Pre-Print Version of:
Guy, Simon and Andrew Karvonen. 2016. District heating comes to Ecotown: zero-carbon housing and the rescaling of UK energy provision, in *Beyond the Networked City: Infrastructure Reconfigurations and Urban Change in the North and South*, ed. Olivier Coutard and Jonathan Rutherford, 72-93, London: Routledge.

District Heating Comes to Ecotown: Zero Carbon Housing and the Rescaling of UK Energy Provision

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> At first glance, heat plants and pipelines *per se* may seem of little interest from a social science perspective. What makes them truly intriguing is what they embody: the tensions and tactics behind their emergence, the complexity of the social organization that supports them, and their long-term implications for the actors they link and the communities they serve.
>
> Summerton 1992: 62

It is now more than two decades since Jane Summerton published her landmark book *District Heating Comes to Town* about the successful development of a district heating system in an 'ordinary' town in Sweden. It was published when sociotechnical studies of urban technical systems were still relatively rare and arrived during a fertile period of intellectual development that was striving to connect studies of large technical systems with urban studies, inspired by new thinking in STS studies (Guy and Karvonen 2011).[1] Her subtitle, 'the social shaping of an energy system,' continues to be a fresh (and to some, a provocative) perspective suggesting that the development of urban infrastructure systems depends as much on the 'cooperation and coordination of many diverse actors' as on the technological and financial means of production. This is a direct challenge to the prevailing epistemological order in energy studies and encourages a relational perspective on the co-production of energy provision and consumption.

While such sociotechnical studies still arguably represent a minority perspective, they are now very much part of the theoretical and policy debate with disciplines across the social sciences developing a keen interest in energy systems (Guy 2006) and an increasing number of recent energy research projects funded by British research council's claiming to be framed by a sociotechnical analytical frame, including a landmark Government Foresight study of sustainable energy management and the built environment, *Powering Our Lives* (Government Office for Science 2008).[2] More recently, Bridge and colleagues have sought to identify connections between energy studies and human geography, foregrounding questions about *spatial difference* and the 'co-existence of multiple transition pathways and possibilities' (2013: 339). They argue that the research goal for energy studies should not simply be 'mapping the consequences of policy' or 'understanding the implications of different policy

[1] See Hughes 1983, Mayntz and Hughes 1988, Summerton 1994, Aibar and Bijker 1997, Graham and Marvin 2001, Guy et al 2001, Coutard 2002, Graham and Marvin 2002, Coutard et al 2004, Hommels 2005, Farias and Bender 2010, Graham 2010, Guy and Karvonen 2011, Guy et al 2011, and Karvonen 2011.

[2] Examples of recent sociotechnical studies of energy funded by the UK's Research Councils include 'Urban Transitions: Climate Change, Global Cities and the Transformation of Socio-Technical Systems' (ESRC, 2008-2012, Bulkeley), 'Governance of the Discontinuation of Socio-Technical Systems' (ESRC, 2013-2016, Sterling), 'Re-Engineering the City 2020-2050: Urban Foresight and Transition Management' (EPSRC, 2010-2014, Eames), 'Interdisciplinary Cluster on Energy Systems, Equity and Vulnerability' (EPSRC, 2009-2012, Bickerstaff), and 'Community Innovation in Sustainable Energy (EPSRC, 2010-2014, Smith).

options for particular places' but should rather be to 'understand how energy transitions are *spatially-constituted*' (p. 339, emphasis in original).

The inspiration for this chapter is not simply the sociotechnical analytical approach, but also the subject matter of British district heating systems. Here there has been rather less development, perhaps due to heat networks only accounting for approximately 2% of domestic, public sector, and industrial heat demand in the United Kingdom (DECC/DCLG 2009), they have not been seen as productive focus of research concern. However that has started to shift with new projects and papers emerging that are exploring the potential contribution of heat networks to meeting national low carbon targets while also strengthening local and regional influence over environmental governance (Hawkey 2009, Russell 2010, Hawkey 2012, Bolton and Foxon 2013, Hawkey et al 2013, Webb 2013, Bolton and Foxon 2014, and Lund et al 2014). For example, Webb has been exploring how locally-owned, small scale heat networks in Aberdeen might become 'scalable models for low carbon, affordable, and locally-accountable urban energy' (2013: 24) while Bolton and Foxon (2014) have been examining the interaction between district heating systems and regulatory regime that underpins the liberalisation of energy markets. In short, the re-emergence of district heat networks as a response to national low carbon targets involves a multitude of tensions and tactics in the reconfiguration of infrastructure networks.

We contribute to this debate by exploring how medium- to large-scale zero carbon housing developments are employing district heating and combined heat and power networks to provide multiple households with renewable energy. Our motivation to focus on district heating is linked to the policy shift around carbon neutrality with its menu of visions and targets that is now exercising the minds and calculations of planners, designers and developers in the built environment. Hodson and Marvin (2013) have recently asked whether a transition to a low carbon Britain creates new 'transformational opportunities', or simply means 'business as usual'. For the purposes of this chapter, we similarly ask if the low-carbon turn presents an opportunity for heat networks to establish themselves in Britain as they have elsewhere in Europe.

To address this question we focus on new housing as a sector, following the emergence of a new generation of urban development schemes that are seeking to achieve carbon neutral status to meet new housing design and construction standards. The journey from policy objective through demonstration house to mainstream commercial development is a process we have been following through an ESRC/DEFRA/Scottish Government funded project that is part of a larger programme of studies around theories of social practice.[3] Our project followed both the formation of a policy discourse around carbon neutral housing and attempts to realize this policy in mainstream commercial development. Not surprisingly for a study influenced by STS, the stories we followed involved deep entanglements of human and non-human actors, strategies of translation, tactics of enrolment, and attempts to configure users, all of which are highly contested. Elsewhere we have highlighted the interpretive response of commercial designers and developers to the policy prescription of carbon neutrality (Fischer and Guy 2009) and the emergence of community-based partnerships for domestic retrofit (Karvonen 2013).

In this chapter, we examine the role of energy systems in the zero carbon housing debate and how a new impetus around district heating is being realised as well as contested on the ground in debates and decisions about design and planning. In doing so, we draw inspiration both from Summerton's attempt to understand the contingencies of successful innovation in energy systems and the more

[3] See the Sustainable Practices Research Group website, www.sprg.ac.uk.

recent sociotechnical thinking about the dynamics and tactics of rescaling energy systems as they move through moments of transition.[4]

The chapter is in four parts. Firstly we introduce the policy context around zero carbon housing in the UK and the various claims and calls for action that characterise the recent debate. We provide an overview of the zero carbon housing sector to give a sense of the scale and diversity of recent development activity and foreground the ascribed role of district heating in the policy discourse as well as emerging mainstream developments. In doing so, we contrast the clarity of the policy goal with the complexity of the development context as the housing sector attempts to come to terms with the new policy landscape. Secondly, we briefly revisit the debate about district heating in the UK to give an historical sense of the role (or lack thereof) of district heating in the British energy system. We identify the importance of international exemplars of district heating as influential in the current policy debate and present the arguments of district heating advocates. Thirdly, we explain the background and methodological approach to the case studies presented here. We introduce the case study developments and explain how and why district heating became part of the housing strategy. In each case, we explore the contingency and complexity of attempts to reconfigure and rescale the energy system, in particular exploring the dynamics of development scale, design, and planning, and how this issue shapes the adoption of district heating. Finally, we make links back to Summerton's work to reconsider the dynamics of district heating as a sociotechnical system. We assess the likelihood of district heating to fulfil the policy aspirations around zero carbon and the associated risks to existing systems of such a rollout. We conclude by exploring future research questions and the contribution of this work to wider studies around STS and urban technologies.

Mainstreaming zero carbon housing

About one-quarter of the total UK carbon footprint is attributed to the construction, operation, and demolition of the British housing stock and thus, it provides an attractive and logical target for climate change mitigation policies (DECC 2011a). With aims to significantly reduce the carbon footprint of the UK housing stock, the Government introduced the Code for Sustainable Homes (CSH) in December 2006 with a gradual tightening specification from Level 1 compliance in 2007 to the highest Level 6 compliance in 2016 that is considered to be 'zero carbon'.[5] The definition of 'zero carbon' was vociferously debated in subsequent years, with the homebuilding industry jockeying with the Government and third sector organisations to determine the carbon footprint boundaries and to decide what types of carbon to regulate in the creation of a stringent yet viable regulatory goal.[6] Giving the homebuilding industry only ten years to completely reform the delivery of new housing was a significant challenge for building scientists, the building trades, economists, and marketers, and produced significant contestation over how zero carbon could be achieved, particularly in a commercial context. In 2014, the Government began to move away from the CSH and as of this writing, is in the process of developing alternative approaches to reducing the carbon footprint of the UK housing stock. However, the debates over CSH from 2006 to 2014 produced new configurations between housing and realising a low carbon future for Britain.

Through the debates over the 'zero carbon' imperative and the alternative pathways of design and development that resulted, regulators and the homebuilding industry agreed upon a hierarchy of approaches to reducing to carbon footprint of new houses. In particular, there was a shared

4 See Smith 2007, Rutherford 2008, Coutard and Rutherford 2010, Hodson and Marvin 2010, Coutard and Rutherford 2011, Hodson and Marvin 2011, Loorbach and Verbong 2012, Bridge et al 2013, Rydin et al 2013, and Rutherford and Coutard 2014.

5 Note that the CSH covered more than energy efficiency and carbon footprints; it was a holistic regulatory framework that addressed the standard elements of green design, construction, and operation. In this chapter, we focus specifically on energy and carbon. For more information on the CSH, see DCLG 2007, 2008, 2010 and Williams 2012.

6 For different perspectives on the debates surrounding the rollout of CSH, see NHBC 2008, UKGBC 2008, ZCH 2009, McManus et al 2010, Rydin 2010, Goodchild and Walshaw 2011, Greenwood 2012, and Reid and Houston 2013.

understanding that carbon reductions should start with creating an efficient building fabric (the 'fabric first' approach) and then reducing demand inside the household and providing onsite energy generation to the greatest extent possible. These two tiers of the carbon reduction hierarchy are referred to as 'Carbon Compliance' and involve onsite solutions. The original CSH called for all carbon emissions to be mitigated via Carbon Compliance measures but as the regulatory requirements were tested on real world houses, the housing industry argued that this was unrealistic to deliver an affordable housing product in the long term (ZCH 2011).

To remedy the situation, in 2008, DCLG introduced the notion of 'Allowable Solutions' that go beyond the Carbon Compliance requirements to include strategies such as smart appliances, communal heat storage, electric vehicle charging stations, retrofit of neighbouring buildings, local micro-hydro power generation systems, investment in low carbon electricity generation, and so on. The Zero Carbon Hub (ZCH) – a public/private partnership established in 2008 to facilitate the delivery of low and zero carbon new housing – was a central actor in translating and interpreting the CSH for the homebuilding industry. Their 2011 report, *Allowable Solutions for Tomorrow's New Homes: Towards a Workable Framework*, states that, 'Allowable Solutions offer flexibility to developers, providing them with an outlet to resolve remaining emissions, where all other technically and commercially feasible on-site options have been exhausted' (2011: 12). These Allowable Solutions account for a significant portion of carbon emissions savings depending on the housing type – estimated to be 56% for flats and 40% for detached houses – and comprised some of the most highly contested elements of the zero carbon housing debate.

Allowable Solutions introduced significant opportunities for the development of new forms of energy delivery. As the ZCH (2011: 15) notes, 'The right Allowable Solutions framework could be hugely important in stimulating the fledgling (but largely unsupported) "mid-stream" sustainable-energy market, which delivers, for example, community scale sustainable energy solutions.' It is here where meso-scale infrastructure such as district heating (DH) and combined heat & power (CHP) networks emerged as important components of zero carbon housing. The Renewables Advisory Board made an explicit connection between the CSH and these meso-scale infrastructure networks, arguing that it is 'important that larger scale CHP and district heating is culturally and commercially attractive in the UK, since it offers a relatively cheap route to compliance' (RAB 2007: 4). Likewise, the Department for Business Enterprise & Regulatory Reform notes that the CSH is 'potentially a significant stimulus for renewable district heating' (BERR 2008: 75).

Allowable Solutions introduced a new spatial dimension of energy provision for zero carbon housing that resides between the individual house and the universal grid. Rather than simply hanging off the end of the conventional electricity and gas central grids or escaping altogether as an island of micro-generation, new assemblies of housing, heating, and powering communities are being imagined and designed, and in certain contexts are starting to be constructed. This is reflected in the Department of Energy and Climate Change's *Carbon Plan* of 2011, wherein district heating is part of the medium-term strategy to wean the UK building stock (both domestic and non-domestic) off of high carbon fuel sources. As the report states, 'The 2020s will be a key transitional decade in delivering mainstream low carbon heat from heating networks and in buildings, and will see the expansion of low carbon heat at scale into residential areas' (DECC 2011a: 33). This new mode of infrastructure provision is evident in recent developments being proposed and built by large housebuilders to meet varying levels of the CSH, which we will discuss in more detail below. Before we do so, we will pause to consider why district heating is being promoted as a key to zero carbon and review some of virtues and challenges of this systemic change.

The importance of the meso-scale

Various terms are used to describe energy provision that lies somewhere between the universal grid and the individual house: decentralised, distributed, dispersed, embedded, and micro-generation (Alanne and Saari 2006). CHP networks involve the simultaneous production of electricity and heat while DH networks involve a complex of pipes to transport heat to a collection of buildings for space heating and hot water. These systems can range from the individual household to a small collection of buildings to a block, neighbourhood, district, or even city (e.g., Vienna), and can function as a single system or a web of interconnected smaller systems (e.g., Copenhagen). What these networks share in common is that heat and/or energy generation is located in close proximity to the point of use. In this chapter, we are particularly interested in those networks that serve several different owners but are smaller than universal networks (between 10 KWe and 50 MWe). We refer to these as a 'meso-scale' networks of energy provision that reside between the conventional grid and the individual household (Foresight 2008, Watson et al. 2010).

Meso-scale heat and power networks are a common strategy in many Nordic countries (e.g. Denmark, Sweden, and Finland) as well as Eastern Europe (Poland, Estonia, Latvia, and Lithuania) (Euroheat & Power 2011). The UK currently has an underdeveloped heat market; only 2% of UK's current heat demand is met with district heating (DECC/DCLG 2009). There are several reasons for the lack of district heat networks in the UK.[7] The liberalised energy markets create separate silos of generation, transmission, distribution, and supply (Toke and Fragaki 2008, Euroheat & Power 2011) and the current arrangement of domestic energy use for space heating and hot water involves boilers fed with gas, oil or solid fuels, or using electric heating systems. These technologies are locked into national infrastructure networks as well as high carbon fuel sources (Unruh 2000, 2002).

However, the UK does have a long history of heat initiatives stretching back to World War I (see Russell 1993, Babus'Haq and Probert 1996, TCPA/CHPA 2008, Hawkey 2009, Russell 2010) and today, there are a handful of projects with established track records including Woking, Sheffield, Southampton, and Aberdeen. However, as Russell (2010: 1) summarises in a review of heat networks in the UK, it is a 'long and mostly sorry history' with 'no simple reason for their neglect'. And while the neglect is multi-causal, Russell sees the exclusion as essentially systematic, characteristic of a particular sociotechnical formation in which heat networks have been *locked-out*, much as in a parallel way heat networks have been *locked-in* to the national networks of other European countries. British energy providers have historically seen bulk heat supply (both pre- and post-nationalisation) as incidental with engineers often hostile and politicians disinterested. However, Russell does note that at times of a major reorganisation of the sector (e.g. nationalisation and privatisation), there was a 'fluid phase' that allowed 'options to be aired and alliances to be built around the idea' (2010: 5). While these moments passed without resolution or much momentum for heat networks, it does raise the question if the current pursuit of low carbon Britain may present another fluid phase in which heat networks might finally emerge as a key element in British energy planning.

Certainly we are witnessing the emergence of a new coalition of interested actors and institutions supporting innovative projects, with Government agencies such as the Department of Energy and Climate Change (DECC), Department for Communities and Local Government (DCLG), and Homes and Communities Agency (HCA) collaborating with third sector organisations such as the Carbon Trust and Energy Saving Trust, as well as trade organisations such as the Combined Heat and Power Association and the UK District Energy Association to realise the benefits of meso-scale networks. They cite three primary reasons for promoting meso-scale heat and power networks: to reduce CO_2 emissions, to tackle fuel poverty, and to develop diverse and secure energy supplies (DECC/DCLG 2009, HCA 2011b). District networks provide more energy efficient forms of generation and

[7] For a history of DH and CHP in the UK, see Russell 1993.

distribution. They use technologies that make more efficient use of primary energy and with CHP, utilise heat that would otherwise be wasted. Beyond their efficiency, district heat and power are more flexible than large grid systems. Energy generation technologies can be upgraded over time, with fossil fuels being replaced with biomass or other renewable feedstocks. As such, district heating networks are agnostic with respect to fuel source and can be leveraged in the transition from fossil fuels to renewables (EST 2009, HCA 2011b). For example, boilers that use renewable fuel sources such as pellets and woodchips are becoming increasingly common for district heating networks (EST 2009). Further, heat can be stored quite easily in an insulated vessel, effectively decoupling generation from demand and avoiding the storage issues associated with electricity supply and demand.

Of course, there are also challenges in introducing meso-scale infrastructure networks. District heat systems have a long lifespan (40 to 50 years) compared to home heating systems but they are capital intensive and involve significant first costs (Hawkey 2012). To justify the high first costs, these networks require high and consistent heat demands. As a rule of thumb, CHP plants need to operate for a minimum of 4000 to 5000 hours per year (the equivalent of 13 to 14 hours per day) (EST 2009). This high demand is easier to achieve in mixed-use developments where heat demand is more consistent, as opposed to domestic developments with high morning and evening peak demands (TCPA/CHPA 2008, EST 2009). Thus, it is common to design a district heat network with an anchor load such as a hospital, university, or office tower, and then add on dense residential development (i.e., flats) (Summerton 1992). Likewise, district heat networks tend to be sited in towns and city centres due to their higher heat density as well as mixed building types (TCPA/CHPA 2008).

Table 1 provides a comparison of densities and costs for different building types demonstrating that the cost per dwelling increases significantly with lower housing densities and longer pipe lengths. The particular qualities of heat generation, storage, and distribution shape urban form and reinforce notions of compact cities and dense, mixed-use developments, and sustainable urban development more generally.

Meso-scale infrastructure networks are often neglected in policy debates, falling between the micro strategies that are addressed with feed-in-tariffs, demand side efficiency, and micro-generation technologies, and the macro strategies that legislate and regulate large-scale utility investments and upgrades. Watson et al (2010: 8) note that there has been a small amount of attention to the meso scale through the Community Renewables Initiative but conclude that ‘there is no established tradition in

Table 1 Comparison of building type, density, pipe length, and cost for various district heating configurations (Source: TCPA/CHPA 2008)

Building Type	*Form*	*Housing density [dwellings per ha]*	*Pipe length per dwelling [m]*	*Cost per dwelling [£]*
High-rise apartment block	Corridor access, 10 to 15 storeys	240	6.75	2,500
Medium-rise apartment block	Corridor access, 5 to 6 storeys	120	8.0	2,800
Perimeter block of flats and townhouses	Stairwell or street-level access, 3 to 4 stories	80	11	4,100
Terraced street of row houses	Street-level access, 2 to 3 storeys	80	13	5,300
Detached/semi-detached houses	Street level access, compact street layout	40	19 to 24	7,700 to 9,550

the UK of either energy technology deployment or energy system governance and regulation at meso (regional or local) scales.' The meso scale introduces a new set of technologies and institutions that differ significantly from the micro and macro scales and require novel regulations and incentives to be viable (**Table 2**). The abolition of regional government bodies in the UK in 2010 could make delivery of renewable energy and district heating networks more difficult at the local scale (Watson et al 2010).

Despite the aforementioned challenges associated with sunk costs, minimum heat densities and demands, governance gaps, and financial disincentives, many national policy documents identify district heating and CHP networks as central components in the modernisation of the UK's energy supply networks. Examples of this include the *UK Renewable Energy Strategy* (HM Government 2009), *The Carbon Plan: Delivering Our Low Carbon Future* (DECC 2011a), *2011 National Infrastructure Plan* (HM Treasury and Infrastructure UK 2011), the *Overarching National Policy Statement for Energy* (DECC 2011b), the *UK Renewable Energy Roadmap* (DECCC 2011c), *The Future of Heating: A Strategic Framework for Low Carbon Heat in the UK* (DECC 2012), and *The Future of Heating: Meeting the Challenge* (DECC 2013). In London, all new major developments are required to connect to an existing DH network or establish a new DH network (EST 2009) and various programmes by government bodies (for example, the HCA's Carbon Challenge and Low Carbon Infrastructure Fund) feature meso-scale infrastructure networks as the centrepiece of exemplary pilot projects. Reflecting on the experiences of the Low Carbon Infrastructure Fund, the HCA (2011b: 13) cautiously concludes that 'community-level energy systems can, in the right conditions, enable developments to achieve higher levels of CSH in a more cost effective way than individual technologies' (HCA 2011b: 13). Likewise, district heat networks are increasingly being promoted as a promising option or even a necessity for achieving CSH Level 5 and 6 (RAB 2007, TCPA/CHPA 2008, Roberts 2008, Williams 2010, HCA 2011b, Williams 2012, CHPA 2014).

Configuring zero carbon housing

Given this familiar policy conundrum of technical potential and multiple 'barriers' to district heating, how might we expect the homebuilding industry to respond? In exploring the emerging landscape of zero carbon housing, we surveyed a range of recent zero carbon housing projects. **Table 3** provides examples of low and zero carbon housing developments that include district heating and CHP

Table 2 Energy systems from the macro to the micro scale (adapted from Foresight 2008, Watson et al 2010)

Scale	*Geography*	*Technologies*	*Institutions*	*Regulations and Incentives*
Macro	International	Large solar PV or wind farms	European Union, International Energy Agency	EU Emissions Trading Schemes
	National	Centralised electricity and gas grids	Central government, national energy regulators	Energy market rules, national incentives
Meso	Regional/City	City scale heat and power networks	Municipal utilities	Regional energy strategies
	Neighbourhood/District	District heat and power networks	Local authorities	Local planning rules, local grants
Micro	Building	Micro-generation, insulation, efficient appliances	Homeowners, building managers, community organisations	Homeowner grants and incentives

Table 3 Examples of recent low and zero carbon housing developments in the UK with meso-scale energy networks

Project	*Housing units*	*District system*
Adelaide Wharf East Ditch, London	143	Gas-fired DH
Centenary Quay Southampton, Hampshire	1620	Two CHP plants
Graylingwell Park Chichester, West Sussex	750	CHP plant
Green Space, Mendip Place Chelmsford, Essex	10	Biomass DH network
Greenwatt Way Slough, Berkshire	10	DH network powered by a biomass boiler, air source heat pump, and two ground source heat pumps
Hanham Hall South Gloucestershire	186	Biomass-fuelled CHP plant
One Brighton Brighton, East Sussex	172	Biomass DH network
Park Dale Airedale, West Yorkshire	91	Biomass DH system
Shine-ZC Derby, East Midlands	9	CHP plant with underground thermal store

networks. There is wide variation in the scope of these developments, particularly in relation to the scale of the projects. Moreover, while some are restricted to domestic buildings, others use DH and CHP to power non-domestic buildings or to supply the grid with electricity. While this is not a definitive survey, it offers a representative perspective of the low and zero carbon housing landscape and suggests that the reconfiguration of the housing/network relationship is a key element in the realisation of zero carbon housing. On the surface, this survey appears to suggest a new trend, a shift towards a meso-level power system that creates a new context for the assembly of housing and networks to complete the carbon reduction hierarchy. Is it the case then that the UK building industry has finally woken up to the 'good sense' of international experience and home grown demonstration projects? Does this wave of experimentation suggest a new era of district heating rolling out across our towns and cities as a growing number of Government agencies and trade organisations suggest?

Two case studies provide insight on the motivations, challenges, and opportunities related to meso-scale and zero carbon housing. In each case study, we interviewed design team actors – developers, architects, housebuilders, and local authorities – to understand how the CSH is being interpreted and implemented. Here, we focus on the implications of district heating networks on two projects, one that successfully implemented a district network and another where it was initially considered but ultimately dropped. The first case study is Park Dale, located in Airedale, West Yorkshire, and built by Wakefield and District Housing (WDH) in partnership with housing developer Keepmoat, architect NPS, and builder Bramall Construction. The project opened in November 2011 and includes 91 CSH Level 6 houses. It is touted as the 'largest zero-carbon social housing scheme in the UK' (WDH 2011) with WDH serving as landlord for low-income renters. The project includes an energy centre with a biomass district heating system (**Figure 1**). The second case study, Vista in Peterborough, Cambridgeshire, is one of two projects delivered under the HCA's Carbon Challenge Programme (the other project is Hanham Hall in South Gloucestershire). The project team included

Figure 1 The energy centre at the Park Dale zero carbon housing development in Airedale, West Yorkshire (note the asymmetrical roof and the three chimneys for the biomass boiler)

homebuilder Morris Homes, architect Barnett North LLP, and Peterborough City Council. The project was completed in 2013 and includes 295 houses at CSH Level 6 (HCA 2011a). The project team initially planned to include a biomass-fuelled CHP system for the project but after the 2008 economic downturn, decided to pursue a design strategy with individual biomass boilers in each house.

In the following paragraphs, we highlight some of the key challenges faced by the design teams in designing and building meso-scale infrastructure networks. We supplement the insights from the design team members of these two case studies with opinions from housebuilders, consultants, and trade industry representatives involved in DH and CHP promotion and development. The findings suggests that there are multiple tensions and tactics involved in designing, constructing, and managing DH and CHP systems at the meso-scale, creating an additional layer of complexity and uncertainty in the realisation of a low carbon Britain.

Decision-making and energy provision

The pursuit of low carbon housing involves nuances in decision-making. As a design team member of the Vista project notes:

> The energy issue is clearly the big question mark and the big thing that holds back developments of this type. You can do high insulation, you can tick biodiversity boxes easily, you can do Lifetime Homes [an additional regulatory requirement] without too much trouble, you can meet the daylighting requirements. But the heat and power requirement is obviously the big thing.

A shared opinion of the respondents was that DH and CHP are the best and perhaps the only option for achieving a low carbon housing stock in the long-term future. As a trade industry representative succinctly notes, 'I've now after four years realised it's the only way forward, it really is the only solution'. This is borne out by the growing number of schemes promoting decentralised schemes (see **Table 3**). Moreover, there is a growing sense within the industry that a rescaling of energy provision somehow symbolises an ecological turn in and of itself, as a builder of Park Dale suggests: 'We did a decision tree to look at the best way forward, of achieving Code 6 and ultimately the one that raised its head most was district heating, supplemented by solar PV'.

However, the implementation of this strategy is rarely straightforward; reconfiguring the system of energy provision has multiple implications that need to be considered. One of the Park Dale design team members notes:

> We're looking at a district heating system, so you'll need fuel pellets in an energy centre, in a boiler house, which will impact upon deliveries. We have to consider the physical aspect of it all, they're delivering every two weeks or four weeks. How do you want to charge your occupiers for using this fuel? We needed the PVs to supplement the district heating, roughly 36 square metres of PVs. And on a normal symmetrical roof or on a balanced roof like that you can't fit it on. So it meant having asymmetric which is like an offset pitch.

What is clear from this account is both the often unfamiliar design and planning challenges associated with heat networks and in response, the pragmatic creativity involved in assembling these systems in the face of standardised solutions and taken-for-granted development routines. The necessity of hybrid systems, the risk involved in abandoning gas supplies, the logistical challenges of fuel pellet delivery, the complexities of financial charges, the reshaping of design priorities and the feeling of risk and uncertainty that accompanies the new system all bring into question the optimism and certainty that pervades the policy literature and its promotion of district systems as the preferred solution.

The scalar implications of zero carbon

The district systems also reinforced the scalar dimensions of each development. At Park Dale, the energy centre that houses the biomass boilers for the district heating system also serves as an educational facility for green living for the residents as well as schoolchildren. In the Vista project, the district heat network was integrated with other site amenities and when the network was abandoned, the amenities also were removed from the project. A Vista design team member states:

> We originally had a small shop, a cafe, this community hall and this sort of spa, because the energy side was going to produce so much waste heat and so we were going to use it to power the hot tub arrangement, but district heating's gone, the spa's gone, the only thing we're actually left with is a shop on the corner, so we've managed to get a small shop, there's going to be a community shop there, not central to the site but it's still there.

What emerges clearly from these case studies is the strong relationality of the technical systems with the design and planning imperatives of each development. In particular, the issue of development form and spatial configuration arises time and again as key to the optimisation of the system. In explaining the emergence of heat planning in London, a local authority engineer has a spatial clear explanation; 'the thing that does it for London is the densification…. there's more people packed into a square meter, which is great because you only have to do a little investment to get a lot of people'. Moreover, micro-generation is often adversely impacted by density as a local authority engineer confirmed; 'From a point of view of renewables, a dense urban landscape's no good for PVs, there's not enough area, you get shading. It's useless for micro wind, you just don't get the airflows sort of around buildings'. Similarly, a trade group representative confirmed that 'micro-generation gets more and more problematic the more dense the size. There aren't big enough roof space for PV…..It makes more and more sense to have a communal solution of some kind, so district heating is that'.

There are a number of inter-related levels linking urban form and system efficiency across thermodynamics, demand dynamics, cost, and design as a consulting engineer illustrated; 'In terms of load, the bigger the scheme the more efficient your CHP becomes, the larger CHP you can get the more efficient it generally is, the longer you can run it for', but also financial cost; 'if you drop below probably 90 to 100 units, CHP doesn't become particularly viable from a financial point of view'. Moreover, the range and diversity of users included in the network can be critical; 'the more diversified users you can get on it, the better really. Baseload then just rockets and if your baseload is high, your low carbon generator can be high'. In other words, 'The bigger that is, the more you're going to save'. Therefore, as a recent DECC (2013) report makes clear, heat networks are more likely to be cost-effective in urban settings, where there are many buildings like blocks of flats where individual gas boilers may not be an option, and also commercial buildings such as hospitals and leisure centres that provide high and predictable heat demand.

Economic viability

The consequences of this density equation in turn shape development calculations. As one homebuilder told us, 'Seemingly anything below about 350 dwellings, it just doesn't generate the revenues that they need to justify an initial infrastructure outlay'. And it's not simply a matter of the number of housing units, as the network itself is very space intensive and fussy about angles and obstructions. A local authority engineer told us, 'You have things like obstructions, bridge crossings, rail crossings… putting them in later across major junctions and things like that is a pain in the arse….Pipework is a linear development, roads and rail systems are linear developments'. And the space challenges do not end with the pipe as a consulting engineer suggests:

> People just don't understand [heat storage], they don't want to put it in. It's a pain. The first thing the clients say is, 'Where am I going to put that?' And a lot of consultants will just say, 'Well, chop that one in half and we'll put in three of a smaller size.' But thermal stores should be tall and skinny, the taller and skinnier the better for stratification.

There are similar challenges with house typologies as a low carbon housing expert makes clear:

> With detached houses, it gets really expensive to start feeding from a central district heating centre, and the pipework has to go down all these different roads and individual roads. I think it would be something like £700 per meter, so if you've got a house down a cul-de-sac, little bit tucked away, you're suddenly up to £5,000 or £10,000, just to get to that one particular plot that's slightly offset.

In particular, the case study respondents highlight the critical importance of the economic cycle to the viability of the system, which was instrumental in the abandonment of district heat network for the Vista project. As a design team member notes:

> We went out to market for a scheme of four hundred and fifty homes, and it might have worked like more easily at that density to get the energy thing sorted out. Clearly you'd be talking more flatted developments which is easier anyway for the district heating stuff. But that was 2006 and that was before the housing bubble went bang and you get to 2009 and it was more and more apparent that that kind of density of development would not be probably desirable and anyway wouldn't be viable because it wouldn't be financed and wouldn't be sold even if it was financed.

What becomes very clear is the requirement for some key stabilising factors to be in place if a transition to decentralisation is to be undertaken successfully. More challengingly, these stabilising factors span the full spread of issues including finance, base load, density, form, use, pubic/private collaboration, and so on. A Vista design team member notes:

> The infrastructural costs associated with biomass power stations, district heating schemes, just do not stack up without public sector pump priming. So unless you've got a significant heat load that is provided by a swimming pool, public sector building, [or] large office block, district heating schemes for residential uses alone are really just not economically viable. And certainly where you've got mains gas, it really just doesn't compete. Without public intervention, particularly fiscal intervention, you are not going to get waste heat, whether it's biomass or coal or gas power stations, as part of the contribution towards sustainable housing and certainly not zero carbon housing.

The Vista development faced a series of intractable issues including; the necessity of standing charges to pay for the infrastructure, which meant that customers would pay probably about the same for their energy as if the house was a normal Code 3 or normal standard building regulation property; the question of security of supply, as the energy companies would only look at a 25- or 30-year concession agreement to supply energy; issues of system reliability if the biomass went down, which led to suggestions of standard house boilers acting as a back up system; and so on. In order to engineer this transition a very experimental orientation is evident both technologically and institutionally, but the final development evaluation and decision is primarily financial with the familiar risk aversion of the homebuilding industry influencing the final design choices. As a Vista design team member states:

> We tried it at Peterborough, we explored all the options possible, on-site generation biomass, glycol, pellets. We tried co-locating it with the football stadium, but the standing charge that was going to be levied was just unacceptable to [the homebuilder] and they saw it as an impediment to actually selling the houses and as such having gone through a full evaluation of a district heating scheme to provide what is a relatively low heat demand, [the homebuilder] took the decision to go back to HCA and argue that district heating scheme wasn't viable. And yeah, from a commercial perspective I think that's a sort of sound move.

Overall, the success or failure of DH in the Park Dale and Vista projects (and more generally in all low carbon housing developments) is not easy to pinpoint. It involves protracted debates and deliberations over energy provision, balancing of low carbon design strategies, scalar characteristics of the particular development, economic modelling and financial viability, and long-term maintenance and upkeep.

Conclusions

As we have seen, meso-scale infrastructure networks for heat and power are increasingly being used in the UK to realise low carbon housing targets. Central provision of heat and/or power can provide energy efficiency gains beyond individual households while also utilising non-fossil fuels and taking advantage of waste heat from power generation. However, these efficiency gains are offset by challenges including significant fixed costs (specifically for the infrastructure network) as well as a new management structure for delivering heat and/or energy to houses. Beyond the technical and economic challenges of district heating networks, there are a number of inter-related challenges that arise with the rescaling of domestic heat and power services. At a national scale, the UK energy industry continues to be locked into fossil fuel and nuclear generation technologies (Foresight 2008).

This is exacerbated by the nationalisation of energy provision in the 1940s, which encouraged a supply-logic, followed by privatisation in the 1980s, which created a profit logic, both arguably weakening any momentum towards energy efficiency and marginalising interest in alternatives to fossil fuels (Wilson and Game 2002, Winskel 2002, BERR 2008). The six main energy companies in the UK are likely champions of district heating but they have a significant stake in the gas supply market, a direct competitor with district heating (Hawkey 2009). Furthermore, the energy networks have been designed for centralised generation and one-way flow; introducing distributed generation requires significant network changes (Allen et al. 2008).

At the institutional level, there is a lack of knowledge about (and almost a fear of) district heating. Local authorities and housebuilders have a limited understanding of the energy services market. Homebuilders have concerns about the marketability of houses that are served by district heating and the acceptance by consumers (HCA 2011b). Meanwhile, energy providers are often unfamiliar with local planning policies and decision-making processes as well as homebuilding economics. Joining up the homebuilders, local utilities, and energy providers is a significant challenge. This is similar issue with other local responses to climate change that cut across conventional divisions within local authorities and other governance structures (Bulkeley and Kern 2006). Due to the lack of in-house expertise, it is commonplace to contract the design, construction, and management of energy services to a commercial energy service company (HCA 2011b) of which there are only a handful in the UK (see Vine 2003, Williams 2010).

There are also competing energy efficiency aims that problematize the introduction of district heating network. Späth (2006: 4) notes that 'with decreasing energy demand of buildings due to improved insulation and "passive house design", the load density of urban areas is becoming critically low for such systems to be economically feasible.' In effect, the realisation of lower heat demand in houses due to higher levels of insulation makes efficient energy supply networks redundant or uneconomically unattractive. This was experienced in exemplary eco-neighbourhood projects of Hannover and Freiburg and was remedied with higher standing charge to cover capital costs (TCPA/CHPA 2008). This suggests that the strategies to reduce carbon emissions from housing may compete with one another. Producing super-efficient houses could make meso-scale heat and power networks an unaffordable and unnecessary luxury for eco-developments. Also, these new district heating networks could lock in specific levels of energy consumption and not allow for future aspirations of energy efficiency (Späth 2006). Meso-scale infrastructure networks would effectively replace the high carbon universal grid with a lower carbon local grid but prevent the possibility of further carbon savings.

The rollout of district heating networks in the UK faces the classic infrastructure issues of cost, governance, and management that Jane Summerton described so vividly in the early 1990s. It is clear that a new momentum is being provided by the pursuit of lower carbon performance of the housing stock, but that challenges of cost, scale, design, logistics, and coordination, and so on remain and are only likely to be solved through context-specific negotiation and compromise. The case studies demonstrate that this can be done with proper funding, planning, and commitment from the design team. Additionally, the emergence of decentralised systems potentially revives a role for local government in energy planning as intermediaries between the various agendas of the actors involved (Vaze and Mayo 2009). The case studies highlight the importance of local actors in the realisation of meso-scale infrastructure networks. Thirdly, a focus on 'heat' as a means to rescale carbon reduction efforts and to influence urban form suggests that a city with heat infrastructure will not only be governed differently but it will also have different physical attributes in terms of density and mixtures of use. This not only involves scaling down energy provision from the national to the local level but also scaling up energy generation from the household to a neighbourhood energy centre. As a local authority engineer told us, 'Now we're going into those heat dense areas and coming out with energy masterplanning, which is really establishing where the network is, how far the network could realistically run and be economic or market competitive, given where the demand is and given what's available as sources of heat'.

Looking forward, it remains to be seen if this is yet another discrete phase of district heating in the UK or if it is building up to a sea change in energy provision. In 30 to 40 years time, will the UK be similar to Denmark where district heating is the norm? Or will these district heating networks and zero carbon housing projects that are currently being designed and built be a short-lived and ultimately failed experiment? In a period of austerity with the building industry very much in the midst of a down turn, it is difficult to predict, but it is clear that the UK is currently experiencing a crucial testing period for district networks. DH schemes that come online before April 2015 are eligible for a Government subsidy but there are no guarantees that this programme will be extended or repeated. The energy consultant at the Vista project notes that without further fiscal support from Government, 'I think you can see the demise of district heating schemes'.

We may find a final clue by looking back to Jane Summerton's work to note the enduring power of the 'invisible grid' of inter-dependent associations that underpin the physical network and the necessity of a 'compatibility of concerns that helps such systems emerge and that shape their rate and direction of system expansion' (Summerton 1992: 258). Seen this way, we might argue that until the concerns of policymakers, consumers, communities, developers, and energy suppliers are better aligned, district heating systems will struggle to find a welcome home in UK energy portfolio. This will involve a more systemic transition than simply 'educating' network providers and users about the virtues of DH through best practice exemplars. Instead, the viability of DH in the UK will require a more fundamental 'unlocking' of the national system and a challenge to the prevailing scalar logics of supply that continue to drive our networks of power.

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