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The role of actor-networks in the early stage mobilisation of low carbon heat networks ☆

Aimee Ambrose *, Will Eadson, James Pinder

The Centre for Regional Economic and Social Research, Sheffield Hallam University, Howard Street, Sheffield S1 1WB, UK

HIGHLIGHTS

- Low carbon heat networks (LCHNs) reduce carbon emissions from heat production and reduce costs.
- Yet market issues and local government cut backs undermine successful delivery of LCHNs.
- Local authorites are charged by government with deploying LCHNS but are not well placed to do so.
- Policy makers need to 'prepare the ground' for LCHN deployment through policy and incentives.

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ABSTRACT

Low carbon heat networks (LCHNs) offer great potential for carbon and heating cost reduction. Despite these benefits, LCHNs provide for just two per cent of heat demand in the UK, when estimates suggest they have the potential to provide for around 43 per cent. These low levels of LCHN provision are in stark contrast to the Nordic nations which exemplify some of the highest quality and most extensive heat networks in the world. It is within this context that the Pioneer Cities project (the project) was launched by the UK government to help local authorities overcome barriers to the deployment of LCHNs. This paper reports the findings of an evaluation of this project, drawing on 86 interviews across five local authorities, analysed using elements of Actor Network Theory (ANT). The evaluation found that the project's success has been limited. Participating local authorities have encountered challenges regarding marketisation, public sector retrenchment and inexperience in mobilising LCHNs. These factors militate against the formation of the robust actor-networks required to deploy LCHNs. Analysis using ANT reveals insights into why LCHNs remain elusive in the UK and suggests that policy makers need to strengthen local authorities' ability to lead and deliver complex infrastructure projects.

1. Introduction

Heat networks (HNs) - systems for distributing heat generated in a centralised location for residential and commercial heating requirements- are an important part of low carbon transition plans across Europe, especially in countries pursuing nuclear phase-out policies (World Energy Council, 2012). They have also been identified by the UK government as an important part of the UK's future low carbon energy supply (DECC, 2012c).

Governmental commitment to HNs in the UK and elsewhere stems from a recognition of their potential benefits. They are well suited to densely populated areas and can reduce carbon emissions when deployed in these environments (DUKES, 2012). A further benefit is that they can be powered using a variety of fuels, including lower carbon sources such as biomass and energy from waste. HNs are also cost-effective compared to individual renewable technologies and have the potential to reduce energy costs for consumers (DECC, 2012a, 2012b, Poyry, 2009; Lund et al., 2010). Indeed, the UK Committee on Climate Change (UK CCC; 2010) stated that where HNs utilise low carbon fuel, they represent one of the most cost-effective carbon abatement measures available.

The promotion of urban HNs, especially low carbon networks, is a priority of the European Commission and of many European countries, yet the proportion of total heat demand served by heat networks varies between European countries, with a higher

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* Corresponding author.
E-mail addresses: a.ambrose@shu.ac.uk (A. Ambrose), w.eadson@shu.ac.uk (W. Eadson), j.a.pinder@shu.ac.uk (J. Pinder).

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proportion in eastern and northern Europe than the west and south (Goodchild, 2015). The Nordic countries in particular possess some of the highest quality, most extensive heating networks in the world, with the potential for exporting technology and consultancy elsewhere.

Contrary to the Nordic experience, HNs of any significance are comparatively rare within the UK, providing for just two per cent of heat demand (DECC, 2012c), when recent estimates suggest that they have the *'technical potential to supply up to 43 per cent of heat demand…by 2050'* (DECC, 2015a).

There are various historical, technical, financial and organisational reasons for this low provision and it is within this context that the Pioneer Cities project (the project) was launched by the UK government in 2013, with the aim of helping to address key barriers that local authorities (LAs) encounter during the early stages of HN development and that often prevent deployment. This is not to suggest that the UK is the only country to experience challenges in the implementation of HNs. Indeed, even in the Nordic countries which exhibit the best quality networks, the drive for greater efficiency, consumer accountability and for carbon emission reduction still continue (Goodchild, 2015). However, the focus of this paper is on the UK experience as an example of a country that faces multiple barriers in mobilising heat networks and as such, can generate lessons for other countries with little history of HN deployment but that are considering utilising them to help decarbonise the heat supply. The learning to emerge from the UK example may also be of interest to countries considering expanding or renewing existing HNs, including, for example, Eastern European states seeking to modernise or replace existing HNs put in place during the Soviet era.

To help galvanise HN development in some of England's major cities and generate exemplar schemes, the project involved the allocation of grant funding (of between £200,000 and £300,000 per city) to five English cities to support the early stage planning and development of HNs powered by low carbon fuel sources (LCHNs). The funding could be used flexibly by the cities but was generally used to hire consultants to produce feasibility studies for new or extended HNs.

The project was developed in recognition of the range of systemic and practical challenges faced by LAs in developing LCHNs in the UK, as documented by Ambrose (2013); UK CCC (2010); DECC (2013); Heat and the City (2011) and Kelly et al., 2010, amongst others. These sources identify four core challenges:

1. Substantial project development costs (in addition to capital costs) including: feasibility studies, attracting finance, master planning and legal advice.
2. Lack of necessary skills and expertise within LAs to deliver such projects, especially in the absence of established procedures.
3. Obtaining funding to cover capital costs for the implementation of HNs, particularly in the context of reduced LA budgets since 2010.
4. Little direct ownership over existing energy infrastructure. In some cases, the ownership and on-going responsibility for existing HNs has been transferred from LAs to private sector bodies.

Each of the five participating cities was at different stages in the development of plans for LCHNs and had varying levels of relevant experience. For example, two of the cities had existing HNs that they wished to expand and de-carbonise, whereas others had no history of implementing and operating them at all. The precise nature of the barriers faced therefore varied between cities and contexts.

The original research objective was to develop an understanding of the extent to which the project helped the cities to overcome both the general and the context specific barriers they faced in developing LCHNs. A secondary focus was to better understand the processes that LAs worked through in pursuit of LCHNs.

Key to the mobilisation of infrastructure projects, such as LCHNs, is the ability of the lead organisation to forge and sustain effective networks that bring together all the actors necessary to enable development or to at least establish its feasibility (Bulkeley et al., 2006). Identifying the actors required is a challenge in itself, and there is no established model for HN development, especially in the UK where there has been and continues to be experimentation with different organisational forms (Heat and the City, 2011). Once a configuration has been agreed upon, the resultant actor-network must find a way to work within and around the various contextual constraints it faces in achieving its goals (King et al., 2011).

While previous research into the mobilisation of HNs has explored the processes involved, focussing heavily on the economic challenges (Hawkey et al., 2013), there has been little consideration of the *'work done'* within those processes to enrol key actors and draw them into a stable configuration or actor-network capable of delivering LCHNs. This paper draws on data that provides insights into the attempts of LAs to enrol key actors into such a network and the relationship between this and their effectiveness in mobilising HNs. The paper therefore contributes towards addressing a gap in our current understanding of the factors that can inhibit HN development.

This paper also recognises that LCHNs represent a'double challenge' in the sense that HNs are challenging enough to mobilise but those that utilise low carbon sources are more complex still (DECC, 2013; King et al., 2011). The specific challenges involved in mobilising LCHNs, as socio-technological innovations, have received little attention in the existing literature, which predominantly considers the development of fossil fuel powered networks (see Hawkey et al., 2013; Williams, 2010).

The innovatory aspects of LCHNs in turn suggest the use of appropriate socio-technical theoretical frameworks to contextualise the processes involved in their development. In this paper Actor Network Theory is applied as a framework through which to understand the work done in the formation of the actor-networks necessary to mobilise LCHNs and if appropriate, where they are falling down in pursuit of this goal.

This paper comprises of six sections, including this one. The following section outlines the analytical framework underpinning this paper. There then follows a brief explanation of the methodology employed before the main findings are set out in the fourth section. Section five provides a discussion of the results in the context of the analytical framework and the paper ends with key conclusions and policy implications.

2. Analytical framework

HNs are the outcome of the construction and stabilisation of a broad collection of human (social) and non-human (technical) elements. As such, a key question for those seeking to understand how new HNs are brought about relates to the processes by which these different elements are drawn together to create a new entity in the shape of the HN or, in this case, the LCHN. In this vein, Hawkey et al., 2013 conceptualise HNs through allusion to actor-network theory (ANT), with particular reference to the need to consider *"the work done to configure the heterogeneous components of the system with the aim of establishing a stable foundation for urban heat and cooling networks"* (pp.23).

ANT is highly relevant to HN development, being mostly concerned with understanding how scientists and technical experts

interact with one another and with pressure groups and politicians. To secure change, experts have to enlist the support of influential groups and build supportive networks that comprise the relevant professions, specialists, and political actors with the potential to influence a situation. They also have to ensure that the non-human world behaves in a predictable and conducive manner (Goodchild, 2015).

In order to forge an effective network, ANT contends that experts also have to provide reliable information and technical calculations proving the viability of their idea or project and to translate their positions and requirements into a language that the other actors can understand and appreciate as being in their best interests (Goodchild, 2015). In this context, Latour, 1999 work on'circulatory systems' can be used to add greater depth to our understanding of the steps that together actors must take to secure the change they seek: in this case, a transition from'traditional' heating systems to LCHNs. Latour outlines five steps, which together form pre-requisites to an effective actor-network, as follows (adapted from Latour, 1999; Tabak, 2015):

- Organisation of the world: the formation of arguments to support the overall objective, using various instruments to build a credible supporting evidence base. Including provision of reliable information and technical calculations.
- Autonomisation: the position reached when actors have assembled sufficient evidence to support their views and are credible enough to be considered an'authority' on a particular matter. Once achieved, actors are in a position to convince others of their arguments and form'alliances'.
- Alliances: actors cultivate interest amongst'powerful groups and institutions' and enrol them into a network.
- Public representation: promoting public acceptance of the idea by aligning it to everyday practice.
- 'Links and knots': achieving all of the above activities simultaneously and in a joined up fashion.

In the context of this paper, there is a stage hidden within Latour's framework which deals with the work done between the stages of organisation and autonomisation, involving the identification and enrolment of key actors required to make the project happen. In ANT, these stages are known as *interessement* and *enrolment* (Boelens, 2010). The incorporation of these additional stages into this analytical framework also responds to Cressman, 2009 criticism that when ANT is used as an evaluative tool, there is a tendency to examine the inputs and outputs of the network but not the work done within it.

These stages of interessement and enrolment are particularly important at the early stages of conceptualising and mobilising HNs, where greater levels of'faith' and trust are required in order to make connections between actors in the absence of tangible or immediate rewards. This task is made harder still when the aim is to incorporate relatively novel forms of energy supply into new developments, as is the case in relation to the use of low carbon energy sources. In this scenario, the potential benefits of enrolling in the emergent actor-network are not only distant but poorly understood, as evidence relating to the economic benefits and'pay-back' periods associated with low carbon fuels is inconsistent (DfT, 2012).

This paper also aims to consider another factor not previously addressed in the literature: the processes of translation required to make a HN project'legible' for and attractive to different interests. This might include the development of a financial business case to attract investors or the identification of social benefits to secure public sector and institutional commitment. This signals the importance of considering questions of interdependency or, in other words, how key actors are enrolled by others to meet their own goals in this process of developing new actor-networks. Rutland et al., 2008 summarises the importance of translation and interdependency to the formation of effective actor-networks:

"If actants end up working together … it is not because of any inherent alignment of interests, but rather because potentially quite different interests have been translated: compromises have been made, and actants with diverse interests have been persuaded that moving toward their objectives can be best achieved by working with certain others." (Rutland et al., 2008 p.632).

Heat and the City (2011) suggest that this process of translation is ongoing and iterative over the lifetime of a project and increases in complexity in line with the range of actors enrolled.

The circulatory system model incorporating the concepts of interessement and enrolment is helpful in conveying the complexity of the process through which an actor network is assembled. However, one key set of issues that it does not explicitly recognise are the additional external pressures that act upon an actor-network as it emerges. In particular, it is important to recognise action at the local level as taking place "in the shadow of hierarchy" (Jessop, 1997). Actor-networks rarely operate in isolation and are likely to need to interact with and draw support from other networks operating at various different levels (for example, in relation to finance and technical matters) if they are to realise their ambitions (Rydin., 2007). In relation to HNs, there is a particular reliance on such external networks in order to secure capital funding.

In the past LAs would have been less reliant on external networks to raise capital and to organise the supply of heat. During the 1950s and 60s in the UK, HNs were a more common source of heat within large LA housing schemes and the relationship between supplier and consumer was relatively simple. LAs would be responsible for the production and supply of heat and consumers charged a fixed price for heat, regardless of consumption (DECC, 2014). Now the context is changed. Geographic consolidation, nationalisation and then later liberalisation of energy markets removed LA control over energy systems and their potential role in LCHNs constrained by state aid and procurement rules (Heat and the City, 2011). These constraints are illustrated by the existing evidence on urban energy restructuring which highlights how LAs are being empowered but concurrently disempowered to act on energy infrastructure and carbon reduction (see Hodson et al., 2013; Buck and While, 2015, Bale et al., 2012). Other constraints include budget cuts and austerity (which have reduced LAs in size and resource); national policy uncertainty (which restricts long term strategic planning) and a lack of skills and experience in undertaking commercial projects.

LAs attempting to deploy LCHNs also face added hurdles in relation to the market for low carbon heat provision, in particular the potential of low carbon fuel sources to compete with the cost and convenience of gas, especially since the removal of subsidies and incentives for renewable energy (DECC, 2015b). Subsidy remains essential, at least in the short term, because consumers will demand concessions to mitigate the perceived risks associated with such an unfamiliar arrangement (Poyry, 2009).

There are also questions regarding the level of profit that LAs and investors would find acceptable and expectations regarding the timescales in which networks should become profitable. A HN may be rendered inviable if expectations of profit are too high (or too distant in time) to enable pricing competitive with gas (Poyry, 2009). Returns on investment from HNs tend to be more gradual (which may not appeal to investors) and therefore require long term interdependencies between consumer and supplier (which may not appeal to the consumer) (King et al., 2010). Hence, there are a great many economic challenges facing the actor-networks charged with driving forward LCHNs.

ANT takes account of economic dilemmas such as these through the concept of economisation, of which marketisation (or the establishment of markets) is one form (Çaliskan and Callon, 2010). Caliskan and Callon (2010) convey the challenges that marketisation pose for actor-networks through their conceptualisation of markets as a space of confrontation and power struggles where *"multiple contradictory definitions and valuations of goods as well as agents oppose one another until the terms of the transaction are peacefully determined by pricing mechanisms."* (pp.4). In relation to a LCHN based in the UK, the pricing mechanism will be determined by the imperative to keep heat costs below those of gas. Part of the consideration here for prospective customers will be the'opportunity costs' of joining a network and the subsequent technical and practical costs and implications. The choice facing consumers is therefore not a simple price comparison between their current and potential heat costs; they must also consider whether, in light of the economic constraints outlined, it is worth their while.

These factors means that LAs are operating in a constrained environment and are not well positioned to take the kind of commercial risks outlined above. However, in spite of these disadvantages, the UK government continues to charge LAs with the task of driving forward various energy and infrastructure initiatives, usually as part of small scale experiments or short term projects rarely linked to larger scale programmes.

The preceding discussion suggests that, as argued by Cressman, 2009, ANT is a suitable tool for enabling deeper analysis and evaluation of actor- networks. The analytical framework used within this paper to frame and interpret the data will comprise of a combination of Latour's circulatory system and broader elements of ANT, such as the concepts of interessement, enrolment and marketisation. While the circulatory system deals primarily with the stages involved in the formation of an actor-network, interessement and enrolment provide more detailed insights into the initial recruitment of key actors, and marketisation accommodates the economic issues bound up with the mobilisation of LCHNs.

The remainder of this paper will focus on the exploration of the following themes through the data:

- What are the key challenges faced by LAs when attempting to mobilise LCHNs?
- What is the role of actor-networks in the mobilisation of LCHNs?
- How have LAs approached the task of mobilising actor-networks capable of deploying LCHNs?
- Are LAs best placed to mobilise actor networks for the deployment of LCHNs?
- How useful and effective is ANT as a way of understanding the mobilisation of LCHNs?

3. Methods

A total of 86 in-depth interviews were conducted with key'stakeholders' in each of the five cities and those who developed and managed the project within central government. Interviews were undertaken over three rounds between 2013 and 2014 to track progress towards implementation. Each city was treated as a case study, enabling a detailed understanding of the local context in which it was delivered.

The research followed the principles of ANT in drawing on the techniques associated with case study research (Tatnall, 2000, p. 80). The aim was to follow the lead of Tabak, 2015 and use in-depth interviews to track the experiences of the actors as they attempted to assemble a network, prompting them to reflect on the process at critical points. As is usually the case in ANT, the'network builders' (in this case the lead officers or'project manager' within the LAs) were the starting point and it was through their eyes that the process of network construction was followed (Cressman, 2009). To enable this, lead officers were interviewed at the start of each round of interviews and were also corresponded with in between interviews to ensure researchers were kept abreast of project developments, including changes in strategy, direction and the introduction of new actors. To ensure a rounded account, the views and perceptions of network leaders were juxtaposed with those of the critical actors that they sought to engage.

The lead officers led us to the other critical actors within each city, who typically included some mixture of the following:

- Project manager.
- Strategic lead (senior officer with overall responsibility for the project).
- Politicians (elected councillors).
- Key LA stakeholders - for instance procurement officers, planning officers or sustainability/energy officers.
- Potential customers of the network.
- Consultants engaged to carry out technical or financial feasibility / business case development.
- Suppliers of heat to the network.

The specific combination of actors interviewed during each round of interviews was determined in line with which actors were considered to be critical to progress at that particular point in the project. This judgement was made by the research team in consultation with the project lead.

Although the focus of discussion varied between the different stakeholders and at different stages in the project, the following themes were explored at each stage of the research: stakeholder engagement; project governance; engendering and maintaining political support; drivers of and barriers to progress; progress towards low carbon fuel sources; progress towards deployment and practical considerations; pricing models.

All interviews were professionally transcribed verbatim and the data coded geographically and thematically using Nvivo 10 software. The former involved looking in detail at the experiences of individual cities as detailed case studies; the latter involved comparing and contrasting data across the five cities, enabling the research team to explain differences in outcomes.

4. Findings

4.1. Making the case for heat networks

The first challenge facing LAs was to make the case for the deployment of LCHNs locally. Prior to taking part in the project, all the cities held ambitions for either the development of new HNs or the extension of existing ones and knew broadly where they wanted to locate them. However, reflecting the observations of Latour, 1999, the LAs were aware that an aspiration alone was not sufficient and that they would need to establish them as a'positive modality' (or an accepted idea) in order to further their ambitions for HN development. Latour, 1999 contends that a positive modality can be constructed by developing a narrative that it is difficult for others to unpick or challenge. An important mechanism for this can be establishing a body of evidence from credible sources in support of your cause. Reflecting this, four of the five cities were aware of the need to enlist experts to help them make a clear business case for HN development and understood that, in isolation, their assertions would lack credibility (amongst both the public and investors).

"I do not think anybody should underestimate the power of the fact that it's independent. Partners are a bit sceptical because it's us trying to sell something, whereas in this case we are trying to broker a contract for the project, but the work's been done by people independent of the LA. I think the fact that you've brought in people who are independent and know the market, it gives it that sense of professionalism, but it gives it that stamp of authority as well to say it's not just a couple of people sitting in the Civic Centre who have dreamt this up. "(Project sponsor, case study #2).

Four of the five LAs therefore commissioned consultants to provide an assessment of the technical and economic feasibility of their proposals. The fifth city chose to conduct this feasibility work internally to conserve resources.

Further reflecting Latour, 1999 observations, consultants across the four cities employed a common set of instruments to give form to the concept of a HN, build an argument for its viability and create an image of HNs that engenders political and public support. These instruments included heat mapping (to identify clusters of heat demand); techno-economic assessments (establishing technical and financial viability to enable shortlisting of possible HNs) and characterisation (more detailed assessment of the feasibility of short listed schemes) and were 'layered up' to form the building blocks of the case for HNs. However, as Latour reminds us, the instruments themselves also require sufficient modality for a robust and credible case to be made, thus underlining the importance of appointing specialists with sufficient cognitive authority (Wilson, 1983). Because only these specialists have command of the instruments that they themselves have established as being the most valid and credible means of assessing viability, they establish themselves as'gatekeepers to the field' (Tabak, 2015). In this sense, such consultants have achieved the state of autonomisation, described by Latour as *"the way in which a discipline, a profession, a clique or an'invisible college' becomes independent and forms its own criteria of evaluation and relevance"* (Latour, 1999 p.102). LAs therefore have little choice but to delegate responsibility for this task to consultants.

4.2. Identifying and engaging with key actors

Once autonomisation is achieved the next challenge is to cultivate interest amongst'powerful groups and institutions' or'allies' (Tabak, 2015). In most of the cities, efforts to identify and enlist the support of such groups and institutions, which may also be described as'key stakeholders' (external to the LA), had been limited prior to the beginning of the project. In most cases it was left to the consultants, with some input from the LAs, to identify who they needed to speak to and lead on initial interessement. LAs believed that consultants, as the'cognitive authority' were better positioned to cultivate interest and speak the language of'business'.

In order to obtain the energy data required to assess viability, consultants focussed on identifying and approaching the potential customers of the proposed new or extended network(s) and, where applicable, organisations who might be able the heat. Their aim, initially, was to focus on potential consumers with higher levels of heat demand, including public sector and larger commercial organisations who had been identified through heat mapping and could provide an'anchor load' for the network. Concurrently, LAs worked internally to enlist the support of local politicians and senior managers within their organisation, who would need to sanction plans to emerge from the project.

As feasibility investigations progressed, it became necessary to engage a broader range of stakeholders including infrastructure owners and operators, land owners and later, investors/financiers (although the research ended before this stage). Each type of stakeholder brought its own challenges in terms of interessement and enrolment and also dissidence.

There was no doubt that the LAs themselves would lead the actor-networks. This might be seen as surprising given the LAs acceptance that they did not represent a credible authority in relation to HNs, sitting outside the'invisible college'. And, whilst it is true that LAs have traditionally driven municipal HN development, this is no longer an inevitability. Nevertheless, LAs were perceived by government to be the right organisations to lead the projects due to their (supposed) authority over planning, local knowledge, social and environmental aims, ability to appeal to a range of actors and to act as an'honest broker' (Heat and the City, 2011; Wedawatta et al., 2014; Pielke, 2007). For these reasons, it is argued by Heat and the City (2011) that LAs do need to participate in actor-networks aiming to develop HNs but are not necessarily best placed to lead them, and that different organisational arrangements may be required at different points in the project development cycle.

4.3. Challenges in the interessement of external stakeholders

The process of interessement proved to be challenging, reflecting Latour's view that the creation of allies involves an*'enormous labour of persuasion and liaison'* (1999, p.104). LAs often lacked relationships with local businesses, which meant that consultants were'going in cold' and trying to establish contact and build trust with decision makers. This was further complicated by the fact that in larger private organisations, decisions about the purchase of energy tend to be made centrally, often as part of bulk contracts. One LA officer (in case study #3) expressed the belief that medium-sized organisations were amongst the easiest to enrol because, for them, HNs made more commercial sense than they may do for smaller and larger organisations. Such organisations, it was reported, tend to experience large energy bills but do not benefit from bulk buying. Smaller organisations, he argued, were not as heavily affected by high energy costs due to relatively low usage, so the upfront costs of connecting to a HN would be difficult to justify.

Although LAs tended to have established relationships with other large public sector organisations, including healthcare trusts, colleges and universities, these organisations needed to be persuaded about the benefits of switching from their existing heat source. Issues of marketisation were prominent once again because the price of heat generated from HNs was often estimated to be similar to or more expensive than gas and it was therefore necessary to highlight the other benefits of HNs, such as energy security and carbon savings. Although carbon savings were an attractive to organisations with carbon reduction targets to meet, many already had long-term energy contracts or had invested in their own energy generation. While they were generally happy to express an interest in principle, most potential customers were reluctant to make a firm commitment to connecting to a HN until exact prices and contract terms had been fixed, and they had confidence that the network would be built. This created a'catch-22' situation, whereby LAs and other investors were unlikely to progress with building a HN before there was a firm commitment from customers.

"It's chicken and egg because we're not going to get a network until somebody signs up to one, they're not going to sign up to a heat network until there's a heat network, and that is common across any heat network you choose to develop." (Consultant, case study #3).

Consultants were keen to highlight the difficulties experienced in relation to the interessement of'allies' or potential customers, recounting how organisations were reluctant to share information and sceptical about the benefits of connecting to a HN. In some cities these difficulties were exacerbated by HNs having a reputation as being unreliable, but also because of a political landscape in which previously adversarial relationships continued to

affect attitudes towards collaboration. Reputational issues can be critical to the public acceptance of an idea; or the creation of a positive modality. Tabak, 2015 underlines this point in his discussion of Latour, stating that ideas must be relatable to people's' *everyday practice and their systems of belief and opinions'* (p.105). Consultants faced the'double whammy' of trying to engage potential customers in an initiative spearheaded by the LA, which may not be trusted or viewed as a credible business partner, and that utilises a form of heating that has suffered reputational damage in the past, is unfamiliar to most and perceived as inherently risky (Heat and the City, 2011). Negotiations between potential customers and key actors will therefore be protracted and iterative (Heat and the City, 2011), something borne out by the data presented here.

Commercial sensitivities also played a part and some organisations were reluctant to release data to a third party. Other consultants recounted the more practical constraints, for instance: buildings with electrical heating systems and historic buildings, making retrofitting a connection costly and some potential consumers could not make the decision to connect to a network, because they were tenants in a building owned by someone else.

4.4. Challenges in the interessement of internal stakeholders

Mobilising HNs also involves the interessement of actors within LAs. At a strategic level, the support of senior managers and local politicians was required, without which progress would be impossible. This'high level' support was galvanised by the opportunities the project afforded to deliver against strategic commitments to low carbon heat solutions and by the funding for feasibility studies provided by central government. There were, however, instances where local contextual factors made it challenging to engender and maintain this support. For example, organisational and political flux in one city made it difficult to maintain focus on the feasibility work, despite support from senior officers:

"The [senior manager] left in May and then we went into a black hole while all that was playing out and it's taken me all this time to get some enthusiasm back for it because of everything else that's going on." (Project lead, case study #2).

Elsewhere (in case study 5) dwindling resources, loss of key personnel and changes in senior management resulted in delays and a loss of direction.

The second aspect of internal engagement involved the interessement of departments within LAs. HN development cuts across a wide range of different departmental'silos', including property management, waste management, finance, legal, regeneration and planning. However, securing the support of these departments often proved challenging given their competing priorities. For instance, ensuring that a HN links in with and benefits from future urban development means adopting a'joined up' approach with regeneration and planning departments, making HN connections mandatory for new developments in particular locations. However, those responsible for encouraging new development may see this as undermining efforts to attract inward investment into the city because potential developers may be deterred by the policy. These challenges were prominent in the account of a senior LA manager in case study 3, who recounted how:

"… getting the buy-in politically was no problem, getting the buy-in from other departments has been quite frustrating and often the project's only been able to progress at the pace of the slowest person who also has a million other things to do."

Such difficulties were also attributed to the fact that the mobilisation of HNs involves a degree of cultural change within authorities, requiring officers and elected members to think more commercially and see the LA in the unfamiliar role of energy provider.

4.5. Enrolment and autonomisation

As a consequence of these challenges, only one participating LA successfully enrolled all of the actors that they needed into an actor-network, ostensibly as a result of efforts over a number of years preceding the project. The others had assembled'loose networks', where key actors had agreed to take part in the project in principle but remained tentative in their commitment. One example of this reluctance to fully enrol can be found in case study 2, where a critical actor- a major civic institution generating waste heat that the LA envisaged would supply the network- avoided committing to the project whilst they explored ways of selling their heat directly to potential customers in the vicinity, thus displaying dissidence and attempting to bypass the LA altogether. This particular example highlights difficulties in relation to mobilisation and the nomination of LAs as network leaders and raises questions regarding the extent to which they necessarily represent the interests of and have the trust of their'constituents'. This narrative points to the difficulties for LAs in autonomising on energy matters and an associated challenge to craft the cognitive authority that is arguably a prerequisite of network leaders.

The LA's leadership of these projects was questioned in three of the cities and LAs widely reported difficulties of securing support from private sector actors, in particular. In case study 5 such difficulties ultimately led to the collapse of plans developed through the project, forcing the LA to focus on an existing development led by a public-private partnership- an altogether'softer' target to convince of the merits of HNs. This example illustrates that certain actors will always be more critical to the success of projects than others the dissidence of these actors can be detrimental to a network.

4.6. Utilising low carbon sources

As outlined previously, participating cities were grappling with a double innovation by trying to introduce not only an unusual form of heating but one powered by low carbon sources. The cities were all driven to utilise low carbon sources, primarily due to strategic carbon reduction commitments.

"Driving progress, we've got strategies, we've got a carbon target and we have the ability and the will to decarbonise our heat generation" (LA officer, case study 4).

In three of the cities there was also evidence of pressure from civic actors (universities, colleges and hospitals) to ensure that their heat was generated from low carbon sources to help them achieve carbon reduction targets. As previously outlined, these organisations were critical players- as either major customers or suppliers of the network- and tensions were evident between them and those representing private sector or residential customers' interests for whom securing the lowest prices was a higher priority.

"The council's listening to the customers, so what we were hearing was they want lower carbon heat because the higher education sector's now got carbon targets which they are seeking to hit, so the drivers in that sector were greater than perhaps the drivers in other commercial and residential sectors and that's been quite important." (LA officer, case study #3).

Indeed, across the cities it was conceded that heat costs remained the key factor determining whether a potential customer was likely to connect to the network.

"These projects […] offer lower cost energy and energy security to businesses and homes in the region. They're probably the key drivers over the low carbon drivers, although they are important as well." (Senior Manager, case study 1).

Consequently, despite commitments to the principle of low carbon sources in all of the cities, three of the cities proposed (at

least in the short to medium term) to fuel their networks using gas. In these cases, the cities were relying on the increased efficiency of energy supply through the economies of scale derived from a HN to deliver carbon savings, as opposed to the use of low carbon sources.

Of the available options for low carbon sources, energy from waste was the most popular and was either being used in existing networks, or being considered for new networks in four of the five cities. However, energy from waste plants were reported by their operators to be strategically and financially viable without the inclusion of heat generation: they provided a means of waste disposal for LAs and additional income through electricity generation for the plant operator. HNs were a secondary consideration and the key issue was ensuring that the plant operator did not suffer financial loss as a result of the costs of connecting the plant to a HN. It could not always be assumed that the operators of energy from waste plants would agree to supply a HN.

There is evidence in these accounts of LCHNs struggling to compete with the low gas prices available in the UK and the relative simplicity of installing gas based systems. Overall, therefore, the scope for the delivery of LCHNs appeared limited, at least in the short to medium term.

4.7. Constrained actor-networks

The challenges that LAs had encountered, in introducing low carbon sources to projects, serve as a reminder that the nascent networks were not operating in isolation and that there were many external pressures and contextual factors acting upon them.

Common challenges included dwindling resources resulting from severe budget reductions imposed by central government since 2010. This meant the loss of key staff and an associated loss of knowledge, skills and connections. LA actors felt that they did not possess the levels of resources and influence necessary to drive forward large infrastructure projects. In several cases, it was clear that LAs lacked the'bargaining power' over other actors. In one city, the LA had, for financial reasons, signed over control of their HNs to a private company on a long lease and felt frustrated that they no longer had the power to drive forward its expansion. In another, the main heat supplier saw no reason to involve the LA in the network, viewing them as a'middle man'.

5. Discussion

The previous section provided insights into challenges encountered by LAs when mobilising LCHNs. It is evident that, in most cases, the cities struggled to progress the deployment of LCHNs.

Different challenges were manifest at different stages of network formation. At the beginning of the process, LAs did not possess the skills to produce a robust technical and economic case for LCHNs (Latour's'organisation of the world'), deferring attempts to create a positive modality to the consultants that sit within the'invisible college'. However, even supported by ostensibly credible consultants, cities struggled with the interessement of local actors in the absence of immediate and compelling incentives. The interessement of internal stakeholders appeared easier as they were more driven by environmental and societal goals around carbon reduction, as opposed to exclusively commercial considerations.

Given these difficulties, the task of enrolling key actors into an actor-network proved difficult and resulted in a series of'loose' networks of wavering actors unwilling to firmly commit before a clear financial proposition was made. This low level of commitment increased the likelihood of acts of dissidence amongst key actors, with potential to further destabilise emergent actor-networks. These issues were exacerbated by the inability of LAs to achieve'autonomisation' and establish themselves as a cognitive authority in relation to LCHNs. Yet, despite their lack of credibility as network leaders, they continued to attempt to fulfil this role, exercising the mandate given to them by central government.

Incorporating low carbon sources into plans for new HNs proved equally challenging for LAs and their consultants, who struggled to develop proposals that could compete with the low cost and convenience of gas. In addition, broader constraints were bearing down hard on LAs, depleting their resources, power and influence. Despite their apparent advantages and greater levels of credibility, consultants also struggled to persuade key actors to enrol fully, suggesting that'public representation' (widespread acceptance of LCHNs) remained a distant prospect.

A central challenge here relates to translation, which both Latour, 1999 and Rutland and Aylett (2013) suggest is common, whereby network leaders are unable to translate their vision and potential benefits to other key actors in a way they can all appreciate as being in their best interests. Where translation is successfully undertaken, public representation follows more easily. In particular, LAs struggled to effectively 'pacify' (Caliskan and Callon, 2010) the HN as a market object within established, obdurate market and infrastructural arrangements. HNs are a disruptive local innovation. Network-builders therefore face difficulties in economising their projects: turning it from an innovative to conventional project in order to make it part of established market arrangements, as well as material energy and urban infrastructures (Rydin et al., 2014). Important factors in establishing a pacified market object include standardisation and price-setting (Caliskan and Callon, 2010). Caliskan and Callon (ibid. p.7) note that actor-networks are more stable when *"… a commodity has undergone specific processes of standardisation that transform it into an entity described in both abstract and precise terms, certified and guaranteed by a series of textual and material devices"*. Using consultants to produce positive modalities through techno-economic calculations and feasibility studies was an attempt to do this, but there was no standard approach to HNs as market objects – indeed, each city was approaching it in different ways and were often uncertain about how best to proceed. The chief means of stabilisation, and in turn, price-setting was through reference to mainstream gas markets. This was problematic because potential customers struggled to see beyond the transaction and opportunity costs of moving to (in their eyes) the uncertain, monopolistic service provided through a HN.

This led to a 'catch-22' situation where no-one made a firm commitment to the project in the absence of clearly defined prices, terms and payback periods. Across the five projects, no such resolution had been reached and potential suppliers and customers remained reluctant to enter into a negotiation with the LA and their consultants. If potential customers had been dissatisfied with their current heat supply arrangements, they may have been more willing to engage on a more speculative basis. The push factors – such as the price or reliability of existing services – were insufficient to outweigh the costs associated with moving away from the status quo. These unfavourable conditions suggest that LAs had arguably been set an impossible task, in so far as the socio-technical systems for the provision of heat (gas boilers) are too firmly embedded and aspirations for moving away from them are undermined by their relative affordability. We might therefore posit that the failure of the cities to secure progress towards LCHNs had at least as much to do with issues of marketisation and the supremacy of the existing gas infrastructure than network leadership.

Government maintains that there are considerable benefits associated with LCHNs, including reductions in carbon emissions

and costs. However, the conditions are not currently right for the innovation (or double innovation) of LCHNs to break into the mainstream, particularly as the UK government wavers on their commitment to carbon reduction and scales back incentives for renewable energy (DECC, 2015b).

LAs were empowered by government to attempt to roll out an innovation whose benefits are contested, rendering public representation very difficult to achieve. It feels, therefore, that it was premature to charge LAs with the task of propagating LCHNs and that further work is required to 'prepare the ground' through the development of a supportive policy framework, incentives and enticements. Indeed, if the UK government are committed to the deployment of HNs as a key means of decarbonising the heat supply, they will need to provide more resource to both enable and ease the transition.

If a central problem was effectively stabilising and mobilising the concept of the LCHN in order to make it legible as a market object to other actors, this raises questions regarding the extent to which LCHNs are currently best mobilised through financialised, market arrangements. At least one participating city responded to this by introducing mandatory HN connectivity as part of planning agreements for new developments, thus embedding HNs as the default form of heat provision. More generally, if LCHNs are seen as an important tool in low carbon transitions, there is a need for greater market and non-market incentives for LCHN growth. This might include greater financial resource from central government to allow network leaders to proceed on the basis of social and environmental benefits, without immediate need to pay off the capital costs, which would potentially enable the development of subsidised provision that could effectively 'compete' with established gas networks. This is perhaps a simplistic solution, but in order for innovations to become mainstream there is a need to nurture their progress. The rapid increase in the deployment of solar photovoltaics as a result of generous subsidy regimes in a number of EU states is one example of how this can work.

It is also important to reflect here on the extent to which it has been useful to apply Latour's circulatory system and other elements of ANT to the problem of LCHN deployment. A strength of the Circulatory System is that it encourages detailed and critical consideration of the process of mobilising an actor-network. In doing so, this paper contributes towards a notable gap in the literature around HN development, which has focussed heavily on economic challenges (Rydin et al., 2014), paying little attention to the *'work done'* to enrol crucial actors. However, one lesson to emerge from this analysis is that the circulatory system does not enable sufficient interrogation of the processes of actor-network formation that play out between the stages of 'organisation' and 'autonomisation' involving the identification and enrolment of key actors. The addition to the analytical framework of Boelens, 2010 concepts of *interessement* and *enrolment* are valuable in elucidating these processes, which can be so critical to the success or otherwise of an actor-network.

As emphasised in other literature, the findings suggest that economic factors *are* an important barrier to LCHN deployment. Yet it is important to set this within the context of the economic as a constructed, not *a priori* phenomenon made up of simple arrangements of costs, prices, supply and demand: the concept of marketisation allows us to interrogate these issues within the broader context of actor-network formation. As the data also highlights broader constraints are acting upon those attempting to mobilise LCHNs, such as the retrenchment of LAs in the UK. Therefore, although ANT provides a useful framework for exploring the role of actor-networks in the mobilisation of LCHNs, its application should be accompanied by an appreciation of the broader factors at play.

6. Conclusions

The success of the project in helping LAs to overcome key challenges encountered in the early stage development of LCHNs was limited. Although exact circumstances differ, participating LAs encountered a common set of interrelated challenges associated with the marketisation of LCHNs; the weakened position of LAs in the face of public sector retrenchment and their lack of experience in mobilising LCHNs. These factors militate against the formation of the robust actor-networks required to deploy LCHNs.

But how essential are extensive actor-networks to mobilising LCHNs? The evidence presented here suggests that LAs could not act alone in such projects, especially not in a de-regulated energy market where both users and suppliers of heat freely choose where, how and from whom they buy and sell heat. Under these circumstances, LAs must become either masters of persuasion or wield impressive incentives. Yet, they find themselves poorly positioned to do either, undermining their credibility as leaders of efforts to mobilise LCHNs.

In an attempt to overcome constrained resources and a lack of credibility, LAs enlisted consultants to broker an appropriate actor network. However, despite their apparent credibility, consultants also struggled to engender the commitment of key actors, suggesting that the incentives on offer were insufficient and the economic case too weak. As such, this paper provides a clear indication that the dominance of the existing gas network creates a climate within which any network leader may struggle to engender commitment. Under these circumstances, although LAs ability to develop such complex infrastructure projects is being increasingly weakened, the wider infrastructure and regulatory environment mean that other actors are not necessarily any better placed to develop LCHNs.

The application of ANT to this scenario has been useful, providing a framework through which to identify where efforts to mobilise LCHN projects are falling down. Analysis conducted using different elements of ANT indicated that marketisation difficulties and broader economic factors undercut the ability of LAs (and their partners) to deploy LCHNs, making it difficult to get past the first stage of the circulatory system: the organisation of the world. The combined work of Latour and Boelens then illustrates how a failure to achieve this first stage prevents progress through subsequent stages, providing insights into why LCHNs remain elusive in the UK.

7. Policy implications

This research highlights a range of activities that policy makers might usefully undertake to support transitions to LCHNs. Although some of these recommendations relate more specifically to the UK context, most will resonate to some degree across countries developing new HNs, extending existing networks or making the transition to low carbon fuel sources. Activities in support of LCHNs may include:

- promoting a better image for HNs and dispelling persistent myths around unreliability and negative environmental impacts (supporting public representation)
- (re)introducing financial incentives to promote the use of low carbon fuel sources (thus reducing the supremacy of gas in a UK context) and promoting the development of new low carbon infrastructure (aiding marketisation);
- covering initial infrastructure costs to help overcome prohibitive' opportunity costs';
- strengthening planning authorities' resources and powers to mandate heat network connectivity, as part of a broader ethos which prioritises low carbon development

- Supporting the development of a standardised approach to techno-economic appraisal of the viability of LCHNs that can be universally understood by investors and stakeholders, aiding transparency and enabling comparisons between schemes (supporting interessment and promoting standardisation).

As part of this package of support, consideration would also need to be given to the critical question of which agency is best positioned to lead major infrastructure projects such as LCHNs. Acknowledgement of the possibility that, in the UK at least, such initiatives are best led outside of the public sector would, in turn, raise questions over how societal and environmental objectives associated with LCHNs would be upheld.

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