Organisation and Governance of Urban Energy Systems

District Heating and Cooling in the UK

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1. The UK political-economic context for district heating and cooling

The transformation of fossil fuel energy systems into sustainable energy for resilient urban settlements is a profound challenge. Global demand for energy is accelerating and prices are increasing, at the same time that climate science is demonstrating the major risks of unabated carbon emissions. In addition, in many of the older industrialised centres of Europe, ageing plant and infrastructure are reducing system resilience, in the face of a changing climate. This paper focuses on the situation in the UK, where there are significant uncertainties about the organisation, governance and financing of low carbon energy systems, despite ambitious climate change legislation. Public policy is focused mainly at macro and micro levels: national-level responses emphasise legislation and regulation to incentivise large-scale utility investment, while building-level responses focus on household behaviour change, demand-side efficiency and micro-generation. Our research examines the neglected meso-level of city- or urban-scale responses, particularly in relation to district heating and cooling[2] (DHC) and combined heat and power (CHP). It examines the ways in which the potential for locally innovative leadership at city-scale is conditioned by structures of finance capital and system incumbents. From the perspective of city authorities, an active role promises local social and economic benefits including mitigating pollution, retaining greater proportions of energy payments in local economies, reducing energy costs and cost fluctuations for residents, businesses and public sector organisations, and contributing to regeneration.

Locally-accessible technical, financial and legal expertise and capacities for municipal authorities to play an active part in transition to sustainable urban heat and power are however tenuous. UK local authorities have had very limited roles in energy services for almost a century. Their role in provision was radically reduced by reorganisation of small municipal companies into central and regional boards in the 1920s, and then removed by the post-war nationalisation and centralisation of the 1940s, which spurred the corporatist era spanning the 1950s to the 1980s (Hannah 1982; Wilson & Game 2002). The current UK energy system can be characterised as a web of social and technical commitments (or 'lock-ins') to large scale and remote production and generation, and associated delocalised ownership and governance. In the 1980s, industry liberalisation and privatisation (and the freeing-up of oil and

[2] The majority of UK initiatives focus on heat provision, but we include cooling to reflect provision by some systems such as Birmingham and Southampton; heat networks can provide cooling by connection of in-building absorption chillers.

gas reserves internationally), prompted a further profound shift away from national systems of energy production, to international flows of capital, technology, fuel supplies, and international ownership of power companies and equipment suppliers (Winskel, 2002). International flows of capital via the dominant energy companies seek delocalised, replicable investment opportunities, which produce predictable returns on investment. Liberalisation hence resulted in running-down of long-term investment programmes, a shift away from capital intensive technology, and an emphasis on ‘asset sweating’ and short-term investment horizons.

Significantly, some other longstanding features of the UK energy system survived liberalisation: the relative neglect of energy efficiency and conservation, and of regional and local interests (Smith, 2007) have worked against combined heat and power (CHP) with DHC (Russell 1996). Despite a host of recent policy initiatives introduced to help meet ambitions for decarbonisation and enhanced security of supply, the UK energy system of the early-2010s still reflects an embedded orientation to large scale supply technologies, fossil fuels, and national level infrastructures, and a relative neglect of energy demand management, regional or local interests, and environmental policy imperatives. In the absence of strong and persistent external pressures or system shocks, these features privilege some pathways for system change above others (Winskel, 2011).

CHP-DHC has a long history at the margins of the UK energy system. This stands in contrast to the municipal energy companies in Scandinavia which were able to develop DHC systems as part of an integrated approach to urban infrastructure (Dyrelund & Steffensen, 2004; Ericson, 2009; Rutherford, 2008). For much of the twentieth century, UK engineers pursued a strategy of increasing efficiency through larger turbines, leading the electricity system to develop both physically and institutionally around large centralised plant, and creating conditions which undermined the economics of small scale CHP (Russell, 1993). Much of this infrastructure remains, and the liberalised market structures which have emerged around existing plant favour the large incumbent companies (Mitchell, 2008; Toke & Fragaki, 2008; Kelly & Pollit, 2010). In the 1970s, Walter Marshall highlighted the potential of CHP/DH to supply a significant proportion of overall heat demand (Department of Energy, 1979). However, he also noted that without active planning and policy instruments, its role in the UK was likely to be greatly restricted by the growth of natural gas.

The recent return to planning and top-down steering of the UK energy system (viz. the Carbon Plan (DECC, 2011a), National Infrastructure Plan (HMT, 2011), and National Policy Statements for Energy (DECC, 2011b)), nevertheless raise questions about whether the long-identified potential of CHP-DHC may now be realised – or whether it will continue to suffer from the relative neglect of being caught between large scale supply-side projects and infrastructure, and householder-level demand-side measures. As of the early 2010s, policy support for CHP-DHC had yet to manifest itself forcefully onto the centre-stage of UK energy policy. There are some signs that UK policy and regulation may undergo a more thorough remaking, possibly including measures to support CHP-DH under the forthcoming UK Heat Strategy, but a combination of deep-seated path-dependencies and recently imposed imperatives for expansion of national-level infrastructures seem likely to work against a radical change toward urban community-led heat provision. The UK Government recently concluded that there was ‘no reasonable alternative’ to a massive re-investment in the UK’s national system of electricity generation and transmission: ‘[we do] not believe that decentralised and community energy systems can lead to significant replacement of larger-scale infrastructure’ (DECC, 2011b, p.24).

Despite these circumstances, urban authorities are expected by central government to reduce regional carbon emissions. Some of these have developed urban DHC networks by finding an array of niche solutions to myriad challenges. In this paper we explore three of these projects, framing them as *Local Energy Governance and Organisation* (LEGO) models to emphasise both their atypical (in contemporary UK context) nature, but also to highlight the work done to configure the heterogeneous components of the system with the aim of establishing a stable foundation for urban heat and cooling networks.

2. Socio-technical and economic characteristics

DHC systems transport heat and cooling through highly insulated pipes. Assets have long lifespans, typically forty years for pipework, and in common with other infrastructure, the upfront development costs are high, while the marginal costs of system use (generation, distribution and transfer of heat) are generally low (Helm, 2010). Sunk costs are typically recovered by above-marginal-cost charges for heat, with business models requiring a number of years to break even. The lifetime costs of the system can be reduced by maximising the heat delivered, targeting areas of high heat demand and recruiting users with diverse daily and seasonal heat demand profiles. Large anchor loads stabilise a system by reducing the risks and complexity of ensuring sufficient heat demand over the long term (Pöyry Energy, 2009; Roberts, 2008; Summerton, 1992).

The character of DHC creates particular organisational constraints. The temporal dislocation between sunk costs and subsequent revenues means that judgements of economic viability of particular system configurations are highly sensitive to the cash-flow discount rate adopted. This is in turn dependent on the objectives of the organisation(s) developing and financing the system, and the risks they perceive. The long cost recovery period establishes mutual interdependencies: system builders rely on the on-going heat demand of subscribers. Consequently they are exposed to off-take risks created by uncertainty in users’ long-term heat demand and potential to switch to alternative supply systems. Subscribers are dependent on the system for provision of a critical service, and may face significant cost and information barriers to changing supply. The long term cash flow profile also creates a risk to the system owner that, at some future point, public authorities will introduce regulations requiring reduced heat prices which reflect marginal costs rather than average lifetime costs, effectively forcing the write-off of sunk costs (Helm, 2010).

Cash flow characteristics are not the only constraints on project structures. The socio-technical terrain into which a system is woven is complex and place-specific, encompassing the physical characteristics and ownership of land and buildings, existing building heating technologies, established energy contracts, user practices and expectations, and interfaces with other energy systems. Windows of opportunity for retrofitting, created by regeneration or new infrastructure construction, are frequently difficult to coordinate with the variable timescales of different actors. Social constraints, such as the willingness of subscribers to connect to DHC, can be more difficult and time consuming to resolve than physical constraints (Summerton, 1992).

3. Theorising local energy governance and organisation (LEGO)

Creating and maintaining viable DHC consequently requires discovery of project pathways adapted to the demands of political-economy, network technology and local circumstances. This type of place-specific socio-technical formation has been variously characterised as a locally-styled socio-technical system (Hughes, 1982), a Grid Based Multi-Organisation (GBMO) (Summerton, 1992), and as a local network organisation comprised of 'an array of the heterogeneous bits and pieces that is necessary to the successful production of any working device' (Law and Callon, 1992: 22). The configuration of the local network organisation enables development to proceed, but the actors vary in their relationship, and commitment, to the particular system and locality. In Law and Callon's terms, the local network may need access to non-local financial and technical knowledge networks to support development. During the establishment of DHC in Sweden, for example, the Swedish District Heating Association (SDHA) was a key site for knowledge development and dissemination. It was critical to the speedy elimination of poorly performing pipework, and set technical standards to prevent municipalities becoming locked-in to particular component suppliers and incompatible infrastructures (Ericson, 2009).

In the UK, establishing development pathways is likely to be more demanding than Scandinavian experiences suggest, due to the political-economy of centralised energy markets and global finance, matched by uncertain state commitment to regional contributions to low carbon energy. The institutions and networks of the UK DHC system are weakly developed, as indicated by lack of dedicated regulation, intermittent and unpredictable grant funding, under-developed technical standards, and knowledge held as intellectual property of consultants and contractors rather than in the public domain (Hawkey, 2012). Knowledge about, and legitimacy of, urban DHC is therefore lacking. Significant transaction costs, associated with complex intra- and inter-party negotiations, are incurred in establishing de novo the legitimacy, and the sustainability value, of the technology, and of local energy investment. A common understanding of objectives, governance, business models, and shares of risks and rewards has to be built among stakeholders. Multiple organisations are likely to be involved in gathering data, recruiting subscribers, and designing a network, as well as in construction, operation and maintenance.

In this context, the municipal authority is likely to be a key actor. It has unique potential to develop the requisite knowledge and legitimacy. In more favourable circumstances in other European countries, local authorities have conventionally played important roles in supporting and stabilising (if not actively developing) heat networks (Grohnheit & Gram Mortensen, 2003). Their local democratic status confers long-term commitment to place, legal powers and duties, and control over assets and resources. As the operator of a large diverse estate with low risk of insolvency, and local responsibilities for many services, municipalities can act as focal customers and intermediaries. In addition their planning powers can be used to ensure co-location of heat demand and heat sources, and to coordinate DHC development with other infrastructure or regeneration investments. They can help to recruit subscribers by adopting supportive planning policies, ranging from requiring developers to calculate the costs and benefits of joining a system, to the more directive option of stipulating that buildings within particular areas are required to connect. In the absence of regulatory frameworks, LAs play an important role in quasi-regulation, reducing the risk of future changes to the regulatory regime, and avoiding the prospect of having to write off sunk investments. The municipality may hence play a critical part in risk mitigation, co-ordination and deployment.

UK local authorities (LAs) have less autonomy than their European counterparts, however: they are subject to centralised budgetary control of taxation and revenues (Wilson & Game, 2002) and are constrained by the *ultra vires* principal to undertake only those activities permitted by statute. Reforms to their role in service delivery, driven from the centre since the 1980s by neoliberal imperatives of competition, have complicated and weakened local governance. A range of functions previously undertaken, including housing provision, public transport, waste management and estate management, have been variously outsourced or privatised (Leach & Percy-Smith, 2001). This has both multiplied the number of actors involved in local governance and reduced the in-house capacities of LAs to develop and provide services.

Their relatively weak position makes LEGO models for the UK highly challenging. Even though municipal capacities are expected to be a necessary component of development, experience shows that they are not sufficient; only some urban authorities have developed DHC. Other research suggests that local social capital may be an essential component in urban energy innovation, especially in poorly performing regional innovation systems. Without this ‘most important missing ingredient’ (Cooke et al. 2000: 152), the other factors of the necessary GBMO/local network are unlikely to be adequate. Though a contested term (Tura and Harmaakorpi, 2005), the concept of social capital essentially refers to the potential of a social system to learn effectively through interaction. The OECD defined social capital as ‘the networks … norms, values and understandings that facilitate co-operation within or among groups’ (OECD, 2001, p.41). A distinction is made between *bridging* social capital (manifested in interactive learning which connects together different types of actors), and *bonding* social capital (which supports interactions within a group, or between the same kinds of actors). A recurring theme in relation to technological innovation is the importance of bridging social capital for more ‘disruptive’ technologies (Christensen, 1997; Ehrnberg and Jacobsson, 1997; Lundvall et al., 2002; Maskell, 2004; Tura and Harmaakorpi, 2005).

Social capital is hence likely to be implicated in the mobilisation of local and non-local technical, legal, financial and commercial knowledge resources to support development. The process of engaging local social capital with non-local networks, in customised combination with legislative, policy or public finance measures, is expected to create the means to legitimising investment and configuring effective local solutions. Social capital is therefore likely to be a key factor in structuring and sustaining LEGO models. Decisions taken at this stage are in turn likely to result in differential significance for social capital in future urban energy transformation.

Drawing on theories of the role of social capital in place-specific socio-technical systems, and also, our detailed case study analyses presented below, a number of key dimensions can be identified which seem likely to differentiate LEGO models: decisions about *ownership and control* (locally embedded vs. non-local); the *governance* of subscriber, or customer, relationships, and level of commitment to in-house vs. outsourced techno-economic *expertise*. As we elaborate in the next section, these dimensions interact to define place- and case-specific trajectories for urban DHC.

4. UK local energy governance and organisation in practice (LEGO)

Three contrasting UK case studies illustrate the range of objectives, ownership and business structures, from locally-controlled non-profit community energy, to public-private partnerships with corporate ownership and control. Case study evidence is derived from semi-structured interviews and documentary analysis, conducted as part of comparative research on DHC development.[3] The local authority plays a critical, but distinctive, role in each case. Each has different origins and different development pathway dynamics, and subsequent organisation structures reflect these differences. In every case, DHC has been developed by a newly established ESCo, rather than as an in-house initiative, thus mitigating time- and resource-management conflicts.

<<< Insert Figure 1 about here. Caption: “Locations of DHC/CHP case studies. Reproduced from Ordnance Survey map data by permission of the Ordnance Survey © Crown copyright 2010.” >>>

4.1. Overview

4.1.1. Aberdeen Heat and Power Ltd (AH&P)

Aberdeen is a small city in the North East of Scotland. In 2003, Aberdeen City Council (ACC) established AH&P as a non-profit company, limited by guarantee, with a volunteer Board, to develop and operate CHP-DH. The

[3] The *Heat and the City* research project is funded by the UK Research Councils, Grant No: RES-628-25-0052 www.heatandthecity.org.uk

company is constituted under a general obligation to work ‘for the benefit of the citizens of Aberdeen’ by tackling fuel poverty. As a non-profit organisation, any surplus is used for reinvestment or reduced heating costs. Under a fifty year framework agreement with the council, AH&P has developed several communal heat schemes, focusing on (predominantly[4]) council owned multi-storey residential blocks, schools, and sports and leisure facilities. Some of the co-generated electricity is sold via a ‘private wire’ to a school; the remainder is sold into the public electricity network via a consolidator.

4.1.2. Thameswey Energy Ltd (TEL)

Woking, in Surrey, is part of the Greater London Urban Area. The Council commitment to DHC resulted from environmental politics combined with financial concerns for energy cost saving, and in 1999 Woking Borough Council (WBC) created Thameswey, a commercial company wholly owned by the council. Thameswey in turn established TEL as a joint venture with a Danish commercial energy services company, to develop and operate DHC systems and other energy initiatives, such as solar PV arrays, within Woking and elsewhere. Currently TEL operates several CHP-DHC networks in Woking and one in Milton Keynes (about 60 miles away). Each serves municipal and commercial buildings, plus a small number of privately owned flats. Thameswey’s ‘articles of association’ require it to operate commercially, but to recycle its profits into environmental and energy services projects. Its subsidiary, TEL, also operates commercially, and profits are disbursed as dividends. At its incorporation, the private sector partner was the majority shareholder, but following a lessening of restrictions on LA trading, and financial constraints on its private sector partner, Thameswey became the majority shareholder (with a 90% stake). Thameswey’s directors are senior council officers, company executives, independent non-executives and a WBC councillor. TEL’s board is similar, but includes representatives of the private sector partner.

4.1.3. Birmingham District Energy Company Ltd (BDEC)

Birmingham is the UK’s second largest city and CHP-DHC has been developed as a component of the city authority’s local regeneration strategy. BDEC was established in 2006, as a wholly owned subsidiary of a private sector company under a partnership agreement with Birmingham City Council. BDEC’s parent company, Utilicom, has since been acquired by GDF-Suez and restructured as energy services company, Cofely. BDEC operates under a 25 year ‘concession contract’ with the council. It has developed and operates networks serving council and other public and commercial buildings, plus a small number of council housing tenants. BDEC’s directors are employees of Cofely. The company has a *partnership board* for large subscribers, but this does not exercise formal control over the company. The first 5% of BDEC’s profits are taken to pay Cofely’s costs, and subsequent profits are split 50:50 to Cofely, and to partnership board members in the form of an energy rebate.

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[4] In the UK, social housing tenants have the ‘right to buy’ their home from their landlord, so some of the Aberdeen multi-story blocks include a small proportion of privately owned flats.

4.2. LEGO: urban niche origins

While specificities of goals of politicians and officers, and location, of the respective urban authorities inform the different CHP-DHC models, common themes concern the centrality of social capital as a resource for local learning, and its bridging role to national or international networks of expertise. In each case, such social capital played a key part in establishing legitimacy of the technology, and of the role of the LA in investment, financial accounting, and accountability and governance in relation to subscribers/customers. Successful *demonstration* or *pilot projects* drawing on, and enhancing, local social capital proved to be important catalysts in local learning about the technology and mobilising wider support.

In Aberdeen, legislation under the UK Home Energy Conservation Act (1995) enabled the Council to appoint a housing officer with responsibility for energy conservation. Access to public funding for energy saving in turn provided the means for formal appraisal of options for affordable warmth for the worst of the council's electrically heated multi-storey housing. An appraisal metric of "cost in use" to tenants was used to justify rejection of the lowest capital cost option (refurbishment of electric heating) in favour of gas CHP-DH. The officer's access to formal and informal social networks and experience in anti-poverty campaigns brought skills in negotiation and influence, and created a bridge to non-local networks of community energy knowledge and expertise. Combined with a change in financial opportunity structure, in the form of UK government grant funding for community energy, this enabled Council commitment to developing locally-controlled CHP-DH. Preparatory work completed under the options appraisal gave the Council an advantage in successful bids for funding, but local political support was critical to eventual legal and financial approval. The officer proposal to the housing committee set out rationales and financial solutions, but Council legal advice recommended rejection, because of the risk to Council finances. The Deputy Leader of Council, as chair of the Committee, noted the advice as required, but set it aside and recommended agreement. The Committee decision resulted in the formation of a new ESCo, AH&P, as contractor to the Council for the provision of energy services. The interaction of local social capital, activation of non-local knowledge networks and provision of public finance proved to be critical to local innovation to bridge the gap between infrastructure costs, projected cash flows, and locally available housing capital. Aberdeen's first pilot system was a relatively[5] simple design, supplying only residential multi-storey buildings. Its homogeneous load profile limited its operating efficiency, but it enabled both ACC and the embryonic AH&P to build internal experience, as well as stronger legitimacy for both the technology and the governance model, further enhancing local social capital.

Establishing legitimacy of CHP-DHC in Birmingham stemmed from committed actors in city engineering services, who negotiated over a long period with sceptical Council finance and legal teams. Risk-averse accounting and legal criteria, plus a short-term cost focus for procurement, and cautious local

[5] This simplicity is relative, as delivery of the first system was an extraordinary achievement, requiring determination and courage.

interpretations of EU procurement and state aid rules, proved to be obstacles to establishing a common view of the value of the technology. As in Aberdeen, fuel poverty was the initial stimulus for a pilot project, but it was gradual establishment of the whole life cost advantages of CHP-DHC, in interaction with economic regeneration goals, which provided the eventual justification for investment. Heat-users were an important instigator of change: in the 1980s, public housing tenants successfully brought court cases against the council, forcing them to improve building insulation and heating in a number of multi-storey blocks. The anticipation of successive court defeats, and resulting unplanned-for housing improvement costs, forced the Council to reconsider refurbishment priorities. Engineers were however unable to convince the finance team of the value of CHP/DH, and the majority of the multi-storey housing stock was treated with the lowest capital cost option (dry-lining and refurbished electric heating). Building engineers did however convince colleagues that a small-scale *pilot* was feasible: a gas-fired CHP/DH system was installed at a local leisure centre and swimming pool, and connected to adjacent multi-story residences. The system received considerable positive publicity, with tenants able to heat their homes at affordable rates, and local politicians became more supportive.

Around 2003, a new opportunity to establish CHP-DHC emerged when city centre regeneration plans coincided with scheduled replacement of gas boilers for a national convention centre. By this stage carbon management goals were more prominent in public policy. In the past, city engineers had found it difficult to contest the lowest cost criterion for building refurbishment, and struggled to establish the credibility of a ‘cost in use’ or *whole-life costing* (WLC) evaluation. Under best practice guidance from the UK government, however, whole life accounting has gradually begun to be adopted by LA finance teams. BCC finance team doubts were assuaged by training, which initiated senior acceptance that WLC potentially provided more powerful control of engineering costs, and could be used to identify and allocate *risk* to different parties. Crises arising from plant failure and breakdowns had traditionally been accepted as inevitable, and the scope for unplanned costs was high. WLC promised better management of costs, and revised *accounting frameworks* hence created more support for DHC investment.

In contrast with Aberdeen however, integrating CHP-DHC into regeneration strategy entailed risks of low take-up of heat by commercial subscribers; BCC was wary of taking on these risks. It was influenced in its search for a viable business model by a visit to the Southampton Geothermal Heating Company (a Utilicom/Cofely subsidiary), which relied on a private supplier to own and operate the system. The eventual decision to proceed to technical feasibility and procurement coincided with the same UK government funding for community energy which prompted action in Aberdeen. Negotiations between the Council and the preferred bidder proceeded, despite concerns about risks of failure continuing to be expressed by municipal finance and legal teams. The project is now regarded by local politicians and officers as a success, and has proved to be a foundation for ambitious plans for city-scale district energy.

Woking Borough Council’s (WBC) investment in CHP-DHC can be traced back to the environmental and economic priorities of local politicians. These informed its 1990 Corporate Energy Efficiency Strategy to reduce the council's energy consumption by 40% within ten years. Energy efficiency and environmental considerations were mainstreamed within the council through training and use of environmental impact assessments (Morphet & Hams, 1994). In 1992 a £250,000 rolling energy efficiency fund, which again embodied a WLC approach, was established. The fund focussed initially on energy management and, through the 1990s, developed small scale CHP and solar PV projects for council buildings. The perceived success of these pilot initiatives, in both financial and environmental terms, strengthened political support for 'environmental entrepreneurialism', and the Council expanded the model to more ambitious initiatives. Towards the end of the 1990s, recognising the efficiency potential of diversifying heat loads through urban energy, the council began examining the potential for CHP-DHC in the borough. In 1998, supported by a grant, WBC explored the relatively uncharted territories of how a local authority could develop energy services within its legal constraints.[6] It developed *Thameswey*, an arms length company participating in joint ventures, as a means of continuing the rolling-fund energy efficiency programmes, while drawing in private sector expertise and finance, and shielding the council from financial risks.

The "environmental entrepreneurialism" of the *Thameswey* governance model required it to seek opportunities for profitable investments outside the borough, and in 2002 it successfully bid to deliver a sustainable energy system for new commercial developments on land held by English Partnerships (a national regeneration agency). Continuing the logic of risk encapsulation, a subsidiary of TEL, *Thameswey Central Milton Keynes* (TCMK) was established to deliver and operate the project.

In earlier attempts to develop DHC in the UK, stringent accounting requirements, designed to prevent cross-subsidy of any LA activities defined as ' non-core', have often prevented investment (Russell, 1993). In these three cases, the adoption of *discounted cash flow appraisal* is a central feature of justification. Different whole life financial formulae were used to further different primary objectives, but the reframing of cost calculations to bridge the traditional divide between *revenue* and *capital* budgets in UK LA financing enabled concerns to be addressed. Project development, supported by and further enhancing local social capital, could then proceed.

4.3. Developing Project Pathways: business models, finance and non-local expertise

The chequered history of DHC in the UK results in investment being perceived as risky and non-commercial (Russell, 1996). The lead actors in each of our cases pursued distinct strategies to establish a viable and legitimate business model. High infrastructure costs were mitigated by municipal commitment, although these were dealt with differently, depending on local objectives. The key LA role is manifested in two ways: either direct public investment enabled the creation of a business model with a positive cash flow, and/or long-term contracts between an ESCo and the LA provided

[6] At the time a local authority was required to have less than a 20% equity share in a trading company for their accounts to be treated separately.

secure heat loads and revenues. Each LA 'ring-fenced' project finances through creation of dedicated energy supply organisations, whether as commercial or non-commercial enterprises. Long-term contracts served as significant financial assets, giving stability to income projections from heat sales. Aberdeen council created a fifty-year framework agreement with AH&P. Birmingham signed a 25-year energy services contract with Utilicom/Cofely, creating BDEC. Woking established TW and TEL as ESCos designed to shield the council from financial risk, while allowing CHP-DHC developments to proceed.

In other dimensions however, the business models reflect locally-defined objectives. In Aberdeen, in addition to government grant funding, a Cooperative Bank loan was raised to enable the first investment. The Affordable Warmth Strategy justified Council commitment to act as a loan guarantor for AH&P, which lowered the cost of borrowing. Housing capital payments, transferred on a staged basis, enabled payment of interest on the loan. Council evaluations of the first scheme were positive, and built political confidence, legitimating further capital investment. Increased confidence meant that subsequent project funding was managed via the Council's access to low interest Prudential Borrowing[7], with loans repaid from housing capital, as funds became available. The terms and conditions of the government grant contribution to funding for each project required demonstrable carbon targets to be met. In the third energy centre and heat network development, the ability to meet the target was threatened by the poor condition of the building fabric in some of the multi-storey housing blocks. In order to secure the funding, alternative heat loads had to be found quickly. An Aberdeen Council leisure complex was selected as a means of achieving the carbon savings, but at additional cost for pipework. AH&P were concerned about the risk to business finances and cash flows, placing considerable pressure on Board members. Independent financial advice was sought by the AH&P Chair, which provided a solution in the form of an overdraft facility with the Co-op Bank, again underwritten by the Council.

In Birmingham the Council stance was more emphatically risk-averse and regarded direct ownership of energy systems as creating unacceptable financial risks. The preferred solution was a public-private partnership (PPP) contract, with risks of system failure managed by the private company. Creation of BDEC required Utilicom to underwrite the financial risk, but the 25-year contract signed by the Council provides guaranteed income. Again a share of project finance was contributed by UK government community energy grants, with conditions set about eventual public ownership of assets. BCC had a further concern about the risk that a monopoly heat/power supplier may charge higher prices than the best market rate. This is managed by an opportunity for annual challenge to proposed prices, compared to gas and electricity market prices. Formal contract negotiation to resolve details of legal and risk allocation issues between parties took considerable time. The business has continued to evolve with investment in energy centres at a local NHS hospital and University, bringing new partner members to the Board of

[7] Prudential Borrowing is the UK framework for public sector borrowing without central government sign-off.

BDEC. Negotiations over contractual relationships and assets have continued with the building of a new public library, designed with an integral energy centre owned and operated by BDEC. The whole life cost model has been further developed and extended to evaluate DHC potential for the city's 400+ schools, which are regarded as 'hubs' for eventual interconnected energy provision across the city.

In Woking, the original TEL business model gave the council a 19% share. The first DHC project was financed on an 80:20 debt to equity ratio, making the council liable for only a fraction (3.8%) of the upfront finance. TEL's debts are not underwritten by the council, but secured against cash flow from other Thameswey activities. However, the council's current contribution to TEL's financing is substantially greater than 3.8% for two reasons. First, changes in shareholding mean the council now ultimately owns 90% of the equity in TEL. Second, the council effectively operates as a long-term refinancing bank for the company. Initial project development draws finance from commercial lenders over periods of around five years. As these loans fall due (roughly tracking reductions in technology risks as system components are commissioned), debt is rolled over into loans from the council. Compliance with state aid rules requires these loans to be offered at commercial interest rates, but the council's ability to borrow on a long term (fifty year) basis translates into long term stability in TEL's repayment commitments. The council finances this lending by its own (lower cost) borrowing, and the difference between TEL's interest payments and WBC's are taken into the general revenue budget of the council.

4.4. Developing Project Pathways: configuring subscribers

Different LEGO models are informed by the composition of subscribers who presented the original opportunity to develop CHP-DHC: council tenants and leisure facilities in Aberdeen; public and commercial buildings and small numbers of domestic users in Birmingham and Woking. Initial subscribers also influence the heat available for subsequent network expansion.

In Aberdeen, heat pricing is reflective of costs, and the main customer of AH&P is the council. The council manage tenant payments for heat on a fixed charge basis with rent. All except one of the other buildings connected are under council control; risks associated with supplying third parties are correspondingly reduced. The governance of AH&P is hence managed by its subscribers, with councillor, ex-officer and community organisation board members, as well as provision for tenant representatives. Expansion of the network to commercial subscribers would introduce new risks of bad debt, which the council would not underwrite. In addition the council is concerned to ensure that any future commercial supply would not impinge on AH&P's capacity to supply public housing and facilities.

In Woking and Birmingham, the mix of public and commercial subscribers introduces significant governance challenges. Thameswey uses the subsidiary TEL as a means to shield the council from underwriting commercial contracts, but this exacerbates recruitment difficulties. Lack of local familiarity with the technology, the small scale of the Thameswey group (in comparison with dominant energy utilities), and the lack of consumer protection and industry standards for heat supply, contribute to perceptions of risk. In the absence of WBC financial guarantees, lengthy legal negotiations with commercial customers have been necessary to establish a bespoke contract designed to protect their interests.

Similar issues have been confronted in Birmingham. While Utilicom (subsequently Cofely) could rely on its parent company to underwrite commercial contracts, early negotiations with potential subscribers were marked by demands for extremely high insurance compensation rates for supply failure. Businesses were eventually persuaded about reliability through evidence of Utilicom system performance and experience. In neither Birmingham nor Woking are subscribers meaningfully integrated into governance. In BDEC, a partnership board has representation for founder subscribers, but the board does not control decision-making. Heat prices are benchmarked against equivalent gas heating, with the opportunity for annual challenge. Although the city council is lead subscriber, it faces difficulty in delivering network connections to housing tenants, because of the BDEC commercial model. Housing tenants represent relatively high cost and high risk customers for a business whose priority is profitability. This means there is little incentive to extend the system to the multi-storey housing in regeneration areas. Extensions to public housing so far have required public funding, and in one case have been done directly by the council. In Thameswey and TEL, the council is the only subscriber integrated into governance. Heat prices are benchmarked against gas and electricity prices, and subscribers can request price review after five years. A small proportion of TEL's heat and electricity is sold to domestic subscribers, though as owner occupiers and private rentals these are treated as lower risk than social housing tenants.

4.5. Developing Project Pathways: engagement with energy markets and techno-economic expertise

While DHC networks can use heat from a wide range of sources, gas CHP is a commonly used technology in the UK. The availability of gas from domestic and imported sources mitigates supply risks, and the higher price of electricity over gas (the "spark spread") enables CHP heat to be priced below that of individual gas boilers, the main competing option (Kelly & Pollitt, 2010). Electricity revenues from CHP are also 'naturally hedged': UK electricity prices generally follow wholesale gas prices, because gas fired power stations are often the marginal (price-setting) electricity generating plant.

Electricity produced by CHP generators may be used in different ways, including (in order of net revenues generated): on-site, or supplied directly to other users via a private wire, or sold via the public system through other companies (Toke & Fragaki, 2008). The LEGO models described here adopt different approaches, reflecting the degree of expertise held within the ESCo. A proportion of the electricity generated by AH&P is supplied via private wires to a school, but the majority is sold at a fixed tariff through a consolidator. The contract with the consolidator shields AH&P from requirements to balance electricity supply with demand; hence the CHP engines are operated in response to heat demand without the complexity of responding to electricity markets. Since the consolidator bears the electricity balancing risks, the tariff offered is relatively low: Toke & Fragaki (2008) estimate that the consolidator model provides around three quarters of the revenue that an equivalent generator selling directly onto wholesale markets would receive.

Thameswey's longer history of system performance data, and development of local expertise, enables it to take more active positions in energy markets, trading on spot and forward markets for gas supply, and selling electricity in response to market conditions. While administrative and credit requirements of participation prevent Thameswey selling directly to wholesale markets, its consolidator arrangement offers a higher average tariff in return for exposing the company to electricity grid balancing risks. TEL also offers Short Term Operating Reserve services to the electricity network operator as part of an aggregation of small generators. Both of these arrangements yield higher revenues than fixed-tariff consolidator models, but require greater in-house expertise. They also create incentives for operation of the CHP engines in response to electricity market demand, rather than local heat demand. Given limited heat storage capacity, this can lead to heat dumping, which diminishes carbon savings.

4.6. Dimensions of Local Energy Governance and Organisation

Four key dimensions can be identified to differentiate between the niche origins and development pathways of the case studies described above; these are summarised in Table 1. The dimensions are not necessarily exhaustive of all possibilities, but they do usefully highlight consequential variations of governance and organisation.

None of these three developments could have taken shape without the commitment of local actors (politicians and officers) to the mobilisation of social capital through wider networks of knowledge and expertise. Such UK-wide networks derived from civil society anti-poverty campaigns (Aberdeen and Birmingham) and environmental movements (Woking) on the one hand, and, on the other, from businesses supplying urban energy development, finance and engineering services (all three cases). Success was also dependent on a component of public finance, the availability of which depended on policy recognition of the contribution of urban distributed generation to affordable low carbon energy.

Social capital is positioned differentially with respect to future extension of the projects, however, with different local objectives (affordable warmth in Aberdeen, energy and carbon saving in Woking and economic regeneration in Birmingham) lending different emphases to governance. In AH&P enhancement of social capital across different sections of civil society (housing tenants, community organisations, urban energy knowledge networks) is critical to the non-profit model of the business. In Thameswey social capital is integral to profit-oriented business development, with profit directed to socially-defined goals of energy and carbon reduction. For Birmingham council, BDEC is the instrument to deliver low carbon energy services, on a profit-making basis, using non-local techno-economic and finance expertise. Social capital is notionally on the margins of the business model, but is central to attaining public goals for city-wide low carbon energy. The latter will not be delivered in the absence of on-going engagement between the municipality and BDEC's parent company, whose primary goal is profitability.

Table 1. Key dimensions of organisation and governance for CHP-DHC in the UK

	Aberdeen	**Woking**	**Birmingham**
Balance between social and financial capital in business model	Social capital orientation: tackling fuel poverty priority	Mixed social-financial capital, 'environmental entrepreneurialism'	Dominant financial capital orientation; commercially-led
Locally embedded /non-local ownership	Locally embedded, with strong ties to Aberdeen Council	Locally embedded, with European minority partner	Locally specific delivery vehicle; partnership with local actors; non-local ownership (Cofely UK/ GDF-Suez)
Governance role for main subscribers	Main subscriber (the Council) is integral to organisation and governance, but Board is independent and voluntary	Multiple commercial and public subscribers, among whom only the local council is part of governance structure	Major subscribers are members of a partnership board, but do not have formal control over decision making
In-house or outsourced techno-economic expertise	Reliance on third parties for development, maintenance and financial control; progressively bringing in-house	Drew on expertise of private partner, but developed commercial expertise in-house	Reliant on parent company expertise

5. Discussion and Conclusions

Although wide-ranging reforms of the UK energy regime are on-going, and the potential for urban low carbon heat and cooling networks is recognised by policy-makers, DHC remains caught in the squeezed middle ground between greater efforts at large-scale national infrastructure investment on the supply side, and individual householder incentives on the demand side. In these cases urban energy is irreducibly bespoke and tied to local context, and to multi-organisation networks of expertise, bridging local knowledge, governments and financial and energy markets. Our findings support Kelly and Pollitt's (2010) conclusion that the technology offers long term benefits to the UK, but faces significant short to medium term barriers, arising from economic risk, regulatory uncertainty and energy system lock-in to large scale technologies and networks. Business sustainability is sensitive to factors largely outside the control of the CHP-DHC system, including relative fuel prices and access to electricity distribution networks. Ultimately, a number of systematic barriers remain, especially the challenges of long-term infrastructure development, stemming from upfront costs, energy market volatility and long payback periods. Its development faces particular challenges in the context of UK energy institutions and organisations which, oriented significantly to financial capital, emphasise de-risking by delocalising and standardising investment propositions.

Given the current uncertainties over policy and regulatory support for urban governance of sustainable energy, prospects of significant urban energy transformation remain marginal. The cases show that development in unsupportive circumstances requires forms of social capital which enable project developers to overcome the difficulties posed by delocalised investment finance. In two cases, Aberdeen and Woking, where local actors sought to retain control over the revenues (as well as the risks) from urban energy provision, governance and the mobilisation of finance continue to prove highly demanding. The instabilities and short-termism of globalised finance capital tend to weaken social capital, trust and cohesion in innovation governance: 'increasingly it is finance capital that judges what is "good-practice" among firms as well as among governments … the uninhibited rule of finance capital gets into serious conflict with some of the fundamental prerequisites for the sustainability of the learning economy' (Lundvall et al., 2002, p.225). Interactive learning, and development of locally-embedded expertise seems to be facilitated in more stable social and financial arrangements, such as those evident in the less formal, trust-based German system than in US more formal contract-based innovation system, characterised by relatively mobile flows of capital and personnel (Nooteboom, 2000). The UK context resembles the latter more than the former.

While the UK arguably represents an extreme case of local governance fragmentation, European local governance has undergone parallel shifts. Scandinavian DHC systems were generally developed by municipal authorities, either as in-house projects, or more commonly through municipally owned energy companies, as part of an integrated approach to urban infrastructure development (Dyrelund & Steffensen, 2004; Ericson, 2009; Rutherford, 2008). Liberalisation is diminishing municipal control over energy provision, and financial pressures, coupled with political difficulties in adopting market-based tariffs, have led European local and regional authorities to greater privatisation of their energy companies (Monstadt, 2007; Ericson, 2009; Rutherford, 2008). Attempts to develop (or enable the development) of DHC in UK cities, therefore, illustrate more general European issues concerned with the interaction between energy and financial markets and local governance and control. They also provide insight into interactions between governance and socio-technical infrastructures (energy, waste, water, transport) whose reconfiguration could address urban priorities, but whose organisation is rarely controlled at city level (Hodson & Marvin, 2010).

Indeed, an over-arching lesson from these three cases is that effective governance and organisation for socio-technical DHC is likely to require not top-down command and control planning, but a combination of centrally-established supportive standards and incentives with devolved municipal powers. As well as responding to the problem of infrastructure finance for heat networks, UK and devolved governments could ensure more strategic use of spatial planning powers, and development of common technical DHC standards and consumer protections. The necessary counterpart to such central measures is greater devolved municipal control over financial and technical resources for sustainable urban energy. The four dimensions of local energy governance and organisation we identified here suggest ways in which this could be achieved. The ESCo shell structure used in each case provided a device for clarity in business governance, without determining the particular combinations of social and finance capital, knowledge and expertise. It gave latitude to actors to develop locally-viable multi-organisation models. Parameters of financial risk were made susceptible to greater transparency and accountability, and compliance with LA trading regulations was enabled. In sum, a combination of social and financial capitals was critical to the structuring of ownership and control, governance roles for subscribers, and developing local capacity to access global expertise and energy markets effectively.

Support from central governments to change the regulatory parameters would reshape the risk calculus, by integrating social and environmental goods into dominant financial evaluation practices, as practiced under a number of other European models.[8] Within this, scope needs to be retained for empowering local actors to shape innovative solutions, while reducing uncertainties, streamlining development and mobilising investment. This would allow for greater recognition of the value of locally-optimised solutions devised by meshing of local and global expertise. It should enable accelerated transferable learning between projects, and shared standard templates for legal compliance. This approach optimises the value of municipal capacities (long-term commitment, local democratic participation, and local knowledge) and enables the local authority to act as a quasi-regulator to reduce downstream transaction costs, improve systems design and energy saving, and to give greater clarity to the implications of different control and ownership arrangements. By this means, rule-oriented and decontextualizing finance capital could be made to work better in support of social capital, local commitment and capacity, rather than devaluing these resources. In turn, the enhancement of knowledge and capacities contribute to more resilient local economies and sustainable urban energy.

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[8] Surveying CHP-DH development in Scandinavia, a contrast emerges between the strong state-level co-ordination seen in Denmark (manifest in the Danish 'heat law' which required heat networks to be operated on a non-profit basis, with cost-reflective pricing), and the more distributed governance in Sweden and Finland; as our cases illustrate, the latter resonates more strongly with the contemporary UK context.

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Figure