Emergence of district-heating networks; barriers and enablers in the development process

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Abstract— Infrastructure provision business models that promise resource efficiencies and additional benefits, such as job creation, community cohesion and crime reduction exist at sub-national scales. These local business models, however, exist only as isolated cases of good practice and their expansion and wider adoption has been limited in the context of many centralised systems that are currently the norm. In this contribution, we present a conceptual agent based model for analysing the potential for different actors to implement local infrastructure provision business models. The model is based on agents' ability to overcome barriers that occur throughout the development (i.e. feasibility, business case, procurement, and construction), and operation and maintenance of alternative business models. This presents a novel approach insofar as previous models have concentrated on the acceptance of alternative value provision models rather than the emergence of underlying business models. We implement the model for the case study of district heating networks in the UK, which have the potential to significantly contribute to carbon emission reductions, but remain under-developed compared with other European countries.

1. Introduction

Infrastructure systems are vital to enable modern, sustainable societies to prosper. The infrastructure systems that have been developed since the industrial revolution are largely unfit for this purpose. Utility provision infrastructure (i.e. energy, water, transport and waste removal), in particular, is characterised by carbon intensive generation and supply for unconstrained and unsustainable levels of demand[1]. The transition to environmental, social and economically sustainable infrastructure systems requires a fundamental transformation of both the physical infrastructure and the business models operating it, in the context of enabling governance regimes[2].

Alternative business models exist that operate more resource efficient physical infrastructure and are capable of creating and capturing wider forms of social and environmental value. These, however, exist only as isolated 'niche' examples of good practice and are far from becoming mainstream. In this contribution, we present a modelling framework to study the barriers facing the mainstreaming of these types of business models and the attributes of actors and policy interventions that can enable them. Our model framework concentrates on the actors involved in an infrastructure business model throughout project development and operation, both embedded in the broader socio-technical context. This builds on previous work that studied the barriers to MUSCos (Multi-utility service company) business models[1,3] and local authority energy planning[4,5].

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[1] Roelich, K. *et al.* Towards resource-efficient and service-oriented integrated infrastructure operation. *(submitted)*.
[2] Geels, F. W. The dynamics of transitions in socio-technical systems: A multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930). *Technol. Anal. Strateg. Manag.* **17,** 445–476 (2005).
[3] Knoeri, C., Steinberger, J. K. & Roelich, K. End-user centred infrastructure operation: Towards integrated infrastructure service delivery. *(submitted)*

A socio-technical modelling approach brings a number of advantages and insights. First, it forces the clarification of an interdisciplinary system representation that includes physical infrastructure, actor behaviour and their interactions, and the relevant policy environment. Second, it goes beyond standard economic assumptions of rational choice and a demand-driven market to capture complex behaviours and interactions between agents across both the demand side and the system of provision. Finally, a socio-technical model allows us to explore the emergence of different systemic patterns of behaviour under varying policy regimes. Agent-based modelling (ABM) is able to capture such complex interactions between policy interventions, social and technical structure, and individual behaviour[6,7]. While agent-based models of social systems abound, only recently, work has emerged to simulate the long-term development of infrastructure and other socio-technical systems[8,9,10,11]. In this contribution we describe the insights gained from developing an agent-based socio-technical model specification for analysing the emergence of alternative infrastructure operation business models, exemplified by the roll-out of district heating networks in the UK.

District Heating in the UK

District heating networks have the potential to significantly improve the energy efficiency and carbon intensity of heat and hot water supply to domestic and commercial buildings[12], particularly where heat can be sourced from combined heat and power (CHP) generators. Although this potential is recognised by the UK government, progress in achieving this potential is still very slow. The UK has very low penetration of heat networks with only around 1% of the population getting heat from a district heat network[13]. This is much lower than most European countries where some, including Denmark, Poland and Estonia, have more than 60% of the populations heat supply provided by district heating[13].

The barriers to a larger roll-out of district heating networks in the UK have already been identified in a number of studies[4,14,15,16]. In some of these studies, the barriers are also linked to the type of actors and where in the development process they occur. A full listing of the barriers we have collated is beyond the scope of this paper, but they generally fall into one of five categories:

financing and risk	e.g. access to development finance and willingness to hold debt
knowledge and data	e.g. a motivated and knowledgeable individual within the instigating organisation
relationships	e.g. access to an appropriate network of partners

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4 Bale, C. S. E., Foxon, T. J., Hannon, M. J. & Gale, W. F. Strategic energy planning within local authorities in the UK: A study of the city of Leeds. *Energy Policy* **48,** 242–251 (2012).
5 Knoeri, C., Goetz, A. & Binder, C. R. Generic bottom-up building-energy models for developing regional energy transition scenarios. in *9th Conf. Eur. Soc. Simul. Assoc.* (2014).
6 Grimm, V. & Railsback, S. F. *Individual-based Modeling and Ecology*. (Princeton University Press, 2005).
7 Janssen, M. A. & Ostrom, E. Governing socio-ecological systems in *Handbook of Computational Economics II: agent-based computational Economics* (eds. Tesfatsion, L. & Judd, K. L.) (Elsevier, 2005).
8 Van Dam, K. H., Nikolic, I. & Lukszo, Z. *Agent-Based Modelling of Socio-Technical Systems*. (Springer, 2013).
9 Bergman, N. *et al.* Modelling Socio-Technical Transition Patterns and Pathways. *J. Artif. Soc. Soc. Simul.* **11,** (2008).
10 Kempener, R., Beck, J. & Petrie, J. Design and Analysis of Bioenergy Networks. *J. Ind. Ecol.* **13,** 284–305 (2009).
11 Knoeri, C., Nikolić, I., Althaus, H.-J. & Binder, C. R. Enhancing Recycling of Construction Materials; an Agent Based Model with Empirically Based Decision Parameters. *(submitted)*
12 Department of Energy & Climate Change. *The Future of Heating: Meeting the challenge*. (2013).
13 Euroheat. *District Heating and Cooling Statistics*. (2009).
14 Department of Energy & Climate change. Research into barriers to deployment of district heating networks. (2013).
15 Hawkey, D., Webb, J. & Winskel, M. Organisation and governance of urban energy systems: district heating and cooling in the UK. *J. Clean. Prod.* **50,** 22–31 (2013).
16 Poyry & Faber Maunsell. The Potential and Costs of District Heating Networks: A report to the Department of Energy and Climate Change. (2009).

legal capabilities	e.g. drawing up contracts and meeting requirements of a supply licence
market and regulation	e.g. access to a guaranteed heat demand over the lifespan of the scheme

The growth of district heating in the UK can happen either through the development of entirely new networks, or the expansion of already existing ones. The development of new networks is often linked to the development of new housing or commercial buildings, but can also be part of a retrofitting process for old housing stock. In either case, the process of developing a district heating network depends on both the agents decision making and housing stock dynamics. Drawing on policy and guidance documents[14,17,18] we separate the process into three broad phases: feasibility study and business case development, procurement and construction, and operation and maintenance. We use these phases and the barriers described above as the basis of an agent based model specification, which is described in the following section.

AGENT-BASED Socio-Technical Model

According to DECC statistics[12], there are around 2,000 individual district heating networks in the UK supplying 210,000 dwellings and 1,700 commercial and public buildings. Heat networks can be categorised into three types: large campus based schemes serving universities or hospitals; private sector developments including commercial and housing schemes; and 'public' schemes that serve social housing and may include connections to public buildings such as schools or swimming pools. In some cases, for example the Byker estate[19], social housing heat networks are taken over by community organisations. We hence include three types of instigators and operators of district heating networks: community organisations, local authorities and commercial developers.

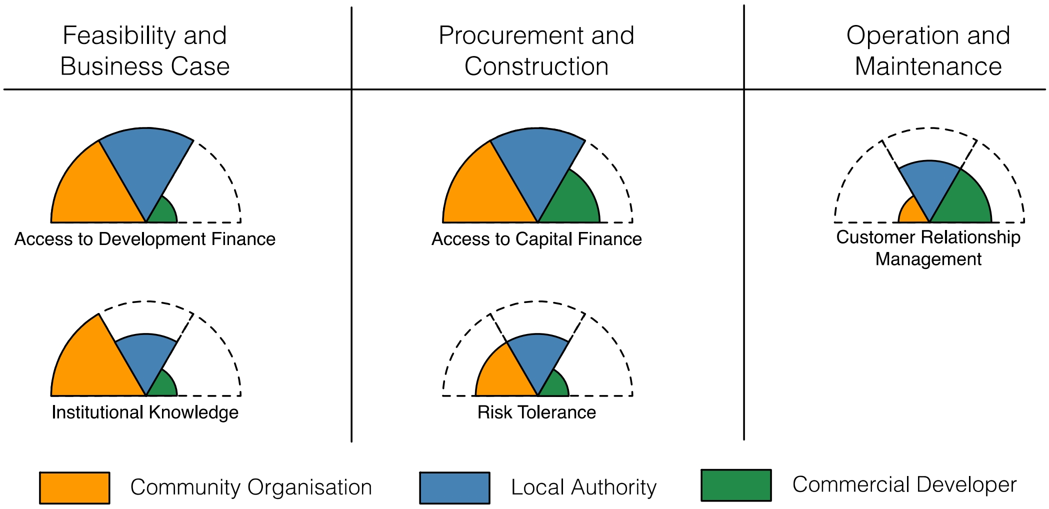

Figure 1: A subset of barriers faced in the three phases of the development and operation of district heating networks with a preliminary estimate of the severity of each for the three different types of actors indicated by the size of the coloured wedge (small = low severity, large = high severity).

[17] King, M. & Shaw, R. Community Energy: Planning, Development and Delivery. (2010).
[18] Ove Arup & Partners Ltd. *Decentralised Energy Masterplanning A manual for local authorities*. (2011).
[19] Byker Community Trust. *CORPORATE PLAN 2012-2015*. (2012).

Figure 1 shows a small subset of relevant barriers faced by these actors in the phase of the process they are encountered and a preliminary estimate of the severity of the barrier for the different type of actor. The severity estimates are based on the study into barriers to district heating commissioned by DECC[14], with some additional assumptions for community organisations. Future work will carry out a comprehensive analysis of all the identified barriers with severity estimates derived from case study interviews. At this stage already, however, it is clear that there are significant differences in the barriers faced by communities and local authorities on the one hand and commercial developers on the other.

Based on the above description of actors, barriers and processes we have developed a conceptual socio-technical model. The purpose of this model is to analyse the most significant barriers preventing the emergence of district heating networks in the UK, and where policy interventions can have an impact in removing these barriers.

Modelled entities: The model includes three basic types of agents: instigators who seek to develop a heat network; heat demand agents; and heat source agents. The instigators are the community organisations, local authorities and commercial developers discussed in the previous section. Heat demand agents are further classified into private housing (including owner-occupied and private rented), social housing (both local authority owned and other social housing providers), public (for example swimming pools, schools, hospitals and council offices) and commercial. Heat source agents represent existing sources of waste heat that can be integrated with a district heating network, in practice the only relevant heat sources likely to be integrated are large incinerators.

Key processes: The model procedure runs on the back of a bottom-up building stock model, which includes demolitions, construction and refurbishment processes[11]. Two drivers can start the process for developing a district heat network: the initiation of a new housing or commercial development, or the decision by a housing operator to refurbish housing and install a district heating network. In either case, if a heat network already exists in close proximity, expansion will be considered. Once started, the development and operation process proceeds through the actions of the relevant instigator and interactions with other agents. The instigator actors possess a set of attributes that determines their likelihood of successfully completing the actions they must take throughout the development process. These attributes are derived from the barriers they face where a high severity barrier translates into an attribute having a high chance of falling short. In the initial implementation of the model we include only a small number of attributes, namely those shown in Figure 1, as these where previously identified as the most common and severe[14].

Model development: Starting with a very simple model will allow us to test the explanatory power of the variables we have chosen to include and then incrementally add further variables to determine their impact. Policy interventions are included in the model through the ability to change key variables used in conjunction with attributes: for example the availability of development finance and capital finance and the availability of guidance and support to ease development planning. Development will be informed through both case study interviews and workshops to elicit stakeholder validation of the model structure and outputs.

Conclusions and Further Work

The development of the model specification described above has brought useful insights into the relationship between the barriers to district heating network development and the attributes of different types of actors involved in this process. The approach of developing a socio-technical model of district heating has highlighted that the key drivers are intimately related to both the dynamics of the built environment stock and the motivations of a number of key actors that include local authorities, commercial developers and potentially community organisations (although these are still rare cases).

A further important methodological improvement is in the separation of barriers and actor attributes. By assigning attributes to different actors to represent their ability to overcome the barriers they face in the development process, it becomes clear that the relevance of barriers is likely to vary widely between different types of organisations, scale and scope of the projects. This observation leads to an issue that we intend to investigate with an extended model – how different forms of value creation and capture can be enabled by policy intervention. Different organisation, by virtue of their purpose, motivations and geographical extent are capable of generating different kinds of social and environmental value, as well as economic value at different scales. Local authorities are motivated by fuel poverty reduction, community groups may seek to create community cohesion and both may create jobs locally more than a national scale commercial developer. Policy interventions that enable one type of actor more than others will consequently favour the creation of a different set of values.

The model development we have presented here is based on a highly interdisciplinary research approach that integrates technical infrastructure and building stock models with agents that make decisions based not only on economic considerations but also based on their capabilities. This interdisciplinary approach is crucial in studying infrastructure systems, which, due to their scale and key role in providing societies needs, are tightly regulated, difficult to finance and capable of causing enormous environmental damage. The agent-based modelling approach also allows us to connect the micro-level analysis of barriers and actions to the wider governance regime. Barriers at the micro-scale are often a manifestation of a meso- and macro-scale policy regime and landscape that favours the incumbents. A socio-technical model can connect changes to the policy regimes back to the micro-level of actors implementing alternative infrastructure business models.