Energy Policy 142 (2020) 111494

Contents lists available at ScienceDirect

Energy Policy

journal homepage: http://www.elsevier.com/locate/enpol

Disruptive and uncertain: Policy makers' perceptions on UK heat decarbonisation

Richard Lowes *, Bridget Woodman

University of Exeter Energy Policy Group, Penryn Campus, Cornwall, TR10 9FE, UK

ARTICLE INFO

Keywords:
Heat
Transformation
Policy
Perception
Disruption
Uncertainty

ABSTRACT

The decarbonisation of heating represents a transformative challenge for many countries. The UK's net-zero greenhouse gas emissions target requires the removal of fossil fuel combustion from heating in just three decades. A greater understanding of policy processes linked to system transformations is expected to be of value for understanding systemic change; how policy makers perceive policy issues can impact on policy change with knock-on effects for energy system change. This article builds on the literature considering policy maker perceptions and focuses on the issue of UK heat policy. Using qualitative analysis, we show that policy makers perceive heat decarbonisation as disruptive, technological pathways are seen as deeply uncertain and heat decarbonisation appears to offer policy makers little 'up-side'. Perceptions are bounded by uncertainty, affected by concerns over negative impacts, influenced by external influences and relate to ideas of continuity. Further research and evidence on optimal heat decarbonisation and an adaptive approach to governance could support policy makers to deliver policy commensurate with heat decarbonisation. However even with reduced uncertainty and more flexible governance, the perceptions of disruption to consumers mean that transformative heat policy may remain unpopular for policy makers, potentially putting greenhouse mitigation targets at risk of being missed.

1. Introduction

Decarbonising heat is a pressing global climate change mitigation issue and the scale of the required low carbon heat transformation means that '*careful planning and policy are required*' (Nature Energy, 2016, p1). Heat currently represents around half of global energy use (IEA, 2014) and is responsible for around 40% of global energy-related carbon dioxide emissions (IEA, 2017). While modelling has suggested that residential heating can be decarbonised at a rate commensurate with the 1.5 °C target in the Paris agreement, this will require '*substantial*' policy efforts and '*stringent*' policy instruments (Knobloch et al., 2019, p521 and p541).

However, the development of policy is normally messy and unpredictable (Cairney, 2016) and policy to drive a heat transformation may not necessarily be objective and based on the best available evidence.

Heating requires a rapid transformation where fossil fuel combustion is replaced by low carbon alternatives (IEA, 2013). Transitions of large systems such as energy systems are '*inherently political*[1]' (Meadowcroft, 2011, p71) and the heat transformation may challenge and need to overcome existing interests (Geels, 2014).

The UK debate around the optimum pathway for decarbonisation of heat, let alone the required policy to deliver it, already appears messy and affected by interests. Heat related incumbents[2] are already promoting decarbonisation approaches which maintain a gas based system in spite of other technological approaches (which may, but not necessarily, be better) (Lowes et al., 2018a).

UK Government literature which previously highlighted a need for mass electrification of heating for decarbonisation now considers two

Abbreviations: CCC, Committee on Climate Change; CCS, Carbon capture and storage; ZCH, Zero carbon homes.

* Corresponding author.
E-mail addresses: r.lowes@exeter.ac.uk (R. Lowes), b.woodman@exeter.ac.uk (B. Woodman).

[1] Politics can be seen as ' … *the formulation and execution of decisions that are binding upon the population of a community or society and the relationships between those who make or implement such decisions and those who are affected by them*' (Johnston, 2007, p18).

[2] Based on a previous review: '*We define incumbency in the context of sustainable transformations as the presence of existing actors within a specific socio-technical system. An incumbent will be currently active in the socio-technical system or a part thereof and therefore likely to be or have been involved in unsustainable practices. Incumbents have the economic, social or technological capacity to influence system change*' (Lowes et al., 2017, p32).

https://doi.org/10.1016/j.enpol.2020.111494
Received 27 September 2019; Received in revised form 11 March 2020; Accepted 5 April 2020
Available online 12 May 2020

competing approaches, electrification of much heat demand or converting the UK gas system for heat to run on low carbon hydrogen (HM Government, 2017). The UK heat outlook is deeply uncertain and progress towards decarbonisation is limited.

In order to develop understandings of transformative heat policy and build on previous analysis of policy makers' perceptions, this article investigates the perceptions of UK policy makers involved with heat decarbonisation towards options for heat decarbonisation. Basing our analysis on semi-structured, expert interviews, we push the policy maker perceptions literature forward by utilising ideas from the literature on the psychology of by policy making.

1.1. Context and research focus

The lack of progress on heat decarbonisation and the current uncertainty around heat decarbonisation is a key UK energy policy issue. This article investigates the following research questions:

1. How do policy makers perceive options for heat decarbonisation?
2. Can these perceptions be linked to existing theory on the psychology of policy makers?
3. Do the findings from this research have any implications for the UK and wider international heat decarbonisation policy?

The paper is structured as follows:

- Section 2 considers the status of UK heat decarbonisation policy;
- Section 3 reviews relevant literature associated with transitions and policy maker perceptions and psychology;
- Section 4 describes the research methodology;
- Section 5 discusses findings from the research;
- Section 6 considers specific UK conclusions and policy implications and also considers wider international policy implications.

2. The UK's heat juncture

Fossil fuels currently dominate heat consumption in the UK, with 84% of homes using fossil gas for heating (Xoserve, 2018) and oil and solid fuels providing around 10% of overall non-industrial heat use (BEIS, 2018a).

Under the 80%[3] greenhouse gas reduction target introduced in 2008 Climate Change Act (Parliament, 2008), near total UK heat decarbonisation was seen to be required in order to allow residual emissions in other sectors which were seen as more difficult/expensive to decarbonise (Committee on Climate Change, 2016).

The UK's recently introduced net-zero goal for 2050 (Parliament, 2019) implies more rapid and total heat decarbonisation. Statutory government advisor 'The Committee on Climate Change' (CCC) suggests that to reach net-zero emissions by 2050, no fossil fuel heat systems can be installed after 2035 (Committee on Climate Change, 2019a). Despite the long term goal for heat decarbonisation, how to reach it appears uncertain and progress is limited.

While mass electrification of heat has been assumed to be a requirement of heat decarbonisation[4] (Chaudry et al., 2015; DECC, 2013; UKERC, 2009), the potential technology options for heat decarbonisation have become more diverse and pathways include roles for heat pumps (and electrification in general), district heating, bio-energy, hydrogen and varying levels of increased energy efficiency (Lowes et al., 2018b; Winskel, 2016) highlighting significant uncertainty.

The UK's progress towards decarbonised heat has also been extremely limited with number of energy efficiency installations significantly falling in 2013 and not increasing,[5] low levels of heat pump and heat network deployment and the majority of new homes being connected to the gas grid (Committee on Climate Change, 2016; UKERC, 2018). The key policy instrument to deliver low carbon heat, the Renewable Heat Incentive, which opened in 2011 (Connor et al., 2015), has not supported the deployment of low-carbon heat at the expected rate (National Audit Office, 2018).

2.1. The emergence of a potential role for hydrogen and heating hybridisation

Uncertainty around heat decarbonisation appears to have increased. Recently, and potentially partly as a result of the efforts by incumbents to protect their own interests through political influencing, UK policy makers have been paying increased attention to the idea of converting the UK's existing gas grid to run on low carbon hydrogen as a means to decarbonise heating as opposed to an electrification based approach (Lowes et al., 2018a).

The 2017 'Clean Growth Strategy' white paper contained three pathways, one which included 76% of domestic heat in 2050 being provided using electricity with 0% hydrogen for heat, one where electricity provided 60% of domestic heat and 0% hydrogen (alongside emissions removal technologies) and one where hydrogen provided 62% of domestic heat and electricity 14% (HM Government, 2017, p151). The variance between these pathways highlights clear uncertainty for policy makers who have suggested that heat is the Government's '*most difficult policy and technology challenge to meet our carbon targets*' (HM Government, 2017, p76).

Further complexity has been added by the potential for 'hybrid' systems which combine a heat pump and a gas boiler, possibly using hydrogen, which are potentially more suitable for buildings with lower thermal efficiency and can reduce system impacts and costs of full heat electrification (Strbac et al., 2018). Strbac et al.'*s* (2018) analysis fed into the Committee on Climate Change's analysis considering technology mixes for reducing emissions to 'net-zero' levels with the CCC suggesting a significant increase in both district heating and heat pumps providing the majority of heat in most homes but with hydrogen potentially providing an important back-up role (Committee on Climate Change, 2019a, 2019b). It should however be noted that the CCC, in their previous hydrogen review, '*do not recommend that a full hydrogen pathway be pursued*' for reasons of technical feasibility, and potential challenges around import dependency and insufficient emission reductions (Committee on Climate Change, 2018, p94).

Choosing whether to electrify, hybridise or convert to hydrogen, heating represents a clear challenge for policy makers who are aiming to develop a policy framework for heat by mid-2020 (BEIS, 2018b).

3. Literature review: sustainability transitions and the role of policy makers

A significant research focus on the transitions of large socio-technical systems from being unsustainable to less unsustainable has developed over the past two decades and continues to expand rapidly (Köhler et al., 2019). However, transitions approaches have been accused of being undermined by not paying due attention to the importance of power, including more specifically the attempts by and ability of actors to drive systemic transformations in alignment with self-interests (e.g. Avelino and Wittmayer, 2016; Hendriks, 2009; Meadowcroft, 2011; Shove and Walker, 2007, 2010; Smith et al., 2005).

The development of public policy associated with transitions is recognised as being one specific power related '*black-box*' issue which needs '*opening up*' in order to further enhance understandings of ideas of

[3] Compared to 1990 levels.

[4] Often with heat pumps and alongside significant reductions in heat demand, growth in heat networks.

[5] Significant energy efficiency deployment has been achieved before 2013. See Committee on Climate Change, p96 (2018b).

power in transitions (Smith et al., 2010, p446). Scholars have increasingly considered the importance of public policy associated with transitions (Kern et al., 2014; Kuzemko et al., 2016; Lockwood et al., 2017; Lowes et al., 2019; Wesseling et al., 2015).

This article contributes to the literature on policy associated with systemic transitions by focusing on the policy process associated with the UK's potential transformation to low-carbon heating. It provides novelty for analysis considering policy associated with transitions through its focus on the roles and perceptions of policy makers.

The following two sub-sections consider firstly, how policy makers, i.e. the individuals involved in policy development, in particular those working in or for Government,[6] can be understood as a part of the policy process and secondly how the perceptions of policy makers may affect policy change and have been investigated before.

3.1. Policy makers and the policy process

While multiple models and approaches to understand the policy process exist, individuals are central to the process (Sabatier and Weible, 2014). Cairney and Heikkila (2014) explain: '*People making choices are at the heart of policy studies, but not all theories conceptualise this process extensively*' (Cairney and Heikkila, 2014, p364). Reviewing eight policy analysis frameworks, Cairney and Heikkila (2014, p367) highlight the various and often opposing ways policy makers are viewed with, depending on the framework, policy makers seen as:

- Comprehensively rational and able to make perfectly rational decisions;
- Acting based on rational choice, i.e. maximising personal utility;
- Ambiguous and inexact;
- Affected by 'bounded rationality' which implies the impossibility of perfectly rational decisions in light of incomplete evidence and can lead to satisficing i.e. finding satisfactory outcomes;
- Affected by values, emotions and heuristics;
- Affected by existing institutions;
- Affected by existing beliefs and prone to 'devil shift'.[7]

Overall, there is little (if any) agreement across policy approaches to understand the role of individuals with some quite opposing views taken, particularly around ideas of rationality (or a lack of it). It is however clear that policy makers are understood to be affected by a range of issues including beliefs, values and institutions.

Despite the importance of the role of policy makers on policy change, the specific literature considering the psychology of the policy process is very limited and '*We are still scratching at the surface of the links between psychology and policy making*' (Cairney, 2019a). In combining general insights from psychology and policy studies, Cairney and Kwiatkowski (2017) suggest that as well as being affected by '*bounded rationality*' (p2), the policy making process is affected by the emotions of and cognitive shortcuts (heuristics) taken by policy makers (highlighting the work of Lewis (2013)).

3.2. Policy makers and their perceptions

While the specific theory on the psychology and policy change may be limited, an existing, but separate, literature considers the 'perceptions' of policy makers, focusing on perceptions as beliefs.

The policy maker perceptions literature can be considered as descriptive, rather than explanatory, focusing on what the perceptions of policy makers are, with little consideration of the policy impact of these perceptions. Key relevant literature is now reviewed briefly.

The lens of policy maker perceptions appears to have been most applied to health policy research. Corrigan and Watson (2003) suggest that because of the importance of information in shaping policy makers views, those attempting to influence policy makers working on the distribution of resources for mental health services should provide useful data on which supportive policy decisions can be made. Striking a similar conclusion on the role of information, Morrison et al. (2015) investigated '*perceptions and beliefs*' of policy makers in Barcelona with regards to health inequality issues. They suggested that their results showed more information (particularly from researchers) could support policy makers who, based on their analysis, do not believe they have enough information to make affective policy on health inequality.

Taking a different approach, Haghdoost et al. (2017) made policy recommendations directly based on Iranian policy makers' perceptions on what would enhance fertility; this approach however lacked a clear theoretical justification.

Nuclear energy is another issue where policy maker perceptions have been considered. Thomas et al. (1980) showed that policy makers' perceptions of the public's view on nuclear energy accurately reflected the publics actual beliefs; the authors suggested that how this translated into policy making was of interest from a policy development perspective but didn't investigate this further.

More recently, Li et al. (2018) investigated how policy makers perceive the role of science in driving nuclear energy policy and suggested that policy makers, supportive advocacy groups and industry stakeholders saw science as less important for nuclear policy development than non-profit groups (such as think tanks). Li et al. (2018) went on to suggest that their analysis had filled a gap in the literature by showing how 'issue concern', i.e. the importance of the most salient issues for policy makers (p778) had affected nuclear energy perceptions.

3.3. Section summary

The policy process is seen to be an important element of transitions to sustainability. The psychology of policy makers, including their perceptions, forms an important element of policy processes yet the literature on the specific effects of psychological issues on policy change is limited.

Focusing on the UK's potential transformation to sustainable heating, this article considers the perceptions of policy makers associated with heat decarbonisation policy. This article provides novelty through focusing on the live policy issue of heat decarbonisation in the UK.

4. Methodology

The previously identified existing literature considering policy maker perceptions has used interviews or questionnaires for data collection. For this analysis a 'large N study' was not suitable because of the relatively small number of policy maker experts working on UK heat decarbonisation and because of the exploratory nature of the research. The overall methodological approach closely follows that of Morrison et al. (2015) who investigated the perceptions of heath policy makers in Barcelona.

4.1. Data collection

Ten in depth, semi-structured interviews were carried out with policy network actors with expertise in UK heat policy issues during December 2018 and January 2019. While the majority of interviewees

[6] The term 'policy-maker' is not well defined in the policy literature. Cairney (2019b) expands on the issue and, considering 'policy makers' and 'influencers' together, suggests these actors can operate across policy networks and coalitions and work to unwritten rules and beliefs.

[7] 'Devil shift' can be considered as a form of distorted perception where a certain advocacy coalition over-estimates an opposing coalition's 'evilness' and level of influence while underestimating their own power (Vogeler and Bandelow, 2018, p718).

worked or previously worked in Government or politics on heat issues, some non-government actors with relevant heat policy expertise were also interviewed. While non-government associated actors do not have the legal authority to make policy decisions, they can be an important element of policy networks and associated policy formation (Compston, 2009; Sabatier and Weible, 2014) and their inclusion allowed a larger number of interviews and has provided more rounded and open insights. The focus of interviews was specifically on the perceptions of policy makers.

The group of interviewees was made up of[8]:

- 1 politician (1);
- 1 political advisor (2);
- 1 independent government advisor (3);
- 1 ex-political advisor (4);
- 2 industry based heat decarbonisation policy experts (5 and 6);
- 1 non-party-political think tank energy analyst (7);
- 1 consultant with heat decarbonisation policy experience (8);
- 2 civil servants (9 and 10).

Semi-structured interviews were chosen to allow a deep focus on particular issues but with scope for a broader discussion (Kvale, 1996). Interviews were based around a set of exploratory questions which had been tested during pilot interviews. An interview outline is included in annex 1.

Questions were designed to be exploratory and open ended and considered the interviewees general view on heat decarbonisation technology options (namely conversion of the gas grid to hydrogen and heat electrification), how potential options linked to general policy goals, the potential for technologies to disrupt or support continuity, deliverability of options and the impact of uncertainty on policy making.

Interviewees were selected based on the research team's a priori knowledge of the UK heat policy network and a snowballing process was used where interviewees were asked to identify to provide other potential interviewees. In order to gain personal (rather than corporate/party political) views, interviewees were advised that all interviews were completely anonymous[9] and were also reminded that this research was interested in policy makers' perceptions.

4.2. Data analysis

Interview data was transcribed and then coded using the NVivo software package. The interviews were coded to emergent codes and also to pre-established codes linked to research questions. Following coding, codes were organised into larger themes and these themes and the codes they contained formed the basis of results. Where relevant grey literature can enhance interview results, this is included in section 5. Interview transcripts were sent to all interviewees who were given an opportunity to comment on transcripts in order to validate results. While some clarifications were made to transcripts, these changes had no impact on final results.

5. Results and discussion

This section describes the results of the policy maker analysis and considers the importance of these perceptions for heat decarbonisation policy development. The technological options of heat electrification or converting the gas grid to hydrogen featured frequently in interviews and this apparent binary is reflected in the results.

Comments or ideas from interviews are referenced with a number in brackets and the type of interviewee can be identified by referring to section 4.1. Relevant quotes are included to highlight specific issues and to provide a more direct connection to underlying data. Relevant grey literature is considered in these results if of value.

The structure of the results section is based on the coding structure which reflects both emergent codes and codes based on the pre-determined foci, linked to both research and interview questions.

5.1. Disruption or continuity for policy makers

The issue of 'disruption' emerged as a key issue for policy makers involved in heat decarbonisation. Disruption is frequently seen as the opposite of continuity; while some change may be constant, disruptive change is suggested to be either rapid or high magnitude deviations from past trends (Ketsopoulou et al., 2019). Ideas of 'disruptive innovation' focus more specifically on the challenges of new entrants against incumbents through product innovation (Christensen et al., 2015). Reflecting the emergence of varying disruptive issues from our analysis, we take a broad view of disruption, viewing it as rapid or large deviations from past trends with the expectation of major impacts on actors.

All interviewees saw heat decarbonisation as challenging and disruptive whatever technology route may be pursued. Concerns were raised over potentially '*invasive*' (4) disruption to homes where new heat systems or energy efficiency measures would be needed (2, 4, 5, 8, 9) and potential energy bill increases caused by decarbonisation (5, 8, 9). Heat was suggested to have more consumer disruption than electricity or transport decarbonisation (5).

Regarding the options of electrification or hydrogen, one civil servant explained '*I think they're equally bad, equally difficult*' (10) and an ex-political advisor went on '*there's nothing compelling. There's just lots of problems with both options*' (4). This general negativity towards decarbonisation appeared to be ignoring potential positive impacts such as meeting decarbonisation targets, reducing energy imports and creating more efficient and comfortable buildings, all potential outcomes. Interestingly, meeting decarbonisation targets was not mentioned as a specific positive by any of the interviewees despite this being a key policy outcome. This suggests perhaps that while the UK decarbonisation target is set in law, and heat decarbonisation is an explicit policy focus, the actual perceived benefit of heat decarbonisation to policy makers and its perceived importance is limited.

According to policy makers, the approach of converting the gas grid to hydrogen could provide some continuity because '*a substantial part of the system remains intact*' (1) and the existing gas based skill set could support hydrogen (3).

5.1.1. Disruption for consumers

Of particular concern to all interviewees was the fear of disruption to consumers. The ideas of disruption were associated with anything that impacted consumers, varying from required modifications to people's homes to the potential performance of low carbon heating systems compared to current systems:

'*it's* [consumer impacts] *definitely a concern*' (10)

'*people like gas, don't they? People like to cook on gas and to heat on gas*' (9)

'*There's never been a moment when any government said, "You have to do this thing to your house"*' (2)

[8] The number in brackets is used for reference in the results section.

[9] Relevant ethical considerations were taken including total anonymity for interviewees in light of the political nature of the research. Results have also been presented so that interviewees are not identifiable. The research project was subject to University of Exeter ethical processes and approved (application i.d. eCORN000064 v2.1).

'*it actually is something that people can feel and will potentially have to change their behaviour in their homes. I think that's quite important from a policy perspective*' (5).

A specific concern raised was that a small number of high profile stories about poor performance of low carbon heating systems could affect wider public opinions on overall heat decarbonisation.

'*all it takes is a couple of horror stories or something to go wrong to really change public perception quite quickly and certain newspapers publishing certain things can (laughs) really shift the dial. So it's a massive concern for us and that's for all the options*' (10)

An industry representative explained, '*if it's mishandled it risks losing widespread support for decarbonisation in general*' (6). An energy consultant continued '*something needs to be done on both of those technologies* [electrification or hydrogen] *to make sure the consumer experience is going to be a good one. Otherwise this will get completely derailed*' (8).

Unless consumers were supportive of decarbonisation, driving '*disruptive*' change with policy would be '*impossible*' (3). A politician agreed that unless consumers saw some benefit, heat decarbonisation was unlikely to progress (1). A consultant explained '*anything that puts people's bills up is a big issue. And anything involving intervening in people's homes is a big issue. You've got them all. It'd be an absolute car crash*' (8).

Some interviewees believed consumer issues associated with heat decarbonisation in general may be more solvable than generally believed and could be solved by a better functioning and larger market (particularly for heat pumps) (2) alongside better marketing (4).

Consumer disruption *per se* was also not necessarily seen as a bad thing, e.g. mobile phones were actually massively disruptive but are viewed positively (4) although it should be noted that this is one specific example which varies significantly to the sorts of potential disruption associated with heat decarbonisation. It was suggested that disruption from heat decarbonisation could also be minimised e.g. if carried out during house upgrades (2, 3) and technologies could be made '*sexy*' or '*exciting*' to drive uptake (3). The example of lithium batteries being installed in homes was given which are '*perhaps, the most boring products in the world*' (4). However, lithium batteries do not appear particularly disruptive and are not specifically associated with heat.

5.1.2. Electrification

Specific disruptive issues associated with the option of heat electrification were perceived by policy makers.

Two interviewees perceived electrification as particularly problematic from a householder perspective, linked to ideas in the previous section, highlighting the need to replace gas boilers with potentially large ground and air source heat pumps (1) and a need for bigger radiators and a smart control system, a '*completely different way of heating your home*' (3).

The issue of the capacity of the electricity system not being able to meet the demand for potential heat electrification was raised by a number of interviewees (1, 5, 7, 9). Highlighting the association of disruption linked to rapid and large magnitude changes, a politician explained '*the capacity of generation that you're going to require would have to expanded by something like three or even more to cope with the six toll variation in daily demand. Which looks a bit improbable in terms of a policy ask for generation over the next 30 years*' (1). A civil servant agreed that variability and peakiness of heat demand could cause challenges for electrification (9). Another interviewee suggested that the goal of electrifying road transport could increase the demand on the electricity system further compounding the heat issue (1).

While recognising uncertainty, a civil servant believed the UK's liberalised electricity market could deliver capacity and growth in heat pumps if correctly designed (10) going on to explain:

'The electricity market works and you have the heat pump products that are available. So you have people in place. It's easier, I think, to think about the actors. Would you change everything for electrification of heat? I don't know. I probably doubt it. Ultimately, it's just more electrons going through the grid'.

Interestingly, a consultant believed that policy makers generally feel more '*comfortable*' with the idea of an all-electric future (8). However, it was suggested that if a national electrification programme happened, a national oversight body would be needed (3), implying significant change from business as usual.

5.1.3. Hydrogen conversion as a means to reduce disruption?

The majority of interviewees believed that *if* converting the gas grid to hydrogen appeared to be less disruptive than other heat decarbonisation pathways, this would appeal to policy makers. This was because it is perceived to have the potential to be delivered at '*a system level, rather that the household level, instead of full conversion household by household'* (3) and from a consumer perspective it could therefore reduce disruption (4, 5, 8, 9, 10).

However, hydrogen was perceived to have some potential but uncertain disruptive impacts (4, 5, 6). These uncertainties are explored in section 5.2.2 and are associated with whether hydrogen would require the replacement of internal domestic gas pipework (8, 10), the need for new boilers and more specifically changes to '*burners*'[10] (3, 9), how hydrogen is produced at scale (4) and the length of time needed for a hydrogen conversion programme (10). It should be noted again that many of these 'in the home' issues relate to the issues of consumer disruption considered in section 5.1.1.

A government advisor explained frankly

'it may well be that it is a similar level of buggeration to have the hydrogen based solution but I don't think that's been tested and neither does that seem to matter at this stage writing the policy … I don't think that matters, the story is compelling and that's why policymakers are interested. And I haven't at any great length spoken to the current energy minister about this but I know that she's very drawn to hydrogen as a solution because of that story, this idea of not buggering about in the home' (3).

The fact that detail is not perceived to matter suggests in this instance policy maker perceptions may be based on un-evidenced judgements rather than technical knowledge. While it may be naïve to expect all perceptions to be based on objective evidence, this specific example of such a senior member of the Government, highlights the importance of perceptions.

Overall, interviewees did not generally view hydrogen conversion or heat electrification as any more disruptive than the other. Four interviewees did not believe it was possible to know whether full hydrogen or full electrification would be more disruptive, one interviewee believed both pathways were perceived to be as disruptive as each other, three interviewees perceived electrification to be more disruptive than hydrogen and one perceived electrification as less disruptive than hydrogen. The only interviewee who suggested that hydrogen was perceived as much less disruptive than electrification was associated with the gas industry and this may reflect that interviewees own beliefs or their corporate position.

The uncertainty over potential disruption for each option was highlighted by one interviewee who explained:

'I can see both hydrogen and electrification being as bad as each other. I can see hydrogen in a world where it could be much better than the other. And I could see a world where, actually, hydrogen is worse than electrification' (8).

[10] The burner is the element of a gas boiler where burning takes place and burners are affected by variations in gas supply.

5.2. Uncertainty

While uncertainty (not just over levels of disruption) emerged as a key theme from the analysis, this is perhaps unsurprising as existing government literature has highlighted the perceived challenges associated with heat decarbonisation and questions over technological pathways (BEIS, 2018c; HM Government, 2017). Based on interview data, the following section considers the key perceived uncertainties associated with heat decarbonisation.

Interviews highlighted perceived uncertainty across a range of fundamental issues:

- '*in the assumptions under analysis*' used in models future energy pathways (10);
- Associated with technologies and technological performance (2, 8, 10);
- Around how lifestyles and culture may change (2, 10);
- On technology costs (7, 8, 9);
- The potential geographical variance in optimal technology deployment (1, 5, 9).

5.2.1. Trilemma

The trilemma approach which considers, costs, security and sustainability is a widely used normative approach to appraise energy systems and the interview approach explicitly explored how heat decarbonisation options we perceived alongside the trilemma and its associated elements.

Overall, half of interviewees did not currently believe that the trilemma was a suitable way to evaluate options for heat decarbonisation (2, 3, 6, 8, 9). This unsuitability was linked to general uncertainty over technology pathways as well as perceived uncertainty over costs across technologies (6, 9), uncertainty over potential for carbon reduction potential of technologies (6), a belief that energy security would never be compromised (3) and because the trilemma approach does not take the issue of disruption into account (9).

Perceptions on costs varied across interviewees with costs:

- Perceived to be higher for heat decarbonisation compared to doing nothing (4, 10);
- Expected to be similar for either hydrogen or electrification (10);
- Potentially cheaper for electrification compared to hydrogen (depending on technologies used) (4);
- Potentially cheaper for hydrogen conversion compared to electrification (5, 7, 9);
- Totally unknowable (8) with one interviewee explain they had heard total heat decarbonisation costs ranging from £150 billion to £500 billion (9).

One interviewee highlighted specific significant uncertainties around costs for carbon capture and storage (CCS) and batteries (8). Another explained:

> '*The error bars around the costs and the levels of disruption for the different options are so great, that there's no clear winner. No clear winner has emerged, until the error bars narrow and there's daylight between the different options, and then you can say, "Right."' (9).*

On energy security, interviewees highlighted the rapid increase in electricity generation capacity as a potential security issue for heat electrification (1, 10). On hydrogen, a civil servant explained '*if you're going to use a natural gas to produce it,* [hydrogen] *has big energy security implications. We might be using more natural gas than we do now and obviously we're already a net importer, so that might increase unless we get a lot of indigenous shale, which is perhaps unlikely*' (10).

A government advisor explained that, because of the absolute requirement for individuals to have warm homes, energy security of heat was not in general a good metric (3). Of the interviewees to make judgements:

- One thought that both heat decarbonisation pathways had similar levels of security (5);
- One thought electrification could be more secure (7);
- Another suggested that if electrification was based around 'indigenous renewables production, that's quite secure' (9).

Perceptions of sustainability of heat decarbonisation pathways varied with one interviewee saying it was impossible to judge (2), two interviewees suggesting that electrification would be more sustainable as it may be able to achieve lower carbon levels (4,7), one suggesting both could be low carbon but not zero carbon (5) and one interviewee explaining that if hydrogen was produced from natural gas alongside carbon capture, for some that is: *'not really playing the game. Storing the problem for future generations, as far as they're concerned. So, yes, not very environmentally sustainable in their eyes*' (8).

The perception of uncertainty and the expectation of disruption means that the widely used trilemma approach is not seen as suitable for considering heat decarbonisation options. This is particularly interesting because of the historic use of this measure for energy policy analysis. However, the value of the trilemma may increase if uncertainty around options can be reduced.

5.2.2. Hydrogen's uncertainties

While heat electrification was seen as clearly disruptive and hydrogen perceived as potentially less disruptive, the technical issues of converting the gas grid to hydrogen were perceived to be deeply uncertain. This is not to say there are not uncertainties associated with electrification, however, the uncertainties for hydrogen appear to be more significant in interviewee perceptions.

Two interviewees suggested that reforming low carbon hydrogen from natural gas, while the key current proposed solution, would have issues delivering at the scale needed (1, 4) echoing the capacity concerns associated with electrification. Relying on CCS to be low carbon, which the reformation approach does, was also seen to be a key issue (3, 4, 9). The actual suitability of the gas grid to transport hydrogen was also seen to be uncertain (4).

Issues were raised around the safety issues associated with producing, transporting and using hydrogen (1,4, 10) and the perceptions of the general public to these safety issues was also seen as important (1).

At a household level, there was uncertainty over:

- Whether or not people would need to be at home in order to let an engineer carry out a switch over (5);
- Questions around the suitability of existing internal pipework for hydrogen (5,8, 10);
- The need for and availability of hydrogen suitable gas boilers (1, 3, 5, 8) or changes to the 'burner' (3);
- The requirement for new hobs and ovens for cooking (3).

One interviewee suggested that policy makers viewed hydrogen as simple: '*partly because incumbents have an interest in saying it'll all be fine. Or just need to go in and do a small flick of a switch and it'll be fine. As far as I am aware, that doesn't yet exist, as a technology'* (laughs) (8). This again highlights that judgements, perhaps not based on objective evidence, may be having an impact on the perceptions of hydrogen. If this is the case, further analysis into how these perceptions have come to be, particularly in light of how they issue is framed by incumbents, may be of value. An important question is, are incumbents, or other interests, shaping policy makers' perceptions?

Another interviewee explained that to manage the switch to hydrogen '*I think you might need to create something bespoke to oversee the transition …* ' (3). A lack of both an existing low-carbon hydrogen

production market and suitable hydrogen products as well as consumer offerings was also perceived to be a particular issue for hydrogen (10), with electrification: '*you have products, you have a market which works. Hydrogen, you don't have any of that yet*.' (10).

5.2.3. False dichotomy

While most comments focused on hydrogen or electrification as a means to decarbonise heat, not all interviewees perceived the pathways as mutually exclusive.

Half of interviewees mentioned the potential for hybrid heat decarbonisation pathways where gas and electricity are used together in buildings (1, 2, 3, 5, 10), which may be less disruptive (10). Hybrid heat pumps which combine a heat pump and a secondary heat source such as gas were perceived to have seen support from gas network owner Wales and West Utilities (5, 10) and the Committee on Climate Change (2, 3). As explained in section 2.1, hybrid heating systems may have energy system benefits; they can potentially reduce electricity system impacts of full electrification, while also potentially limiting the requirements for within household upgrades.

As mentioned previously, uncertainty is also perceived around where may be the best place to use certain heat technologies with certain technologies suited to certain geographies (1, 5).

There was a perception that the debate has recently moved from 100% hydrogen towards hybridisation: '*a year or so ago I'd have said definitely hydrogen is the dominant option now, when people are talking about it in that way, I think now we're at a slightly different stage. We've moved into a more mixed space and potentially more sensible space*.' (10).

5.3. Policy and political challenges

The scale of the political challenge of heat decarbonisation led one interviewee to suggest:

> *'I think it's [heat] the key test of the Climate Change Act … This is unlikely to be a vote winner, huge cost, major intervention in people's lives so this is always for the next term of office. So, I think the barrier to this is a political one rather than an analytical' (3).*

Low political awareness of heat decarbonisation means political support for change is perceived to be limited (1, 7). The disruption to consumers and work inside homes is perceived as a particularly significant policy and political issue for heat (3, 5, 8) with a suggestion that '*all hell is going to break loose*' (8) if low carbon heating technology was mandated soon. A particular policy concern was the impact on consumer costs (1, 3, 7, 9); increasing costs and disrupting consumers was not seen as something that politicians could support (7).

Uncertainty was also seen to be limiting policy making (1, 2, 5, 8, 9): '*various people are paralysed in the face of decisions they're not sure about the efficacy of*' (1). UK heat policy discourse was perceived as being '*in a pretty woeful state*' representing a '*stand-off*' between industry and Government with one waiting for the other to act first (4). Another believed that the '*big binary* [between electrification and hydrogen] *gets in the way of making sensible choices*' (2) and an industrial interviewee explained: '*I still think we're in discovery stage for heat. So, I think the pathways are still being developed in their* [policy makers] *eyes*' (5).

It appears that the perceived binary and the associated uncertainty is limiting the ability to make rational policy decisions highlighting ideas of incomplete evidence and bounded rationality, however perhaps, a rational response to the current perceived uncertainty is to avoid policy decisions.

Concerns were also perceived regarding the influence of external actors on heat policy with the cancellation of the 2016 'zero carbon homes' (ZCH) policy (10) attributed to house builders (who admitted lobbying against the policy (House of Commons, 2019) and the popularity of hydrogen among policy makers linked to influencing efforts of incumbents (2, 7, 9) (investigated previously by Lowes et al., 2018a).

The Government's reliance on external data and ideas for policy development, particularly by inexperienced and non-expert civil servants, was believed to cause the policy process to be affected by undue influence from existing incumbent interests. Government documents then reflect those who '*shout the loudest*' and these views become institutionally engrained (2). This suggests those with capacity to lobby, may be successful at getting ideas onto the agenda. While it is clear that larger organisations may have greater capacity to lobby and engage in policy, an alternative view suggests that small and energetic entrepreneurial actors may also achieve significant policy success (Fitch-Roy et al., 2019; Mintrom, 2019).

Further research, which is beyond this article, could investigate this issue for heat decarbonisation in further detail through a more forensic approach to policy analysis as has been used previously in the sector (e.g.Lowes et al., 2019). A more discursive approach which considers the changing use of ideas and language within policy networks could also have particular value for understanding the impact of ideas and how they become embedded (e.g Carstensen and Schmidt, 2016).

Some interviewees also believed that limited deployment of heat pumps had affected perceptions of policy makers (4, 6, 7, 8, 9, 10) causing a policy '*rethink*' (10) and a focus on hydrogen to decarbonise the gas grid. It should however be noted that it has been suggested that policy failures, rather than technology issues, have resulted in a lack of heat pump deployment (National Audit Office, 2018).

5.3.1. Timescales and short term foci

Despite the need for a transformation of the UK's heat system within 30 years, a number of interviewees thought that decisions on heat could wait until between 2020 and 2025 (3, 5, 7, 10); mass deployment of renewable heat was suggested to be needed from the 2030s (4). The UK Government's climate change advisor suggests that a decision will be needed regarding the future of the gas grid in the mid 2020's and a longer term milestone is for all heating replacement systems to be low-carbon after 2035 (Committee on Climate Change, 2019c) suggesting a 2025 timescale may be suitable before major decisions are made. Flexibility in the UK's carbon budgets could also reduce the need for immediate action for heat (2).

However a civil servant suggested that the '*next couple of years are critical for starting, for establishing the ideas of showstoppers here, the main showstoppers to different pathways, and starting that discussion around deliverability and the policy discussion*' (10). There was also a belief that the potential for hybrid pathways could complicate timescales by increasing uncertainty over the optimal pathway (3).

Before a strategic decision on the gas grid was made, interviewees believed there were no-regret technologies which could be delivered today (1, 2, 7) including heat pumps (2), biomethane (1, 2), energy efficiency for existing buildings (4, 6) and low carbon new homes, described as a 'no-brainer' (6). A focus on homes not connected to the gas grid was also perceived as sensible (4).

There was a perception that better data on information and heat decarbonisation could support policy makers (1, 5, 9) alongside better networking to bring heat interests together (2). Better data could lead to more rational and evidenced policy decisions. The potential adoption of a net zero goal (which has now happened (Parliament, 2019)) was something that could support and motivate policy makers to act on heat (2) alongside the development of low carbon heat customer propositions which could support policy makers with policy development (4).

5.4. Methodological and theoretical considerations

Overall, the methodological approach and our sample provided a wide range of view-points on policy maker's perceptions and there didn't appear to be a need for additional specific interviewees consider 'other' perspectives. While further interviews with civil servants and politicians could have provided a broader perspective on views within government/parliament, only certain civil servants were willing to

speak, possibly reflecting time pressures and the belief that providing one interviewee would be satisfactory. With regards to politicians, the potential for further interviewees was limited by the number of Members of Parliament with an interest in energy issues.

A greater number of interviewees in general could have further strengthened our results and allowed analysis of whether certain perceptions on technologies linked to certain types of interviewee. It is interesting for example that the only interviewee who suggested that policy makers perceived low-carbon gas as much less disruptive was from the gas industry. While analysis linking views on policy maker perceptions, to type of interviewee is beyond the scope of this research, this approach could provide interesting results for others interested in analysis of policy maker's perceptions.

The limited existing literature on policy maker perceptions suggests that in some cases, more information can support policy makers to make decisions (Corrigan and Watson, 2003; Morrison et al., 2015). Indeed, a lack of knowledge around future options appears to have led to uncertainty in perceptions of policy makers working on heat which could be limiting decision making. While information may help policy makers, for heating it appears that the required knowledge, regarding optimal heat decarbonisation pathways is currently not available. This suggests that new knowledge may be needed. In section 6, we explain that relevant trials and demonstrations of heat technologies may be able to reduce uncertainties for policy makers however, we recognise that it is difficult or perhaps impossible to guarantee certainty.

5.4.1. *Biases and heuristics: an area for future analysis?*

'Heuristics' and 'biases' are psychological tools which are used by individuals to make '*fast and frugal*' decisions (Mousavi, 2018, p70) which require limited '*computation*' (Vis, 2019). While these tools haven't been the specific focus of this research, they are suggested to have particular value at times of uncertainty (Maitland and Sammartino, 2015) and have specifically been suggested to be important at times of policy uncertainty in order to support decision making (Vis, 2019). With the policy uncertainty around heat decarbonisation, analysis of 'biases' and 'heuristics' associated with policy makers and the policy process could be a valuable area of future research.

Lewis (2013) suggests some key '*heuristics and biases*' (p5) relevant when thinking about policy change:

- 'The availability heuristic' means salient and vivid events and experiences are easy to retrieve;
- 'A representative heuristic' magnifies the impact of rare but vivid events;
- 'Prospect theory' (associated with ideas of 'loss aversion') means potential losses are perceived as more significant than equivalent gains;
- 'Framing effects' suggests emotional or moral judgements may have an effect on well thought out preferences;
- 'Confirmation bias' means material which corroborates what is already believed is given particular credibility;
- 'Optimism bias' causes individuals to perceive previously made choices as working out well even if they are not;
- 'Status-quo bias' means individuals prefer to stick with existing decisions or familiar things.

A number of issues associated with these heuristics emerged from this analysis of policy maker perceptions including:

- A recognition of negative perceptions of heat decarbonisation particularly around consumer disruption which echoes ideas of prospect theory.
- Where perceptions of technologies had been affected by framing effects such as lobbying around the issue of hydrogen and subsequent positive perceptions in spite of clear uncertainty.
- Perceptions of technologies linked to a 'status quo bias' where both elements of hydrogen and electrification are valued because of the perceived potential continuation of existing systems.

Subsequent detailed analysis of heuristics and biases associated with policy change may add value to the somewhat descriptive nature of much policy maker perceptions research. Further analysis could also provide insight into how UK heat policy maker's perceptions have formed and the potential impact of heuristics and biases on policy change.

6. Conclusions

In providing a novel approach investigating a contemporary UK energy policy issue, this article set out to consider:

1. How do policy makers perceive options for heat decarbonisation?
2. Can these perceptions be linked to existing theory on the psychology of policy makers?
3. Do the findings from this research have any implications for the UK and wider international heat decarbonisation policy?

Section 5 explored how policy makers perceive heat decarbonisation in detail. Overall, policy makers view heat decarbonisation as fundamentally disruptive, particularly for consumers, with little 'up-side'. Perceptions of disruption are compounded with perceptions of uncertainty associated with potential heat decarbonisation technologies and their wider system impacts. So great is the expected disruption and uncertainty that the stalwart approach for assessing energy systems, the trilemma, is not currently seen as particularly useful by heat policy makers.

While policy makers recognise uncertainty, what this uncertainty is, appears to be relatively well known. There is particular uncertainty over whether converting the UK's gas system for heat to hydrogen at scale would be technically possible, given its novel approach and reliance on CCS (for the production of low carbon hydrogen) which is surprising considering the attention given to this approach by policy makers.

This article has also linked perceptions of policy makers with the issues associated with the psychology of policy makers. The impacts of bounded rationality have been highlighted in the perceptions of uncertainty associated with the electric versus hydrogen heat future. Apparently, partly as a result of uncertainty, policy decisions which may have clear benefits for decarbonisation, even in light of some uncertainty, are not being made. Policy makers perceive themselves as bounded as a perception exists that a lack of evidence is limiting policy making, and more/better evidence could support better policy making.

While bounded rationality emerged as an issue particularly linked to uncertainty, rather than bounded rationality leading to imperfect policy decisions, the level of uncertainty means that it appears difficult for policy makers to make decisions on heat decarbonisation. Despite the urgency of heat decarbonisation timescales, satisficing resulting from imperfect information appears to have led to an acceptance of uncertainty as a reason to wait before decisions are made. The belief that greater certainty can be provided by new evidence echoes much of the literature considering policy makers' perceptions considered in section 3.4. It is however unlikely that simply having more evidence will drive heat decarbonisation because other issues, such as disruption to consumers under any decarbonisation pathway, are at play.

Overall, this study has provided novel analysis which contributes to the literatures considering the perceptions of policy makers and the psychology of policy makers. Future analysis associated with heat decarbonisation policy may also benefit from wider consideration of the heuristics and biases associated with policy maker's perceptions. As well as providing interesting theoretical insight to build on the perceptions literature, the recognised importance of heuristic and biases at times of uncertainty, could provide significant practical value for UK policy

makers looking to decarbonise heat who are faced with significant uncertainty.

Further investigation into how the perceptions of policy makers are shaped by various interest groups could also provide further valuable analysis on the role of power associated with socio-technical change.

As explained in section 3.2, much of the existing literature considering policy maker perceptions has considered the healthcare sector. Healthcare research, for example around drug development, will use 'large n' quantitative research and policy decisions may often (but not always) focus on specific clinical issues. Many energy policy and specifically, heat policy issues are considering long-term strategic, infrastructure based socio-technical transitions with potentially varying geographical, building level and citizen impacts. Further research into policy maker perceptions, and the role and use of 'evidence' across different sectors may become a fruitful area of research, with potential to provide unique insights from different sectors which can support various policy processes.

If policy makers perceive heat decarbonisation as fundamentally disruptive and uncertain, and the development of policy is delayed, there may be implications for whether the UK's goal for decarbonised heating will be met. It will never be possible to eradicate uncertainty but it may be possible to reduce this uncertainty. There may also be approaches or technologies which can reduce the consumer disruption associated with heat disruption and again further research, analysis and collaboration may support this. In a market like the UK's where the penetration of low carbon heating is so limited, focusing on deployment of low carbon heating in areas where costs are lowest such as in areas not connected to the gas grid, valuable learning may take place. Continuing the focus on international approaches to heating, as others have done (Hanna et al., 2016), may also provide examples of ways to reduce disruption and uncertainty.

Nevertheless, the scale of the potential heat transformation and the asset lives of heating appliances and infrastructure mean that the difficulties should not be under-estimated. It may be the case that uncertainty associated with heat decarbonisation is not actually a high as is suggested and uncertainty is being used as a reason to delay action which is perceived to be deeply disruptive and politically unpopular. With just three decades to decarbonise heating in the UK, rapid policy development is needed and even if there is uncertainty, which there always will be, decisions will need to be made in the face of it. The following sub-section considers policy issues in more detail.

6.1. Policy implications

This section considers the third research question.

Perhaps most significantly for UK heat decarbonisation efforts, these results highlight the perceived requirement for more evidence before UK policy makers feel comfortable making more interventionist decisions on heat. However, the key uncertainty highlighted by this research is regarding the future heat sources for buildings currently connected to the gas grid rather than heat decarbonisation more generally. The following suggestions are likely to have value for other countries with significant gas distribution infrastructure such as the Netherlands, Italy, the United States and Canada.

We propose heat policy makers should focus on three goals:

Reduce uncertainty: significant efforts should be made to reduce uncertainty through research and analysis and technological trials. In particular, technological trials associated with the performance of hydrogen in the existing gas system should be prioritised in order to understand the technical viability and costs of this option. While relatively small trials are underway and supported by UK Government funding,[11] a demonstration to combine all technological elements including low carbon hydrogen supply, conversion of an existing gas grid area and deployment of appliances would provide valuable learning and possibly reduce uncertainties. This trial could build on previous studies led by gas distribution network companies (e.g. Northern Gas Networks et al., 2016).

We also note that the current 'Heat Electrification Demonstration Project', which aims to install heat pumps across a range of property types, could reduce uncertainty around electrification options (HM Government, 2019).

While natural policy-learning is likely to take place around current and future heat technology studies which can inform future policy (Dunlop, 2017), ensuring that trials and results are independently verified may be important for such a transformative and challenging policy issue. Government should therefore provide resources to ensure such verification and to ensure that the best available evidence is used as a basis for policy making. It should however be considered that further research could further highlight existing uncertainty further (Jensen and Wu, 2016) and it has been suggested that a decision on the future of the UK gas network is required by the mid-2020s (Committee on Climate Change, 2018).

Focus on low regrets options initially: There are a range of very low regret heat policy options around deployment of energy efficiency, decarbonisation of off-gas-grid buildings and mandating low carbon heating for new buildings which are not affected by the uncertainty over the future of currently gas heated buildings (Committee on Climate Change, 2019c).

Energy system modelling, including that carried out for Committee on Climate Change has also repeatedly shown a requirement for an increase in the use of heat networks (Committee on Climate Change, 2019b) and indeed the UK Government's own analysis has suggested a significant increase in the amount of heat provided to UK homes from heat networks by 2050 across all scenarios, including where hydrogen is prioritised (HM Government, 2017). Deployment of heat networks is therefore a low regret area which Government can continue to support through both existing projects around guidance (The Heat Networks Delivery Unit) and capital funding (Heat Networks Investment Project) (HM Government, 2020).

Accept uncertainty: It will never be possible to remove uncertainty associated with the optimal low carbon heat solutions and, with short decarbonisation timescales, some uncertainty and therefore risk, will need to be accepted. A major uncertainty currently appears to be how many homes currently connected to the gas grid will need to use heat pumps in the future. In light of this specific uncertainty, policy makers could initially provide specific support to these households for example providing finance or policy support, such as grants, which create no additional costs or risks for consumers. This, and other policies which are associated with technological uncertainty can be modified as evidence becomes clearer.

There are existing tools which UK Government policy makers have to deal with uncertain futures, one example being 'The Futures Toolkit' which includes various approaches to attempt to understand the future and to test potential policy approaches (Government Office for Science, 2007). 'Adaptive governance' processes involving ongoing iteration and assessment have been proposed as one option to deal with policy uncertainty (Jensen and Wu, 2016; Root et al., 2015; Walker and Marchau, 2003) and are seen to have particular value for climate change mitigation policy (Roelich and Giesekam, 2019). Further research investigating a potential role for adaptive governance specifically associated with heat decarbonisation could add value.

While these proposed steps may support policy makers, and uncertainty may be reducible or manageable, significant disruption, particularly for consumers, appears likely whatever approach to decarbonisation is taken. Politicians (who will need to deliver heat decarbonisation policy) who are seeking re-election appear unlikely to be supportive of policies which disrupt consumers and increase energy costs, which heat decarbonisation may do.

[11] E.g. 'Hy4Heat' is investigating within building safety and appliance testing (Hy4Heat, 2020).

Further still, the need for rapid decarbonisation implies that policy must rapidly support the deployment of known technologies which can support heat decarbonisation such as heat pumps, energy efficiency and the deployment of heat networks. Despite the cost-effectiveness and decarbonisation potential of some of these technologies, particularly energy efficiency technology, recent deployment has been and remains limited (Committee on Climate Change, 2019c) suggesting that even economically 'rational' policies are not being progressed.

If rational policy cannot be delivered then this suggests that more disruptive policy stands little chance of being introduced. The UK Government's proposed policy of banning new homes from using fossil fuel heating systems from 2025 (HM Treasury, 2019) is a sensible initial regulatory step[12] but this could be introduced sooner and further much more significant interventions will be required.

Funding

This research formed part of the programme of the UK Energy Research Centre and was supported by the Research Councils UK under the Engineering and Physical Sciences Research Council award EP/L024756/1.

Declaration of competing interest

Richard Lowes was previously employed in the UK gas industry and is currently an independent advisor to a UK gas network operator.

CRediT authorship contribution statement

Richard Lowes: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Project administration, Funding acquisition. **Bridget Woodman:** Conceptualization, Methodology, Writing - review & editing, Supervision, Funding acquisition.

Acknowledgements

Thank you to all interviewees who took the time to speak to us for this research. The frankness of interviewees has allowed the paper to be both real world applicable and we believe, very interesting for researchers and policy practitioners.

Annex 1. Interview outline

All interviews were carried out by the lead author with around half in person and half over the phone. This structure of interviews was based around the following topics but further discussion, some organic and some based around probing by the interviewer, took place.

1. The project was introduced explaining that the focus was on the views of UK policy makers on heat decarbonisation pathways or policy in the context of three potential key heat decarbonisation technology options, low-carbon gas, electrifications and hybrid approaches. To start discussions, interviewees were asked to explain how they viewed current debates around heat decarbonisation technology and policy.
2. The second element asked interviewees to consider the idea of the 'trilemma' and to consider how different heat decarbonisation technology options could be associated with the trilemma issues of cost, environmental sustainability and energy security.
3. The element of interviews specifically considered the issue of the impacts of heat decarbonisation on 'consumers' and industry to investigate whether certain approaches were perceived to reduce impact and disruption.
4. Interviewees were asked to consider if certain technology options appeared more deliverable for policy makers and if so why.
5. This question focused on the potential issues for policy makers associated with converting the UK's gas grid to run on low carbon gas.
6. This question focused on the potential issues for policy makers associated with converting much heat demand to electricity.
7. Interviewees were then asked to consider how the issues considered in questions 5 and 6 compare.
8. Interviewees were then asked whether the deployment of certain technologies could be achieved with existing actors or whether the role of government and industry would need to change.
9. The question asked whether policy makers currently felt able to make major decisions on heat decarbonisation and if not, how these decisions could be supported.
10. This question asked whether recent lack of deployment of low carbon technologies had affected policy making.
11. Interviewees were asked to consider timescales for heat decarbonisation and whether decarbonisation by 2050 was possible.
12. The final question asked whether general concerns over disruption could limit policy making for heat decarbonisation.
13. Finally, interviewees were given the opportunity to raise any other issues.

[12] It should be noted that the previous policy goal to mandate 'zero carbon' new homes in 2016 was cancelled by the 2015–2016 Conservative Government on the grounds of reducing regulation on builders (HM Treasury, 2015).

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