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Improvising innovation in UK urban district heating: The convergence of social and environmental agendas in Aberdeen

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HIGHLIGHTS

- UK policy proposes district heating for urban low carbon heat.
- Technical and economic feasibility are insufficient to drive take-up.
- In Aberdeen convergence of social and environmental goals gave impetus to improvisation.
- The resulting non-profit ESCo has three CHP and district heat networks, supplying 34 MWh of heat pa.
- Carbon and cost savings are 45% in comparison with electric heating.

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ABSTRACT

Research on district heating has focused on technical-economic appraisal of its contribution to energy and carbon saving in urban centres. There is however lack of analysis of political and social processes which govern its actual take up. This paper examines these processes through a case study of Aberdeen, Scotland. Interviews and documentary analysis are used to examine the 2002 development of Aberdeen Heat and Power (AHP), an independent energy services company (ESCo). Technical-economic feasibility was a necessary component of appraisal, but not sufficient to govern decision-making. In the UK centralised energy market, DH investment is unattractive to commercial investors, and local authorities lack capacity and expertise in energy provision. In Aberdeen, the politics of fuel poverty converged with climate politics, creating an a-typical willingness to innovate through improvisation. The welfare priority resulted in creation of a non-profit locally-owned ESCo, using cost- rather than market-based heat tariffs. AHP has developed three combined heat and power energy centres and heat networks, supplying 34 MWh/pa of heat. Carbon savings are estimated to be 45% in comparison with electric heating, and heating costs are reduced by a similar amount. The conclusion outlines potential policy improvements.

1. Introduction

The UK Government Carbon Plan 2011 set a target for radical reduction of greenhouse gas emissions from the entire building stock: 'by 2050, all buildings will need to have an emissions footprint close to zero' (UK Department of Energy and Climate Change (DECC), 2011: 5). Forty-five per cent of these emissions are from heating, however:

> 'There has been a historic failure to get to grips with one enormous part of the energy jigsaw; the supply of low carbon heat' (Secretary of State, UK DECC, 2013: 1).

Using technical-economic modelling to assess the feasibility of low carbon options, UK government strategy concludes that heat networks or district heating (DH), using gas-fired combined heat and power (CHP) in the short run, could supply 'up to 20% of UK domestic heat demand' by 2030 (UK DECC, 2013: 45). Renewable or recovered heat sources are expected to replace gas at the end of a 12–15 year investment cycle, leaving a heat network infrastructure which is considered to be an economically viable route to meeting up to one half of anticipated 2050 low carbon heat demand. Calculations are based on energy, carbon and cost efficiencies compared with individual building heating and hot water in urban centres where demand is high and concentrated. If followed through, such provision would constitute a radical transformation of current UK practice, where DH, distributing heating and hot water[1] from shared fuel sources to multiple buildings via

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[1] Such networks may also be used to provide cooling services, using an absorption chiller linked to a CHP generator.

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insulated underground pipes, supplies only 2% of heating. Fossil fuel gas-fired individual building boilers supply the majority of heating[2] with the remainder from electric heaters, open fires or oil-fired central heating[3] (UK DECC, 2013); low carbon sources are estimated to account for only 2% (UK Committee on Climate Change (CCC), 2013). Previous UK CHP and DH support policies, also based on high level technical-economic modelling, have had limited impact (Russell, 2010), indicating that the material take up of such technologies is not solely a matter of formal efficiencies, but is governed by the political and social dynamics of retrofitting CHP and DH into a centralised energy system and established settings where it is largely absent.

In those European countries where DH is established, urban authorities have typically played a critical part in development, and UK policy also identifies local authorities as

> 'critical players in increasing the deployment of heat networks as they can create a supportive environment… and support or sponsor specific projects' (UK DECC, 2013: 50).

In the UK, however, local authorities have had no direct role in energy systems since the mid 20th century, when local and regional energy suppliers were nationalised and reorganised into vertically integrated structures. Privatisation of gas and electricity in the 1990s, and a regulatory framework geared to short-term cost efficiencies, has reinforced centralisation (Mitchell, 2008). At present a small number of large-scale corporations[4] control the majority of generation and supply. Energy-related action by local authorities has correspondingly centred on incremental efficiency gains through building insulation or use of digital energy management systems; some urban authorities have ambitious sustainable energy plans, but these remain largely aspirational and subject to unresolved questions of governance of innovation (Hawkey et al., 2014; Hodson and Marvin, 2010, 2012).

The purpose of this paper is to explore the social and political processes which shape the actual take up of such technologies in centralised energy markets, and which govern shares of costs and benefits in use. An in-depth case study of DH development in the city of Aberdeen, north-east Scotland, is used to analyse the governance process from origins to operation. Establishing the technical-economic feasibility of DH, with combined heat and power (CHP), was an essential element, but was in many ways more straightforward than the social and political dimensions of such innovation. Political confidence in legitimacy of localised energy provision, and mobilising capacity, expertise and finance were particular areas of difficulty.

The paper does not offer further technical-economic analysis of carbon and cost efficiencies of DH versus other technologies, although it does, in Section 2, summarise the features of conventional cost-benefit appraisal, before introducing the social and political dimensions of UK energy systems as context for establishment of CHP and DH. Section 3 describes methodology and data sources. Section 4 presents case study results. Section 5 discusses the Aberdeen developments in relation to the UK market and regulatory context and Section 6 concludes with suggested policy measures to improve the likelihood of sustainability benefits attributed to urban DH being secured in the UK.

[2] In 2013, 70% of all UK heating was from fossil fuel gas (UK DECC, 2013).

[3] UK DECC estimates that 10% of buildings use oil-fired central heating.

[4] Known in the UK as the 'Big 6', these are British Gas Centrica, EDF Energy, E.ON, Scottish and Southern Energy, Npower and Scottish Power. They have a 98 per cent share of the household gas and electricity markets. Five are owned by transnational entities headquartered outside the UK.

2. Urban heat networks as sustainable energy resource

2.1. Environmental, technical and economic dimensions

Technical-economic scenarios for low carbon heat for buildings in cold climates, as in UK strategy (UK DECC, 2013), are typically constituted in relation to a heat hierarchy, or ladder, of first *reducing demand* through insulation, second *efficient supply* through more efficient infrastructures, and third *use of low carbon sources*. This technically rational hierarchy is not however necessarily adhered to in practice. In the UK, although low carbon energy scenarios initially focussed on large-scale electrification of heat in highly insulated buildings, there is growing recognition of difficulties and costs of this model. Progress in insulation of a highly diverse building stock, much of which is in private ownership, has been incremental and patchy, and planned zero-carbon standards for all new developments remain uncertain (UK CCC, 2013). Building-scale electric heat pumps have also performed poorly in field trials, and there is recognition of the high costs of electricity grid reinforcement and stand-by generation capacity necessary to serve highly seasonal peak heat loads (Spiers et al., 2010; UK Committee on Climate Change, 2013).

In this context, there is increasing interest in more diversified heating solutions customised to the particular socio-economic and spatial characteristics of localities (UK DECC, 2013). In areas of high, and concentrated, heat demand, heat networks are represented as a means of efficient supply, reducing carbon emissions while contributing to security and affordability. Technical and economic modelling of European heat demand and supply also advocates DH, with improved building insulation, as a means of reducing the total cost of transition to low carbon energy by approximately 15% compared with the EU Energy Roadmap 2050 Energy Efficiency (EU-EE) scenario (Connolly et al., 2014). In the UK, any new DH development is regarded as likely to proceed from gas CHP, because of its status as a proven technology with expected source fuel conversion efficiency of 80% (http://chp.decc.gov.uk/cms/, accessed 26/09/2014). Once established, however, heat networks are seen as having long-term value due to attributed capacity to connect multiple local low carbon heat sources, which are inaccessible or uneconomic at individual building scale; these include waste heat from industry, biomass, or heat recovery from geothermal sources. UK Committee on Climate Change (2010) modelling for example concluded that DH using heat recovered from low carbon electricity generation (fossil fuel with CCS or nuclear) offered the most cost effective carbon abatement (−£110/tCO_2) measure. Formal assessments also tend to conclude that there are system-wide efficiency gains from localised DH and CHP, because heat supplied via networks means less electrification of heating, therefore reducing the cost of grid reinforcement and reducing the need for higher carbon stand-by generation. Embedded electricity generation from meso-scale CHP is also regarded as increasing energy system resilience, because it can contribute to energy storage and short-term operating reserve. This is expected to become more significant as increasing levels of intermittent wind energy are connected to the grid, while anticipated new load from electric vehicles and heat pumps increase peak demand (International Energy Agency (IEA), 2014).

There are limitations to CHP and DH as carbon saving measures. First site- and location-specific factors govern relative costs and benefits. Establishing heat networks entails significant infrastructure investment, and their effective sustainability value, relative to other options, consequently depends on long term secure, high levels of heat demand, with temporally diverse patterns of use, concentrated in a relatively small area. Large heat loads, such as hospitals or leisure centres with swimming pools, are significant to economic viability. Improving their economics is also

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related to connection of any locally available, otherwise wasted, low cost heat sources to nearby areas of high demand, where they command higher value (Wald, 2013); this can be politically, economically and technically challenging (Hawkey and Webb, 2014). Second DH users typically sign a long-term heat contract with a monopoly supplier. Heat price is hence likely to require regulation, either by requirement for non-profit operation and cost-based tariffs, as in Denmark, or by market-based tariffs fixed in relation to the main alternative supply, as in Norway. Third, as with other grid infrastructures, DH creates a form of path dependency, which may lead to incentives to maximise heat sales, rather than to reduce demand through building insulation. Fourth, DH may add to risk of lock-in to fossil fuels, with gas-fired CHP as a commonly used starting technology. These third and fourth points apply equally however to the UK's current fossil fuel gas grid; even gas-fired CHP is estimated by government to reduce carbon emissions by 40–50%, compared with current separate generation of electricity and gas and individual building heating (UK DECC, 2013).

2.2. Social and political dimensions of UK energy systems: the context for DH development

Given the claimed efficiency benefits of DH and CHP in high density areas, one might ask why, in countries such as the UK, they remain relatively unused. Historically their formal technical-economic feasibility has proved insufficient to drive investment. Indeed the context-dependent factors outlined above indicate that the performed, as opposed to theoretical, energy, cost and carbon saving value of CHP, DH (and indeed other energy technologies), are conditional not simply on technical capacities of generators, pipes and so on, but also on the social systemic inter-dependencies between suppliers, network operators, regulators and users. In this sense, the energy system entails a ‘seamless web’ of social, organisational, economic and technical factors; any technical reconfiguration is inter-twined with the reconfiguration of socio-economic institutions of supply and use (Hughes, 1982; Summerton, 1992).

In the UK energy system, this seamless web has evolved around increasingly segregated, and vertically-integrated, gas and electricity markets and physical infrastructures in a sector governed by commercial economies of scale. Fuel source energy efficiency has historically been a low priority, resulting in limited scope for the coordinated long-term planning associated with deployment of meso-scale CHP and heat networks (Hawkey, 2012; Russell, 2010). Although UK policy is again highlighting the formal techno-economic potential of DH, those authorities which have analysed technical and economic feasibility have struggled to move forward, with projects stalling at planning stage, declining in scale, and/or taking many years to advance to construction (Wiltshire et al., 2013).

Under privatisation, technical expertise and ownership of energy assets resides predominantly with the large-scale corporate utilities. Liberalised regulation of gas and electricity networks guarantees a return on investment to a monopoly provider, under a periodically revised price control formula (Ofgem, 2013). This does not however extend to heat networks, and hence provides no incentive for private sector investment. To the extent that there is any initiative for urban retrofit of DH, this rests therefore with larger heat users, particularly in the public sector, who face legislative obligation to respond to carbon reduction targets, and whose socio-economic responsibilities mean that DH may serve objectives not necessarily associated with energy *per se*, but with local welfare, and economic regeneration, as well as environmental protection.

Research on the role of local authorities as intermediaries in urban climate governance, and low carbon experiments, has however revealed the limited capacity of contemporary city authorities to govern material change in energy infrastructures (Bulkeley et al., 2014; Hodson et al. 2013; Rutherford, 2014). In Europe, the neo-liberal political-economic shift away from direct provision of public services to a market commissioning model, has limited the capacity of urban and regional authorities for planning and coordination of low carbon infrastructure (Monstadt, 2009). They are obliged to work instead as intermediaries, at the interface between service domains, territorial jurisdictions and the differing interests of states, markets and civil society (Guy et al., 2011; Moss, 2009). When intermediaries have attracted private sector investment in commercially viable low carbon projects, these have tended to remain marginal to dominant energy regimes, rather than initiating a process of transformation, (Bulkeley et al., 2014; Rutherford and Coutard, 2014). In the UK the challenges are more pronounced, because of the structural weakness of urban authorities, with limited financial autonomy. Relationships between UK central and local governments are marked by a history of low trust, with reforms progressively centralising budgetary control over local spending, and extending market commissioning (Le Gales and Scott, 2010). Local powers of comprehensive territorial planning, and capacity to realise locally-defined goals are correspondingly circumscribed, and the lack of statutory powers in relation to provision of energy means that authorities lack resources and expertise. Hence they struggle to articulate and constitute a strategic orientation to energy as a sphere of action amenable to *local* priorities (Hodson et al., 2013).

It is unsurprising then that most UK local authorities have made only incremental and piecemeal progress in low carbon energy initiatives; around 30% have nevertheless made some direct investment in energy saving and/or localised provision (Hawkey et al., 2014). In the absence of codified procedures and dedicated budgets, there are questions about how those urban authorities seeking to engage in DH developments are creating capacity. Social science research suggests that improvised learning and bricolage are likely to be deployed in circumstances where institutionalised rules and procedures prove unproductive in relation to substantive goals and priorities (Engelen et al., 2010; Garud and Karnøe, 2003; Turkle and Papert, 1992). Improvised learning is compared by Weick (1998) to the extemporisation displayed in jazz performances: formal rules and routines provide the foundation for innovative adaptation, producing embellishments on, and reinterpretations of, established practices. Such improvisation may entail forms of bricolage, characterised by a practice-based (rather than formal) rationality. Bricolage is analysed by Levi-Strauss (1966) as a contrasting means of knowledge formation to that of formal rationality. Hi work shows that such practical rationality is built up from sequences of indeterminate, but interconnecting, events, resulting in the creation of a lattice-work, rather than top down hierarchical, form of organisation. This may appear limited to those trained in Anglo-American analytic reason, but in a comparison of technological innovation in the wind energy sector, the Danish bricolage model was found to be more effective, at least in early stages of development, than the formalised rationality of a top-down ‘break through model’ pursued in the USA (Garud and Karnøe, 2003; Hendry and Harborne, 2011). Improvised learning and bricolage typically rely on capacity building through a ‘community of practice’ (Wenger, 1998) where interested parties interact in mutually-acknowledged joint enterprise, to develop knowledge through applied reason, use and interaction (Amin and Roberts, 2008). The development of DH, under UK market structures, seems likely to require such a community of practice oriented to combining formal financial, legal and technical expertise in energy systems with local knowledge, resources and political interests. In the following sections of the paper, such processes are discussed in relation to a case study of

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Aberdeen DH and CHP development.

3. Methodology

Case study data is derived from semi-structured interviews with cross-sector participants in project planning and development, and analysis of Aberdeen Council, Aberdeen Heat and Power Ltd. (AHP) and related policy documents. Interviews were conducted with the lead council officer, two AHP Board members, one district energy consultant who was the second Chair of the Board of AHP, the AHP general manager, three representatives of the accountancy firm involved in establishing the financial model, and one representative of the legal firm advising on business structure, governance framework and contracts. These varied in length from one to four hours and were audio-recorded and either partially or fully transcribed. Updating has occurred through district energy network events, industry conferences, community energy meetings where AHP representatives have advised others on business development, and lastly joint researcher- and practitioner-led knowledge exchange workshops. Observation and participant observation by the author in Scottish and UK government energy and climate change policy meetings have provided contextual data on district energy policy processes.

4. Case study results: developing low carbon, affordable energy in Aberdeen

The absence of an energy services function in UK local authorities means that energy-related initiatives may emerge from a range of service specialisms, and be structured by different goals in different localities. Aberdeen is a north-eastern coastal city with long periods of cold weather in winter, and a relatively concentrated population of low income households: fifteen per cent live in relative poverty, and the poorest are concentrated in multistorey housing, where the council estimated that 70% of households were experiencing fuel poverty. These geographical and spatial factors indicate the likely suitability of DH and CHP for provision of affordable warmth while also reducing CO_2 emissions. There are however similar configurations of cold winter weather and concentrations of low income, fuel poor, households in other UK cities, where such developments have either not commenced or have prioritised large non-domestic public and private sector heat loads with commercial rates of return to investors. While urban economic geography, climate and built environment are key factors, they are hence not sufficient to explain particular patterns of development.

In Aberdeen, the indeterminate interaction of local, Scottish and UK political processes created an a-typical willingness to innovate through improvised means. The original initiative came from housing services, and focused on combining goals of social welfare, increased housing revenues and the need to improve its stock of 1970s multi-storey social housing to meet higher energy efficiency standards. Environmental protection and reduction of CO_2 emissions converged with the welfare agenda as the improvised development of strategy took shape.

This culminated in 2002 in establishment by Aberdeen city council of a non-profit energy services company, Aberdeen Heat and Power Ltd. (AHP), with the legally inscribed purpose of working for the benefit of the citizens of Aberdeen. AHP now owns, operates and maintains three gas-fired CHP energy centres, supplying cost-based heating and hot water to around 2000 flats in 26 of the city's 59 multi-storey housing blocks, as well as a school and a further twelve public buildings and leisure facilities. Some of the co-generated electricity is supplied via private wire to the school; the remainder is sold into the public network, with revenues used to maintain a low heat tariff, and to create a contingency fund for further investment.

Council lead objective	Affordable warmth for social housing
Organisation structure	Company limited by guarantee and by membership, under local ownership and control, with asset lock
Business model	Non-profit ESCo; any surplus reinvested or used to lower cost of heat to housing tenants
Governance structure	Volunteer board of directors including councillors, community and business organisations and former council officers
Heat tariffs	Cost-based
Main customers	Public housing tenants
Other customers	Community sport, leisure and education facilities
Finance	UK and Scottish government grants, city housing capital, prudential borrowing, bank loan and overdraft
Risk mitigation	Loans guaranteed by city council; council long term contract for purchase of energy

Fig. 1. Governance and organisation of urban energy in Aberdeen.

During 2012 – 13, the network was extended into the city centre. Total network length is currently 14 K, and annual heat supply 34 MWh. Carbon saving is estimated to be forty five per cent, in comparison with former electric heating systems in multistorey blocks and replacements for central heating boilers in public buildings. Heat tariffs for tenants are cost – rather than market-based (currently £10.54 per week, estimated as saving between 25% and 45% on electric heating for an equivalent dwelling). The National Home Energy Efficiency Rating (NHER) of the housing blocks with improved insulation and connected to the heat network was reported by council as improved from 3.3/10 in 1999 to 7.19/10 in 2009.

AHP governance and organisation structure is summarised in Fig. 1. Technical systems developed under the fifty-year framework agreement between AHP and the council[5] are summarised in Fig. 2.

4.1. Origins of the Aberdeen DH and CHP initiative: UK multi-level governance and fuel poverty politics

A key initiating factor in Aberdeen innovation was the interaction of local, Scottish and UK politics, which connected UK Conservative government legislation with Scottish and Aberdeen cross-party anti-poverty politics, leading unpredictably to creation of a local, non-profit, energy business, serving social welfare goals. 'Fuel poverty' and home energy saving campaigns in the UK date back to at least the 1970s, and as in Aberdeen, have a strong local dimension (Koh et al., 2012). In the 1990s the Association for the Conservation of Energy campaigned for UK legislation as a means to integrate environmental and social goals. A chance UK by-election of a Liberal Democrat politician, in a constituency with a large elderly population, coincided with a Conservative government plan to introduce a 17.5% rate of VAT on domestic energy. The politician consequently saw advantage in the campaign to reduce fuel poverty through domestic energy saving, and sponsored the

[5] This is governed by a *Teckal* exemption which provides that, in certain circumstances, the award of a contract by one public body to another separate legal person will not fall within the definition of 'public contract', with the result that EU law will not require the contract to be put out to tender. The exemption comprises both a 'control test' and a 'function test'. (1) The local authority must exercise similar control over the contractor to that which it exercises over its own departments, and (2) the contractor must carry out the essential part of its activities with the controlling local authority or authorities.

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Energy Centres and Networks	CHP capacity	Capital Funding	Total Infrastructure Cost
Stockethill	210 kWe 300 kWth	53% Housing capital 40% UK CEP grant 7% Energy utility EEC	£1.8M
Hazlehead	300 kWe 488 kWth	53% Housing capital 40% UK CEP grant 7% Energy utility EEC	£1.6M
Seaton	2100 kWe 3000 kWth	Phase 1 60% Housing capital 40% UK CEP grant Phase 2 60% Housing capital 40% Energy utility CESP	£3.3M
City centre network		Scottish Government grant	£1M

Fig. 2. District heating and combined heat and power developments, Aberdeen Council and Aberdeen Heat and Power Ltd. *Note*: the energy utility Energy Efficiency Commitment (EEC) was the energy company obligation in place in 2002; subsequently replaced by the Community Energy Savings Programme (CESP) and currently the energy company obligation (ECO).

legislative proposals. The Home Energy Conservation Act (HECA), introduced in 1995, resulted in a requirement on local authorities to identify cost effective measures for a reduction of 30% in home energy consumption, and CO_2 emissions, between 1997 and 2007.

HECA targets were weakly enforced, but in Aberdeen they aligned with established fuel poverty activism,[6] and local and Scottish anti-poverty politics, articulated in opposition to UK Conservative government, acted as a lever for allocation of new resources. Local political consensus, matched by commitment of council Chief Executive and Housing Directors, who were fuel poverty and environmental activists, led in 1998 to appointment of a Home Energy Co-ordinator with expertise in community development, rather than local government and technical housing services. She initiated a correspondingly wide-ranging and improvisatory approach to appraisal of options for energy saving:

> 'It was a blank sheet of paper, you could do whatever you wanted with it and it gave the emphasis just to focus on … how you could reduce home energy consumption, how you could assist people with education, how you could look at poverty related issues, look at the environmental issues.' (Aberdeen Home Energy Officer).

4.2. *Affordable warmth: a 'boundary object' to mobilise political support for CHP and DH development*

In 1999 the council formally adopted an 'Affordable Warmth' Strategy, which acted as a form of boundary object (Bowker and Star, 2000), facilitating negotiation and discovery across specialist interests, without having to achieve precise consensus on ends and means. The programme of work was unspecified, but the strategy established the legitimacy of accessing housing capital budgets. Since there was no council structure for governance of energy strategy, and no necessary connection between HECA and localised energy provision via DH, the Affordable Warmth Strategy The efficacy of such objects depends on intermediaries, such as the Aberdeen officer, interpreting their capacity to serve the different, potentially competing, interests of multiple council specialisms and inter-agency bodies. As in the improvisatory performance of jazz (Weick, 1998), the officer deployed her community development expertise and knowledge of council processes to elaborate and embellish the concept of affordable warmth. Technical devices of housing condition surveys; National Home Energy Efficiency Ratings (NHER) of council stock; thermal images of the city, and news updates geared to political mobilisation formed the materials for intermediary activity.

Emerging alliances between the home energy officer and other officers and politicians articulated a locally-inflected connection between climate politics and fuel poverty: 'we had this climate change action group, which was people from all different departments within the council, but also we had representatives from each political party' (Aberdeen home energy officer). Mobilisation through a council climate change conference in 2002 (predating Scottish and UK legislation) led to:

> 'an energy policy which B, M and myself wrote in the pub one day, you know, but it got written and it got adopted by the council. And therefore once you've got something like that adopted what you can say is "what we're doing is implementing *your* policy"' (Aberdeen home energy officer).

The convergence of social and environmental agendas was embedded in subsequent strategy: 'The environmental aim of reducing CO_2 emissions, and the social aim of eliminating fuel poverty, have consistently been viewed as two sides of the same coin by Aberdeen City Council' (Aberdeen City Council, 2012). Further commitment was developed through a Carbon Trust 'Pathfinder' programme which established a city Carbon Management Plan.

Over this period, the Affordable Warmth Strategy and embryonic energy policy served as a means to align differing internal purposes – tackling fuel poverty, mitigating climate change, meeting government-required energy efficiency standards and improving council finances – around the idea of regeneration of the least thermally efficient, electrically-heated, multi-storey housing. Formal technical-economic options appraisal was then commissioned and was expected to serve as a means to identify the best value solution which was also affordable to council. Despite the dominance of short-term cost models in UK local government, local political mobilisation around the joint principles of affordable warmth and carbon reduction had in this instance advanced a definition of best value as lowest 'cost in use' of heating for tenants.

4.3. *An emerging community of practice*

Technical and economic assessment concluded that the short-term lowest cost solution was additional building insulation and new electric heating. The report also included an evaluation of CHP and DH for clusters of neighbouring buildings, which showed that its relatively high capital cost could be justified by the low 'cost in use' of heating to tenants, and its carbon savings. In fact the lowest 'cost in use' option shown was external insulation combined with CHP and DH, but the high capital cost of the insulation (and lack of affordability to council), relative to the small additional saving for tenants, resulted in a decision to recommend CHP and DH without external insulation.[7] Technical and economic feasibility did not however translate into acceptance of efficacy. Calculations of cost and value were contested by politicians, housing, finance and legal officers. Tenants with fuel debts, accustomed to controlling bills by self-disconnection using a prepayment meter, were also sceptical, but cautiously interested in a fixed heating charge paid with rent to enable budgeting. The risk

[6] A key organisation, SCARF (Save Cash and Reduce Fuel), was set up in the 1980s as a registered charity with financial support from the council under the Urban Aid programme and was one of a number of inter-connected anti-poverty projects.

[7] In practice many of the tower bocks were externally insulated as part of regeneration, with part or full cost covered by successive variants of the UK government energy efficiency obligation on energy suppliers.

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to council finances of accepting liability for non-payment of heating bills, however, incurred objection from finance officers. The prevailing attitude was, suggested the officer, 'If it hasn't been done in Aberdeen, it's not worth doing'.

Resolution again required intensive research and intermediary action, contributing to, and drawing from, a loosely configured, geographically diffuse project latticework (Levi-Strauss, 1966). This was critical to formation of knowledge about, and establishment of shared belief in, the integral social, economic and environmental value of localised energy. The local latticework bridged multiple statutory service domains of Housing, Environment and Infrastructure, Finance, Planning and Resources, and Highways. It drew in external intermediaries, such as the UK HECA officer network and community energy agencies, to assemble technical, legal and financial expertise, but also 'moral support' (Aberdeen home energy officer) and practical reasoning in the form of 'many hours walking the streets' (officer) with the design engineer to establish confidence in feasibility of infrastructure routes and configurations.

The flexibility of the proposed CHP and DH solution as a hinge connecting multiple local interests was critical: as a formula for addressing fuel poverty, it had to be made congruent with improved financial returns from housing stock and carbon reduction; tenant support was contingent on a fixed price for heat,[8] and the expected energy cost reduction to council persuaded finance to support the strategy, and in principle to accept the risk of tenant non-payment under the tenant-preferred heat with rent formula.

The anti-poverty focus of Aberdeen and Scottish politics also provided a lever for negotiation, with acceptance that the primary return on investment would be in relation to local well-being and economic benefit, rather than the rate of return on finance. Negotiation eventually resulted in a recommendation to council to create a stand-alone non-profit business, with local control over system design, development and asset ownership. The final decision required full agreement of council, supported by three Committees (Housing, Environment and Infrastructure, and Planning and Resources), where claims of value, risk and affordability were strongly contested. Council legal advice opposed the proposal on the grounds of financial risk. The deputy council leader however chaired the key meeting, and his expertise in the oil and gas sector conferred confidence in relation to local energy: 'At the founding meeting he said "we are obliged to seek the advice of the council's solicitor, but we are not obliged to take it. Therefore it is noted." So he put it to one side. So he had the political courage' (member of AHP Board and district energy practitioner). The decision to proceed led to establishment of AHP Ltd.

4.4. The practice-based economics of DH and CHP in Aberdeen

Technical-economic rationality did not govern the selection of the first Aberdeen CHP/DH scheme. Decision principles were derived instead from an improvised economics of practice around shared learning, creation of political and social capital, and the need to develop capacity in energy project management. Local knowledge about non-monetarised costs and organisational structures, characterised as 'non-technical information known to the housing investment staff' (council evaluation report), governed site selection. Pragmatic decision criteria were based first on tenant demographics rather than technical features of buildings and heat loads. An older, stable population of householders in the selected area were expected to understand the benefits, and thus to reduce the risks of delay and poor implementation; this group were also identified as likely effective tenant ambassadors for subsequent schemes. Second, the project was relatively simple in relation to council finances, requiring capital contributions only from housing services. In subsequent developments, more typical of the diverse heat load connections needed to optimise CHP and DH technical-economic efficiencies, funding required coordination of multiple specialist interests and budgets, with the complexities of legal contracts and consent.

Disputed affordability necessitated financial bricolage to assemble components of funding 'without revealing to anyone what amounts other bodies were giving' (Coordinator). In this instance, a change of UK government from Conservative to Labour in 1997 proved fortuitous. The election resulted in greater devolution of power to Scotland, Wales and Northern Ireland, and also increased the momentum of climate change politics. The latter resulted in short-term (2002–2007) financial commitment of £50M from UK Treasury for a Community Energy Programme (CEP) to provide a share of costs of technical feasibility assessment of DH developments led by public bodies, and up to 40% of capital. The Programme made cross-sector expertise available to advise on governance structures, and business and financial planning. The Aberdeen CHP/DH feasibility study had already provided costings for a sample cluster of multi storey housing blocks, enabling a successful application for development of a pilot scheme. A loan had to be raised to finance the high risk construction phase, to be undertaken by a company with no track record or assets. The city council social welfare priority was used to justify the underwriting of financial risk, reducing the rate of interest and associated heat tariff:

> 'Council has an interest in giving a guarantee as this gives them a degree of oversight of the projects enabling them to be clear their objectives are being met' (council financial auditor).

The creation of an independent business, governed by an unpaid board of local politicians and community representatives, also avoided the risk of initiatives becoming 'lost in the detail' (accountant) of overall council funding. Independence enabled affordable warmth targets to be met efficiently, while spreading capital cost over several years and providing potential access to third-party capital (Energy Saving Trust, 2003). The financial risk is however retained by the council, with loans secured against council revenues.

The practical economics of the third, and most ambitious, CHP/DH project in the Seaton area of the city proved most contentious, but also provided the key to subsequent expansion. All CEP funding was contingent on contracted carbon savings; hence the late discovery of poor fabric condition of a number of blocks planned for connection in this third phase resulted in their withdrawal, risking loss of grant. The Aberdeen beach leisure complex was selected as an alternative, but at additional infrastructure cost, causing temporary cash flow crisis and dissent among the AHP volunteer board of directors. Council agreement to establishment of financial underwriting of the business had been conditional on direct management of AHP accounts. The crisis however provoked board challenge to the adequacy of the arrangement, resulting in resort to independent financial expertise which supported increasing strategic orientation to managing cash flows, as well as interaction with wholesale gas markets. Access to legal expertise also supported development of competence in multi-party contracts and agreements. Bricolage continued to be critical to assembling finance after the CEP programme ended in 2007. Notably, carbon savings from CHP/DH extensions have been structured as tradable currency and offered to the highest bidders under successive UK energy efficiency obligation on utilities. The oversizing

[8] There are of course disadvantages to the fixed heat charge, associated with the potential waste of energy. In practice systematic engagement with households in understanding how to use the new heating has led to a record of heat use in line with AHP forecasts and has limited bad debt.

of pipework associated with the earlier business crisis has also allowed for network extension to the city centre through ad hoc Scottish government funding, in turn resulting in establishment of a commercial subsidiary of AHP.

Practical economic value, in the form of political capital from material impact on fuel poverty and carbon saving, has accrued to the council during DH and CHP development, and the associated reconfiguring of social and economic institutions around a local heat supplier. Other forms of value have been realised in relation to community welfare and health, which has in turn improved CHP and DH economics: 'Now word has got round [in the Seaton area], take up of the new offer is 80%, while the original project had around 40% take up' (accountant). Council revenues have hence increased with improved housing stock, higher occupancy rates and reduced building maintenance costs.

5. Discussion

The Aberdeen development of DH and CHP is not explicable as a component of a formally rational technical-economic assessment of least cost pathways for UK low carbon energy transition. Instead it represents the convergence of local anti-poverty political aspirations, with climate politics, resulting in an improvised local economics of energy use which was able to exploit the political dynamics of UK multi-level government. Like many cities, Aberdeen has a culture of 'civic pride' in independent-minded adaptation to circumstances (Fraser and Lee, 2000). This contributes to potential for a community of practice, based on the urban political alliances necessary to holding power, which would provide a counterpoint to current UK centralised energy markets and regulation. During the short-lived CEP, the re-established Scottish government funded a cross-sector district energy network, demonstrating the significant potential for regional and inter-city networks of shared learning and knowledge formation to develop: forty per cent of projects receiving CEP capital funding were in Scotland, which has eight per cent of UK population, and Aberdeen became lead UK recipient.

In 2013 AHP received a global district energy award; a further 11 tower blocks are being connected by 2015, and the subsidiary company is positioned to move into commercial heat supply. A city 'heat main' has long been the imagined long term goal, characterised by those involved as the 'ring of fire' and drawn as a red line on city maps in the AHP office. The trajectory suggests that a small, improvised social innovation, commencing with a £1.8M pilot scheme to connect four 1970s multi-storey housing blocks to a gas-fired CHP engine could deliver a city non-profit, locally owned and operated heat network. Consistent political, policy and regulatory support for a resilient low carbon urban energy system would however be required. There is some potential for heat policy itself to work as a 'boundary object' in catalysing such development. The relative neglect of heat in energy policy has created scope for improvised policy learning and for divergence in energy governance in relation to the geography and politics of locality: heat policy has perhaps been devolved 'by omission rather than by decision' (UK DECC officer). At a 2013 UK Workshop organised by the author and colleagues, the UK DECC officer's presentation stated 'we want the heat policy paper… to explain why decentralised solutions will be important'. UK DECC has funded pilot projects in English 'pioneer cities' and set up a Heat Networks Delivery Unit, with a small budget to support technical-economic feasibility assessments. Scottish government has also furthered coordination through a Heat Network Partnership and loan funds: 'Governments can always find money; if there's a will there's a way' (Scottish Ministerial comment during his speech at a DH Leadership event).

6. Conclusions and policy implications

The actual trajectory of such a user-led model of innovation, underpinned by a regionally- or locally-situated economics of energy and carbon saving is however unclear. Energy market regulation and taxation powers largely remain with the UK government, which limits authority and capacity at urban and regional scale. The Aberdeen latticework organisation conferred a precarious hold on energy expertise and finance: project evaluation reports note the intensive work loads, few resources and responsibility without clear authority, associated with multiple uncertainties and lack of capacity in energy at local level. UK and Scottish government strategies acknowledge the need for longer-term institutional changes, but the means of systemic change to capture the attributed welfare, carbon, and energy efficiencies of DH and CHP are unclear under current commitment to market principles:

> 'Across all the different heating strands, the Government wants to make progress without prescribing use of specific technologies. Instead, information for market players, including households and businesses, should be improved to enable effective decision-making' (UK DECC, 2013: 79).

In the absence of an existing market for heat, and associated affordable long term capital for heat network infrastructure, technical and economic feasibility alone are insufficient. The UK energy market context creates systemic risks for DH and CHP investment, indicating the need for a regulatory framework to bridge the gap between policy statements and practice. Some basic principles can be derived from the Aberdeen case study. Benefits of urban authority momentum could be secured by provision of affordable long term finance or financial guarantees for non-profit or joint public-private ventures. This could come from UK infrastructure funds, GIB finance structured to underwrite risks for local enterprises, or European sources such as regional development funds. More devolution of powers and finance to city regions would contribute to capacity for economic regeneration, and could include requirements relating to urban heat network infrastructure, where this is effective under a whole life cost model incorporating social and environmental benefits.

Where CHP is used as a heat source, the electricity exported could be granted the same status as large scale nuclear or offshore wind, under the new 'contracts for difference' strike prices for low carbon electricity supply. This would reflect the efficiency gains from electricity generation close to its point of use. Operators would then have a risk underwriting mechanism. This is however a form of regressive taxation, because it operates as a levy on energy bills. The same is true of current energy company obligations (ECO) to provide finance for carbon and energy saving projects; ECO, and its predecessors, have contributed to locally-led heat network retrofit projects, but have been complex and subject to inconsistent carbon pricing. Recent reductions in the scale of funding have again stalled projects. Such levies could be funded fairly, and their resources deployed more speedily and consistently, through general taxation.

For heat network investment to be cost effective, the transaction costs currently incurred in multi-party coordination of building owners, heat suppliers, planners and system operators need to be resolved. This requires more directed use of planning powers to prioritise areas for network development and anchor load connection, as in other European countries such as Norway or Denmark. Much heat mapping work has been completed in the UK, but strategic use has been limited. Having identified areas of high density demand, and network feasibility, large building owners would need to be under an obligation to connect to local heat (and cooling) networks, and producers of waste heat would need to be obliged to identify means to supply the network, in line with EU Energy Efficiency Directive requirements. Such obligations assist in maximising cost effectiveness and carbon and energy savings, and in turn provide secure revenues. With stronger government mandates, public buildings and multi-storey housing in urban centres could be required to connect to heat and cooling networks on a timetable aligned with renovation and heating replacement schedules. Commercial building users required to register for the UK energy efficiency tax, the CRC, already have a financial incentive to connect, because heat supplied via heat networks is rated as zero carbon. A general energy efficiency tax could be used to incentivise all commercial building owners to connect. Such revenue support measures need to be balanced with a system for licencing and regulation to prevent abuse of long-term monopoly supply contracts. The Danish Energy Regulatory Authority (DERA) for example regulates electricity, natural gas and district heating markets. For district heating, both production and network companies are regulated as non-profit undertakings, with pricing transparency.

Whatever their exact form, any policy changes seem likely to be more effective in shaping a sustainable energy system if they capitalise on urban momentum for a practice-based social economics of energy use. From this perspective, energy technologies such as heat networks may be constituted as a means to multiple socio-economic and environmental benefits.

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