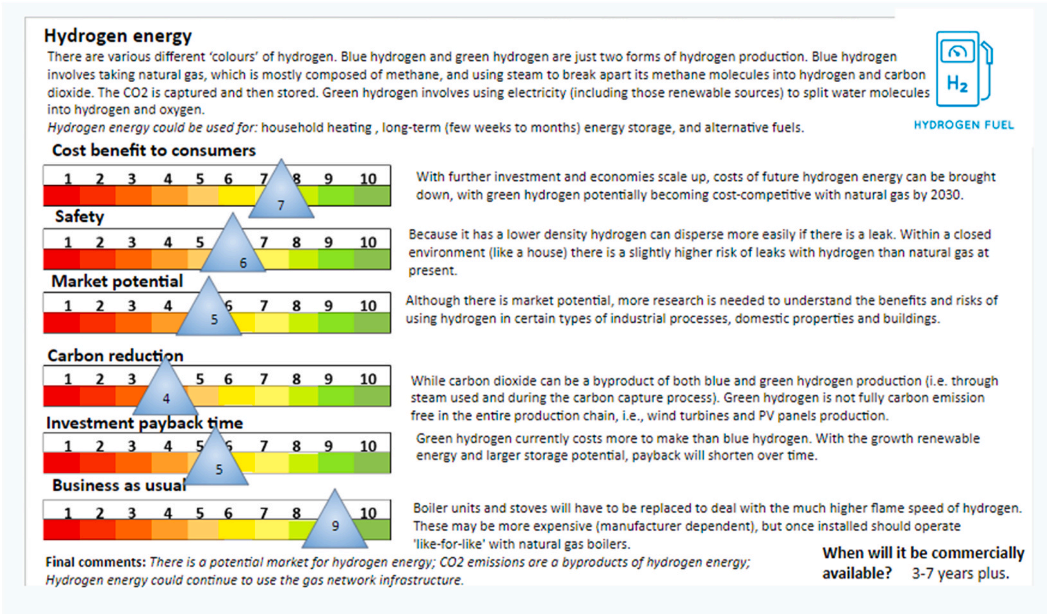

Fig. 1. The hydrogen 'Top Trump' information flashcard used to prompt discussion within the stakeholder interviews.

Table 2
Description of the criteria used to rate each of the residential home heating options within the flash cards.

Criterion	Description
Cost benefit to consumers	The monetary benefits to consumers (e.g. prospective savings on energy bills) after installing or accessing the option. Higher scores equate to greater cost benefit.
Safety	The degree to which a product can cause health and/or safety risks to consumers when used in residential heating applications. Higher scores equate to greater safety.
Market potential	An estimate of the potential revenue that could be secured by retailing the option within existing industry, investor and consumer markets. Higher scores equate to higher market potential.
Carbon reduction	The reduction of carbon emissions that could be yielded were there to be widespread deployment of the option in the UK residential sector. Higher scores equate to greater carbon reduction potential.
Investment payback time	The length of time that it would take those investing in the option (including consumers) to recover the costs of their financial outlay. Higher scores equate to quicker return on investment.
Business as usual	The degree of disruption caused to householders and/or the wider community when installing and using the option. Higher scores equate to less disruptive and more 'business as usual' continuation of residential heating practices.
Commercially available (years)	An estimate of when the option will become widely commercially available to installers and consumers.

lower risk).

2.3. Analysis approach

Qualitative thematic analysis was conducted by the lead author using NVivo (Version 12). All the stakeholder interview discussions were transcribed and analysed using inductive six-phased framework as outlined by Braun and Clarke (2006) (i.e., data familiarisation, initial code generation, search for key themes and sub-themes, review of themes and sub-themes, final definition of themes and subthemes, and write-up). This approach is commonly used to categorise and link prominent themes and opinions within qualitative data, allowing for meaning to be negotiated, codified and presented (Williams & Moser, 2019).

3. Findings

Four primary themes were identified from the interview transcripts: (1) Relative risks and benefits; (2) Public choice and control over residential heating options; (3) Engaging with the public throughout the energy transition; and (4) Envisioning future energy transition scenarios for residential home heating. Central to the practitioner discussions was the critical appraisal of the viability of repurposing of the gas pipeline network to support each of the different technology options considered. This critique, both positive and negative, is reflected in the quotes presented in the below subsections 3.1 to 3.4. In each case the interviewee number (#1 to #12) and affiliation of the person providing the quote is provided.

3.1. Relative risks and benefits

Interviewees considered the risks, benefits and feasibility of the six presented options, in the context of wider residential heating reforms and the pursuit of Net Zero. These critical discussions, both positive and negative, were prompted by the criterion assessments presented on the flash cards and map to the following sub-themes (3.1.1–3.1.4): health and safety issues, the practicalities of repurposing the gas network, carbon reduction potential, and implications for workforce employment. While there was consideration of all six options presented, the primary focus of the practitioners was on considering the relative benefits of hydrogen versus heat pumps. CAES was considered to be less applicable within the context of residential sector heating applications, and practitioners were less familiar with the technology, and so it tended not to be discussed as frequently.

3.1.1. Health and safety issues

Safety was a primary focus for the practitioners when considering the technology options presented. Most practitioners identified hydrogen as posing the most substantial safety risks and drawbacks. There was concern about the safety risks posed by hydrogen both during its transportation (particularly if using the existing gas pipeline network) and during its use within the home environment. Concern not only related to the general potential for gas leakages (and related human health implications) and changes to the gas flow in the pipeline, but also the potential for the build-up of the flammable gas within enclosed household environments. While analogous to the safety risks posed by natural gas, being a lighter gas and one less familiar to consumers, hydrogen was considered to pose additional safety risks in this regard. For example, one participant noted:

"I am concerned by the safety issues of hydrogen because of the interaction with the user. You know, hydrogen is a fundamentally different chemical. It can leak out of a really tiny hole and really quite quickly. As long as you've got enough ventilation then that is not a problem because it disperses. … And the idea that the householder won't go, that's a bit draughty. I'm going to shove something in there and block it up. That worries me because that's what people do if they don't understand a new system. And if you tell them they absolutely can't cause otherwise the house might blow up. Well that's scary" (**#12, Industry Professional**).

By contrast, the interviewees tended to view air-source, ground-source, and especially water-source heat pumps as being relatively safe options. This both extended to considerations of their use within the home environment and, in the case of water source heat-pumps, to the prospect of transporting water to homes using the legacy gas pipeline network. Interviewees tended to refer to heat pumps as being 'tried and tested' options, which have a long history of use for residential heating. That said, while acknowledging their general safety record, one interviewee did caution (based on anecdotal experience) against the fire risks associated with heat pumps. In doing so, they referred to the public underestimation of risk associated with electrical appliances (relative to gas appliances), which could lead to potential complacency among heat pump owners:

"*A heat pump is pretty safe. I would note that. We actually had a fire on the electrical installation on our heat pump. Thankfully the fire was outside the house. But people have a very different attitude towards gas safety than they do electrical safety. But the reality is you have a higher number of electrical instances in homes than you do gas*" (**#4, Energy Provider**).

While heat pump technologies were generally favoured in terms of their safety, some concerns were raised about the installation and use of thermochemically-assisted heat pumps. Practitioners voiced their inability to reflect on safety issues associated with repurposing the existing gas pipe network to support this technology, due to their unfamiliarity with the concept. However, citing this option's reliance on hazardous chemical substances (e.g., ammonia), there were questions about the potential risks to human health (if the system was not self-contained) within households supporting this technology, and whether it was safe for residents to directly handle the chemicals:

"*You know ammonia is not nice really. I mean, OK, you wouldn't expect it to leak. It should be self-contained.*" (**#9, Senior Policy Adviser**).

3.1.2. Practicalities of repurposing the gas network

Most interviewees reflected on the practicalities of repurposing the gas pipeline network to support each of the different options. The nature of their reflections tended to relate to their general roles and responsibilities within their sector. While hydrogen and compressed air (CAES) were generally felt by most to offer a more '*business as usual*' means of repurposing the network – given that these options essentially exchange natural gas for another gas (i.e., hydrogen or air) – others welcomed the potential to use the network to support alternative residential heating options, including the water-source heat pumps proposed by the *XXXX* project. The reasons cited for this primarily centred on the cost-effectiveness of repurposing the gas pipeline network for transporting water to homes as opposed to extracting and installing new infrastructure. It was also anticipated that repurposing would be less disruptive to different stakeholder groups (e.g., industry, householders), and would lessen competition for subterranean road space:

"*Yeah, why not? I mean, if it's fit for purpose because it's, you know, huge volume, it's widely spaced and it's you know more widely available. Again, it's bringing the principle back to being close to the point of use. You know it would help tick that box.*

"You could carry on as you are. Digging up the roads. And pouring money into digging up roads and putting our big pipes of water in under the roads. … [Or] why don't we use the gas companies' big yellow pipes [that] are already there. Gas companies can then buy that off us and sell it on to the customer at the other end or we will pay the gas company and use the system charge" (**#12, Industry Professional**).

While there was some enthusiasm for the potential to repurpose the existing gas pipeline network, this was tempered by considerations about the necessary work that would need to take place ahead of any such repurposing, whether to support the transport and storage of another a gas or to provide other services (e.g., to carry water or chemicals). It was reasoned that repurposing the network would need to be done for a single dedicated purpose (e.g. for the transportation of hydrogen *or* for use in CAES), with repurposing for multiple purposes seen as creating a variety of health and safety concerns (e.g., those that might come associated with the mixing compressed air and hydrogen). It was also recognised that there would need to be (potentially costly) upgrades to parts of the existing gas pipeline network to support any repurposing, whether through the creation of additional pipeline infrastructure (e.g. to remove thermochemical waste from homes) or the need to exchange parts of the pipeline network to store and transport hydrogen gas more effectively. This led some interviewees to question the value of repurposing the network to support residential heating applications:

"*Even if we're reusing the natural gas network, we can't simply put hydrogen straight into the existing natural gas network. So, there's considerable costs associated with upgrading that. I think it's got quite an infrastructure cost. I think there's better uses of hydrogen, certainly. As we begin to ramp up green hydrogen production, I think it's better used for that in industry and potential in transport than large vehicles. So, I would prioritise using it there first and I think we need to do something else for building it*" (**#11, Academic**).

3.1.3. Carbon reduction potential

Interviewees discussed the relative carbon reduction benefits that could be yielded reasonably achieved from each of the six options. The benefits that could yielded by hydrogen, for instance, were considered with reference to the way in which the hydrogen would be produced. For some, it was felt that 'blue' hydrogen (derived from fossil fuels with carbon capture) or 'grey' hydrogen (derived from fossil fuels without carbon capture) would be the primary source in the short term, until such time as lower carbon options were more readily available (e.g. 'green' hydrogen produced through the electrolysis of water using renewable energy). This led to some scepticism over the potential carbon reductions that would be achieved by switching to hydrogen the short term and thus whether 'Net Zero' targets would actually be attainable via this route alone. This, in turn, raised the question of whether there would also need to be the larger-scale deployment of other energy technologies (e.g., heat pumps) within the residential sector need to support the switch to hydrogen.

Other interviewees queried whether or not it would be feasible to scale-up the production of hydrogen sufficiently to satisfy UK residential heating demand. As such, the prospect of using hydrogen to support other sectors (e.g., industrial sector) was seen as a more appropriate goal:

"I mean, there seems to be a bit of a leaning towards green hydrogen, which is fine. The challenge with that is going to be the availability of it in sufficient quantities anytime soon" (**Interviewee 11, Academic**).

In contrast to hydrogen, heat pumps (including water-source and thermochemical option) were perceived as having greater potential to reduce carbon footprints within residential heating. This positivity was, however, caveated by an awareness that the potential decarbonisation that could be afforded by heat-pumps would be tied to the decarbonisation of the electricity used to run them and also, in the case of the thermochemical options, the carbon-footprint of the chemicals. It was also recognised that there could be geographical restrictions around the use of water-source heat pumps in certain areas:

> *"It does [water-source heat pumps] have good carbon reduction. So, the grid continues to be carbonised and heat pumps continue to become increasingly green"* (**#8, Energy Provider**).

3.1.4. Implications for workforce employment

Interviewees were also keen to point out the employment opportunities presented by the decarbonisation of residential heating in the UK. For instance, most interviewees noted that the innovation in this sector presents opportunities for those working in the natural gas industry to be retained and retrained, as well as improving the prospect of attracting a more diverse workforce (e.g. providing more women and ethnic minorities with more prominent and leadership roles):

> "*And I think that a more diverse workforce could also help the workforce better understand the people that are making decisions and the home and better trust in the workforce*" (**#3, Energy-focused consumer body representative**).

Some interviewees emphasised the associated need for a rapid roll-out of accredited training programmes (e.g., heat pump installation training) in order to achieve the target of transitioning quickly towards a Net Zero residential heating sector, regardless of the energy options eventually used. One interviewee noted that without the provision of such training there could be a risk of redundancies and/or job displacement (e.g., established engineers being usurped by younger engineers trained in modern heating systems):

> *"But they're hanging their own workers out to dry, aren't they? Because at some point the tide will turn and these people will find themselves with the skills mismatch.*
>
> *"And I wonder, are the same people that are going to be installing and servicing heat pumps as are doing the gas boilers? I don't think it's necessarily the same people unless there's a clear intervention. I think those coming out of college or whatever are going to do the more modern heating systems and these more established gas engineers will be obsolete"* (**#7, Policy Advisor**).

3.2. Public choice and control

Interviewees engaged in an interesting discussion around the concept of choice and autonomy for householders when selecting how they wish their home to be heated. While empowering people to choose was considered to be important, it was reasoned that the extent of the choices available to householders might need to be restricted. For example, options reliant on the repurposing of the gas pipeline network would likely necessitate a connection to the network in the first place. The majority of interviewees thus described the future residential heating sector as a "*patchwork of feasible low carbon energy options*", the make-up of which would vary depending on the specifics of the deployment circumstances:

> "*I think there's a phrase that I think that the gas networks and people like to use is consumer choice. Infinite choice is not helpful when we don't have the tools to make the right decisions. I think we need to empower decision making, which actually doesn't mean making every choice available. It's like either [the] area is going to have predominantly gas networks, gas, or hydrogen. We can't have both in an are*a" (**#9, Policy Advisor**).

Interviewees also highlighted that in some cases, consumer 'choice' might not be determined on an individual basis, but at a communal scale. This being due to the viability and cost-effectiveness of certain options being contingent upon the synchronised rollout at a street, neighbourhood or community scale (e.g., CAES, heat networks, hydrogen). This is likely be of particular relevance when considering the *XXXX* project options, given that these would involve a large-scale repurposing to the legacy gas pipeline in order to be practicable.

> It was suggested that the (essentially) "like for like" operation of hydrogen boilers and natural gas boilers, people's general familiarity with gas central heating and their knowledge of how to respond in the event of a boiler breakdown or emergency, as well as the continued use of the existing gas network, would likely work in favour of consumer decision regarding hydrogen.

Akin to the findings of other research, the upfront cost and operational affordability, installation disruptions (e.g., developing new or repurposing existing pipe networks), and investment payback time were anticipated to be key drivers of householders' preferences for different technology options.

> "*Costs are probably the biggest one, or rather, affordability [of installing heat pump options]. Think about the infrastructure that's required? The appliance changes in the homes? The wholesale costs? Which not everyone always considers.*" (**#10, Academic**).

Considerations of affordability of the different options also gave rise to broader discussions about accessibility and equity of access to these options (i.e., the concept of the 'just' transition). This was particularly seen as an issue among those in fuel poverty and/or those living in rented accommodation, where there might be less opportunity or control over whether to switch their means of household heating, and where such households might be further (inadvertently) penalised by efforts to reduce the carbon-footprint of the sector (e.g., through higher taxes on the use of natural gas):

> "[There's] environmental levies. *So, if we shifted towards putting the [tax] levies on gas instead of on electricity, then that might have a big impact on the investment in electric focused options. There [would be] risks around the fuel poverty impacts of this"* (**#3, Energy-focused consumer body representative**).

3.3. The need for continuous public engagement

Implementing best practices to enhance public awareness and engagement were commonly identified as key things needed to support the energy transition, both in the UK and abroad. The interviewees emphasised the need to foster trust between industry, the government and publics during the transition period, as well as the need to deepen (individualised) public understanding of the practical issues associated with installing the different types of residential sector heating options. This latter point included raising public awareness of each option's feasibility for different property types, any disruption that could be faced (e.g., timescales for installation, changes to the physical home environment), potential health and safety considerations, and any qualitative change to the heating quality (and associated sensory experience) that would be implied:

> *"It's about having conversations with every single household. To explain to them what their options are, and understand their own cause. Some homes might be perfect for a heat pump. Some homes might [not]"* (**#5, Energy provider**).

Perhaps mirroring their own perceived lack of knowledge about the *XXXX* Project options discussed at interview, the practitioners tended to believe that public-facing information on the range of heating-sector decarbonisation options was currently deficient. Even among the more well-publicised options like hydrogen and air-source heat pumps (and related things like insulation schemes), there was concern about misinformation entering the public domain (e.g., via social media) and even the deliberate spread of disinformation by fossil fuel lobbyists. For instance, some interviewees suggested that fossil fuel lobbyists had propagated disinformation relating to a prospective switch from natural gas to hydrogen, leading some people to believe that existing boiler systems would not need to be changed. The assertion here was that fossil fuel companies could continue to profit from the continued use of the existing gas pipeline network to transport hydrogen, and so had a vested interest in encouraging a favourable public response to this option.

The low uptake of heat pumps amongst members of the public was attributed by some interviewees to a general lack of information about the technology. For example, it was suggested that the true financial costs associated with installation of air and ground-source heat pumps, and the existence and/or size of the incentivisation schemes available to facilitate their installation, had not been well communicated to the public:

> *"We've seen some publications around boilers that are saying they're hydrogen ready and it's green that's just not true. I don't expect people to know these things. I'm not saying that they should know. There's a really big grey area. And there's certainly a lot of misinformation around heat pumps out there and there's a lot of misinformation arounddifferent types of insulation"* (**#1, Energy-focused consumer body representative**).

'Peer-to-peer communications' were also regarded both as an enabler and hindrance on people's decisions to adopt new heating technologies, particularly air and ground-source heat pumps. While some saw such peer-to-peer communication to be a positive thing, offering people a vicarious 'try before you buy' exposure to the technologies, it was also considered problematic where testimony from peers was unfavourable.

> "*Knowing people, because that's how you try it. It's like all my friends have got one of those. They say it's fantastic and I've been to their house and it feels quite nice*" (**Participant 10, Academic**).

Commonly cited complaints about heat-pumps were stated to include the noise generated by them, the space required for them, and the qualitative difference in heat quality supplied by them:

> "*Our imagination of how to make these things something that people are not worried or will complain about. For instance, the sight of them and the noise of them and the whatever you know*" (#8, Energy Provider).

Although the focus of the practitioners' discussions on this point centred around the more familiar and recognised types of heat pump (i.e., air and ground-source), there was a sense that the sentiments would likely be extended to those types of heat pump being proposed by the *XXXX* project (i.e., thermochemical and water-source).

3.4. Envisioning future transition scenarios for residential sector heating

When envisioning the residential sector heating transition, it was common for interviewees to highlight other options that had not been considered as part of the structured conversation. For example, infrared heating panels were identified as a potential solution for hard-to-retrofit and listed properties. When specifically considering options that could see the repurposing of the gas pipeline network, many participants were quick to question why heat networks or hybrid heat pumps were not considered. Hybrid heat pumps being a standard heat pump backed up by another source (e.g., natural gas or hydrogen):

> *"There are small apartments and town houses within the district heating technology option, there are both some brilliant opportunities, but also some limitations*" (**#12, Industry Professional**).

Some interviewees, particularly those from energy-focused consumer bodies, took the opportunity to question whether or not the repurposing of the gas pipeline network to support hydrogen was even necessary; given the ongoing advances in electric-based options (e.g., renewable energy technologies) available via some of the larger electricity suppliers:

> *"You like continuing to use gas and burning gas in your home. It feels unnecessary when you could use electricity"* (**#3, Energy-focused consumer body**).

Interviewees were keen to reflect on the government's ambitious residential sector decarbonisation targets. While the technologies discussed within the interview (including the *XXXX* project options) were seen as helping the advancement towards these targets, the sense was that there were some key factors that were delaying progress. These factors included: (a) the belief that the funding and incentive mechanisms designed to encourage consumers to install heat pump technologies were inadequate and/or ill-informed; (b) a perceived lack of quality among some industry stakeholders (e.g., 'cowboy builders') and the need for appropriate training and accreditation; and (c) the need to move beyond the 'trial phase' of some technology options, in order to see the wider roll-out of them. The urgent need for a change to the status quo was reflected in deliberations about the remaining timescales over which to achieve 'Net Zero':

> *"The longer we leave it, the harder it is to build the supply chains, the less we'll have the skills. So, whilst I remain optimistic that if we did the right things now we could do it. We haven't got long left"* (**#7, policy advisor**).

Part way through our series of interviews, in September 2023, the UK Prime Minister (Rishi Sunak) announced his government's revised plans to achieve Net Zero by 2050. This included the announcement of an increase to the boiler upgrade scheme (helping people to move from gas boilers to heat pumps) but simultaneously extending the timescales for the phase out of gas boilers (pushing it back from 2026 to 2035). This shift in policy altered how some interviewees envisioned future energy transitions. For some, this shift in policy further strengthened their beliefs in the need for a stronger political direction (e.g., to create investor confidence) and better public guidance around the decarbonisation of residential sector heating (e.g., a roadmap). The delay also raised questions as to whether residential sector heating targets would actually ever be achieved:

> *"Because there's just not enough time, and there's only perhaps two allocation rounds to go that would meet delivery by the 2030 target deadline. … You know the ripple effects of it all are that it impacts [public] investor confidence. You know we keep saying we're leading the way on net zero and it's like. Are we? I mean, there are lots of good things that have happened. You know, through the last decade we've built a lot of wind, coal is nearly gone off the system. But it needs to be speeding up a bit more"* (**#12, Industry Professional**).

In response to this announcement, other participants alluded to the evident political tension between the need to promote economic growth and the need to rapidly decarbonise. While some were frustrated over the UK government's apparent prioritisation of economic growth – ostensibly undervaluing the potential climatic risks that could be implied by delaying the phasing out of gas boilers – others believed that the delay could be beneficial. It was seen as providing space and time for businesses to make better, more strategic investment decisions relating to their products; allowing for the development of improved technologies and supply chains and for the repurposing of existing energy infrastructure (e.g., the gas pipeline network) to support their introduction. In turn, this would help to avoid snap decisions that might favour the investment in and roll-out of sub-optimal solutions:

> "*We operate a low carbon energy business and we always have done. Therefore we embrace government policy to promote low carbon energy. We need time and we need money and we need stable technologies and we need mature supply chains. Decisions that would be locked in for decades*

and they are not decisions we are ever going to make. The fact that the government is taking some of the pressure off in terms of timelines may help us and help our business and others like us because we see that there will be extensive mistakes made" (**#8, Energy Provider**).

Most interviewees were also keen to outline alternative strategies for residential sector heating decarbonisation to those currently being pursued by the UK government. In addition to calls for more strategic policies and stronger leadership, the recommendations included the need for more localised planning (underpinned by accurate modelling and forecasting) around the delivery of decarbonisation options, as well as a plan for the 'final few', to ensure a just transition for all and to safeguard against certain people being left behind. Others also expressed the need for future proofing households against different forms of extreme climate challenge (e.g., by installing units offering heating and cooling functionality for those who might have to contend with hotter summer periods):

"I think it's like France or Italy where the majority use the other type of heat pump. One that does cooling as well. And all of the [heat pumps] talked about in the UK don't … think about future proofing." (**#10, Academic**).

4. General discussion

The aim of this study was to consider the perceptions of key stakeholders ('practitioners') in the UK residential heat decarbonisation sector about: (a) policies pertaining to this sector; (b) the factors likely to shape public acceptance of hydrogen and heat-pump technologies; and (c) the prospect of repurposing the gas pipeline network to support heat decarbonisation. Interview discussions centred around four primary themes: (1) Relative risks and benefits; (2) Public choice and control over residential heating options; (3) Engaging with the public throughout the energy transition; and (4) Envisioning future energy transition scenarios for residential home heating. These findings can be used to support decision-making around practicable ways to decarbonise the sector in accordance with 'Net Zero' aspirations (Lowes & Woodman, 2020).

4.1. Key findings

Our findings build on those from prior research into societal perceptions of individual low-carbon residential sector heating options (Fernández-Dacosta et al., 2019; Acar et al., 2019; Gaur et al. 2022; Bartela et al., 2022), by providing a comparative assessment of several established and emerging technologies within this sector.

4.1.1. Risks and benefits

Due to their relative familiarity and proximity to residential heating applications, interviewees mostly discussed the relative benefits of heat pumps and hydrogen. By comparison, CAES was only occasionally referenced. While there was some consideration of the implications for non-public social actors (e.g., investors, planners, etc.), the primary lens used when considering the options was how they would interface with householders and the wider public. This focus makes sense given the sector under consideration, but perhaps also reflects the recognised power that the actions of publics can have over the success of technologies (Boudet, 2019; Devine-Wright et al., 2017) and the duty of care that 'elites' have when making decisions that could impact upon the health, safety and wellbeing of citizens.

Given this, it was unsurprising that many of the initial exchanges focused on the relative risks to human health of each of the options under consideration. In principle, it was considered that, while not devoid of risk, heat pumps were a safer alternative to hydrogen. Consistent with other findings (Scovell, 2022), the prospect of undetectable leaks and explosions principally underpinned this preference. The exception to this 'rule' were thermochemical heat pumps, which were considered separately from air, ground and water-source options due to the potential need for householders to handle chemicals. Interviewees were also less familiar with this option.

Discussions branched into a consideration of public perceptions of risk and how this might drive adoption decisions and use practices for both these technologies. In the case of hydrogen, it was suggested that a familiarity with gas-based residential heating could be appealing. The perceived continuity and 'simplicity' of substituting natural gas with hydrogen (e.g., for heating practices, heating quality, etc.) was also anticipated to dull some of the health and safety concerns associated with this option, thus driving consumer acceptance. Although, the 'simplicity' of this switch was seen to be contentious and something that might be a product of mis-information sharing. In the case of heat pumps, there were general concerns that publics might view them as 'just another electrical device' which could promote complacency around the risks associated with their use. This raises the crucial importance of developing and disseminating appropriate risk communication for householders, to counter subjective under-estimation of risk and promote the safe use of these technologies (Renn & Benighaus, 2013).

In addition to their comparative safety, heat pumps were also considered to be a scalable, 'plug and play' means of decarbonising the residential heating sector (provided the national electricity grid could be decarbonised). By contrast, the role that hydrogen could play in this regard was questioned both on the grounds of source and supply. Specifically, unless there is a rapid scale-up in the production and supply of low-carbon hydrogen, then residential sector heat decarbonisation based on hydrogen was deemed impractical.

In reality, interviewees tended to believe in a portfolio solution for the decarbonisation, with the mix of technologies being determined by the physical (e.g., existing infrastructure) and social (e.g., demand profile, demographic) context of different regions of the UK. As such, the 'hydrogen versus heat pump' distinction was often considered a false-comparison. Not only because the practicability of each option can vary by context, but also because a broad, abstracted distinction glosses over the relative strengths and weaknesses of different sub-classifications of the technology (e.g., air-vs. ground-source heat pumps), and the fact that hydrogen and heat-pumps can be hybridised. This reflection likely stems from our research approach, where a limited set of options were presented, stimulating a desire to consider different pathways to decarbonisation among our interviewees.

4.1.2. The need for a just transition

Consistent with prior research (Thomas et al.2024), interviewees referenced the need to ensure that the decarbonisation of residential heating was fair and 'just'. Considerations here ranged from: (a) ensuring that householders were provided with appropriate agency over heating upgrades (e.g., ensuring appliances and running costs were affordable and/or suitably subsidised); (b) limiting disruption during installation or construction; (c) promoting consumer protections and workforce sustainability (e.g. through training, accreditation and regulation of installers); and (d) providing assurances that certain groups (e.g., renters) would not get 'left behind' (or actively penalised) if they were not in a position to upgrade.

The desirability of affording householders with choice and control was juxtaposed with some of the difficulties in doing so. These included variability in the practicability of (and thus access to) technology options in some contexts (e.g., the absence of a suitable water source to support a water-source heat pump), as well as the need to ensure wider community support for the introduction of technology options in other contexts (e.g., converting from natural gas to hydrogen). Both of these examples evidence an impingement on a householder's 'freedom to choose', and could pose problems for acceptance. Relatedly, interviewees referenced the need to increase the volume and specificity of public outreach programmes around innovations in residential heating;

helping to combat the spread of misinformation, while making householders aware of the practicability and implications of different options for their homes (e.g., for heating quality and practices). Such a suggestion is consistent with recommendations from cognate studies that advocate for the need for further public outreach and involvement in discussions about energy transitions (e.g., Gordon et al., 2022; Ren & Ogura, 2021; Suboticki et al., 2023).

We argue there could be benefits to developing outreach programmes explicitly tailored around the promotion of contextual (e.g., street, neighbourhood) 'equity' rather than equality. This would give people a more realistic sense of the options available to them in their context and could be paired with efforts to illustrate how heating upgrades could assist regional (and by proxy national) efforts to decarbonise. A focus on community-centric, equity-based communication plays both to the calls from this study for more localised decision-making, but also to the wider literature attesting to the value of targeted and tailored messaging (Bostrom et al., 2013). This could be very important in situations where there is a need for communal 'buy in' to schemes (e.g., conversion to hydrogen), particularly given the reported influence that peer-to-peer communication might have upon attitudes and actions towards residential heat decarbonisation.

4.1.3. Opinions on gas pipeline repurposing

A key aspect of this study was on gathering practitioner perspectives on the prospect of repurposing the national gas pipeline network to support an array of low-carbon residential heating options (i.e., the focus of the *XXXX* project). In principle, the concept of repurposing was well-received due to the fact that such steps would make good use of an otherwise redundant legacy asset, and given that repurposing could link more citizens to more technology options (e.g., water-source heat pumps). However, while the concept had broad appeal, the practical and economic feasibility of the idea was questioned. Interviewees variously referenced issues like the engineering complexity, construction disruption, and fuzzy or uncertain financial costs. It was suggested that the electrification of heating (incl. standard air, ground and water source heat-pumps) might negate the need to repurpose the gas pipeline network. And, although born from a lack of familiarity with the concept, there was also speculation over the potential for repurposing to introduce additional health and safety risks, particularly where might different options might interface (e.g., hydrogen and CAES).

Given that most of the interviewees agreed that a 'patchwork of options' would be needed for the just and practicable decarbonisation of the sector, there is a need for further development, costing and knowledge exchange with practitioners about the concept of repurposing. Not only will this provide clarity over the type and scale of repurposing required to support different technology options – particularly those considered to be more 'niche' (e.g., thermochemical extraction) – but also so that the technical, economic and social viability of repurposing can be weighed-up against the alternative solutions (e.g., the capping and/or removal and backfilling of the pipeline network). The recent announcements by the UK government regarding the timescales for phasing out traditional gas boilers have extended a window of opportunity to consider and cost the relative benefits of repurposing, and to provide strong and evidenced-based policy and market recommendations before decisions are taken.

4.2. Methodological strengths and limitations

The use of comparative flash cards (Jones et al., 2014; Kalehsar, 2021) within this study proved to be a useful means of eliciting conversation with the interviewees. Some interviewees even recommended that these flash cards to publicly accessible, to improve awareness of the options and to allow householders to make more informed choices about the options available to them (Becker et al., 2023). However, the flash cards only presented brief details of the six options being considered by the GasNetNew project, with some practitioners questioning the omission of other options from the discussion (e.g., district heating networks), options which might serve as future considerations, and also referencing their lack of (basic or applied) familiarity with some of the options presented. Thus, while the flash card discussions were still fruitful, the potential value in presenting extended details about a greater number of technology options in future work cannot be dismissed. Similarly, while we were able to recruit an appropriate number of interviewees from different practitioner groups for this study, the insights yielded are somewhat specific to those who were interviewed.

The study principally engaged interviewees in a high level, conceptual discussion about the practicability and acceptability of the six residential heating decarbonisation options. While such conceptual discussion holds value, there can be discrepancies with how technologies are received and responded to when they are physically deployed (Schively, 2007; van der Horst, 2007). Future research will therefore be needed to chart how the technologies discussed within our interviews perform 'in practice', particularly those that are more niche or innovative (e.g., thermochemically-assisted heat pumps). Indeed, practitioners requested further research into the safety and performance of each alternative residential heating options, most notably in the case of hydrogen and thermochemical heat pumps.

The fairness of energy transitions for those employed within the sector, was interesting topic of discussion within the study. References made to the risks of not upskilling existing gas engineers resonate with other studies exploring shifting employability and skills development in the energy sector (e.g., van der Ree, 2019; Saussay et al., 2022; Bray et al., 2024). However, the opportunities presented by this evolution (e.g., in terms of diversifying the workforce and furthering the sector's corporate social responsibility) also have credibility (Bray et al., 2024).

4.3. Future research

Scaling-up and broadening recruitment in future studies would be a suitable way to investigate if the findings of this study (e.g., in terms of content and reasoning) are transferable beyond the immediate circumstances. For instance, while this study focuses exclusively on residential sector decarbonisation, investigating the determinants of the social acceptance of the energy options among different sectors will be important. Further, employability-themed discussions need further unpacking, as the implications for the composition and sustainability of workforces in this rapidly changing sector, remain relatively understudied.

4.4. Policy implications

There was a general sense among the interviewees that successful decarbonisation would be determined by better programmes of funding and incentivisation, set alongside more comprehensive training and accreditation of installers. While not disputing this assertion, there is clearly a need to understand the reasons for the continuing underperformance of existing decarbonisation schemes if a policy of further investment is to be successful. To the extent that a lack of trained installers is contributing to the problem, the introduction of comprehensive training and accreditation programmes would be advisable, while also helping to address concerns around the sustainability in the employment of the existing workforce. It is also important to look more closely at the public outreach and messaging around schemes (particularly those advocating less familiar technology options) to not only promote initial 'buy in' to schemes, but to also promote the retention of consumers to the point of installation.

A need for stronger leadership and clearer policies around sector decarbonisation were advocated by our interviewees. Such conditions should not only serve to improve market confidence (i.e., market acceptance), but would also provide a more consistent signal to publics of the need for change. The issues of inconsistent messaging/signalling were brought into focus by the then government's announcement around loosening the timescales for the replacement of boilers. While some practitioners (e.g., energy providers) viewed this positively (buying time to think before further committing the UK to a policy direction), others suggested it might undermine efforts to communicate with publics about the climate emergency. That said, to the extent that affordability (vs. environmental) considerations, principally drive consumer decision-making in this sector (Parrish et al., 2022), perhaps these concerns over the impact of an unfavourable public reaction were overstated.

Efforts to improve and promote the affordability of alternative residential heating options are likely to be crucial in improving their uptake. To the extent that efforts to repurpose the gas pipeline can be leveraged to support the wider introduction of heat-pumps and hydrogen, this could be a useful means of improving their cost-competitiveness. This should not only resonate with the 'affordability bias' driving household decisions around technology uptake (providing a route to improved penetration),but could also improve the general accessibility to different technology options for consumers (providing a route to a more just transition), while also crucially helping to decarbonise the sector (Gorden et al., 2024).

5. Conclusion

Taken together, this study advances our understanding of practitioner perspectives on the social acceptability of several options for decarbonising residential heating in the UK (i.e., heat pumps, hydrogen and CAES), including some that can be supported by repurposing the existing gas pipeline network. The findings confirm that the factors and actors feeding into the relative 'acceptability' of each option are manifold, and that the 'acceptance' of each option is tied to factors, such as: (a) the consistency of policy signals from government; (b) the relative affordability of the technology (incl. the availability and success of financing schemes); and (c) both the physical (e.g., infrastructure) and social (e.g., peer-to-peer communication) aspects of the local development context. The findings of this study can be used to help support evidence-led decision-making about the potential routes to sector decarbonisation and the role that innovative repurposing could play in making this transition more affordable and fair.

CRediT authorship contribution statement

V. Seymour: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **B. Cárdenas:** Writing – review & editing, Methodology, Conceptualization. **A. Urquhart:** Writing – review & editing, Methodology, Conceptualization, Funding acquisition, Conceptualization. **D.L. Pottie:** Methodology, Conceptualization. **J. Day:** Writing – review & editing. **M.M. de Oliveira Júnior:** Writing – review & editing. **E. Barbour:** Writing – review & editing, Methodology, Conceptualization. **G. Wilson:** Writing – review & editing, Methodology, Conceptualization. **S. Garvey:** Writing – review & editing, Funding acquisition, Conceptualization. **C.R. Jones:** Writing – review & editing, Methodology, Conceptualization.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.techsoc.2025.102849.

Data availability

The data that has been used is confidential.

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