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Energy planning tools for low carbon transitions: an example of a multicriteria spatial planning tool for district heating

Ruth E. Bush[a,b]* and Catherine S.E. Bale[c,d]

[a]*Doctoral Training Centre for Low Carbon Technologies, University of Leeds, Leeds, UK;* [b]*School of Social and Political Science, University of Edinburgh, Edinburgh, UK;* [c]*School of Chemical and Process Engineering, University of Leeds, Leeds, UK;* [d]*Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds, UK*

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Energy planning tools can support transitions to low carbon energy by helping planners to identify technology options and scenarios. Exploring a case study of district heating development to support heat decarbonisation in the United Kingdom (UK), this article uses thematic analysis of qualitative semistructured interviews conducted between May 2013 and August 2015 with local and regional government officials, in order to consider how energy planning decision-making tools can be designed to support the early stages of low carbon transitions as a form of strategic niche management. The findings of this analysis are then tested through the development of a spatial heat planning tool covering England and Wales, designed to respond to the needs of niche actors seeking to facilitate early development of district heating projects. The tool is for use by local government actors as they seek to build social networks of stakeholders to support the technology change, to demonstrate its value and to support skills development. The research shows the importance of designing flexible tools which can go beyond techno-economic criteria and reflect the wider motivations and decision criteria of local actors, including social criteria.

Keywords: energy; strategic niche management; transitions; multicriteria tools; low carbon heat

1. Introduction

Energy planning is the process of setting out long term visions for a future energy system, often carried out by governmental organisations and infrastructure providers at both national and local levels (IEA 2000). In the context of low carbon transitions, it can be a useful policy tool that can help to shape and drive low carbon energy transitions. In this article, we consider how tools for energy planning can play a role in supporting the early stages of a low carbon energy transition, and based on our findings, we develop a tool specifically for the case of supporting district heating development in the context of the United Kingdom (UK).

Energy planning can take into consideration a range of factors, including the technical potential of low carbon supply from renewable resources and demand reduction

*Corresponding author. Email: ruth.bush@ed.ac.uk

through energy efficiency savings; environmental factors such as expected carbon reduction trajectories; and socio-economic factors, including population characteristics and investment costs. It may be applied to one technology or infrastructure, or consider the interactions between different energy supply and demand reduction options.

Low carbon energy planning is a complex process. It takes place in the context of an incumbent socio-technical 'regime' made up of existing configurations of technologies, institutional and market structures, user and business practices and government policies (Geels 2004; Foxon 2011). Decisions on energy are influenced not only by the technical or economic viability of a technology but also by the wider social context and cultures. This incumbent regime influences energy transition pathways, potentially acting as a form of resistance or lock-in against changes in the established set up of the energy system.

Transition theories conceptualise the introduction of innovations into this 'socio-technical regime' as initially taking place within a 'niche' space. A niche provides a form of protected environment for early applications of a technology. Actors can experiment with and develop the innovation until it can be diffused beyond the protected niche (c.f. Kemp, Schot, and Hoogma 1998; Schot and Geels 2008).

Strategic niche management is one approach for thinking about how actors can actively facilitate and shape transitions by supporting niche creation. Schot and Geels (2008) set out three important processes for strategic niche management: development of a network of actors to support the technology; improvement in the required skills and technology adaptations for widespread uptake of the technology; and understanding of the technology's values. These processes are seen as important for 'nurturing' an innovation within a niche space (Smith and Raven 2012). Alongside, it is important to consider the processes needed for diffusing an innovation beyond a niche to become an embedded part of the socio-technical regime. These are conceptualised as niche 'empowering processes' and are set in motion through activities such as articulating future visions for the technology innovation to actors working beyond the niche, or influencing wider regime changes to enable the technology to diffuse more easily (Smith and Raven 2012).

For the theoretical basis of the article, we draw on the concepts of strategic niche management, and niche empowering processes, to help us to consider the role of decision-making tools in supporting the application of low carbon energy innovations in the early stages of a low carbon transition, before uptake and use is more widespread. We focus on energy planning at the local level, considering a case study of district heating development in the UK. Although district heating is widely deployed in some national energy systems (Euroheat and Power 2013), it makes up only a small minority of heat supply in the UK context, which is dominated by use of natural gas (DECC 2012a). However, the need to decarbonise heat has brought about an increased interest from both national and local governments in developing new district heating systems to unlock potential renewable heat, such as geothermal or waste heat sources, and to create more efficient supply in urban areas (DECC 2013; Eisentraut and Brown 2014).

Various decision-making tools have been developed to assist actors with the complex task of energy planning (and heat planning, in particular) and some have attempted to take into account the socio-technical context (Centre for Sustainable Energy 2012; DECC 2012b; Keirstead, Jennings, and Sivakumar 2012; Scottish Government 2012; Energy Technologies Institute 2013). These tools are a means of gathering and structuring evidence to inform actors' decision making. Tools can vary

in their levels of sophistication, from simple tools which consist of checklists or process steps that frame a decision, through to advanced computational modelling tools which aim to offer understanding on more complex system dynamics (Nilsson *et al.* 2008; Runhaar 2016). The advancement of computing power in recent decades has enabled an increase in the number and range of modelling tools being developed (Keirstead, Jennings, and Sivakumar 2012).

Despite the proliferation of decision-making tools in recent years, tool 'non-use' is common (Radaelli 2004; Nilsson *et al.* 2008; Gibson *et al.* 2017). There are a variety of reasons for this. For example, in the energy field, tools are often focused on techno-economic criteria, yet the motivations of many policy makers extend beyond simple economic or carbon reduction drivers, to include wider social considerations such as fuel poverty, tackling deprivation and job creation (Bush, Bale, and Taylor 2016; Gibson *et al.* 2017). Similarly, tools may be too complicated to be used directly by the actors who need them and appear as a 'black box.' This can lead to decision makers having a lack of trust or understanding of the tools' outputs (Nilsson *et al.* 2008; Rogers *et al.* 2015; Kolkman *et al.* 2016). Conversely, where tools are used, they might be applied in politically motivated ways, to support the existing beliefs or agendas of the actors employing them (Radaelli 2004; Nilsson *et al.* 2008).

For the early stages of low carbon transitions, energy planning tools are often being used in the context of inexperienced actors with little knowledge or understanding of the technology, undeveloped supply chains and support networks, and a lack of skilled professionals able to support implementation. This context requires a different type of decision support tool than for a context where a technology is more familiar to actors.

In this article, we investigate if and how energy planning tools can support niche development in low carbon transitions, exploring the case study of district heating development in the UK. We use thematic analysis of qualitative semistructured interviews conducted between May 2013 and August 2015 with local and regional government officials involved in district heating development. We consider how these actors currently make use of energy planning tools and identify opportunities for these existing tools to better support strategic niche management. Testing the findings of this analysis, we put them into practice to create an example of a tool that might better meet the needs of the local government officers in the case study who are seeking to facilitate district heating deployment at the early stages of a transition in the UK. We address the following research questions:

1. Do energy planning tools provide functions highlighted as important in the transitions literature for strategic niche management and empowering innovations?
2. How could energy planning tools be designed to better support the development of niches at the early stages of a low carbon transition?
3. What would the design of such a tool look like in practice?

The article is structured as follows: Section 2 reviews the relevant literature on use of decision-making tools in policy and practice; Section 3 summarises the case study context of district heating development in the UK; Section 4 sets out the methodology used for data collection and analysis within the research; Section 5 sets out the results from the analysis, first for how energy planning tools can support strategic niche management and empowering innovations, and then, second, lessons for tool design for this purpose. The second part of Section 5 presents the resulting design of a tool for

district heating development in the UK. Section 6 discusses the results and implications of the work as a whole.

2. Use of decision-making tools in policy and practice

The existing literature highlights how decision-making tools can be utilised for a range of purposes within policy and practice, from ensuring compliance with regulations, to 'softer' applications, such as structuring stakeholder engagement or encouraging inclusion of environmental or social factors into decision making (Runhaar 2016). The literature is often concerned with the factors that affect the uptake and influence of tools, but it has never before been linked explicitly with the strategic niche management literature, and the application of tools at the early stages of transition. This section considers what the existing research can tell us about how tools are used within policy and practice in general, and the factors that influence their uptake.

Tool-use in policy making and practice is influenced not only by the tool design and functionality, but also by the types of actors that are using the tool, and how the legitimacy of the tool is established within the decision-making process (Radaelli 2004, 2005; Nilsson *et al*. 2008; Hughes 2013). Design factors that are seen as important include the compatibility of a tool with existing users' skills and access to software; its flexibility for users to adapt the model as their needs change; and its ability to be used with incomplete data (Runhaar 2016; Gibson *et al*. 2017). A tool's functionality must also be aligned to user objectives, enabling users to consider all relevant dimensions of a decision (Runhaar 2016).

Beyond technical tool design, the transparency of the tool in terms of how it functions and data sources is important for building user-trust. The organisational context within which the tool is being applied is also an influential factor. For example, is there an existing 'problem' that users desire support with? Can the tool provide actors with an evidence base to politically justify their decisions? (Adelle 2015). Nilsson *et al*. (2008) discuss the growing use of policy assessment tools in ex-ante policy making. They highlight how tools were "likely to be selected primarily on the basis of organisational routines and standard practices, and on the expectation that they will produce evidence that speaks directly to, and supports, the core beliefs of governing coalitions" (Nilsson *et al*. 2008, 352). They found that actors particularly made use of 'simple' tools because they had more predictable outcomes that actors could anticipate and use when it supported their agenda. These findings highlight how actors are unlikely to make use of a particular tool unless it can be easily embedded within existing working processes and can support existing objectives.

Tools need to be established as a legitimate method of decision making before they will be used consistently. Radaelli (2005) suggests that legitimacy is established by tool users having 'acceptable' answers to the following questions: "Who sets the assumptions within decision-support tools? How are they designed? Why should the process be considered legitimate to all stakeholders?" (Radaelli 2005, 932). Sterk, van Ittersum, and Leeuwis (2011) add that, during tool development, attention should be given to how to embed the tool in the intended social and organizational context.

In this article, we are particularly concerned with the design and use of decision-making tools at the early stages of low carbon transitions. At the early stages of application of a technology innovation it is not necessarily clear what decision criteria

should be applied. Particularly in the context of wider system change, and uncertain policy direction, which is often the case in low carbon energy policy. There is also a need to increase understanding and support of a technology which may be unknown to many actors involved in decision making. The lack of established approach with a clearly defined collective priority for the energy system means it is hard to define a tool with pre-conceived, quantitative criteria.

Our consideration of tool-use as a form of strategic niche management, therefore, needs to consider the political and policy context, as well as the actors for whom the tool is designed. Tools must be designed with sufficient flexibility to meet the requirements of niche actors working within an uncertain and changing context.

3. Case study: decision-making tools for district heating in the UK

In order to address our research questions, we focus our analysis on a case study of district heating in the UK. District heating has been recognised by the UK government and UK Committee on Climate Change as a potentially important part of the technology mix and a 'low-regrets' option for decarbonising heat in the UK, particularly for areas with dense heat demands such as towns and cities (DECC 2013; Webb 2016). However, the high penetration of natural gas networks across the country, the high upfront infrastructure costs of district heating, and the need for alternative business models to support decentralised heat provision have kept the penetration of the technology to less than 2% of heat supply in the UK (BRE University of Edinburgh & Centre for Sustainable Energy 2013; DECC 2013). This case study, therefore, represents an example of an early stage of a low carbon transition. Local actors involved in project development seek to create supportive local conditions that enable successful delivery of new district heating projects, effectively creating a form of protective niche space which enables deployment of the technology.

Decision-support tools in the form of heat maps are often used by UK local governments in the early stages of developing a district heating network (see Section 3.1 for examples), as they provide spatial information about factors that influence the viability of district heating networks. Users are able to map a range of spatial data such as estimated heat demand density, the locations and capacities of existing heat sources, as well as nontechnical indicators such as fuel poverty or income segments, building types (domestic/commercial/public) or building ownership (privately owned, private rented, social rented). For example, at the European level, the Pan-European Thermal Atlas (PETA) uses data sets from across European Union (EU) member countries to model heating and cooling demand to a resolution of 1 km^2.

Heat maps can be used for two purposes in relation to energy planning:

1. At the early stage of development, to inform the identification and prioritisation of potential district heating projects for developing further with detailed feasibility studies;
2. And/or for strategic heat planning, to identify strategic areas for district heating development to enable greater system benefits over the long term.

For the first point, the process of heat mapping for project identification seeks to reduce the uncertainty that surrounds applying resources in developing a project up to an investable standard. Figure 1 shows the district heating development stages as an

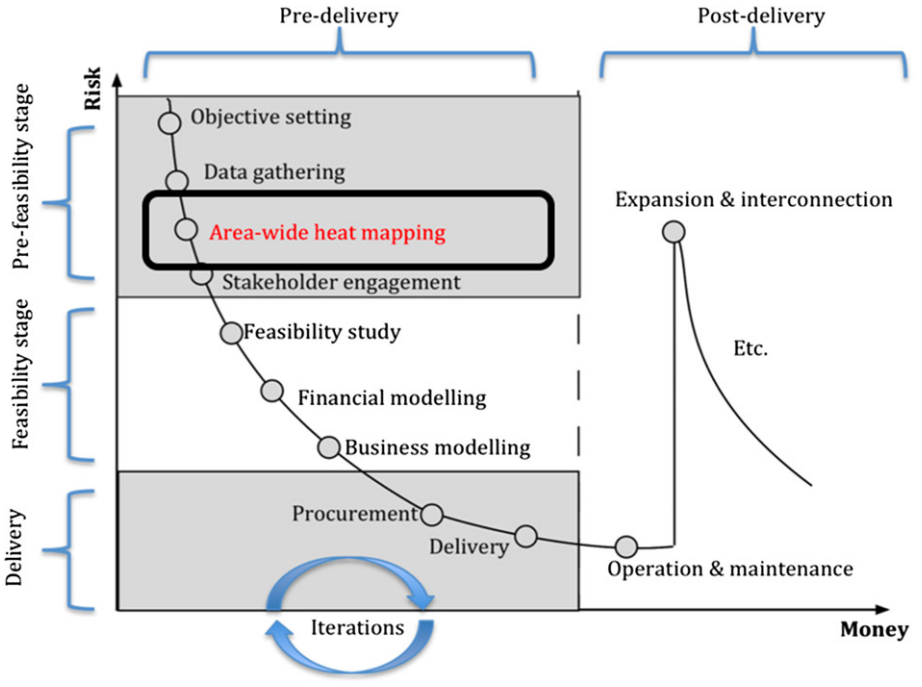

Figure 1. The project development process of a district heating scheme, "illustrating how the risk of project failure should reduce as the project proceeds through the stages of development." The diagram indicates where area-wide heat mapping is undertaken during the pre-feasibility stage (diagram adapted from King and Shaw [2010]).

iterative process to identify a potential project, and to reach delivery and operation. Heat mapping tools are used for this purpose at the early stages of project development when uncertainties around projects are high.

For the second point listed above, heat mapping tools can also be used to inform strategic energy planning. They enable energy planners to identify which technology solutions are most appropriate across a given area. For example, in Denmark, a country with a high penetration of district heating (67% in 2011, Euroheat and Power 2013), municipal authorities undertake heat planning, which is enforced through the designation of district heating 'heat zones.' Within these areas, heat customers can be compelled to connect to a district heating network, thereby significantly reducing the risk associated with making the initial capital investment for a district heating company to develop a new network (Chittum and Østergaard 2014). The EU Energy Efficiency directive (Article 14) has also enforced each EU member state to create of a form of heat map as part of undertaking a comprehensive assessment of their potential for efficiency in heating and cooling (European Union 2012).

3.1. Use of heat mapping in the UK

Recognition of the potential of district heating for meeting multiple energy challenges within the UK has led to increased interest and support for heat mapping activities (DECC 2012a; Webb 2016). Local governments have been highlighted by the UK and Scottish governments as key actors that can play a strategic coordinating role and

potentially a delivery role in projects (DECC 2013; Scottish Government 2015). As a result, both the UK and Scottish Government actively encourage local governments to make use of heat maps.

> Heat mapping is a powerful way to visualise opportunities, to assess who needs heat (demand) and where sources of heat might come from (supply), and how these can be connected in an efficient way to reduce the cost of heat supply and the carbon intensity of heat generation. It can also be used, in combination with other spatial datasets, as a tool to focus on areas of need or priority. (Scottish Government 2013)

In England and Wales, the Heat Network Delivery Unit (HNDU) was set up within the UK Government's Department for Energy and Climate Change (DECC)[1] to offer support to local governments in their work on district heating. As part of the unit's work, local governments could apply for a portion of £7 million to support their work on district heating development up to the investment stage of a project. This includes heat mapping, and 70 out of 115 successful local governments were funded for this purpose (accounting for 9% of allocated HNDU funding) between 2013 and 2015 (DECC 2013; CAG Consultants 2015). In Scotland, the Heat Network Partnership offers support to local governments in their use of the Scottish Heat Map.

Given the significant level of activity and investment in heat mapping to support decision making around district heating, it is crucial that the resulting outputs from this work are in a format that is effective at supporting local niche creation for the development of district heating projects.

4. Methodology

4.1. Analysis framework

This section sets out the method used to address our research questions, drawing on analysis of an empirical case study of district heating development in the UK. As set out in Section 3, forms of heat mapping tools are already used by local and regional governments to inform energy planning processes for district heating in the UK. In-depth interviews with relevant local and regional government officials (see Section 4.2) are analysed to consider how these existing tools are used to support niche nurturing and empowering processes, using a framework based upon the concepts of strategic niche management and niche empowering processes (Kemp, Schot, and Hoogma 1998; Schot and Geels 2008; Smith and Raven 2012), alongside identifying gaps where tools are not supportive of these processes. Specifically, our analysis considers the potential contribution of decision-support tools for the three objectives of strategic niche management set out by Schot and Geels (2008):

1. Development of a network of actors to support the technology – for example, Decision-support tools could be used to help instigate and structure dialogue between key actors, building understanding and establishing a consensus on the need for actions.
2. Improvement in the required skills and technology adaptations for widespread uptake of the technology – for example, Decision-support tools could be used to support inexperienced actors to perform activities such as technical analysis or

system planning. This could drive technology adaptations and improve the skills of key actors.
3. Understanding of the technology's values – for example, Decision-support tools could demonstrate the potential benefits and impacts of a technology before it has been implemented.

In addition, the work is concerned with exploring approaches to delivery of niche empowering processes (Smith and Raven 2012). A fourth objective (not previously outlined) is, therefore, added for consideration:

4. Delivering empowering processes for wider system change – for example, Decision-support tools could provide evidence for wider system change, for example by highlighting the links between an innovation technology and the wider energy system.

The examples given here are by no means exhaustive, but are given to show the starting point for analysis of the potential of decision-support tools for supporting the process of strategic niche management (in response to research questions 1 and 2).

Based upon the findings of the interview analysis we go on to develop an example of a district heating data mapping tool that meets the recommendations of the interview analysis. We aim to demonstrate how a tool to better support actors facilitating the early stages of a low carbon energy transition can be developed, and understand the challenges associated with putting these recommendations into practice.

4.2. Empirical data

The empirical data for this work draws on qualitative interviews with UK local and regional governments about their use of heat mapping tools. Local governments are not the only actors that might make use of heat mapping tools. However, their key coordination role within the district heating development process means that they offer a useful focus for this analysis. They have also been actively encouraged and supported by the UK and Scottish governments to use heat mapping tools in their work on district heating.

Using 14 semistructured interviews, empirical data was gathered from 11 UK local governments (five from within Scotland, and six within England) and three regional governments to inform analysis of heat mapping use to support niche processes. All interviews lasted approximately one hour and were recorded and transcribed verbatim. The data was then stored and coded in NVivo and analysed according to the strategic niche management and niche empowering ideas set out in Section 4.1. The interviews included questions about:

- The role and responsibilities of the interviewee;
- The details of their involvement in district heating projects to date;
- Partners and stakeholders they work and engage with on projects, and their interests and motivations;
- Decision criteria and indicators considered within the project planning process;
- Experience of using decision-support tools in district heating project planning (what was useful, what was lacking? What data is used?);
- Available resources and skills to support projects.

Table 1. Summary of the applications and uses of heat mapping tools for achieving the aims of strategic niche management in district heating development in the UK.

Contribution to SNM	1. Establishing new actor networks	2. Skills and technology improvement	3. Demonstrating technology value	4. Delivering empowering processes
Evidence on use of tools	Stakeholder identification; Stakeholder engagement	Introducing the district heating development process to new actors with a structured activity; Increasing actor confidence	Evidence base from heat maps reduced uncertainty about project techno-economic viability Inclusion of relevant data sets enabled heat maps to consider social and environmental benefits alongside techno-economic viability	Evidence base to inform planning of a strategic approach to district heating development, expansion and interconnection

Data included in the study were collected between May 2013 and August 2015 during two phases of data collection. The first phase of eight interviews was part of a research project exploring district heating planning tools and fuel poverty, funded by the Chesshire-Lehmann Fund Trustees (2013).[2] The remaining six interviews were done at a later stage to supplement the existing data for this research article. Interviewees were selected who took a lead or an active role in district heating planning within their local or regional government and had begun to engage with heat mapping activities. A range of experience levels were sought, to ensure there was representation within the data set of actors operating district heating schemes through to those at the early stages of developing a project.

Analysis of the empirical data was conducted using a method of thematic analysis (Braun and Clarke 2006), using an initial phase of coding structured according to the four objectives outlined in the analysis framework (Section 4.1) to explore the role of heat mapping in supporting strategic niche management and niche empowering processes. Based upon this analysis, the discussion in Section 6 draws on the literature on tool-use in policy making to consider how heat mapping tools could be designed to better support development of niches at the early stages of a low carbon transition to district heating in the UK.

5. Results

In this section, we first present the results of the thematic analysis of the empirical data in relation to research questions 1 and 2 (Section 5.1), and then outline a tool that has been developed in response to question 3 (Section 5.2). Quotes from interviewees are anonymised, but have been labelled to indicate whether the speaker was from a local authority (LA1, LA2, …, LA11) or from a regional authority (RA1, RA2, RA3), and where there are multiple quotes from the same interviewee.

5.1. Themes and recommendations

The role or functions of heat mapping tools were explored for each aspect of the analytical framework. Table 1 summarises the identified roles and functions that use of heat mapping tools in the case study is making to these aims. The following sections present the identified themes and accompanying evidence for each aspect in the table.

5.1.1. Establishing new actor networks

Building strong local actor networks, initially reliant on trust and cooperation were seen as a crucial part of the district heating development process. Project plans often relied on a small number of large anchor loads that provided the basis for a reliable and predictable business case. Stakeholder engagement was, therefore, an important part of the development process, to build up a trusted commitment to a project and enable development of an investable business case

> There is always an inherent risk in the process, […] because for instance, your stakeholder suddenly says he's not interested in being involved in that … and he was going to take 75% of your heat. So it can die a death there. [RA1]

Actors within the study used the outputs from heat map analyses, as well as the data collection process undertaken to feed into heat maps, as a basis for stakeholder identification and engagement. The process acted as a mechanism for a focused approach to stakeholder engagement with key stakeholders, such as managers of sites with large heat demand loads that might act as key anchor loads for a scheme. The data collection process, in particular, helped to initiate conversations.

Heat maps were also used as a communication tool within the stakeholder engagement process, providing a visualisation of the potential opportunity to actors who could be unfamiliar with the technology. This visual tool enabled dialogue and building of mutual understanding about the priorities and constraints of other actors.

> It's an incredibly visual thing. […] To have everybody round the table and have a visual tool which shows them exactly where they are, spatially in relation to everyone else and everybody else's agendas. […] The links were very obvious within this. [LA4]

They were also seen as useful for promoting district heating opportunities to potential private investors.

> Our colleagues in economic development and planning can see the benefits of [the heat map] and how we could really use it as a tool to attract investment in the city. [LA3]

A challenge for utilising heat mapping tools for stakeholder engagement was that this function relied upon local governments having sufficient staff resource and skills.

> A constraint is to actually find time to use the tools. We have used some of the modelling tools in the past but normally just gotten in student expertise or student labour in to help with using some of them. Sometimes we use consultants to use them for us as well. [LA2]

Contacting stakeholders for data collection took up large amounts of actors' time and data was often inaccessible for reasons of commercial confidentiality or lack of trust.

> Even some big public sector organisations are reluctant to tell you what their building consumption is. It is nuts. [LA1]

Commissioning of consultants was used to overcome these resource constraints. Conducting mapping exercises over a regional scale, combining several local government areas, also offered resource savings for individual local governments. However, in-house resource was still needed to maintain momentum over the long development time of district heating projects.

> You do want to maintain an element of in house, if you're going to be able to sustain it. [LA2]

In addition, identification of key stakeholders was often a balance between the evidence provided by the heat map and local knowledge of the risks of working with particular partners. Knowledge of the political context and stakeholders' attitudes towards district heating often formed a strong influence over project prioritisation alongside technical information from the heat map. For example, public sector heat loads were often prioritised because of a perception that there was more potential to influence their decision making than private actors.

> So, the very first thing is that quick technical field, to make sure that you've got enough heat density in the area. Then I suppose it is looking at knocking out some of the barriers […] How much does the council own? How much can we guarantee that we can connect to? Then I suppose, looking at other heat in the area. [LA2]

Without embedding capacities for making use of heat mapping tools within the local governments, this need for combining technical information with knowledge of the local context is more difficult to achieve.

5.1.2. Skills and technology improvement

Heat maps offered a form of learning to local actors engaging with district heating for the first time. They offered an initial structured activity for local government officers to begin to build up their understanding and confidence, and the mapping outputs provided an easily understandable, visual representation of the district heating potential across a given area.

> It's building confidence isn't it? We know we've got some resource, but is it that or is it that? [LA1]

The levels of uncertainty associated with the technology caused debate about the required level of data detail and heat map functionality. Some actors wanted increased heat mapping functionality to gain an earlier indication about whether a project was going to be financially viable. They were looking for ways to reassure themselves that

the time and financial resources they were investing in developing a project were likely to be successful in the end.

> It would be absolutely fantastic if you had a tool that was fairly straightforward to use, and used data that was granular enough, that you could plan a network […] with some payback and carbon savings, and revenue generation and basic IRR, and net present value. [LA1]

However, other actors suggested that this was not realistic at this stage in the development process (see Figure 1).

> I think, at this stage, if you did go down to the nitty-gritty, what value would you place on those figures? They would be plucked out of the air because you are at such an early stage of feasibility. [RA1]

The skills required to be able to use heat mapping tools for any of these purposes was another important influence over the extent and manner of tool use. Local government officers leading on heat mapping for district heating did not always have access to staff with Geographical Information Systems (GIS) skills. This made interrogating heat mapping tools without the help of consultants difficult.

> Currently, in the public sector there are major cuts. Front line schools and social care are unlikely to be cut, but back office services, which might include people who look at GIS and do those sorts of things, are highly likely to be cut. So even in the time I've set up the project, I have had a huge turnover of key officers. So even the ones I trained up and got interested have moved on in some cases already, and I have only been in eight months. [RA2]

5.1.3. Demonstrating technology value

Actors saw heat mapping tools as a potential source of evidence to inform prioritisation of project opportunities, building business cases and persuading relevant stakeholders of the potential opportunity presented by a project. This was a form of prospective demonstration of technology value.

> I think it gives you more evidence, and evidence is useful if you're writing applications and trying to make a business case. [LA3]

However, the effectiveness of heat mapping tools for demonstrating district heating technology value was limited by the functionality of the tool and the credibility and resolution of heat map data. For example, eligibility of projects for funding support was an important consideration within the project prioritisation process that was not always included as a data set in heat maps. In dense heat demand areas, high data resolution was needed to be able to make useful project prioritisation and stakeholder identification decisions. However, for reasons such as data gaps or commercial sensitivity of data, this detail was not always available and had to be modelled or assumed.

> Getting down to the building level data is impossible. […] DECC have talked to the Big 6,[3] but you just can't get to that level of detail to be able to just put it up on a map and say, 'if you target these buildings … '. [LA1]

Data accuracy was also a problem for heat demand in fuel poor households, where occupants were known to under-heat their homes. Within an analysis based upon heat demand density, any area with high levels of fuel poverty could seem less economically suitable for district heating than if occupants were able to afford to use the level of heat they needed. This could also have an impact on system sizing in later stages of project development in areas of high fuel poverty, where heat demands could change depending on the affordability of the heat price.

As has been noted in other work by these authors (Bush, Bale, and Taylor 2016), many local government drivers and visions for district heating focused on exploiting potential wider benefits of district heating, for example those that deliver social benefits, such as alleviating fuel poverty. However, although heat maps had the potential functionality to explore these wider types of value, the maps developed for use by local governments did not always include relevant sets of data, and instead, they focused on techno-economic criteria alone[4] (estimated heat demand density, existing heat supply sources, highlighting large heat demand users). "Best practice" guidance from HNDU also did not encourage consideration of these wider factors in any explicit way. Guidance for the fund states that bids from local governments are assessed on "local [government] capacity and commitment and whether the project is likely to become a credible prospect for commercial/financial development." (DECC 2014, 14).

5.1.4. Delivering empowering processes for wider system change

Heat maps had the potential to support niche empowering processes by providing an evidence base for long-term strategic district heating plans across a district. For example, Denmark uses an approach of district heating 'heat zoning,' where local governments hold powers for designated heat zones to require connections to schemes if necessary. These powers enabled Danish local governments to plan where district heating was most useful for the energy system over the long term and ensure implementation of these plans (Chittum and Østergaard 2014).

Analysis of this UK case study showed that although heat maps were not currently used to their full potential, some local government interviewees had begun to use heat maps to inform planning policy for new developments. Use of the maps for planning policy enabled district heating planning to be linked with new-build developments, highlighting opportunities for expansion and interconnection with existing schemes. This approach sought to use new-build developments as a catalyst to enable expansion of networks to retrofit areas at a later point. In addition, energy masterplanning exercises for specific areas of potential were also informed by data from heat maps.

However, even this restricted form of strategic planning for district heating, focusing on planning policy for new builds and energy masterplanning for specific sites, proved challenging to deliver in practice. For example, officers often did not have sufficient powers associated with planning policies to require installation of schemes.

> We really don't have [the ability to require developments to implement district heating] yet. We could write a policy saying it is a requirement and you must do it. That's probably a challengeable policy if we were to write it in that way. So at the moment what we are doing is encouraging and trying to cajole them, rather than require something to happen. [LA4]

There were also no comparable regulations to support strategic planning for retrofitting of networks into existing buildings. As a result, retrofitting projects were mainly limited to social housing and public sector buildings where there were large heat loads and local governments had existing relationships and influence with decision makers.

5.2. *Tool design and application*

In this section, we outline a heat mapping tool design that can meet some of the considerations raised in the previous section. The design of the tool specifically aims to help users to incorporate multiple social, economic and technical criteria into their district heating planning process, identified in the case study analysis in Section 5.1. The tool design is evaluated and some practical challenges that face development of heat mapping tools are highlighted in the discussion (Section 6).

5.2.1. *Summary of the heat mapping tool design*

The heat mapping tool, named the Leeds Heat Planning Tool, was developed as part of a project exploring district heating and fuel poverty funded by the Chesshire-Lehmann Fund Trustees.[5] Building on the findings from the analysis in Section 5.1, it was designed to include a relevant range of data sets beyond techno-economic indicators; and be suitable for use for the existing skill-sets of local government officers.

The multicriteria decision tool was originally built within Microsoft Excel and later a software developer was commissioned to develop it into an interactive online version. The full design methodology for the tool can be found in Bush, Bale, and Taylor (2014) and details are also given in the online supplemental data for this article. The tool can be viewed and used at the following website: http://heatplanning.leeds.ac.uk/

The tool design provides users with the means to incorporate multiple criteria into their heat mapping analysis by calculating a score for the census output areas (small ~600 house spatial areas) in a given local government. Figure 2 summarises the key processes for using the tool. Users can choose which indicators to consider within the scoring process, and weight different factors according to their local priorities. The tool then calculates a score for each census super output area based on the number of criteria and weightings selected by the user. The method used for calculating the score in Step 3 is detailed in online supplemental data. Finally, the scoring is represented spatially with a choropleth map, visualised in Google maps to enable connection with the geographical features of an area. Developing the tool in this way enables it to be open access online and does not require specialist GIS skills in order to use it (in response to a challenge identified in Section 5.1.2). The online supplemental data provides the detailed method used within the tool.

The tool design aims to encourage stakeholder dialogue. The scoring system, with the ability to add weighting and switch indicators on and off, encourages exploration of different priorities. It also makes the strategic objectives for projects more explicit within conversations with local stakeholders.

5.2.2. *Going beyond techno-economic data*

The tool allows consideration of techno-economic, social/environmental and governance criteria. Relevant indicators for local government decision makers in England and Wales

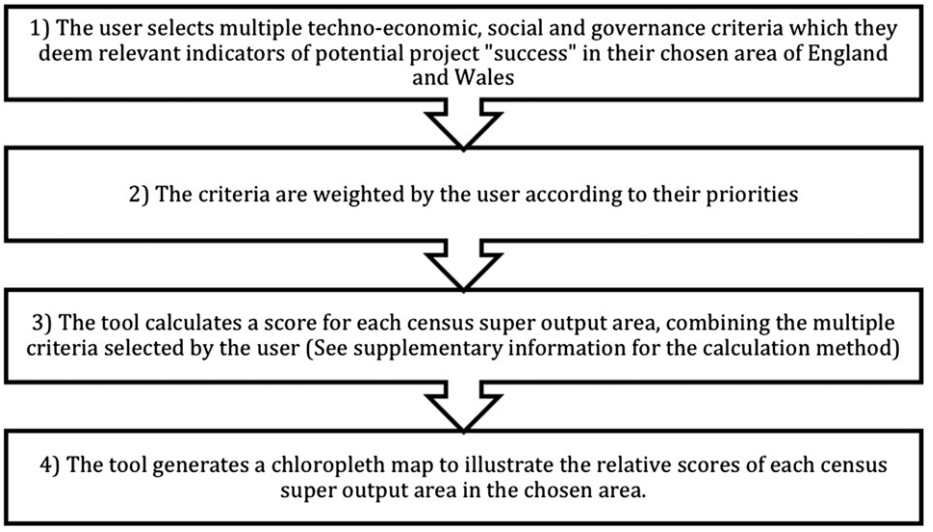

Figure 2. Overview of the user-process for the Leeds Heat Planning Tool.

were identified based upon empirical evidence from the interviews, and further verified with data from a local government workshop discussion (Vanguards Network 2013). This also enabled representation of governance factors and existing local relationships within the decision-making process. These have been labelled as 'governance' factors within the tool. Table 2 details the key indicators identified for inclusion.

Going beyond techno-economic data to include this broader set of indicators supports local governments to tailor their decision-making process for their specific local context and priorities. It also manages the risks perceived by decision makers by explicitly prioritising risk mitigation factors within the prioritisation process.

Data sets were selected from official census data and UK Government statistics to represent the decision criteria that had been identified as influential in local government district heating planning.

In the absence of a data source specifically for heat demand in the UK, building density was used as a proxy for heat density. This was particularly important in the domestic sector when considering potential for fuel poverty alleviation, since households in fuel poverty often under-heated their homes. A proxy based upon real energy consumption of gas and electricity could, therefore, under-represent the potential demand for heat in a given area with a scenario of more affordable heat prices, such as a not-for-profit district heating scheme.

Data availability was still problematic when using a proxy of building density for heat demand, since there were no data sets available for nondomestic buildings. The tool, therefore, allows input of key nondomestic heat demands by the user and encourages them to focus on key large heat demands such as hospitals and swimming pools, which might be able to act as key anchor loads for a network. Where heat demand data is not known, the tool also allows users to input postcodes for key nondomestic buildings and includes this within the calculation for the output area score.

The data sets used within the Leeds Heat Planning Tool are detailed and referenced in the online supplemental data. We discuss the different design features that address the issues raised within the interviews in the next sections.

Table 2. Three categories of indicators used within the tool: techno-economic, governance and social and environmental value.

Techno-economic viability	Governance	Potential for achieving social and environmental value

Heat density
Large heat demands
Existing heat generation sources
Sources of recoverable heat
Existing district heating networks
	Building ownership:
	• Public building
	• Commercial building
	• Domestic building:
	  • Social housing
	  • Private rented
	  • Owner-occupied
		Existing heating types
		Indices of multiple deprivation (such as health issues and fuel poverty)
		Eligibility for funding through the Energy Companies Obligation (ECO)

6. Discussion

Reviewing the results of our analysis and novel multicriteria spatial mapping tool, we now return to discuss our original research questions set out in Section 1. We start by discussing how energy planning tools can provide a means for supporting the objectives of strategic niche management and niche empowering processes, then move to each research question in turn, and conclude each section by discussing what the analysis suggests for energy planning tool design to better support the development of niches at the early stages of a low carbon transition.

6.1. The role of heat maps for supporting strategic niche management

In the UK case study explored here, heat maps provided an evidence base to demonstrate the technology's value to stakeholders, who were often unfamiliar with its capabilities, benefits and costs. They could help to identify where stakeholder engagement needed to take place to build supportive actor networks around the technology. Heat maps could also support learning processes by providing a structured activity to increase niche actors' understanding of the technology. In general, heat maps provided an evidence base to inform and support decisions on project prioritisation, often demonstrating the technology's techno-economic potential.

However, the design of the tools also restricted the way that tools could be used to support the different objectives of strategic niche management. For example, actors in the case study considered many decision criteria that were not reflected in their heat maps. Decision making relied on a significant element of knowledge about stakeholders' existing attitudes, the state of existing relationships and their attitude to risk. The format of heat maps, with a primary emphasis on heat demand density, did not necessarily support local government officers to engage with these key stakeholders beyond providing a basic evidence base for potential viability of a network.

Another influence over whether a tool could provide support for strategic niche management objectives was the level of skill and time that was required to use it. In the case study, capacities and skills to use the heat maps were not always available internally within local governments. This meant that officers relied on external consultants to carry out the analysis, creating the potential for a disconnect between analysis and use of the heat map and knowledge of the local context and stakeholder relationships. A potential for increasing the relevance and impact of heat mapping tools for creating supportive district heating actor networks lies with ensuring the tools are

designed for the available skills and resources within the target users. This allows their use to be embedded for long-term development and understanding.

Local government capacities to utilise heat mapping tools to support nurturing processes varied and depended on local contextual factors. For example, use of detailed heat maps required access to GIS skills, staff resource and cooperation across local government departments and external local stakeholders to enable inclusion of detailed and accurate data. These types of factors were largely determined by the historical context and priorities of the local government, as they had responded to budget cuts. Embedding use of heat mapping tools was, therefore, more challenging to achieve in some areas than others.

The functionality of the heat mapping tool determined the extent to which it could be used to demonstrate the range of values that might be sought from a district heating project. As Nilsson *et al*. (2008) points out, actors tend to use tools in policy making that 'speak to the existing core beliefs' or the organisations and stakeholders they are seeking to influence. The choice of data considered within heat maps was, therefore, important for enabling the tool to be useful within the specific local context; enabling actors to prioritise projects and demonstrate the value of the technology according to their own local priorities. However, the choice of data sets within heat maps was predominantly aimed at identifying the most commercially viable schemes, rather than considering wider local stakeholder priorities for district heating.

Based upon these discussions, a recommendation to increase the impact of heat mapping tools for supporting niche nurturing processes would be: (a) ensure that a range of data sets are included within heat mapping tools that reflect criteria beyond techno-economic priorities to enable decision makers to explore multiple scenarios; (b) to develop a programme of support within local governments around heat mapping tools to provide relevant skills to officers looking to make use of them; and (c) as an intermediate step, develop a simple, easy-to-use heat mapping tool that enables interrogation of publicly available data sets by officers without GIS skills. This would allow elements of heat maps to be explored and utilised, not just by local government officers with access to the right software and skills, but by a wider set of local governments and local stakeholders considering being involved in a scheme as a heat anchor load or heat supply source. The tool we present and discuss in Section 5.2 responds directly to these recommendations.

6.2. The role of heat maps in supporting niche empowering processes

As demonstrated in countries such as Denmark, heat mapping tools have the potential to form an evidence base for local strategic planning for district heating (Chittum & Østergaard 2014). This type of strategic planning can be used alongside regulatory powers or incentives to drive development of large scale, interconnected networks that offer larger benefits for the wider energy system (Woods *et al*. 2005). Use of heat mapping for local strategic planning could, therefore, be seen as a form of niche empowering process within the case study.

The analysis here has shown that the application of heat maps for this purpose was mainly limited to informing planning policy for new build developments. Aside from this, local government officers had little powers or capacities to deliver strategic plans for retrofit areas.

As Radaelli (2005) highlighted, the influence of tools within decisions is dependent on the legitimacy of the tool with the stakeholders acting upon its information. For

example, it was important that stakeholders recognised a tool's assumptions and criteria as appropriate for their local context. It appears that, within the UK context, the legitimacy of heat mapping and the role of district heating in general, has not yet been fully established. As a result, local governments making use of heat mapping to inform new build planning policy did not yet feel confident that they held a sufficiently robust evidence base that would enable them to require district heating development within local planning policy. This concern was reinforced by cases of new-build developers seeking to challenge planning policy where it was in place.

One way to build up the legitimacy of heat mapping for informing local district heating strategic planning would be to designate nationally recognised and transparent criteria for use in district heating strategic heat planning. The formation of these criteria would need to take account of both local and national priorities and visions for district heating to establish an acceptable balance for both local niche actors and national objectives. Some form of stronger enforcing powers for local governments to enable delivery of these plans would also likely be required. However, in the context of fast changing national energy policy approaches, it is likely that establishing this kind of long-term approach could be challenging in practice in the context of resistance to change from established industry actors.

6.3. Application of the Leeds Heat Planning Tool

Building on the lessons from the case study analysis, Section 5.2 presented an example of a tool which tried to better meet some of the tool design specifications which could support strategic niche management and niche empowering processes. In this section, we discuss the benefits and limitations of this tool, using an example of an application to the English town of Cheltenham as a basis for discussion.

Figure 3 presents an application of the Leeds Heat Planning Tool to two example weighting scenarios in the town of Cheltenham, UK (chosen as an example of a medium sized town that currently has no district heating). By setting the tool in scenario 1 to consider only techno-economic criteria it identifies areas in the town that offer the highest potential for schemes to offer a commercial rate of return (the scoring of an area is indicated by its colour shade – the darker an area is shaded, the higher score it has achieved under the selected weighting). When social characteristics are included within the weightings, an area that previously seemed to be an isolated opportunity becomes more interesting in terms of developing a project with fuel poverty alleviation objectives. The weightings used in the two scenarios are detailed in Table 3.

The Leeds Heat Planning Tool represents one example of how heat mapping tool design can be adjusted to offer greater support to the early stages of district heating development. Figure 3 shows an example of how the tool can visually represent scenarios for different policy priorities quickly and simply. This makes it useful for decision makers to consider and discuss the impact of different priorities on their approach to district heating development without expensive consultant studies of multiple areas.

However, there are several limitations of the tool presented here:

- Scenario 2 in Figure 3 was only visible in the tool due to additional user-added data (locations of swimming pools hospitals, shopping centres). Although only minimal extra data was added on top of the publicly available data already

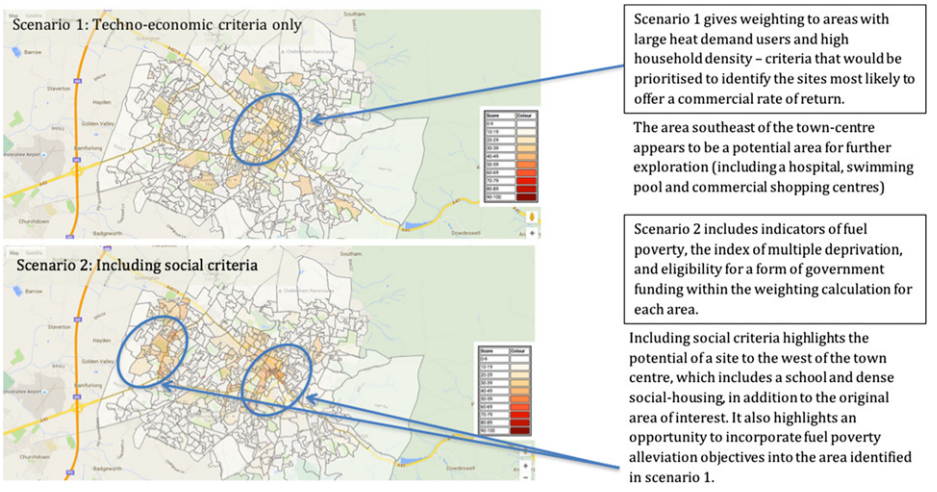

Figure 3. Two heat maps of Cheltenham, produced using the Leeds Heat Planning Tool representing two distinct decision criteria scenarios: (1) Considering only techno-economic criteria, (2) including social criteria (Specific weightings used for each scenario are detailed in Table 3).

included in the tool, if this had not been done then the tool would not have been able to identify this alternative scenario. Lack of data availability is a significant challenge for representing key indicators within the tool, as it is with all heat mapping exercises. Data on potential sources of recoverable heat is also significantly lacking across the UK. This lack of appropriate data limits the potential impact of the tool.

- Figure 3 can display only a low resolution map due to the resolution of the publicly available data. It is, therefore, only useful to offer an indication of potential and is not able to indicate economic or technical viability. Its application should, therefore, be restricted to stimulate and inform discussion at the early stages of development only.
- Despite modifications to enable heat mapping tools to better support strategic niche management, it still relies on an open attitude of users to embed it into the decision-making process through dialogue internally within the local government and externally with local stakeholders.

We intend to gather formal feedback from users of the tool at a later date, in order to evaluate the usefulness of the tool in supporting development of district heating. There are currently users from 44 distinct organisations registered to use it and informal feedback has been received. 40% of registered users are from local governments. In addition, another 38% of registered users are from private energy companies and consultancies (the remaining 22% of users were from universities). The range of actor types registered for the tools suggests that it is of wider relevance to those other than local governments. It would be useful to explore the practical application of the tool in further work. Do the features of the tool support district heating development as they were intended? Can this form of tool build the foundations for the application of more detailed heat mapping tools to support empowering processes for achieving a strategic approach to district heating?

Table 3. Variables selected for two scenarios of the case study town of Cheltenham, UK.

			Scenario 1 – Techno-economic criteria		Scenario 2 – Social criteria added in	
	Data indicator	% cut-off point	Weighting (0 : 5)	Overall weighting %	Weighting (1:5)	Overall weighting %
Techno-economic	Existing CHP plants	n/a	5	100%	2	44%
	Heat sources	n/a	5		2	
	Large heat demands	n/a	5		2	
	Household density (#households per km^2)	0.9	3		5	
	Flats, maisonettes or apartments (number)	0.9	0		2	
	Terraced households (number)	0.9	0		2	
Governance	Social rented households (number)	0.9	0	0%	3	9%
	Council owned social rented households (number)	0.9	0		0	
Social	No central heating system (number of households)	0.9	0	0%	0	47%
	No gas central heating (number of households)	0.9	0		5	
	Oil central heating (number of households	0.9	0		0	
	Solid fuel central heating (e.g. wood, coal) (number of households)	0.9	0		0	
	Electric heating (including storage heaters) (number of households)	0.9	0		0	
	Off-gas households (Centre for Sustainable Energy)	0.9	0		0	
	Fuel Poverty households 10% measure (number of households)	0.8	0		0	
	Fuel Poverty households LIHC (number)	0.8	0		4	
	Index of Multiple Deprivation	0.8	0		2	
	Eligible for CSCO funding (ECO)	0.8	0		5	

7. Conclusion

This article examines the use of decision-support tools within strategic niche management for the first time. The key roles that energy planning can play in empowering niche transitions have been identified and recommendations are put forward to enable better design and use of decision-support tools in supporting low carbon transitions.

In the earlier stages of transitions, our findings suggest it is beneficial to create flexibility in the decision criteria embedded into tools to enable use by niche actors in a range of contexts and who may be working for a range of drivers. When designed well, and embedded in decision processes, energy planning tools can be used to empower niche transitions and bring forward the deployment of complex low-carbon infrastructure such as district heating.

Our new tool, the Leeds Heat Planning Tool, embeds lessons from the case study work and approaches energy planning in a different way. Namely the tool is: (1) easy to use, open access and quick to implement (because it draws on freely available data and resource intensive data gathering is not required); (2) allows users to work with local stakeholders to discuss priorities and scenarios (through the multicriteria functionality), and visualise the results for an area; (3) embeds social criteria alongside standard techno-economic criteria to allow stakeholders to pursue local priorities rather than being led down a more commercial route. Initial use has been promising, from a wide range of stakeholder organisations, and further evaluation and development is clearly warranted.

The findings from the work show that energy planning tools can be a helpful way to enable low carbon transitions, although we call for more tools of this type that meet the needs of local actors (in line with our recommendations in Section 5.1.1 and Section 5.1.2).

Notes

1. The department's name was later changed to the Department for Business, Energy and Industrial Strategy (BEIS) in July 2016.
2. The first phase of the interviews used in this work has also been reported in another paper considering local government visions for developing district heating (Bush, Bale, and Taylor 2016).
3. The 'Big Six' is a term used colloquially in the UK to describe the six largest energy supply companies, who together supply gas and electric to over 90% of the market.
4. In Scotland, where the political priorities for heat policy focused strongly on fuel poverty, the functionality had been built into the Scottish Heat Map and consideration of these factors alongside techno-economic considerations was beginning to be actively encouraged.
5. The Chesshire–Lehmann fund support academics and community groups wishing to undertake active research or evaluation into the relationship between fuel poverty and energy efficiency. http://www.chesshire-lehmann.co.uk.

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No potential conflict of interest was reported by the authors.

Supplemental data

Supplemental data for this article can be accessed here.

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