ORCA – Online Research @ Cardiff

This is an Open Access document downloaded from ORCA, Cardiff University's institutional repository:https://orca.cardiff.ac.uk/id/eprint/139118/

This is the author's version of a work that was submitted to / accepted for publication.

Citation for final published version:

Cowell, Richard and Webb, Jan 2021. Making useful knowledge for heat decarbonisation: lessons from local energy planning in the United Kingdom. Energy Research and Social Science 75 , 102010. 10.1016/j.erss.2021.102010

Publishers page: http://dx.doi.org/10.1016/j.erss.2021.102010

Please note:
Changes made as a result of publishing processes such as copy-editing, formatting and page numbers may not be reflected in this version. For the definitive version of this publication, please refer to the published source. You are advised to consult the publisher's version if you wish to cite this paper.

This version is being made available in accordance with publisher policies. See http://orca.cf.ac.uk/policies.html for usage policies. Copyright and moral rights for publications made available in ORCA are retained by the copyright holders.

This is a pre- copy-editing, author-produced PDF of an article accepted following peer review for publication in *Energy Research and Social Science* (25th February 2020)

Making useful knowledge for heat decarbonisation: lessons from local energy planning in the United Kingdom

Richard Cowell[1] and Jan Webb[2]

[1]Cardiff University
School of Geography and Planning
King Edward VII Avenue
Cardiff University CF10 3WA
UK

[2]University of Edinburgh
School of Social and Political Science
Chisholm House
High School Yards
Edinburgh EH1 1LZ

Email: cowellrj@cardiff.ac.uk, janwebb@exseed.ed.ac.uk

Corresponding author: Richard Cowell

Funding Sources

The research on which this paper is based was funded by the Energy Technologies Institute and Energy Systems Catapult.

Making useful knowledge for heat decarbonisation: lessons from local energy planning in the United Kingdom

Abstract

Heat decarbonisation is challenging in many countries, but few studies address its 'wicked problem' qualities and the implications for producing useful knowledge. This paper elucidates the challenges by applying insights from science and technology studies, especially Callon's concept of knowledge 'frames', to explain the fate of a prominent UK innovation – the EnergyPath Networks (EPN) and Local Area Energy Planning (LAEP) tool of the Smart Systems and Heat programme. The aim of the tool, which coupled an engineering model with local planning, was to provide authoritative knowledge to support local decision making. However, after six years of piloting with local authorities the future take-up of EPN and LAEP remained uncertain, for two key reasons. First the techno-economic knowledge frame encountered numerous overflows emanating from more potent political-economic and technological perspectives governing local priorities. Second the framing of local decision making neglected the marginality of energy planning at local government level. Our analysis shows the problems that arise when lab-based research and development prematurely frame energy system problems, before encountering societal and political contexts of use. Problem definitions and solutions for heat decarbonisation based predominantly on technical-economic knowledge lack requisite authority to progress this wicked problem, and must become more context-responsive.

Key words

Heat decarbonisation; wicked problems; knowledge frames; framing and overflowing; energy; local energy planning

Highlights:

Examines why decarbonising heat is a wicked problem, and implications for action

Shows how science and technology studies help understand decarbonising heat challenge

Technical-economic knowledge, using complex modelling, struggles to effect change

Problematises notion that local authorities should lead heat decarbonisation action

Useful knowledge for decarbonising heat has to encompass societal contexts

1.0 Introduction

Decarbonising heating and hot water systems is a major challenge in countries highly dependent on methane gas, notably the UK, but other countries, including Germany [1] and the Netherlands [2], share the predicament. In such contexts, progress with heat decarbonisation has lagged behind electricity. As climate change targets tighten, so policy-makers, science and engineering professions and environmentalists have recognised heat decarbonisation as a major stumbling block on the path to 'net zero' greenhouse gas emissions [3-6]. However, recognition of the problem invariably comes with acknowledgement of its seeming intractability.

This paper addresses a key ingredient of any solution to heat decarbonisation - the creation of useful knowledge. From the perspective of the social sciences this means knowledge with sufficient authority, potency and trust to influence change and innovation. Processes of knowledge production are pivotal to the complex problems of materialist societies dependent on specialist forms of knowledge for continuity, and arguably increasingly for their survival [7]. In the case of heat decarbonisation, creating such knowledge is treacherous, because it exhibits the qualities of 'wicked problems', as conceptualised by Rittel and Webber [8]. These are problems which are not susceptible either to single definitions, or definitive solutions of the kind associated with a linear cause-effect model of rational scientific analysis. Preferred problem definitions and solutions are interconnected, embedded in the different world views and values of interested parties. By implication, proposed solutions are matters of contention, and any solution typically has extended consequences, leaving 'traces that cannot be undone' [8] (p.163).

The wicked problem qualities of heat decarbonisation have their origins in the historical development of large scale infrastructures and markets for mass exploitation of fossil fuels. In the UK, the extensive gas grid has resulted in reliance on gas-fired central heating in buildings, and gas combustion for high-temperature industrial processes [9]. Given this material legacy, progress towards decarbonisation means confronting a highly stable regime and, potentially, initiating major changes across scales and sectors. Such systemic changes are likely to have long-term and unavoidable distributive consequences, including risks of further unintended outcomes. In the short term, the various alternative low carbon heating appliances and networks – electric heat pumps, hydrogen boilers, district heating or some hybrid arrangements - are expected to be disruptive and more expensive than incumbent technologies [10], dampening public interest [11]. Cost estimates are very large (from £120-£450 billion in the UK alone). Routes to specifying the parameters of 'the heat decarbonisation problem' are ill-defined, and the absence of a straightforward replicable solution or obvious 'silver bullet' means that public or commercial leadership has been elusive.

Academic research on heat decarbonisation reflects the wider societal problem. Across the spectrum of energy scholarship, heat has been much less researched than electricity [12, 13]. Moreover, efforts to render heat decarbonisation researchable by focusing on active, observable phenomena have left the wicked qualities of the problem poorly studied. Most research on sustainable heat has focused either on policy and governance in contexts where there is an infrastructure amenable to low carbon sources (notably district heat networks in Scandinavia: (e.g. [14, 15]), or on the potential for particular technologies (e.g. [16, 17]), or on the perceptions and behaviours of domestic heat users (e.g. 2, 18). One might say that most social scientists have assumed a particular, pre-given framing of the problem, and neglected analysis of the types of knowledge being produced to frame the problem itself and its potential solutions. Where prospective futures are considered, the analytical space has been colonised largely by economists and systems modellers [19]: a significant tendency, to which we give explicit attention.

Our goal is to elucidate the challenges of making defensible knowledge for heat decarbonisation and, in particular, to provide insight into the difficulties of creating an authoritative problem definition and solution. In this, we make two main contributions. Firstly, we seek to show the insights for the heat decarbonisation challenge from science and technology studies (STS). To elucidate why decarbonisation of heat is proving especially intractable, we draw particular attention to the problems of 'framing' in knowledge construction. Framing is conceptualised by Callon [20] as the work of establishing a boundary around knowledge relevant to defining a problem and its solutions. This entails simultaneously dealing with 'overflows' - connections to the wider world that could question or otherwise disrupt the frame. With controversies like heat decarbonisation – given its extensive and intensive socio-technical embedding in gas and electricity networks and building fabrics on the one hand, and business interests, property ownership, thermal comfort, user practices and social welfare on the other – one can posit that any knowledge framing, and containment of resulting overflows, is especially challenging.

Our arguments about the problems of making defensible knowledge for decarbonising heat are grounded in evidence of the outcomes of a prominent UK intervention – the Smart Systems and Heat (SSH) programme (2011-2019), which aimed to 'build the foundations for a market-led approach to decarbonise heat across the UK' [21] (p.10). Explaining what happened to a particular component of this programme - the Local Area Energy Planning (LAEP) project - is our second contribution. The project envisaged comprehensive local planning for heat decarbonisation, using scenarios generated by a new 'whole systems engineering model - EnergyPath Networks (EPN). The model was intended to be the UK's most advanced local energy planning tool [22], informing cost-optimising decisions about necessary investments in local networks, and retrofit of circa 27 million homes with relatively poor energy efficiency for low carbon heat systems. It exemplified conventional definitions of useful knowledge, emphasising technology-led innovation for scalable, replicable commercial solutions [23]. The decision-aid technique (referred to in this paper as the 'EPN/LAEP tool') was piloted with three local authorities. However, by the closing stages of Phase One in 2017, future take-up of the tool remained uncertain, begging questions about why it had not gained the authoritative knowledge and market-leading status to which the programme aspired. Applying STS insights helps address these questions, revealing the contours of the decarbonising heat problem, and the challenges of knowledge construction for wicked problems more broadly. Our study also helps meet calls for further empirical research on the usefulness of energy system models in governance contexts [24].

The structure of the paper is as follows. In the next section we discuss our conceptual approach in more detail, focusing on Callon's analysis of knowledge framing and overflows. Following this we outline our research methodology, which involved a detailed case study of the testing of the EPN/LAEP tool with the local authority pilots. Section four discusses our findings, which show the limitations of framing relevant knowledge in predominantly techno-economic terms, and the uncertain prospects of mainstreaming any singular conception of local energy planning for decarbonisation of heat. In our conclusions we offer some recommendations for modes of knowledge construction better suited to the wicked qualities of the heat decarbonisation problem.

2.0 Making techno-scientific knowledge – Science and Technology Studies insights

While Rittel and Webber [8] neatly delineate the characteristics of wicked problems, they give few insights into how societies construct workable solutions in the face of ongoing disagreement. Herein lies the potential value of science and technology studies (STS), where a key concern has been tracing how new claims to knowledge move from initially uncertain status to acquiring wider authority as, at least part of, solutions. Such knowledge is often encoded in technologies or techniques, whose use may result in wide-ranging societal changes. We identify key elements of STS analysis of processes of constructing authoritative knowledge, or its failure, and consider their analytical purchase on the heat decarbonisation problem.

A basic tenet of STS is that knowledge creation is always a socially-organised process, which governs 'what is regarded as rational or proper conduct, how objectivity is recognized, and how the credibility of claims is assessed' [25] (p.300). Understanding the fundamentally social process of *making* knowledge is a prerequisite to understanding what becomes established as authoritative and why [26]. In STS terms, the authority of knowledge is derived not from an abstract scientific or technical form of superiority, but from its constitution and translation through the highly distributed, but regulative, work of numerous people and organisations [27]. STS encompasses wide-ranging debates about, and analyses of, the constitution of knowledge, but for the purposes of this paper we rely on the strand of work initiated by Latour [27, 28] and Callon [29] to explain how knowledge claims may come to effect significant material changes. Knowledge, they argue, is made durable through the embodiment of propositional claims in technical instruments or systems. Such 'techno-scientific' systems themselves incorporate societal assumptions about key variables, and their weightings and interactions. These may be ranked and evaluated differently by interested parties, influencing judgements of credibility of the knowledge, or the knowledge providers. Making and stabilising knowledge thus entails not just working on 'the science', but simultaneously acting on society, shaping the social contexts of adoption, to keep actors in alignment.

Callon [29] suggests that knowledge claims embedded in technologies may become stabilised, and authoritative, to the extent that they are made obligatory passage points (OPPs) for other work. Such OPPs institutionalise knowledge claims through their embedding in socio-technical networks of action that make knowledge durable, and extend its reach. OPPs encompass technical instruments, procedures or metrics, which work as 'black boxes' standardising practices across space and time. Creating an OPP entails intensive investment in social, as well as technical, work to render areas of controversy (such as decarbonising heat) tractable, calculable and amenable to some form of standardised definition and solution. Standardisation is constitutive of mainstreaming i.e. integration into the social order in a routinised way.

Integral to making OPPs, Callon [20] suggests, are processes of 'framing', or establishing a boundary around, what is relevant knowledge about a problem or its solutions. 'Framing' in this sense differs from the 'problem framing' of interpretative social scientists like Rein and Schön [30], although both perspectives share an interest in the social effects of language. For Callon, however, 'framing' embraces the diverse elements, discursive and material, that might come together to draw boundaries around a problem, and his perspective retains a keen interest in the elements placed outside those boundaries. In uncontroversial situations, framing appears straightforward: 'actors are identified, interests are stabilized, preferences can be expressed'; hence 'calculated decisions can be taken' [20] (p.12). In the case of controversial problems, however, framing is unstable and subject to repeated 'overflows'. The concept of 'overflows' is where perspectives excluded from a proposed frame are brought back into debate by actors with alternative, and differentially valued, claims to knowledge and problem solutions. Managing overflows from a particular framing may require them to be bracketed off [28] and excluded from the picture. Alternatively, overflows can be managed by 'taming' them – i.e. bringing within the frame by rendering them measurable in commensurate terms. The latter may prove difficult, costly and impossible fully to achieve, not least because it requires actors to detach themselves from existing knowledge commitments and to realign with a new frame.

Concepts of OPPs, framing and overflows provide an intellectual architecture for making sense of the struggles to generate defensible knowledge capable of guiding societal choices. Importantly, this enables us to theorise how the issues themselves make a difference to the prospects of achieving closure [31]. Thus, Rittel and Webber's 'wicked problems' can be seen as problems where framing is controversial: repeated and chaotic overflows are the norm, and confounding factors can proliferate, constantly problematising the relevance of candidate facts and creating radical uncertainties about routes forward. These concepts also open up a more nuanced conception of wicked problems: while difficulty in constructing OPPs can be seen as a central characteristic, they also introduce the idea that 'wickedness' varies, both between types of problems and over time. Aspects of innovation systems research have developed this line of thinking. Wesche et al [1], for example, imply that decarbonising heat is at the most challenging end of the spectrum, because supplanting the standardised, high-carbon gas-grid system raises the spectre of immense spatial and socio-economic variation in prospective alternative heating systems. The problem is hence not susceptible to a generic technological innovation system solution, but requires instead *configurational* innovation systems, characterised by being strongly embedded in local contextual conditions. Such systems tend to frustrate creation of easily transferable knowledge and standard products, undermining a linear causal model of innovation of the type often assumed to drive new markets. Proposed constituents of useful knowledge for decarbonising heat are hence highly likely to be contested. Armed with these insights, analysts can usefully examine how, where and from what elements OPPs may be constructed.

In his essay comparing a sociological concept of overflows with the economic science concept of externalities, Callon [20] argues that societal controversies cannot be resolved by experts in 'laboratories'. Nevertheless, most analyses of knowledge framing and OPPs have focused more on the making of techno-science, rather than directly on how the societal context shapes alignment of actors around particular forms of knowledge. Existing research suggests facets of the social context that are likely to matter.

A central facet is trust and its relational dynamics ([25], p.302; [13]). In line with STS's symmetrical treatment of the social and the technical, trustworthiness is not an intrinsic property of knowledge, but bound up with the perceived trustworthiness of those engaged in creating it, and with the capacity of actors and knowledge to co-produce expected outcomes. Trust matters not just for actor buy-in to the suitability of a knowledge frame to address a particular problem, but also for maintaining commitment to a recognisably imperfect frame, despite acknowledged limitations and risks. Furthermore, certain types of actors may be particularly relevant to trust and alignment-building; especially for wicked problems. The complexity of contemporary societal problems has for example been seen as a factor driving the growth of intermediaries who work to structure identities and roles of different actors, and to legitimate knowledge to render it useful [32]. However, intermediaries are not neutral conduits for expert knowledge, but may variously mobilise, contest or resist aspects of it.

One such intermediary is local government. The trusted, democratic basis of local government has long been valued for mediating between knowledge-driven energy policies and publics. Local government's role in climate protection and clean energy is marked positively by the UK Government in positioning 'local areas' as 'best placed to drive emissions reductions through their unique position of managing policy on land, buildings, water, waste and transport' [4] (p.118). UK local government however lacks the political and tax raising powers of European comparators, and declining local government funding, alongside market competition, commissioning and outsourcing rules, have eroded and fragmented knowledge about energy systems, resulting in a pattern of episodic and piecemeal energy projects [33-35]. In this context, considerable uncertainty surrounds the intermediary capacities of UK local government in the energy sphere, with problematic consequences for strategic, systematic local energy planning and development.

In sum, it is our argument that STS concepts have analytical merits for understanding the problem of decarbonising heat that are under-exploited by energy researchers. Callon's and Latour's concepts of OPPs, knowledge framing and overflows are especially useful, drawing attention to the struggles that can ensue in demarcating a specific set of knowledges and technologies as pivotal to solving a problem, in the face of myriad alternative formulations. Theorists have however paid little attention to the variable scale of challenges entailed in framing knowledge and establishing OPPs for different kinds of societal problems. It is our contention that such framing processes will be especially difficult for wicked problems like heat decarbonisation, which – after Wesche et al [1] - exhibit contextually-embedded qualities that are difficult to ignore or manage.

We now turn to examine a high profile strategy that sought to frame knowledge to make heat decarbonisation more tractable and calculable, and to delineate the difficulties it encountered.

3.0 Methodology

To develop our arguments about the problems of making defensible knowledge for decarbonising heat, we analyse the trajectory of a prominent UK intervention - the EnergyPath Networks (EPN) model and its use as a device to support a specific type of 'Local Area Energy Planning' (LAEP). Together they make up the EPN/LAEP tool, which was one component of the 2011 to 2019 Smart Systems and Heat (SSH) programme (for a time-line, see Table 1). The programme was developed and managed initially by the Energy Technologies Institute (ETI), and sub-contracted to the Energy Systems Catapult (ESC) from 2015. The SSH programme was a significant scale, with an estimated public and private sector joint budget for the first phase (2011-2017) of £50 million[1]. Government funding then extended the programme for a further two years.

<Put Table 1 somewhere near here>

What makes the case insightful for analysing the construction of knowledge frames is that the SSH proponents of the EPN/LAEP tool were deliberately exploring the scope for a process that would function as an obligatory passage point (OPP) within organisational decision-making. The EPN model was developed as a potentially pivotal mechanism for identifying cost-optimising heat decarbonisation pathways, customised to localities. However, the task entailed more than creating a model that could produce credible facts about energy networks, building stock and heat use, and hence technical-economic heat scenarios. For legitimacy and ultimate efficacy, the model and its use in area-based energy planning needed to be tested within – and ultimately be trusted and taken up by – local

[1]Source: UK Government officials

authorities, as a device to inform their policy and investment choices, alongside developers, energy network companies, housing organisations and businesses. As the analysis will show, in presenting the EPN/LAEP tool as a particular technical-economic knowledge frame, 'real world' testing threw up numerous overflows.

Our research design followed STS methodological precepts of tracing 'science in the making' [28], and applied it to two tasks. First, we pieced together the history of the EPN/LAEP tool from inception to spring 2019. Second, we assessed the extent to which the EPN/LAEP tool and its results were incorporated in actual or prospective heat decarbonisation actions.

Data collection took place between autumn 2018 and spring 2019, and comprised semi-structured interviews with representatives of the main actors, and analysis of project documents. Interviews focused on the perceptions of actors centrally involved, and responses to the proposed framing of knowledge, and were organised into three phases: first, eight interviews with ETI and ESC managers and engineers working on EPN/LAEP as part of the SSH programme; second, thirteen interviews with key participants in the three pilot local authorities (Greater Manchester Combined Authority (GMCA) and Bury; Bridgend, and Newcastle); finally, six interviews with officials in the UK Government (Department of Business, Energy and Industrial Strategy) and Welsh Government. Each phase of interviews discussed interactions between the SSH team, the local authorities, and government actors involved in development and testing of the EPN/LAEP tool and its outputs. Interviews typically lasted 60-90 minutes, and were audio recorded, transcribed and analysed thematically. To protect the anonymity of respondents, interview data citations refer only to a category of interviewee. We also made extensive use of project documents to help chart the trajectory of the EPN/LAEP tool, identify evolving statements of purpose and knowledge claims, and inform interview questions. Documentary analysis was based predominantly on a set of thirty documents, which embraced: detailed management reports for the EPN/LAEP tool from inception, through interim, to final stage; whole area energy strategy documents produced for the three pilot local authorities by the EPN/LAEP team, and energy documents (plans, strategies) produced by the local authorities themselves. The latter were especially helpful in identifying how far, and in what contexts, the EPN/LAEP tool was connected to tangible outcomes. Detailed reading, comparison and cross-checking of text in documents and interview transcripts provided the basis for the exegesis of knowledge framing and complex overflows.

The main limitation of the research is the short duration of data gathering, which results in requirement to reconstruct the trajectory of the project from actors' accounts of the past, reliant on potentially selective memory, and likely (as in all accounts) to present the informant in a favourable light. Triangulating contrasting accounts from the perspectives of EPN/LAEP developers, local authorities and UK and Welsh governments, and cross-checking between interviews and document contents, nevertheless improves the rigour of the analysis. Early interpretations of findings were also tested with interviewees in short reports and presentations to test validity, and to gather further insights.

We structure our analysis below around three aspects of the EPN/LAEP tool that hampered its translation into an OPP for heat decarbonisation: initial knowledge framings for the problem; divergent conceptions of 'useful knowledge'; and the misplaced assumptions about the nodality of energy generally, and heat in particular, within local authority planning and decision-making.

4.0 Analysis

4.1 Structuring the problem of heat decarbonisation: EnergyPath Networks and Local Area Energy Planning

The Smart Systems and Heat (SSH) programme is an exemplar of UK political commitment to market-led techno-science innovation for competitive advantage and economic growth [23]. The programme developer, the ETI, was a Public-Private Partnership between government and industry, and 'was intended to be a technocratic organisation; we were there to develop technical tools and capabilities' (Senior Engineer, ETI). In a market context, such tools are structured as commercial property governed by legal contracts defining ownership. The SSH EnergyPath Networks (EPN) model was grounded in the ETI's existing Energy System Modelling Environment (ESME), a commercial product, with assumptions about key variables, and weightings largely pre-established. Knowledge framings for heat decarbonisation consequently emerged from the constellation of actors and interests already organised to work in the field.

The model technical specification detailed a whole systems life-cycle cost engineering model, which would specify all plausible or technically possible cross-vector heat energy pathways for an area, against carbon targets. Map-based representations of cost-optimised solutions for different areas were a key part of the outputs.[2] Available data on gas, electricity and heat networks, buildings and energy use were used to map all energy demand and supply for an area, and to model expected growth and network constraints or redundancies. The resulting scenarios were envisaged as the foundation for comprehensive local planning for prioritized routes to decarbonisation, encompassing network investments or decommissioning; new district heating; fuel sources; storage; single building appliances and fabric retrofit. Optimising for a problem definition under this particular set of assumptions and constraints, however neglected the difficulty that choice of assumptions is consequential for the types of scenarios which can be produced, and is itself part of the challenge of assembling a workable problem definition [8].

The risks of the approach to knowledge framing were to some extent recognised by ETI in developing the programme. First, decarbonising heat was regarded as 'a problem in which nobody had any experience' (Senior Engineer, ETI), hence lacking any stabilised knowledge base. Second, it was already perceived to need a 'smarter' solution than universal electrification, which implied high cost investment in grids and stand-by power stations, for use only during the few days of peak heat demand each year. Third, solutions were considered likely to unfold across differentiated social and infrastructural conditions,

[2] For illustrations, see https://es.catapult.org.uk/reports/local-area-energy-planning/ accessed 20th August 2020

problematising steering from the centre:

> ‘I can't really decide how to use local resources effectively sitting in Whitehall; it's not possible to come up with a set of simple technocratic rules, which are then embodied in policies which mysteriously produce the right energy system with the right modification so it will appear everywhere. You've got to get closer to the action.’ (Senior Engineer, ETI)

Local Authorities (LAs) were identified as the means to get closer, positioning them as critical intermediaries. These localist beliefs rested on: LA responsibilities for land use and transport planning; assumed local knowledge, including politics and credibility with publics; and their convening power as a trusted/enduring institution. There was also a tacit belief in a strategic decision-making capability: ‘local government can play … an enabling role in bringing those parties together to look at the future and to create an objective process’ (Manager, SSH Programme). In this, ETI’s approach to the SSH programme reflected the wider convergence on ‘the local’ as an arena for de-carbonisation action[23], as a scale deemed more sensitive to heterogeneity – in building stocks, economies, publics, etc – of the terrain in which change needs to take place.

Beyond the plan to engage LAs, however, the pre-established techno-scienceknowledge framing endured:

> ‘Their [ETI] original thinking was, “Let’s do this in very much the same way as all our other projects. We will write a spec and we’ll go to the market and get them to bid in to do the work for us, and that will come up with a nice bit of research. And, you know, we’ll turn that into an innovation programme”’ (Senior Official, UK Government)

The authority of systems engineering tools would in principle be extended through a ‘higher fidelity ESME model’ (Senior Official, UK Government). Using local data about networks, building stock and energy demand, the SSH team expected the EPN model outputs to provide ‘objective evidence’ (Manager, SSH) for dialogue to create the ‘scaffolding’ (Senior Engineer, ETI) for strategic area-based heat planning. Coupling this more granular cost-optimising EPN model with the specific concept of Local Area Energy Planning (LAEP) would in theory constitute an OPP, aligning complex actors, with different interests and priorities, around a particular set of market opportunities for low carbon heat systems.

Unlike previous ETI programmes, the lack of any commercial champion led to significant in-house investment[3]. Hitachi joined ETI for the SSH Programme, but the focus on protecting commercial intellectual property resulted in geographical demarcation of the SSH team, and arm’s length management, producing a sense of ‘satellite versus the mother ship, them and

[3] A UK Government official estimated the SSH programme team employed up to 150 people at its height.

us' (Senior Official, UK Government). This seems to have reinforced a lab-based knowledge framing for the EPN/LAEP component of the programme; the earlier stance, that the heat problem required engagement with the diverse, localised social worlds that needed to be acted on and with, was bracketed off for later piloting. The approach drew subsequent criticism, however, based on its relative isolation from practical contexts of use:

> 'If you look at the EnergyPath Networks and Operations, 250 pages of spec, not really knowing what the use case would be, or the outcome, and the impact of these outcomes' (Senior Official, UK Government).

In sum, the ETI, as key actor, constructed a knowledge frame that spliced two elements: technical modelling for market creation with anticipated local traction. Recognising the territorial heterogeneity of the adoption context, the intention was to pilot development with LAs – envisaged as a major part of the potential market for any resulting technical-economic tool, and critical to testing EPN model outputs *in vivo*. In 2013 LAs were invited to compete for participation, with the promise of 'a big pot of money to implement, once we had got the strategy agreed' (Senior Engineer, ETI). Sums of £80-100 million were referenced as available for local demonstrators, giving momentum to the strategy. By this stage, however, the problem definition, with tight coupling between the EPN model and a specific concept of local energy planning (LAEP), was effectively 'black boxed'; the EPN/LAEP tool specified the versions of future socio-technical worlds which could be made.

Three LAs were selected to represent heterogeneity, in terms of scale, governance setting, housing stock, technical capacity and political commitment, and thus to capture 'the society' in which LAEP would need to work. Newcastle was somewhat unusual in having an official 'local energy planner' and aimed to extend its technical capability and access to data. Greater Manchester Combined Authority (GMCA) offered political leadership for low carbon energy at city-region level, and was required by the city-region devolution 'deal' to develop a whole area spatial plan; this was seen by ETI as an opportunity for integrating spatial and energy planning. Bridgend represented a smaller mixed urban and rural council, and had Welsh Government backing.

Interactions between ETI and the three local authorities (LAs) were, however, marked by ambiguity and shifting expectations. The final selection of LAs coincided with the decision by public and private partners not to extend the ETI beyond its first phase, because of uncertainty about its projected market value, particularly following the financial crisis. The promised capital for local heat demonstrators, with anticipated regeneration benefits, disappeared. Local authority enrolment in the pilots was immediately destabilised, jeopardising trust, as a key foundation of making authoritative knowledge, and requiring considerable repair work. Local authority uncertainties about their role, relationships to EPN/LAEP, and returns to the locality became a pervasive feature of the process.

Local officials expressed uncertainties about whether they were clients served by a contractor, partners in an energy planning experiment, or passive 'test beds' for the proposition that systems engineering models were key decision aids for local heat and energy planning. ETI commercial concern with protection of intellectual property in the EPN model was not necessarily understood or accepted by the LAs. While ETI aimed to test the robustness of the model using local data, but without releasing it to local users, the LAs had expected to gain some technical capability, conferring a sense of local ownership of results. There was interest in access to EPN to experiment with different scenarios, and to understand the assumptions governing particular results. However, the expected collaborative work, with which they were more comfortable and familiar, did not transpire, leaving ambiguity over who 'owned' the EPN/LAEP process and outcomes. Hence for LA actors the encounters could have 'an odd, contractual feel' (Academic Advisor, Bridgend), creating a sense of hierarchical command and control rather than partnership.

4.2 Making useful knowledge; making knowledge useful

Fundamentally, the removal of capital for heat demonstrator projects introduced doubts for the LAs about the value of participation. The implicit ETI offer to LAs evolved towards that of generating an evidence base for assessing future heat options, with some technical support for preliminary 'strategy' development. Making knowledge central, however, focused attention on its local usefulness. Although UK government and LAs considered the technical expertise to be 'trail blazing', whether the EPN/LAEP tool would generate 'useful' knowledge was less clear:

> 'Without knowing what it's going to look like in the end and what that means, it's really difficult to say whether it's ... not right or wrong, because there is no right or wrong answer, but whether it meets your needs' (LA Officer, Bridgend).

During the pilots, the systems engineering framing, that had earlier bracketed societal dimensions of heat decarbonisation, perpetually encountered the inextricably socio-technical qualities of the problem, entrained in differing conceptions of useful knowledge. An extended, often implicit, multi-faceted power struggle evolved, marked both by challenges to the technical robustness of the model, and by overflows from the technocratic knowledge frame, embedded in local political and socio-economic priorities. There were high stakes: ETI/ESC sought technical innovations with commercial value in resolving the heat decarbonisation problem, while safeguarding intellectual property for market advantage; LAs aimed to secure the future of localities, and local political capital, at a time of declining budgets, linked to UK financial and political upheavals.

From one direction, the technical-economic knowledge framing, specified by ETI as a whole system, cross-vector EnergyPath Networks model, was challenged on its own terms. Its validity was contested on the basis of local formal, as well as tacit, knowledge about building stock, housing types, physical geography and legacy infrastructures. In addition, the framing was questioned on grounds that it did not adequately integrate all energy vectors needed to make it locally useful. For example:

> ‘it didn’t factor in hydrogen ... if you look out the window here, now a lot of the houses are terraced houses, pre-1900, and heat pumps don’t fit in there really ... So we certainly pushed for the green gas route’ (LA Officer, Bridgend).

Neither did it integrate transport:

> ‘what it's not capable of doing in its current guise is being able to turn around to me and say if I overlaid in transport and traffic issues, if I overlaid in other energy related layers, could it tell me where to put the correct EV infrastructure?’(LA Officer, GMCA)

There were further questions about the ‘realism’ of the assumptions such as those relating to urban access to, and combustion of, significant biomass fuels. Mis-aligned knowledge frames caused frustration for LAs expecting both a more locally-sensitised and technically ambitious ‘whole systems’ model, integrating low carbon heat, electricity, energy storage and transport, all of which were likely to impact homes and businesses across their areas.

From another direction, overflows stemmed from the exigencies of local political economy and budgetary decline, service loss and restructuring. LAs were obliged to be opportunistic about local energy planning and expected pragmatic guidance on immediate, feasible and tangible projects. Useful knowledge meant responsiveness to immediate social responsibilities for ameliorating fuel poverty, improving job opportunities and incomes, and securing new revenues to protect services, as well as managing energy and carbon. From this perspective, the ‘local use value’ of the EPN/LAEP tool was ambiguous and hard to align with local corporate objectives. The SSH team were perceived as lacking insight into the problem: ‘they didn’t see it coming that actually the use was much more important than sophistication of the tools’ (Senior Official, UK Government).

For the local authorities, maintaining long term participation in the pilots, without clear short-term benefits, required officer commitment and resources, to supply data, and to translate detailed technical-economic scenarios into serviceable results for specialist colleagues. Knowledge needs of land use planners differ from those of an economic regeneration team, or housing team, or a corporate energy and climate change team. Here OPPs constituted by LA statutes, social housing standards, performance metrics and national planning regulations were more potent. Knowledge about technically cost-optimal scenarios for whole-area heat decarbonisation does not make such scenarios a matter of priority, or a palatable basis for revised local strategy; it does not for example help a regeneration officer to negotiate with developers, in an economic situation where additional short-term cost is ruled out:

> ‘our growth people are saying, “well we're tasked with making the most money from the land that we have”, so that's coming into play. And although they see the benefit of the low carbon agenda, anything that we push, they want it to be acceptable to your commercial house builders.’ (LA Officer, Bury)

One strategy for managing overflows is to bring them within a knowledge frame, thereby 'taming' them [20]. EPN engineers sought to do this by developing a supplementary tool for tracking, recording and encoding socio-economic overflows associated with local welfare, jobs, skills, housing, and business and economic regeneration. The result however served to emphasise the mis-matching, incommensurable assumptions and values. With socio-economic overflows representing the question 'what's the value of the quality of life here… in the end, the two just wouldn't meet in the middle… we couldn't get them to join up' (Systems Engineer, SSH). Such questions were not susceptible to standard cost-optimisation formulae, because these were the very issues where monetisation breaks down as it confronts contrasting 'orders of worth' [36]. Re-engineering the model to bring overflows within the frame by incorporating further technical variables also increased the multi-variable combinations and permutations of spatial, temporal and energy vectors, paradoxically reinforcing dependence on specialist expertise to produce and interpret outputs. This further complexity, with its multiplicity of 'could bes, would bes, maybes and alternatives' (Systems Engineer, SSH), did not make the outputs more useful locally. Instead results were perceived as a 'war and peace scale' of detail (LA officer, Newcastle), making it hard to build local political confidence in their value as a guide to decision making.

As prospective local use of EPN/LAEP remained elusive, a wider set of actions were undertaken outside the core modelling development – in STS terms, working on the social context – to keep the project moving forward. For LAs, local political 'buy-in' required narratives to articulate the value of being involved in developing the tool, hence justifying the costs of continuing. Such narratives included referring to the status gained by their council from working with an expert, well-funded body like the Energy Systems Catapult, as well as longer-term prospects of capturing economic benefits for the area from new heat decarbonisation businesses.

From the SSH perspective, the work of local value cultivation ultimately entailed a slight loosening of the techno-science innovation framing in order to keep the project and social relations intact; this diluted what the pilots would deliver in terms of local strategic planning and innovation. The second, entirely public-funded, 2017-19 phase of the SSH programme included provision for a dedicated officer working between the SSH team and each LA, in effect boosting intermediary capacity. These officers worked to manage the local need for tangible short-term outcomes from small 'low regrets deployment projects', such as heat networks. Such projects gained additional legitimacy from consistency with EPN/LAEP analyses of optimality, bolstering the business case with 'sound science', but the projects typically pre-dated the EPN/LAEP work and were not driven by it.

Encounters between local authorities and the EPN/LAEP tool created a sense that this was not a device capable of 'acting at a distance', to form an enduring and dispersed presence – an OPP - within the decision-making processes of local governments. The complexity of the EPN model, coupled to commercial protection of intellectual property, was itself an obstacle: 'I think that's the most challenging part of it, is EnergyPath is still not something that's really used by the layman' (LA Officer, Bridgend). During the piloting process, the SSH team worked on'present[ing] very complicated model outputs in a way that people find them interesting and engaging and useful' (Systems Engineer, SSH), and LA officers became skilled in representing EPN outputs in terms accessible to internal audiences, but these representational skills were not the same as enabling LAs to run the model. Complexity also exacerbated the cost issue, creating further disincentives if the future market required cash-strapped councils to buy in necessary expertise. Adding to problems of cost and control was the constant tide of temporal, as well as spatial, overflows. LA officers recognised that to deliver useful knowledge, model parameters would need frequent updating to reflect the shifting energy decarbonisation knowledge base, and associated policies, markets and infrastructures, entailing further costs.

4.3 Mainstreaming 'local energy planning' through EPN/LAEP

Our research identified a further set of reasons why the EPN/LAEP tool struggled to form a secure basis for local action on energy, which reflects an integral dimension of the proponents' knowledge frame - the assumed context of implementation. This entailed a model of the local authority willing and capable of integrating energy dimensions into strategic planning, thereby neatly mainstreaming cost optimal heat decarbonisation: the toolkit assumed that energy systems planning could easily be 'baked in' (Senior Manager SSH Programme) to established spatial planning processes. The frame lacked adequate recognition of the institutional apparatus of local authority planning and decision-making – the distribution of power, the multi-scale regulatory framework, and the marginal status of energy issues.

In the UK local authority context, neither energy generally, nor heat decarbonisation specifically, have been the object of a coherent planning process. This further undermined the construction of the EPN/LAEP tool as an OPP, as there was no clear, institutionalised decision-making fulcrum within its intended host organisations to anchor the technique and the knowledge it generated. Since 1945, UK local authorities have experienced progressive diminution of powers over energy, first from a centralised approach to nationalisation, then privatisation and latterly post-2008 austerity. Although climate change has prompted many local councils to engage, including making local energy plans, this has been voluntary and vulnerable to wider policy and economic shifts [37]. As noted above, for local authorities it is other frames – budget formulae, jobs, house completions and statutory services like social care - that constitute the OPPs for most decision-making.

Although SSH managers articulating the market for EPN/LAEP made sensible analogies with other spheres of local authority action that made routine use of models – like transport planning or flood risk management – they neglected the wider social institutions that affixed the role those models performed. It is the combination of legal requirements, targets, standards and professional norms, co-informing each other over years that produced frames with secure roles for models and the knowledge they generated, and bracketed off potential overflows. A new model could not, of itself, create that context.

Indeed, the problems affecting the institutionalisation of model-based energy planning allow us to theorise at a more fundamental level about the challenges in fixing knowledge for wicked problems in energy transition. In land use and development planning, models have acquired established, but confined, analytical roles arguably *because* their role is confined and frame maintenance is therefore relatively uncontroversial; larger, integrated land use models have however gained little traction [38]. There is a clear read across to the vicissitudes of the EPN/LAEP tool, in that the problems of constructing OPPs become more pronounced (rather than resolvable) where analytical techniques push a cross-vector or whole-system view, thereby multiplying the actors implicated, each with their own priorities and conceptions of useful knowledge. Even though 'comprehensive' knowledge is unattainable, pursuing ever-wider scope still multiplies problems of actor alignment. The multi-centred nature of LAs as 'actors' further confounds the institutionalisation of a new energy-focused OPP; so too do the potentially conflicting interests of other actors notionally embraced by local energy planning - gas and electricity network operators.

Interacting over a long period with the pilot LAs, SSH managers came to recognise that creating and stabilising a market for the EPN/LAEP tool entailed acting on society, as well as on technology, and that this was necessarily a multi-level endeavour:

> 'I came to appreciate how much the local authorities are trying to do with very little, in terms of resource... and of course they also have obligations, and that was a real education for me' (Senior Manager, SSH Programme).

SSH managers looked to potential action by higher levels of government that could shift the local decision-making context, especially by making some form of local energy planning mandatory. Our research encountered mixed views on the merits of this. For smaller local authorities, where action on energy was most precarious, officers hoped that 'higher-level' carbon or energy obligations could strengthen their arm in negotiations with recalcitrant colleagues. Respondents from higher levels of government however questioned the value of formal obligations: some doubted the value of strategic local energy planning in a fluid socio-technical situation; others questioned either the competence of local authorities, or the utility of imposing obligations to deliver plans without the powers and resources to deliver outcomes. Moreover, although the research confirmed the existence of a 'discourse coalition' [39] across respondents supporting something regarded as 'local energy planning', it also exposed a lack of consensus about form, purpose, knowledge and resource requirements, or locus of responsibility.

Our investigations did show that the EPN/LAEP tool and its outputs were less marginal in those decision-making contexts already more compatible with the SSH knowledge frame. The GMCA – as a city-region body – necessarily had the kind of strategic perspective that might derive insights from model outputs for comparing across constituent councils. However, the EPN/LAEP work, and local energy strategy-making more widely, was positioned by GMCA as an enabler for a different model of national-to-local relations.

Rather than an obligation imposed centrally, local energy planning would be a regionally-grounded analytical exercise designed to communicate 'up' to central government the changes needed to expedite energy transition. This stance questions the wider power relations of ETI/ESC, LAs and central governments, and their interactions with knowledge framings. It resists the framing of the problem as solely one of technical-economic innovation and market creation, instead positioning tools such as EPN/LAEP as serving local political-economic goals.

Ultimately the struggle over the purposes and local use value of the EPN/LAEP tool, and its uncertain fate, raises stark questions about the optimistically localist assumptions of the chosen frame. Although local energy plans have become 'an emerging trend across jurisdictions globally' [40] (p.884), with analysts exhorting the benefits of contextual attunement from steering energy initiatives at this scale [41], studies have long reported problems of capabilities, agency and institutional constraints that bedevil action on energy at local level (e.g.[42]), problems which the EPN/LAEP project encountered. It is one thing to recognise that heat decarbonisation is a more contextually-embedded, spatially heterogeneous component of energy transition than electricity [1], and to recognise that local authorities have important potential roles; but this should not be elided with the assumption that all local authorities are equally well placed, or willing, to take a leading role, particularly in the absence of redistribution of powers and resources between central and local or regional governments.

5.0 Conclusions

The key goals of this paper are to chart the fate of the EnergyPath Networks/Local Area Energy Planning tool – part of a significant UK heat decarbonisation research and development programme — and to use selected STS concepts to analyse this case and generate wider insights into the knowledge dimensions of the 'wicked problem' of decarbonising heat. We also briefly consider the generalisability of our findings and implications for making useful knowledge to progress with heat decarbonisation.

For the first of these goals, the main finding is that there is ambivalence about whether the EPN/LAEP tool achieved its core purpose, and uncertainty about future take-up. Local authority actors interested in tools amenable to *their* framing of the problem were uncertain about its uses. It had not self-evidently acted to make the problem of decarbonising heat more manageable. Within the SSH team, the view was: 'we've demonstrated a process and its capability, but it has no real traction because no one has the authority and the resources to do anything about it' (Senior Engineer, ETI). At the time of writing (2020), the EPN/LAEP work is positioned as one element of integrated data analysis approaches[4], providing a more granular analytical tool for local energy planning [43, 44]. The SSH team also continues to test simplified 'EPN-lite' formats, which are more

[4]https://erishub.com/service/local-energy-asset-representation/

affordable, accessible and therefore – it is hoped – useful. Nevertheless, the overall impression is of a supply-push effort, as the creators of EPN/LAEP actively seek to generate a demand that has yet to crystallise.

Although the future of the EPN/LAEP tool is uncertain, it remains an insightful case for our second goal – understanding the knowledge dimensions of the heat decarbonisation problem. The LAEP pilots have helped to reveal the immense challenges, and the limited prospects of constructing and mobilising a particular authoritative problem definition and solution based solely on technical-economic expertise. Callon's concept of knowledge frames provides a valuable conceptual framework for understanding why. The EPN/LAEP tool framed the heat problem as one of whole systems engineering modelling, building out from technical expertise, to support local energy planning. Outside the lab setting, however, the model's creators confronted a world in which local planning and decision-making relevant to energy is governed by other priorities, rules and responsibilities. As a result, the techno-scientific work was beset by yet more complex, more spatially and temporally fluid, social, economic and political overflows. These alternative claims to essential knowledge could not be tamed, displaced or otherwise expunged from the decision-making context. This explains why, although still circulating as a *potentially* useful aid to decision-making, nowhere has the EPN/LAEP tool formed a new OPP for heat decarbonisation decisions.

By focusing on the EPN/LAEP tool as a proposed solution to a wicked problem, characterised by controversy over knowledge frames, our analysis has generated insights into the heat decarbonisation problem not yielded by previous research. We have shown first the problems that arise in seeking technology-led 'whole system', or comprehensive, optimising solutions to a problem which is not susceptible to a singular definition and solution, but is marked by different values, resources and priorities of interested parties. This is important because around the world modelling-based initiatives retain pivotal roles (and attract significant investment) in the hope of creating authoritative knowledge for energy transitions [23, 24, 34]. Second the research has shown the mistaken assumptions about local government agency over energy planning that underpinned the EPN/LAEP knowledge frame, notably the assumption that local authorities' spatial planning powers translated straightforwardly to agency in the energy sphere. The erosion of technical expertise in local authorities, through austerity, and the required use of market commissioning and outsourcing of services, has further limited their capacity to systematically capture knowledge, either to challenge dysfunctional aspects of market-oriented problem framing, or to act as intermediaries for systemic innovation.

Our research points to the inadequacy of presumptions that local authorities can, or should, lead energy planning, when the very salience of a locality focus varies with the definition of the problem. The role for local authorities could be quite different depending on whether decarbonising heat is seen as a matter of area-based planning decisions, or as subject to individually-chosen heating appliances and services, or as a matter for centralised government and business decisions about re-tooling gas networks to supply different fuel mixes. It is a concomitant of the nascent, non-consensual nature of the future of heat in buildings as a policy problem that there is no clear, stable organisational home for models and the types of knowledge they embody.

Generalisation from a single case study must of course be considered carefully, and needs to be understood in terms of its strategic importance [45]. The EPN/LAEP component of the SSH programme represents a significant investment in a techno-science knowledge framing for solving heat decarbonisation; it provides a pivotal example of normative beliefs that problems can be rendered tractable through production and application of specialist knowledge per se [46]. Further research is of course needed to test our findings, but the analysis has cast new light on the wicked qualities of the heat decarbonisation problem in the complex intersections of goal formulation, problem definition and equity. This is a valuable contribution in its own right, given Rittel and Webber's conclusions that it is 'morally objectionable for the planner to treat a wicked problem as though it were a tame one' [8] (p.161). Premature techno-economic framing of the problem by experts unduly insulated the R&D process from types of knowledge likely to be useful to actors on the ground, including knowledge suited to winning arguments in their own organisations. This insulation was exacerbated by the commercial model of intellectual property, and associated priority given to competitive, marketable solutions over collaboration.

By identifying features of the techno-science knowledge frame which are particularly insensitive to the wicked features of the heat problem, our research in turn suggests modes of knowledge generation that might be more useful. It supports arguments that 'open', more reflexive, innovation systems, allowing broad inclusion of actors, are more likely to be successful in addressing wicked problems than 'closed' styles, with limited access and private ownership [47]. This requires a new understanding of planning, including local energy planning. Instead of a linear-rational model of knowledge-driven option selection and delivery [48], as framed by the EPN/LAEP tool, planning becomes more 'adaptive' in style [49], as one of a number of important venues for fostering more organic, open-ended, civic deliberation and learning for a workable consensus. For heat decarbonisation, rather than pursuing a single vision, or particular technological approach, this entails commitment to more iterative exploration of a diversity of routes. A portfolio of initiatives underpins cycles of learning and adaptation, potentially connecting diverse technologies to trajectories of change for whole energy systems. Demonstration projects – such as those initially envisaged by the SSH programme – would then be experiments deliberately constituted as components of systemic learning. Treating local energy planning as an opportunity for learning in turn requires greater reflexivity between levels, sectors and actors in the policy system. Questions about governance, including the trade-offs between city-region versus smaller or larger-scale allocation of responsibilities, become part of the decision process.

As is characteristic of wicked problems, there is no perfect, unproblematic solution, and here our analysis points to fundamental governance issues. Diverse actors, with their own forms of knowledge, are unlikely to align straightforwardly with, and accede to, the determinations of a singular analytical process. Any proposed solutions, or the creation of OPPs, for decarbonising heat decisions – as for many energy transition problems – will have to hold firm against prospectively disruptive forces (overflows). Even the more open and reflexive learning processes geared to building a workable consensus cannot avoid exclusions [50] or potentially adverse distributive effects. Upscaling any solutions also entails partly transcending the exigencies of context, and navigating the resulting side effects and mis-fits. This points to a need to encompass the *politics* of decarbonising heat, in the sense of creating a space for contestation [51]. Consequently, knowledge frames of any form cannot have any prospects of lasting legitimacy, potency and trust without engaging societal, political and ultimately ethical domains. Following Rittel and Webber [8] (p.162), '(s)olutions to wicked problems are not true-or-false, but good-or-bad'.

Funding Sources

The research on which this paper is based was funded by the Energy Technologies Institute and Energy Systems Catapult.

References

[1] Wesche J, Negro S, Dütschke E, Raven R and Hekkert M (2019) 'Configurational innovation systems – explaining the slow German heat transition', *Energy Research and Social Science* 52, 99-113

[2] Jansma, S., Gosselt, J. and de Jong M (2020) 'Kissing natural gas goodbye? Homeowner versus tenant perceptions of the transition towards sustainable heat in the Netherlands', *Energy Research & Social Science* 69, 101694

[3] UK Committee on Climate Change (CCC) (2020) *Reducing UK emissions: Progress Report to Parliament*

[4] UK Government (2017) *Clean Growth Strategy: Leading the Way to a Low Carbon Future*, https://www.gov.uk/government/publications/clean-growth-strategy (accessed 30th November 2019)

[5] Energy Institute (2019) *Energy Insight: Decarbonisation of Heat Part 2 - Advanced Economies*, Energy Institute Knowledge Service team, 6th November, https://knowledge.energyinst.org/search/record?id=112960(accessed 22nd April 2020)

[6] International Energy Agency (IEA) (2020), *Heating*, IEA, Paris https://www.iea.org/reports/heating (accessed05 August 2020)

[7] Latour, B. (2018) *Down to Earth: Politics in the New Climatic Regime*, Cambridge: Polity Press.

[8] Rittel H and Webber M (1973) 'Dilemmas in a general theory of planning' *Policy Sciences*4, 155-169.

[9] Pearson, P and Arapostathis, S (2017) 'Two centuries of innovation, transformation and transition in the UK gas industry: Where next?'*Journal of Power and Energy* 231 (6) 478-497

[10] Energy Research Partnership (ERP) (2017) *The Transition to Low-Carbon Heat* London: ERPhttps://erpuk.org/project/low-carbon-heat/ (accessed 15 July 2020)

[11] Carbon Connect (2019) *Uncomfortable Home Truths: Why Britain Urgently Needs a Low Carbon Heat Strategy* Future Gas Series Part 3**.** https://www.policyconnect.org.uk/sites/site_pc/files/report/1251/fieldreportdownload/uncomfortablehometruthsfuturegasseriespart3.pdf(accessed 15 July 2020)

[12] Hawkey, D., Webb, J., Lovell, H., McCrone, D., Tingey, M., Winskel, M., (2016) *Sustainable Urban Energy Policy: Heat and the City*. Routledge, Abingdon.

[13] Sovacool B (2014) 'What are we doing here? Analyzing fifteen years of energy scholarship and proposing a social science research agenda', *Energy Research and Social Science* 1, 1-29

[14] Dzebo A and Nykvist B (2017) 'A new regime and then what? Cracks and tensions in the socio-technical regime of the Swedish heat energy system' *Energy Research & Social Science* Volume 29, Pages 113-122

[15] Vadén T et al (2019) 'To continue to burn something? Technological, economic and political path dependencies in district heating in Helsinki, Finland', *Energy Research & Social Science* 58 Article 101270

[16] Lowes R, Rosenow J and Wu J (2020) 'Hot stuff: research and policy principles for heat decarbonisation through smart electrification', *Energy Research and Social Science*

[17] Gaur A, Fitiwi D and Curtis J (2020) 'Heat pumps and our low-carbon future: a comprehensive review', *Energy Research and Social Science* (27th October)

[18] Miu L et al (2019) 'Going smart, staying confused: Perceptions and use of smart thermostats in British homes', *Energy Research & Social Science* Volume 57, Article 101228

[19] Scamman D et al (2020) 'Heat Decarbonisation Modelling Approaches in the UK: An Energy System Architecture Perspective', *Energies* 13(8), 1869

[20] Callon M (1998) 'An essay on framing and overflowing: economic externalities revisited by sociology', in Law J (ed.) *On Markets*, Oxford: Blackwell.

[21] Energy Systems Catapult (ESC) (2018) *Local Area Energy Planning: Supporting clean growth and low carbon transition*https://es.catapult.org.uk/reports/ssh1-local-area-energy-planning/(accessed 15 July 2020)

[22] ESC/ETI (2018) *Local Area Energy Planning: Supporting Clean Growth and Low Carbon Transition*, ESC, Birmingham.

[23] Hodson, M. and Marvin, S. (2017) 'The mutual construction of urban retrofit and scale: governing ON, In and WITH Greater Manchester', *Environment and Planning C: Politics and Space* 35(7) 1198-1217

[24] Silvast A, Laes E, Abram S and Bombaerts G (2020) 'What do energy modellers know? An ethnography of epistemic values and knowledge values', *Energy Research and Social Science* 66.'

[25] Shapin, S. (1995) 'Here and everywhere: sociology of scientific knowledge', *Annual Review of Sociology*, 21 pp 289-321.

[26] Barnes, B (1977) *Interests and the Growth of Knowledge* London: Routledge and Kegan Paul

[27] Latour, B. (1986) The powers of association, in Law J (ed.) *Power, Action, Belief*, Routledge and Kegan Paul, London, 264-280.

[28] Latour, B. (1987) *Science in Action*, Harvard University Press.

[29] Callon M (1986) 'Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieuc Bay', Supplement to *Sociological Review*, Oxford: Blackwell p.196-233.

[30] Rein, M and Schön, D (1996) 'Frame-critical policy analysis and frame-reflective policy practice' *Knowledge and Policy* 9 (1):85-104

[31] Marres N (2007) 'The issues deserve more credit: pragmatist contributions to the study of public involvement in controversy', *Social Studies of Science* 37(5), 759-780

[32] Beveridge, R.(2019) 'Intermediaries and networks', in Davoudi S, Blanco H, Cowell R and White I (eds) (2019) *The Routledge Companion to Environmental Planning* Routledge pp.181-189

[33] Bulkeley, H.A., Castan Broto, V. & Edwards, G.A.S. (2014) *An urban politics of climate change: experimentation and the governing of socio-technical transitions*. Routledge.

[34] Hodson M, Evans J and Schliwa G (2018) 'Conditioning experimentation: the struggle for place-based discretion in shaping urban infrastructures', *Environment and Planning C: Politics and Space* 36(8) 1480-1498

[35] Webb, J. and Hawkey, D. (2017) On (not) assembling a market for sustainable energy: heat network infrastructure and British cities, *Journal of Cultural Economy*, 10:1, 8-20 http://dx.doi.org/10.1080/17530350.2016.1226193

[36] Boltanski, L. and Thévenot, L. (2006) *On Justification: Economies of Worth* Princeton University Press

[37] Tingey, M. and Webb, J. (2020) Governance institutions and prospects for local energy innovation: laggards and leaders among UK local authorities. *Energy Policy* https://doi.org/10.1016/j.enpol.2019.111211

[38] Couclelis H (2005) '"Where has the future gone?" Rethinking the role of integrated land-use models in spatial planning', *Environment and Planning* A 37, 1353-1371

[39] Hajer, M. (1997) *The Politics of Environmental Discourse: Ecological Modernization and the Policy Process*, Clarendon Press.

[40] Wyse S and Hoicka C (2019) '"By and for local people": assessing the connection between local energy plans and community energy', *Local Environment* 24(9), 883-900.

[41] Neves A R, Leal V and Lourenço J C (2015) 'A methodology for sustainable and inclusive local energy planning', *Sustainable Cities and Society* 17, 110-121

[42] Collier U and Löfstedt R (1997) 'Think globally, act locally? Local climate change and energy policies in Sweden and the UK', *Global Environmental Change* 7(1), 25-40

[43] RTPI (Royal Town Planning Institute) (2019) *Planning for a Smart Energy Future*, RTPI Research Paper, July, London: RTPI.

[44] Ofgem (Office of Gas and Electricity Markets) (2020) *Local Area Energy Planning: The Method*, final review draft, prepared for Ofgem by Centre for Sustainable Energy and ESC, https://es.catapult.org.uk/reports/local-area-energy-planning-the-method/ accessed 31st July 2020

[45] Flyvbjerg, B (2006) Five misunderstandings about case-study research, *Qualitative Inquiry*12 (2) 219-245

[46] Demeritt D (2001) 'The construction of global warming and the politics of science', *Annals of the Association of American Geographers* 91(2), 307-337

[47] Sovacool B (2010) 'The importance of open and closed styles of energy research', *Social Studies of Science* 40(6), 903-930.

[48] Kemp, R.; Parto, S.; Gibson, R. (2005) 'Governance for sustainable development: Moving from theory to practice'. *Int. J. Sustain. Dev*., 8 (1/2), 12–30.

[49] Lessard, G. (1998) 'An adaptive approach to planning and decision making' *Landscape and Urban Planning*. 40, 81–87.

[50] Smith, A. and Stirling, A. (2007) 'Moving outside or inside? Objectification and reflexivity in the governance of socio-technical systems. *Journal of Environmental Policy and Planning* 9(3/4) 351-373.

[51] Barry, A. (2002) 'The anti-political economy', *Economy and Society* 31(2) 268-284.

Table 1: Timeline of the UK Smart Systems and Heat (SSH) programme: EnergyPath Networks and Local Area Energy Planning component

Year	Event
2010-2011	The UK Energy Technologies Institute LLP (ETI) review smart systems concepts and projects, as basis for a UK Smart Systems and Heat (SSH) Programme.
2011	Development of the UK ETI SSH Programme, with three components: consumer solutions; local area energy planning (LAEP) and strategies; and market, business and ICT solutions.
2012	As part of an April trade mission to Japan, UK Prime Minister, David Cameron, announces the ETI-planned £100 million, five-year, SSH Programme. At the same time, it was announced that Hitachi had become ETI associate, as SSH delivery partner.
2013	In February, ETI lease a Birmingham office as location for SSH. A Local Authority partnership manager is appointed. In summer, ETI invite UK Local Authorities to bid to participate in the SSH Programme, by testing the EPN model, and using its outputs to develop a Local Area Energy Plan and strategy; bidders were also asked to identify up to three locations for a heat demonstrator project, with a significant proportion of capital funding from SSH Phase 2 System Level Demonstration.
2014	Three Local Authorities (Bridgend, Greater Manchester, Newcastle) are selected to pilot EPN/LAEP, coinciding with decision to close the ETI at the end of its first phase in 2017. Promised capital funding for SSH Phase 2 local heat demonstrators is withdrawn. ETI commission Baringa Partners LLP to develop a software modelling tool - EnergyPath Networks (EPN) – for use in planning local area energy systems; initial investment in EPN £1.1 million.
2015	The ETI sub-contract delivery of the SSH Programme Phase 1 to the newly established Energy Systems Catapult Ltd (ESC).
2015-2017	Piloting of EPN and Local Area Energy Planning with Bridgend, Greater Manchester and Newcastle continues.
2017	With £9.8 million funding from UK Government, ESC leads SSH Phase 2; work includes collaboration with the three Local Authority pilots to develop Smart Energy Plans, and to support development and expansion of domestic low carbon heating projects.
2018	Local Area Energy Strategies for Bridgend, Greater Manchester (Bury), and Newcastle concluded. ETI investment £2.6 million.
2019	SSH Programme concludes. Local Smart Energy Plans for the three pilot areas are published.

Sources: https://www.eti.co.uk/news/p5?programme=smart-systems-heat&type=news;
https://www.eti.co.uk/insights/the-journey-to-smarter-heat;

https://www.eti.co.uk/library?programme=smart-systems-heat&type=&y=;
https://www.eti.co.uk/programmes/smart-systems-heat/energypath;
https://www.gov.uk/government/publications/smart-systems-and-heat-ssh-programme;
https://es.catapult.org.uk/reports/local-area-energy-strategy-bridgend-county-borough-council/;
https://www.eti.co.uk/programmes/smart-systems-heat/local-area-energy-planning (all sources accessed 4 January 2021).