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Low carbon infrastructure investment: extending business models for sustainability

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Abstract

Investment in infrastructure is recognized as a key enabler of economic prosperity, but it is also important for addressing social and environmental challenges, including climate change mitigation and addressing fuel poverty. The UK Government Strategy Investing in Britain's Future argues that significant investment in "resilient, cost effective and sustainable energy supplies" is needed to meet these challenges. However, current methods of assessing the costs and benefits of infrastructure investment, and the subsequent design of business models needed to deliver this investment, often prioritise partial economic gains over social and environmental objectives. This paper extends the business model canvas approach to allow designing business models and evaluation methods that can incorporate social and environmental value streams and propositions as well as economic values in order to facilitate genuinely sustainable infrastructure investment. It demonstrates the usefulness of this extension through two case studies of the development of smart grids for electricity distribution and local heat delivery networks in the UK. Smart grids are essential for maintaining the security and reliability of electricity systems whilst incorporating increasing amounts of low carbon generation in distribution networks. District heat networks can facilitate the efficient supply of low carbon heat. However, both will require significant levels of investment, co-ordination between public, private and regulatory actors, and will deliver a range of economic, social and environmental costs and benefits to these actors. Drawing on empirical interviews with local actors involved in smart grid and heat network developments, and recent work on valuation and business model canvas analysis, the paper challenges the traditional view of a business model as only creating one form of value. Accounting for multiple types of value helps to identify business models that are more likely to achieve the environmental and social goals of infrastructure transformation and opens the door for new actors. Finally, the paper introduces an approach to complex systems modelling of infrastructure investment decisions to take into account the range of actors and the diversity of motivations of these actors.

Keywords: Valuation; Business models; Low carbon; Sustainability; Smart grids; Heat networks; Complex systems

Background

Infrastructure systems consist of physical and social networks that mediate between physical resource flows and the provision of useful services to households and businesses. The dynamic, multi-agent, multi-level and multi-objective nature of these systems gives rise to complexity (Herder et al., 2008). Investment in infrastructure has been recognized by governments as a key enabler of economic prosperity, and understanding the links between infrastructure systems and economic prosperity is an important research priority. However, infrastructure investment is also important for addressing social and environmental aims, including climate change mitigation and addressing fuel poverty. This raises challenges for current methods of assessing the costs and benefits of infrastructure investment, and the subsequent design of business models needed to deliver this investment, which often prioritise partial economic gains over social and environmental objectives. This paper extends the business model canvas approach to allow designing business models and evaluation methods that incorporate social and environmental value streams and propositions as well as economic values.

The paper explores questions of value creation and appropriation, and formulation of appropriate business models, by drawing on case studies of the development of smart grids for electricity distribution and local heat

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delivery networks in the UK, being undertaken as part of the EPSRC/ESRC iBUILD: Infrastructure business models, valuation and innovation for local delivery consortium (iBUILD, n.d). The UK provides an interesting context for this analysis as the UK Government now produces an annual National Infrastructure Plan (HM Treasury, 2014), which aims to co-ordinate and drive forward infrastructure investment. This recognises the need to consider cross-sectoral interdependencies, for example between energy, water, transport and waste management systems, and strongly emphasises the role of infrastructure in achieving economic goals: "High-quality infrastructure boosts productivity and competitiveness, allowing businesses to grow and enabling them to reach suppliers, deepen labour and product markets, collaborate and innovate and attract inward investment" (HM Treasury, 2014, Executive Summary). However there is less recognition of the interdependencies between economic, social and environmental goals.

The dynamic, systemic and partial public good characteristics of infrastructure pose a significant challenge for standard economic valuation and assessment approaches, such as cost-benefit analysis, since these characteristics are inconsistent with assumptions of fixed, individual preferences underlying standard approaches (Brown et al., 2014). This challenge is amplified when the objective of infrastructure investment is not only to contribute to private economic gain, but also to contribute to social and environment aims, such as addressing fuel poverty and mitigating climate change. The iBUILD research focuses on addressing this challenge at the local delivery level, particularly the role of cities and city-regions, by analysing the potential for innovative valuation approaches and business models for infrastructure delivery. These should aim to create and capture value for local communities, including job creation, social cohesion and a clean environment. This requires attention to more efficient delivery of the services such as warmth, lighting, power and mobility that people and businesses want, rather than just units of gas, water or electricity (Roelich et al., 2015).

The UK is committed under the Climate Change Act 2008 to reduce its carbon emissions by 80 % by 2050, from 1990 levels, with intermediate carbon budgets now in place out to 2027, and an additional target for 15 % of final energy to come from renewable sources by 2020. Whilst policy has largely focused on measures to incentivise large scale centralised power generation from offshore wind and new nuclear build, there is also a significant potential for carbon reductions through more local distributed generation and heat delivery networks (Foxon, 2013). However, current policy measures tend to reinforce the lock-in of current centralised electricity and gas networks, in relation to infrastructures, business strategies and established practices, which creates barriers to the implementation of local low carbon energy systems and more systemic energy efficiency improvements. The economic, social and environmental values that could accrue to local communities, including job creation, enhanced energy security and emissions reductions, are hard to capture under current institutional and regulatory frameworks, and new business models will be needed to facilitate investment in local energy systems and to enable local communities to capture their fair share of these benefits.

This paper discusses the basis for analysing alternative, local business models with social and environmental value streams and illustrates these ideas with examples from the case studies, which are described in greater detail elsewhere. In particular, we draw on the business model canvas approach to specifying business models (Osterwalder and Pigneur, 2010) and analysis of decision-making under uncertainty for investment decisions. These are illustrated by examples from case studies of the development of smart grids for electricity distribution and local heat delivery networks. In both of these cases, investment can help to fulfill multiple economic, social and environmental objectives.

Understanding business models

In order to analyse infrastructure investment, a characterisation of business models of key actors is needed. A business model represents how a business or other organisational form characterises its activities in order to achieve its goals of profit-making or other objectives (Teece, 2010, Zott et al., 2011). The choice of business model will depend on the opportunities that the firm perceives for achieving its objectives in the context of its technological and organisation capabilities, competition from other firms and their business models, and the wider social and institutional context, including user expectations and regulatory incentives.

Recent work has sought to analyse these influences on the adoption of firms' business models for infrastructure investment and delivery of services. The literature on novel business models in the energy sector has been a useful contribution to our understanding of the role of organisational form and value propositions in bringing technological innovations to market maturity (Huijben and Verbong, 2013; San Roman et al. 2011). Yet, to date, it has done little describe how business models create and destroy use values as well as creating and realising exchange value of goods and services. Bolton and Foxon (2013) analysed business models of distributed suppliers of renewable heat and electricity, in the light of changing energy distribution institutions. Giordano and Fulli (2012) propose disruptive technologies such as smart meters and electric vehicles could offer new opportunities for value capture from grid infrastructure, if systemic approaches are applied to understanding new business models and platforms. Hannon et al. (2013) use co-evolutionary analysis to interrogate how utility energy supply business models that rely on selling units of energy (in kWh) are unsuited to delivering energy transitions and highlight the benefits of energy service company (ESCo) business models, which provide end user energy services for fixed fees, capturing value from energy savings. Hannon et al. (2013) characterise the historical path dependency that led to the dominance of the utility model over the ESCo model before outlining an analytical framework to understand the particular contribution ESCos might make to transitions to low carbon energy systems.

Hannon et al. (2013) adopt a particular characterisation of a business model from the business management literature by Osterwalder and Pigneur (2010), referred to as the business model canvas, based on 9 'building blocks' which are putatively relevant to the organisational forms of all private commerce. These building blocks comprise key partners, key activities, key resources, customer value proposition, customer relationships, channels, customer segments, cost structure and revenue stream (Fig. 1).

Infrastructure value: early options and systemic approaches

In conventional economic analysis of commercial investments, the measurement of value is based on the marginal cost efficiency of delivering each unit of product or volume of service. Infrastructure investments differ in that they are often delivered or mediated by the state due to their characteristics as natural monopolies, difficulties of excludability/capturing of spillover benefits and their propensity to impose negative externalities on proximate citizens and ecosystems. This has led to infrastructure investments being assessed using Cost Benefit Analysis, wherein the "golden rule is that all benefits must be quantified" (HM Treasury, 2013 p.51), usually by assigning monetary values to both tradable and non-tradable benefits and costs.

The need to assign prices to benefits and costs that cannot be traded in a marketplace, such as social and environmental externalities, has given rise to methods that try to ascertain the marginal utility loss associated with marginal unit of environmental damage or social harm, for example, through contingent valuation methods or hedonic pricing (Fujiwara and Campbell, 2011; Defra, 2012). There are a number of inherent problems with these approaches including: users' ability to appreciate the systemic benefits, inconsistencies in value attribution, behavioural factors such as loss aversion, and the implied ability to trade-off between economic, social and environmental values (Fujiwara and Campbell, 2011; Dunn, 2012). Furthermore, positive social and environmental externalities, e.g. spillover or co-benefits such as contributions to positive health or welfare outcomes, are also often not valued (Garrod and Willis 1999, Nakamura, 2000). Our concern here is principally with the stage in the process at which these methods can usefully be applied.

In a UK context, best practise for public procurement is defined by the HM Treasury Green Book (HM Treasury, 2011a). The stages in public procurement run from defining strategic need, through options appraisal, option selection and the development of outline and full business cases (HM Treasury, 2011a, 2011b, 2013). The characteristics of the contingent valuation and hedonic pricing methods for assessment of social and environmental values are only functionally applicable once the option selection narrows to characterise specific projects; i.e. they are incapable of providing systemic approaches to

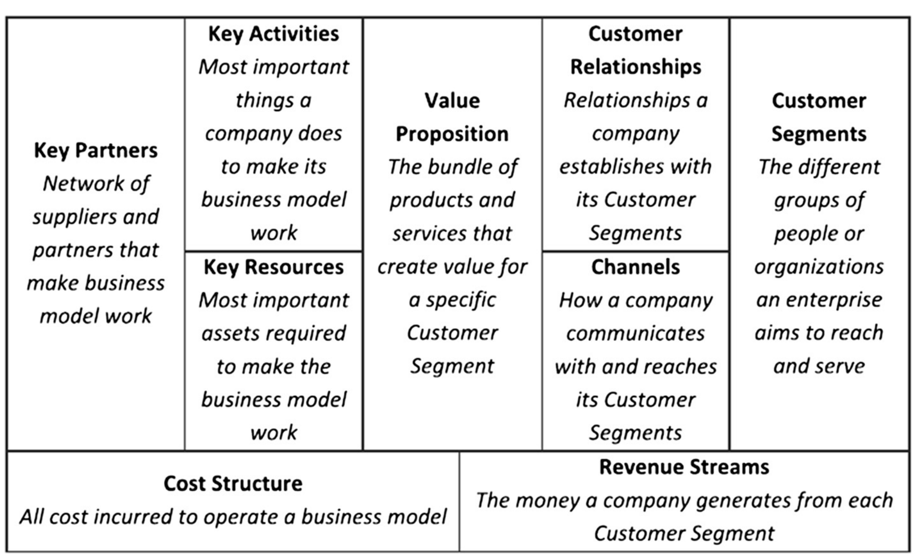

Fig. 1 The nine building blocks of a business model

valuation and cannot be robustly applied during the options appraisal stage.

New approaches to understanding systemic values of different infrastructures in the options appraisal stage are needed. These approaches should enable decision makers to assess a wide range of infrastructural choices, including innovative infrastructure delivery, and assess social and ecological outcomes simultaneously. We argue that more systemic approaches to assessing creation and appropriation of value and alternative business models for infrastructure provision can help to deal with these challenges in appraising options for complex systems. This paper aims to provide steps in the development of this type of approach applied to energy system investments, as this is a complex infrastructural system which includes state and private actors alongside high degrees of infrastructural change and market uncertainty. We argue that social and environmental values need to be explicitly incorporated into decision support tools and potential business models, as attempts to assign monetary values to these at an early stage are likely to lead to loss of information and potentially misleading assessments.

Methods

Energy systems are inherently complex, large socio-technical systems, in that they consist of large number of actors, interacting through networks under changing infrastructures and institutional structures, aiming to provide services including warmth, power and lighting to users (Bale et al., 2015). In industrialised countries such as the UK, these services are largely provided by centralised systems for the generation, transmission and distribution of electricity and the transmission and distribution of gas. In order to achieve a transition to low carbon energy systems, there has been interest in exploring the potential for greater local provision of energy services, through local power generation and heat networks (Foxon, 2013; RTP Engine Room, 2015; Bush et al., 2014). As part of the iBUILD project, the authors undertook case studies of two disruptive energy technologies to examine the range of values that these may create and the potential for alternative business models that actors could apply to appropriate these values. Firstly, smart grids at the local distribution level, which could challenge the dominance of the centralised electricity system model, and, secondly, heat networks that provide an alternative to individual gas central heating, in particular in urban areas where they can offer efficient, low carbon heating services. In each case, we set out to understand the incumbent business models and value capture opportunities in provision of this infrastructure and associated services, and the new ways of capturing/delivering social and environmental values that new business models for infrastructure investment and service delivery could offer, in relation to new disruptive technologies and wider social objectives.

We adopted a purposive sampling technique utilising snowball selection. Interviewees were selected that had specific interests in electricity distribution, heat network development, local economic development, environmental protection or social justice. For the smart grid case study, we undertook 3 focus groups and 10 interviews with 17 individuals from across the electricity generation, distribution and regulation sector, alongside municipal stakeholders drawn from across the UK. This included 2 regulatory professionals, 2 project developers, 5 municipal officers, and 8 distribution network or smart metering professionals (Hall and Foxon, 2014). For the district heating case study, qualitative data was collected through a series of eleven semi-structured interviews with key stakeholders including four from local authorities, one local enterprise partnership, two from central government, two industry representatives (2), one network operator and one housing association in the UK. Interviewees were selected based upon the extent of the organisations' activities in district heating development, and through recommendations from experts in the field. Further details of this work can be found in Bush et al. (2014).

Interviews and focus groups were undertaken both face to face and over the telephone. Interview transcripts were analysed using NVivo. Additional information was gathered from policy documents and government reports to support analysis of the interviews.

Results and discussion

We begin by describing the case of smart grids, showing how financing and value capture opportunities change when the values that smart grids confer on municipalities are integrated into the smart grid investment problem. Secondly, we describe the multiple values inherent in the case of heat network investment and the challenge of incorporating these into business models. We then discuss how these cases demonstrate the need for broadening the elements of a business model for application to infrastructure, and how this extended business model canvas can be used to define sustainable value capture opportunities when appraising infrastructural needs. Finally, we introduce the type of complex systems modelling that we are undertaking to represent these value creation and appropriation processes.

Smart Grid investments

If the national grid is the motorway of the electricity transmission system, then the distribution grids are the regional A roads and B roads of the system. These regional distribution networks are managed and operated as regulated monopolies in the UK by Distribution Network Operators or 'DNOs'. There are 14 regional distribution networks in Great Britain, currently operated by six DNOs. The national grid is already 'smart', in that it is designed to be able to instantaneously manage electricity supply in order to match fluctuations in demand. However, the distribution grids are currently predominantly 'dumb' in that they enable very little intelligence to be gathered remotely and very little grid management beyond on/off states. There are particular hard engineering additions, ICT upgrades, business model innovations and institutional changes that enable a DNO grid to become 'smart' (Anaya and Pollitt, 2013; Giordano et al., 2013). The benefits of adopting the necessary elements of a smart grid are: being able to reduce peak loads, enable more low carbon and distributed generation, reducing the cost of maintaining the system, better use of existing generation assets and reduced 'downtime' in the form of brownouts or blackouts (Jackson, 2011, Xenias et al. 2014). Relatively 'smart' grids can exist without distributed generation but truly smart grids incorporate distributed low carbon generation. As well as traditional financial returns, investing in smart grids and distributed generation can contribute to economic development benefits; social redistribution through municipal revenue generation; and reduce emissions from the energy system through faster and cheaper connection of renewable generation technologies (Hall and Foxon, 2014).

Traditional value capture from electricity distribution networks

After the privatisation of the UK's energy system, the state ensured distribution infrastructure was maintained and renewed by adopting a regulated asset base approach. This meant that the energy regulator Ofgem would set a regulatory framework under which only certain types of investment would give rise to allowable revenues for distribution network operators. These included system maintenance, direct asset renewal and expansion to incorporate new loads (i.e. new industry, commerce, housing or energy generating assets), but other investments to enhance the capabilities of the system were not encouraged. The regulatory framework was known as the 'RPI-X' formula and was the mechanism used under the distribution price control reviews (DPCRs) to set allowable revenues for the Distribution Network Operators (DNOs). The DPCRs ran for five years each-at the time of writing the network remains under the DPCR 5 period (2010–2015), the last to use 'RPI-X' mechanism (Ofgem, 2010). Together with separately calculated service incentives, this represents the revenue structure of the UK's regulated distribution network business model. Due to new duties placed on Ofgem, particularly to take account of climate change targets, energy security and social objectives (Balta-Ozkan et al. 2014), the RPI-X mechanism has been recognised as unfit for purpose. In particular, a need was identified to create an institutional regulatory framework that would provide greater incentives for investment in local renewable generation technologies and expansion of other technologies with environmental benefits, such as electric vehicles and energy storage. To this end, RPI-X is now being replaced by the RIIO framework, starting from 2016 (Ofgem, 2010; Müller 2011). The RIIO (Revenue = Incentives + Innovation + Outputs) framework is a significant shift towards an allowable revenues structure that better incentivises smart grid solutions. Space constrains a detailed assessment of the RIIO incentives (see Balta-Ozkan et al., 2014; Müller, 2011; Ofgem, 2010). What is important to our analysis is whether or not the new price control framework will provide sufficient revenues for DNOs to deliver the necessary volume of smart grid infrastructure to underpin the decarbonisation of the electricity and transport sectors.

The industry and municipal stakeholders interviewed reported that there was significant uncertainty as to whether the new revenue structure would be sufficiently transformative to deliver smart grid infrastructure. DNO representatives, in particular, were clear that delivering smart grid solutions meant working in new partnerships with new stakeholders, and that developing the business models to facilitate this may be challenging:

> "It's not the technology and the smart grid stuff because that's … I refrain from saying easy but that's sort of a known quantity, we know how to do that, it's the business models and the contractual relationships between people that throw up the shaky ground I think; to work within the regulatory framework to make a business model that is going to work and make everyone happy" (DNO Respondent, 2014)

Identifying alternative values using a business model approach

Local municipal authorities were identified as a new potential partner for DNOs in smart grid development, based on recent calls for more municipal participation in electricity distribution infrastructure both nationally and internationally (Core Cities, 2013; Fei and Rinehart, 2014). Our empirical analysis and findings are detailed in Hall and Foxon (2014), but can be summarised into three relevant categories for this analysis.

Firstly, DNOs currently offer connection agreements to renewable energy generators based on a first come first served basis. When there is capacity within existing infrastructure to accommodate the electrical load, a renewable scheme can be placed on the network, and connection charges are relatively inexpensive as a proportion of the capital cost of the project. When several developers are looking to connect capacity within a specific geographic area (e.g. somewhere with high wind resource), however, the cost of reinforcement falls on the developer unlucky enough to apply for connection once the local network is at capacity. Innovative connection agreements with multiple developers and associated technical solutions to this problem are emerging, but DNOs find it difficult to co-ordinate developers due to issues of commercial data sensitivity and regulatory structures. DNO representatives identified a need for a scheme aggregator who could play this co-ordination role, in order to increase connections in high demand areas. We suggest that municipalities, with their spatial planning function, provide a natural home for this role. Further, if, as the UK government is proposing for fracking operations, business rates from new renewables installations can be recycled to the municipality, a sensible economic solution could be reached for developer co-ordination that could benefit all parties.

Secondly, we identified several cases in which municipalities had designated economic development zones where new commercial activity planned, but for which electricity grid constraints meant infrastructure costs would be prohibitive for relocating firms. In these cases, respondents were investigating the possibility of using economic development funds and innovative tax structures to subsidise smart grid solutions that would reduce the need for conventional reinforcement. This would make firm relocation far more likely and unlock land for development that was hitherto constrained by electricity distribution infrastructure.

Thirdly, we found that the way the smart meter rollout in the UK has been undertaken is hindering demand side response (DSR) functions, a key component of the smart grid. When DNOs have access to smart meters homes or businesses, they can offer financial incentives for consumers to allow them to remotely control non-essential load (such as freezers, chillers and storage heating) at periods when demand peaks threaten system integrity. Facilitating this type of demand response is a recognised option for prudent infrastructure spending (HM Treasury, 2013). However, as electricity suppliers (who sell energy but have no role in distribution system management) have been given the responsibility for installing smart meters in domestic and commercial properties in the UK, this provides little incentive for facilitating demand response options for grid management. If municipal supply companies were able to sign up bundles of geographically concentrated load, they could act as an aggregator, offering load control to the local DNO. This would provide the benefit to the DNO of avoiding expensive conventional grid reinforcement.

However, in order to be able to capture these type of system-wide benefits of smart grid investments, new types of business models involving partnerships between DNOs and municipal and other stakeholders are needed, and institutional regulatory frameworks such as RIIO need to be designed to enable these business models to generate returns for all the actors involved.

Thus, municipalities in partnership with DNOs were investigating infrastructure business models that were able to incorporate more renewables in high demand areas, incentivise economic development, and offer smart grid services that would otherwise be absent in the UK. In so doing, environmental values can be secured in the proliferation of renewable energy technologies and the advancement of smart grid systems.

Heat network investments

Heat networks (sometimes referred to as district heating) provide an alternative to individual household or commercial property gas or electric heating. Heat networks are an infrastructure technology made up of a series of highly insulated pipes that transport heat from a heat source to a heat demand using hot water or steam. Use of the technology creates flexibility to the source of heat, enabling use of local, low carbon resources, such as waste heat from industrial processes or waste incinerators, or locally sourced biomass. Alternatively, the network can be linked up to a purpose built heat source, from a dedicated gas or biomass boiler or as part of a combined heat and power (CHP) plant. The majority of existing UK heat networks use gas-fired CHP which can reach in excess of 80 % efficiency by generating both electricity and heat outputs (BRE et al., 2013). As a result, these systems can be more energy efficient than conventional building-level gas or electric heating systems and therefore offer reduced carbon emissions and potential fuel bill savings.

The viability of a heat network depends upon a number of local and physical factors. These include the length of the network pipes required for transporting the heat, the choice of heat generation technology, the costs of any fuels used, and the heat demand profile of the buildings that it is supplying. Actors' perception of risk is also a critical factor in determining whether a network is successfully developed. These systems require a high capital investment to procure and install the infrastructure to transport the heat. This is particularly costly in retrofit situations where existing infrastructures such as roads must be dug up to install the network pipes alongside other utilities. However, over the lifetime of their operation, which can span over 40 years, they can offer multiple benefits including significant cost reductions compared to individual building heating systems, both by allowing use of cheaper or more efficient heat sources, and by lowering the cost of maintenance (Davies and Woods, 2009). This means that actors must choose to make a high upfront investment in order to realise the potential long-term benefits offered by the technology. Networks are therefore often developed in phases so as to reduce the financial risk to developers in terms of upfront capital investment and establishing a customer base (Davies and Woods, 2009, Hawkey et al., 2013).

Barriers to value capture for heat network infrastructure

The current paradigm in the UK energy system is a challenging environment for the development of suitable business models to deploy heat networks at the local level, with largely centralised heat provision through national gas and electricity networks owned and operated by private companies. Penetration of the technology in the UK is still relatively low (2 % versus a suggested potential of 14 % (DECC, 2013)) despite the strong political interest in the potential. The UK government heat plan (DECC, 2013) suggests that the UK could achieve between 7 and 20 % of heat from district heating by 2050, while the Energy Technologies Institute estimate that a proportion as high as 43 % of the current British building heat market could be economically connected to large scale district energy schemes (Energy Technologies Institute, 2013). However, this will require new activity and involvement from actors at the local level. Local municipal authorities are seen to have an important facilitation role as well as, potentially, a delivery role in new projects.

DECC commissioned a study that identified a number of barriers to the deployment of heat networks from the perspective of local authorities (BRE et al., 2013). Local authorities are taking on the role of coordinating the range of local actors and interests who need to cooperate to allow the creation of a feasible business case upon which to base the upfront investment and offer some long term certainty of heat sales. However, local authorities have not traditionally been involved in energy system development and in the context of recent cuts to local authority budgets and staffing levels they face constraints in terms of knowledge, experience, and staff time (Bale et al., 2012). Financial resources are also limited for procuring feasibility studies and other consultancy services, legal advice, and the significant upfront capital costs of networks (BRE et al., 2013). Despite these barriers, the involvement of local authorities, with their wide ranging local responsibilities such as social housing provision, and commitments to wider social concerns such as fuel poverty reduction and carbon reduction, means that the viability of heat network development is assessed based on a wider set of drivers and responsibilities than financial profit (as discussed in more detail in the next section). The identification of appropriate business models is critical to ensuring successful investments which allow the complex value of these opportunities to be captured.

Identifying alternative values using a business model approach

At present, discussion of viability for a heat network is often dominated by a project's potential for functioning under a business model aiming to maximise financial profitability. Techno-economic assessment methods are used in initial pre-feasibility studies. Current methods are predicated on modelled heat-density data based upon today's heat loads. For example, the National Heat Map (DECC, 2012) developed by the Department for Energy and Climate Change in the UK, displays modelled or actual heat demand data at a postcode resolution. It offers an initial view of whether heat networks might be technically feasible and whether it would be likely to offer a financial return on investment. For business models seeking to achieve the maximum return for investors, this is an appropriate approach, but it also potentially misses wider opportunities that exist through development of a project. For example, in areas where there are a high proportion of households in fuel poverty, it could underestimate the potential for a heat network. In these areas, a lower price supply of heat is likely to see significant increases in heat demand.

Local authorities are often seeking to achieve wider objectives with heat network development. For example, many local authorities see heat networks as bringing benefits for tackling fuel poverty and this is often cited as a key motivation for developing schemes. Recently, the Scottish Government (CHPA, 2014) and Hull City Council (Yorkshire Post, 2013) have both announced the development of heat networks to support fuel poverty reduction. In support of this observation, by analysing interviews with four local authorities and a local enterprise partnership, and noting the mention of motivations for developing district heating projects, the following social, environmental and economic drivers were identified.

Social drivers were identified as a primary reason for development of heat networks by local authorities; in particular for regenerating housing stock and mitigating fuel poverty. The second most frequently mentioned motivation was factors related to environmental drivers, mainly reducing carbon emissions. Interviewees saw the potential of widespread, interconnected development of heat networks across towns and cities, as opposed to isolated islands of smaller schemes, for achieving maximum emissions reductions. Economic drivers were also considered an important co-benefit, and while clearly necessary, they were not the primary driving force behind scheme development. Motivations such as contributing to regional competitiveness, e.g. attracting industries wanting low-carbon heat and electricity and contributing to local economic growth through job creation were cited.

This analysis highlights the range of values that are being sought by local authorities as new actors in the energy market, that go beyond the aim of economic value capture (Bale and Bush, 2014, Bush et al., 2014). However, the high perception of risk associated with heat networks means that energy officers in local authorities often need to demonstrate and persuade decision makers not only of the economic viability of a scheme, but also the wider value that it would be bringing to the local area. The choice of business models used to develop and operate new schemes is critical for enabling successful delivery of news schemes and realisation of this range of values.

Building new values into heat infrastructure business models

Increased uptake of business models that facilitate capture of value beyond the economic will require changes in the way business cases are developed and in the way infrastructure is valued at the local level. We highlight two key aspects of the use of valuation in current business case development for heat networks that could be altered: heat demand mapping tools, and appraisal and evaluation of infrastructure (related to The Green Book (HM Treasury, 2011a)).

Current modelling tools use heat demand mapping as their basis, such as the DECC Heat Map (DECC, 2012). However, an issue arises from the use of estimated heat demand as the main criteria for assessing feasible heat network sites. It is particularly difficult to assess heat demand for households in fuel poverty who may use less heat than they require for a healthy living standard. Fuel-poor households, often have lower heat demand per m^2 floor space than non-fuel poor households. This, therefore, makes them a less attractive area for profit-driven providers to invest in a heat network (Bush and Bale, 2014b). For those local authorities seeking to develop district heating as a means of reducing fuel poverty, heat mapping tools may overlook schemes with potential to address fuel poverty.

Authors Bush and Bale have developed the Leeds Heat Planning Tool (Bush and Bale, 2014a, Bush et al., 2014) which aims to offer energy planners a quick and simple way to include social factors right from the early stages of heat network planning; offering an additional evidence base to support business cases for potential schemes and to open up discussions with stakeholders. This is a step towards valuing social considerations, aligning with the motivations stated by local authorities, and facilitating further involvement in the development of a heat network.

In addition to heat mapping tools, there are some more general recommendations to be made regarding valuing heat network infrastructure. Real option valuation (Dixit and Pindyck, 1995) is needed so that, for example, oversized pipes can be laid, in the case that the scheme is later expanded to incorporate additional heat sources and demand. Flexible design allows for new development to come online at a later date. Furthermore, additional planning policy measures can ensure this passive provision is used in the future (Bale et al., 2014a). For example, local authorities can use their influence through planning to require that connections to an existing heat network are made where possible. Alternatively, in the absence of a network, planners can require that facilities such as waste incinerators are made 'ready to connect' in the case that a heat network is developed.

This case shows that non-market actors, such as local authorities, can have a more diverse and long-term understanding of the value that infrastructure can deliver for social and environmental benefits, as well as economic benefits. Support tools for developing and assessing business models for use by new energy system actors such as local authorities need to move towards a more complex understanding of value that links social, environmental and economic benefits.

New business model development incorporating social and environmental values

These analyses show the utility of adopting a business model approach to early options appraisal for infrastructure systems. This framework for analysis has, in both cases, identified new revenue streams and value capture opportunities by taking a systemic perspective early on in the definition of infrastructural need. We now turn to the question of how the building blocks approach within Osterwalder and Pigneur's original canvas can be adapted to fit with the particularities of infrastructure provision.

Relating these findings to the business model canvas represented in Fig. 1, it is apparent that the value proposition and revenue streams need to be broadened in order to enable new business models to be represented for smart grid and heat network investments incorporating wider social and environmental benefits to new actors and society. In particular, our analysis has identified new revenue streams for a specific infrastructural need, and identified new partnership-based business models that could deliver real environmental and social benefits.

Our empirical work demonstrated the limitations of the existing 'business model canvas' framework due to its inability to fully capture value concepts beyond consumption and revenue exchanges. Using our empirical data, and the theoretical insights below, we are proposing an extended version of the business model canvas for application to infrastructure business models that defines opportunities to capture social and environmental value. We further propose this could be used as a tool to compare options in the early stages of infrastructure procurement, enabling social and environmental value to be considered much earlier in the procurement process.

The particularities of infrastructure business models

By their nature, infrastructure systems exhibit a number of traits which set them apart from other goods and services that can be delivered within the business model canvas approach. The exclusion of 'infrastructure' from traditional private provision (as captured by the canvas) was historically based on the broad consensus, which held until the 1970's in developed western contexts, that infrastructure networks required high degrees of state involvement, especially in the early stages. This was due to three particular features identified by Graham and Marvin (2001) and Chan et al. (2009):

- Infrastructure networks are often managed as natural monopolies; this is due to high capital requirements for entry as a direct investor and infrastructure's geographic fixity, meaning consumers must either move geographically in order to access alternatives, or quasi-market structures must be created by some level of the state.
- It is very difficult to capture spillover benefits in traditional ways and prevent free riding, leading collective provision to be undersupplied by individual companies.
- Externalities can occur from the operation or construction of infrastructure (traffic fumes, sulphur dioxide from power stations, effluent from sewage treatment) that are equally difficult to price or directly compensate.

Each of these three traits presages a closer mediation of infrastructures by the state than in other sectors.

Utilising these understandings for infrastructure alongside our empirical data, we can extend the business model canvas approach. The value proposition within the business model canvas is inherently more complex for infrastructure than in the current formation (Fig. 1). The business model canvas can be usefully extended to characterise the elements that make up an infrastructural business model. This may be defined as "the system of physical artefacts, agents, inputs, activities and outcomes that aim to create, deliver and capture economic, social and environmental values over the whole infrastructure life cycle" (Bryson et al., 2014, p.7).

Since the conditions above alter the value proposition and value capture possibilities, we propose that for infrastructure, the value proposition (Fig. 1) needs to incorporate the direct values from infrastructure use, as well as the indirect values infrastructure can realise. The above case studies have shown that infrastructure in the energy system has the potential to contribute to social goals, economic development objectives and environmental protection. Thus, we propose that the central component of the business model canvas, i.e. the 'value proposition' building block could be split into four sections for infrastructure investments. These four value 'propositions' are: direct consumption value, economic development value, ecological value and social value (Fig. 2). This also affects the 'revenue stream' component of Fig. 1, as this new appreciation of values requires an understanding of how these values are captured. We thus extend the 'revenue stream' building block to a 'value capture' building block and include fiscal, economic development, social and ecological value capture.

An example of social value capture is how this framing would enable the deployment of general taxation to deliver heat network infrastructure where the value proposition is 'alleviation of fuel poverty' but the customer base is unable to provide sufficient 'fiscal revenue stream' to repay the initial capital investment needs, and where the infrastructure is fixed (a CHP plant in social housing) but the customer base (tenants) are mobile.

The 'revenue stream' component of the business model still includes traditional revenues, but needs to be extended to include broader fiscal value capture. By broadening revenue out as a category, this can be used to compare fiscal flows within infrastructure provision more systemically. For example the achievement of demand side response through a municipal smart meter could reduce consumer bills as well as reduce the need for grid reinforcement. The consumer bill reduction is a fiscal flow but not a direct revenue to the DNO. Thus, we extend 'revenue stream' to 'fiscal value stream', which can include traditional revenues such as user charges, but can also capture the non-cash values outlined in the value proposition.

For ecological value capture, the example of a city investing in a smart grid system not only enables the distribution network operator to capture value from capital expenditure avoided and maintenance savings, but also helps to proliferate renewable energy schemes in the area by offering innovative and economically attractive connection regimes. For economic development value capture, the integration of smart grid systems onto historically constrained sites can materially increase both employment opportunities in the area and tax capture from growing businesses.

Complex system modelling for energy infrastructure investment decisions

The case studies analysed in support of this article have identified the potential for new actors, including local authorities, to engage in infrastructure delivery and operation. Furthermore, it has highlighted the broad range of motivations for this engagement, which target very

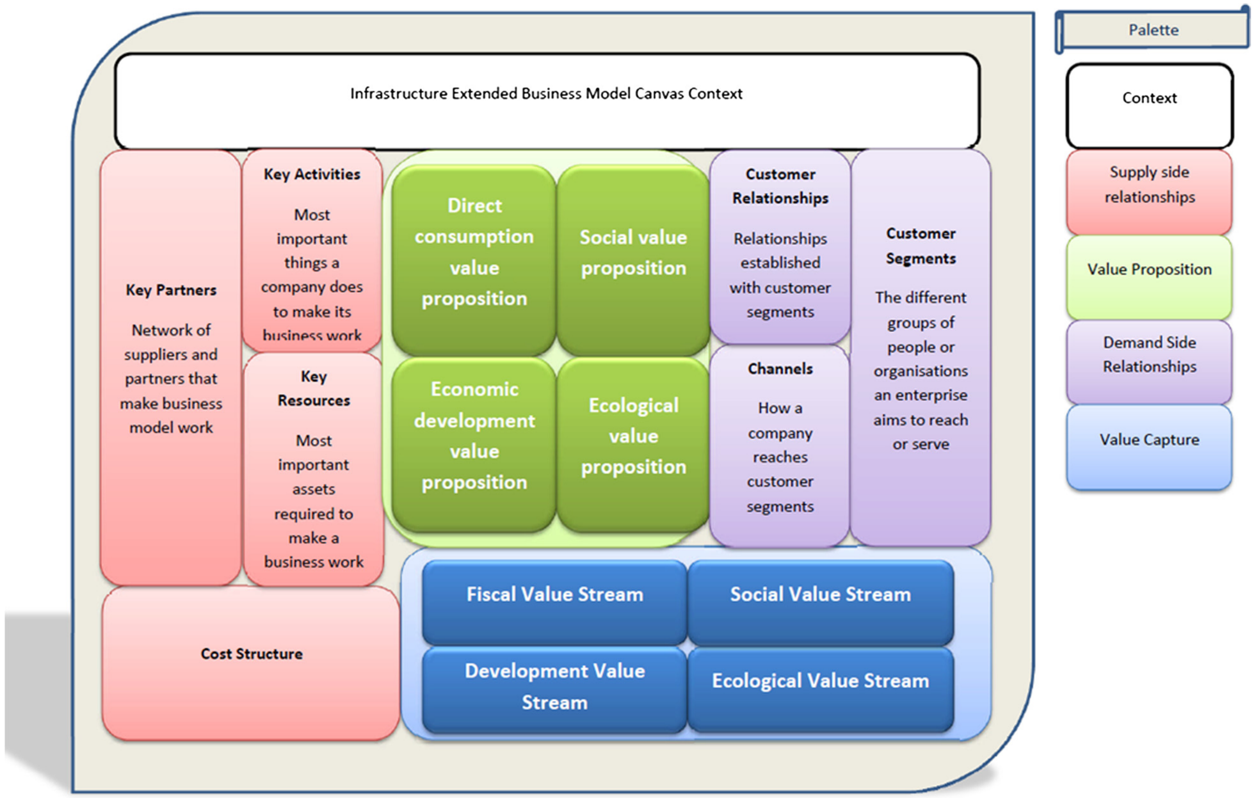

Fig. 2 The business model canvas approach extended for infrastructure

different customer segments and the creation of different forms of value. For example, a local authority motivated to reduce fuel poverty would predominantly target heat provision for households in poor quality housing and in socially deprived areas. By contrast, a commercial provider of heat would target larger and consistent users of heat to deliver an appropriate return on investment. This adds significantly to the complexity of the problem faced by these new actors when justifying investment in infrastructure. Their decision is no longer based simply on financial returns, but on a combination of economic, social and environmental value propositions.

The developments in the heat planning tool described in section 3.2.3 and the business model canvas described in section 3.3.1 allow for much more detailed analysis of individual cases and a better representation of the range of values that can be derived from infrastructure. These offer the potential of significantly improving decision-making processes and business case development to include social and environmental value. However, the increasing complexity that results from the diversity of actors engaged in infrastructure and in their motivations and decision-making processes makes systemic analysis of the infrastructure transition extremely challenging. This is particularly challenging when assessing the potential of interventions into the system to accelerate change.

More sophisticated tools are needed to identify how policy and regulation could adapt to accelerate the engagement of new actors in infrastructure delivery and operation. Complex systems modelling is increasingly being applied to problems in the energy domain such as this, where actors and their decisions are embedded in the broader socio-technical context (Bale et al., 2015). A complex systems modelling approach brings a number of advantages and insights. First, it enables representation of an interdisciplinary system that includes physical infrastructure, actor behaviour and their interactions, and the relevant policy environment. Second, it goes beyond standard economic assumptions of homogenous rational choice and a demand-driven market to capture complex behaviours and interactions between heterogeneous agents across both the demand side and the system of provision, which include the multiple motivations and values described above. Finally, a socio-technical model allows us to explore the emergence of different systemic patterns of behaviour and coevolutionary trends 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 (Grimm and Railsback 2005, Janssen and Ostrom 2005). While agent-based models of social systems abound, only recently has work emerged to simulate the long-term development of infrastructure and other socio-technical systems (Van Dam et al. 2013, Bergman et al. 2008, Kempener et al. 2009, Knoeri et al. 2014, Rylatt et al. 2013). These models offer significant advantages over the predominantly techno-economic models that are more traditionally used to examine infrastructure transitions. In particular, they can include influences such as social dynamics, culture, politics and environmental change, which cannot be represented in a purely economic model. However, existing models tend to be limited to one-off decisions; to adopt a technology or practice (Bergman et al. 2008) or to trade, produce or consume energy in response to price signals (Rylatt et al. 2013). In reality, engagement in infrastructure, to develop a new facility or set up a new business model, requires an iterative series of interconnected decisions over a period of time and a wide range of capabilities to implement the results of these decisions. Therefore, the iBUILD project will build on this nascent body of work and develop an ABM of infrastructure project development that incorporates the physical infrastructure, heterogeneous agents, and their policy environment, but will also consider the complex decision process required to deliver infrastructure, rather than isolated decisions.

The model includes a range of project instigators, including community groups, local authorities and commercial developers, that interact with consumers and large sources of heat supply or demand throughout project delivery. Importantly, we are able to represent the different motivations of these instigators to explore how this affects both the success of projects under different policy environments and the distribution of projects in a geographic area. Along the development process, instigators must make decisions (for example, whether a particular project is feasible) which allow them to progress to the next stage of development. The ability to make these decisions depends on the attributes of that actor (their capabilities, resources and motivations), the suitability of the physical environment (the nature of housing stock, the proximity of point sources of heat demand and supply) and variables that represent the policy environment (for example, ease of access to finance). If an instigator is not able to pass a certain decision point along the process, then the project fails and the model is able to record at which point of the process each project fails; giving insight into where policy intervention is most needed for different actors.

The impact of policy interventions can be analysed by the variation of the resources available to instigators, for example the availability of development finance and capital finance and the availability of guidance and support to ease development planning. The model is first being implemented for the case study of district heating networks in the UK, and development has been informed through both case study interviews and workshops to elicit stakeholder validation of the model structure and outputs (Bale et al. 2014b).

Conclusions

This paper has argued that investment in infrastructure is important, not only for contributing to national economic prosperity, but also for furthering social and environmental objectives, such as mitigating climate change and addressing fuel poverty. This raises challenges for forms of creation and appropriation of value, and design of business models, that can incorporate social, environmental and economic factors into infrastructure investment decision making. As we have illustrated through examination of smart grid and heat network investments at a local level, these challenges are already being faced by public and private actors. We have argued, however, that current tools and approaches tend to prioritise economic factors, meaning that potential social and environmental gains may be lost, and are less useful for early stage options appraisal, due to the dynamic nature and systemic uncertainties inherent in infrastructure investments.

The paper has proposed new and enhanced tools and approaches to aid infrastructure investment decision making, particularly at the early stage options appraisal phase. These tools and approaches need to recognise the dynamic, systemic and partial public good characteristics of infrastructure. An enhanced business model canvas has been proposed that incorporates social, ecological and economic development value propositions and value streams, alongside the direct consumption value proposition and fiscal value stream. Application of this to the case of local smart grid investments highlights the opportunities for new types of business models involving partnerships between DNOs and municipal and other stakeholders, to realise system-wide benefits (Hall and Foxon, 2014). The heat planning tool (Bush and Bale, 2014a, Bush et al., 2014) offers energy planners a quick and simple way to include social factors right from the early stages of district heating planning. Finally, we highlighted how complex systems modelling tools could accelerate the engagement of new actors in infrastructure delivery and operation, by taking a systemic approach, incorporating multiple motivations and values, and exploring the emergence of different systemic patterns of behaviour and coevolutionary trends.

Further work under the iBUILD project is ongoing to develop and test these tools and approaches, in order to demonstrate their utility for aiding more socially and environmentally, as well as economically, sustainable local infrastructure investment decisions.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
TF co-ordinated the paper and wrote the Background and Conclusions sections. CB and RB undertook and wrote the heat networks case study. SH undertook and wrote the smart grids case study and the business model canvas development. KR and JB undertook and wrote the complex systems modelling. All authors read and approved the final manuscript.

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References
Anaya KL, Pollitt M (2013) Understanding best practice regarding interruptible connections for wind generation: lessons from national and international experience. EPRG Working Paper 1309

Bale CSE, Bush RE (2014) Valuing energy infrastructure: Local authority motivations and national policy, International workshop on Sustainable Heating Provisions and Cities. Theory, Practice and Future Implications, Edinburgh

Bale CSE, Bush RE, Hawkey D, Webb J (2014a) Chapter 5: Valuation of passive provision for heat network investments. In: Brown A, Robertson M (eds) Economic evaluation of systems of infrastructure provision: concepts, approaches, methods. iBUILD, Leeds

Bale CSE, Bush RE, Roelich K, Busch J, Powell M (2014b) Application of a decision theatre concept to the development of an agent-based model. Presentation to Policy Modelling In Practice, CRESS Workshop

Bale CSE, Foxon TJ, Hannon MJ, Gale WF (2012) Strategic energy planning within local authorities in the UK: A study of the city of Leeds. Energ Pol 48:242–251.

Bale CSE, Varga L, Foxon TJ (2015) Energy & Complexity: New Ways Forward. Appl Energy 138:150–159

Balta-Ozkan N, Watson T, Connor P, Axon C, Whitmarsh L, Davidson R, Spence A, Xenias D, Cipcigan L, Taylor G (2014) Scenarios for the development of the smart grid in the UK, synthesis report. UK Energy Research Centre

Bergman N, Haxeltine A, Whitmarsh L, Kohler J, Schilperoord M, Rotmans J (2008) Modelling socio-technical transition pathways and patterns. J Artif Soc Soc Simulat 11(3):7

Bolton R, Foxon TJ (2013) Urban Infrastructure Dynamics: market regulation and the shaping of district energy in UK cities'. Environment and Planning A 45(9):2194–2211

BRE, University of Edinburgh & Centre for Sustainable Energy (2013) Research into barriers to deployment of district heating networks. London

Brown, A, Passarella, MV, Robertson, M (2014), 'The economics of infrastructure', in A. Brown and M. Robertson (eds), Economic Evaluation of Systems of Infrastructure Provision: Concepts, approaches, methods, iBUILD/Leeds report, October 2014, https://research.ncl.ac.uk/ibuild/outputs/9940_iBuild_report_v6.pdf

Bryson J, Pike A, Walsh C, Foxon TJ, Bouch C, Dawson R, (2014). Infrastructure Business Models (IBM) Working Paper. iBUILD Briefing Note 2, https://research.ncl.ac.uk/ibuild/outputs/briefingnotes/

Bush R, Bale, C. (2014a). Leeds Heat Planning Tool [Online]. SuRe-Infrastructure. Available: http://sure-infrastructure.leeds.ac.uk/leedsheatplanningtool/

Bush R, Bale C (2014b) Realising the social benefits of district heating through strategic planning. The 14th International Symposium on District Heating and Cooling, Stockholm, Sweden

Bush R, Bale C, Taylor P (2014) Spatial mapping tools for district heating (DH): helping local authorities tackle fuel poverty. Report for Chesshire Lehamnn Fund, Leeds

Chan C, Forwood D, Roper H, Sayers C (2009) Public Infrastructure Financing: An international perspective. Australia Productivity Commission, Melbourne

CHPA (2014) District heating to tackle Scottish fuel poverty [Online]., Available: http://www.chpa.co.uk/district-heating-to-tackle-scottish-fuel-poverty_2070.html [Accessed March 2014]

Core Cities (2013). Core Cities Growth Prospectus Policies Step 6: Power Up the Cities, Core Cities, Accessed February 2nd 2014 at: http://www.corecities.com/what-we-do/publications/core-cities-growth-prospectus-policies-step-6-power-cities

Davies G, Woods P (2009) The potential and costs of district heating networks: a report to the department of energy and climate change. Poyry Energy, Oxford

DECC. (2012). The National Heat Map [Online]. Available: http://tools.decc.gov.uk/nationalheatmap/ [Accessed 13.05.13].

DECC (2013) The Future of Heating: Meeting the Challenge. Department of Energy and Climate Change, London, UK

Defra (2012) Accounting for environmental impacts: Supplementary Green Book guidance. HM Treasury and Department for Environment, Food and Rural Affairs, London, UK.

Dixit AK, Pindyck RS (1995) The options approach to capital investment. Harv Bus Rev 1995:105–115

DNO Respondent (2014). Distribution Network Operator primary interview. Undertaken by author Hall, S.

Dunn H (2012) Accounting for environmental impacts: Supplementary Green Book guidance. Department for Environment Food and Rural Affairs

Energy Technologies Institute (2013) ETI Macro Distributed Energy Project-Summary Report. In: Paul Woods (AECOM), C. T. O

Fei C, Rinehart I (2014) Taking Back the Grid: Municipalization Efforts in Hamburg, Germany and Boulder, Colorado. Heinrich Boll Foundation, Washington DC

Foxon TJ (2013) Transition pathways for a UK low carbon electricity future. Energ Pol 52:10–24

Fujiwara D, Campbell R (2011), 'Valuation Techniques for Cost Benefit Analysis: Stated Preference, Revealed Preference and Subjective Well-Being Approaches', available on the HMT website: https://www.gov.uk/government/publications/valuation-techniques-for-social-cost-benefit-analysis

Garrod G, Willis KG (1999) Economic valuation of the environment: methods and case studies (pp. 132–133). Edward Elgar, Cheltenham

Giordano V, Fulli G (2012) A business case for Smart Grid technologies: A systemic perspective. Energ Pol 40:252–259

Giordano V, Meletiou A, Corvig FC, Mengolini A, Ardelean A, Fulli G, Jiminez MS, Filiou C (2013) Smart Grid projects in Europe: Lessons learned and current developments, European Commission Joint Research Centre. JRC Scientific and Policy Reports, Luxembourg

Graham S, Marvin S (2001) Splintering urbanism: networked infrastructures, technological mobilities and the urban condition. Routledge, London.

Grimm V, Railsback SF (2005) Individual-based Modeling and Ecology. Princeton University Press, Princeton

Hall S, Foxon TJ (2014) Values in the Smart Grid: the co-evolving political economy of smart distribution. Energ Pol 74:600–609

Hannon MJ, Foxon TJ, Gale WF (2013) The co-evolutionary relationship between Energy Service Companies and the UK energy system: Implications for a low-carbon transition. Energ Pol 61:1031–1045

Hawkey D, Webb J & Winskel M (2013) Organisation and governance of urban energy systems: district heating and cooling in the UK. J Cleaner Prod 50:22–31

Herder PM, Bouwmans I, Dijkema GPJ, Stikkelman RM, Weijnen MPC (2008) Designing Infrastructures from a Complex Systems Perspective. J Des Res 7(1):17–34

Huijben JCCM, Verbong GPJ (2013) Breakthrough without subsidies? PV business model experiments in the Netherlands. Energ Pol 56:362–370

iBUILD (n.d.) Infrastructure Business Models, Valuation and Innovation for Local Delivery, EPSRC/ESRC Research Project, Newcastle University, https://research.ncl.ac.uk/ibuild/

Jackson J (2011) Evaluating Smart Grid Investments at Cooperative and Municipal Utilities in US. Metering International 1:76–78
Janssen MA, Ostrom E (2005) Governing socio-ecological systems. In: Tesfatsion L, Judd KL (eds) Handbook of computational economics II: agent-based computational economics. Elsevier, Amsterdam, The Netherlands
Kempener R, Beck J, Petrie J (2009) Design and Analysis of Bioenergy Networks. J Ind Ecol 13:284–305
Knoeri C, Nikolic I, Althaus H-J, Binder CR (2014) Enhancing Recycling of Construction Materials; an Agent Based Model with Empirically Based Decision Parameters. Journal of Artificial Societies and Social Simulation 17(3):10
Müller C (2011) Advancing regulation with respect to smart grids: pioneering examples from the United Kingdom and Italy. Fourth Annual Conference on Competition and Regulation in Network Industries, Brussels 2011
Nakamura H (2000) The economic evaluation of transport infrastructure: needs for international comparisons. Transp Policy 7(1):3–6
OFGEM (2010) RIIO - a new way to regulate energy networks. Office of Gas and Electricity Markets, London
Osterwalder A, Pigneur Y (2010) Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers (Wiley Desktop Editions). Wiley, Hoboken
RTP Engine Room (2015) Distributing Power: A transition to a civic energy future. Report of the Realising Transition Pathways Research Consortium 'Engine Room'. University of Bath, Bath
Roelich K, Knoeri C, Steinberger JK, Varga L, Blythe PT, Butler D, Gupta R, Harrison GP, Martin C, Pumell P (2015) Towards resource-efficient and service-oriented integrated infrastructure operation. Technol Forecast Soc Chang 92:40–52
Rylatt M, Gammon R, Boait P, Varga L, Allen P, Savill M, Snape R, Lemon M, Asdestani B, Pakka V, Fletcher G, Smith S, Fan D, Strathern M (2013) CASCADE: An Agent Based Framework For Modeling The Dynamics Of Smart Electricity Systems. Emergence: Complexity and Organization 15(2):1–13
San Roman TG, Momber I, Abbad MR, Miralles AS (2011) Regulatory framework and business models for charging plug-in electric vehicles: Infrastructure, agents, and commercial relationships. Energ Pol 39(10):6360–6375
Teece DJ (2010) Business models, business strategy and innovation. Long Range Plan 43:172–194
HM Treasury (2011a) The Green Book: appraisal and evaluation in central government: Treasury guidance. Stationery Office, 2011
HM Treasury (2011b) Valuing infrastructure spend: supplementary guidance to the Green Book. Stationery Office, 2011
HM Treasury (2013) Public Sector Business Cases: using the five case model green book supplementary guidance on delivering public value from spending proposals https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/277345/green_book_guidance_on_public_sector_business_cases_using_the_five_case_model_2013_update.pdf
HM Treasury (2014) National Infrastructure Plan 2014. Stationery Office, 2014.
van Dam KH, Nikolic I, Lukszo Z (2013) Agent-Based Modelling of Socio-Technical Systems. Springer, Netherlands
Xenias D, Axon C, Balta-Ozkan N, Cipcigan L, Connor P, Davidson R, Spence A, Taylor G, Whitmarsh L (2014) Scenarios for the development of smart grids in the UK: Literature review. UKERC Working Paper, REF UKERC/WP/ES/2014/001
Yorkshire Post. (2013). District heating scheme 'would cut fuel poverty' [Online]. Available: http://www.yorkshirepost.co.uk/news/main-topics/local-stories/district-heating-scheme-would-cut-fuel-poverty-1-6084486 [Accessed March 2014].
Zott C, Amit R, Massa M (2011) The Business Model: Recent Developments and Future Research. J Manag 37:1019–1042