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Jukka Syväterä
Pinni B 3002
33014 University of Tampere
Finland
email: jukka.syvatera@uta.fi

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Guest Editorial

The Politics of Innovation for Environmental Sustainability: Celebrating the Contribution of Stewart Russell (1955–2011)

The focus of this special issue is on the politics of innovation for environmental sustainability. Environmental sustainability is a key issue facing society. It has become a central concern for many involved in science and technology studies (STS) who have sought to understand the form and direction of sociotechnical innovations, their implications for environmental problems and their remediation. Studies in this area require broad consideration of how people live and work, rather than taking as their starting point a particular area of scientific or technical innovation. By highlighting the politics of innovation we wished to particularly encourage contributions i) which situated sociotechnical changes in their historical context and current institutions and practices, and, coupled to this, ii) which considered the scope for influence and engagement by individual and collective actors. We were interested in exploring the type and extent of such politics and their impact on our sociotechnical systems and their environmental consequences. In an area which is dominated by high level policy announcements, which rarely deliver what they promise, and grassroots initiatives which, while often inspiring, frequently fail to transfer to other locations or 'scale up', this political understanding of sociotechnical change is of critical importance.

The stimulus for this special issue was a symposium held at the University of Edinburgh in March 2012 to celebrate the contribution of Stewart Russell, who died in 2011 to STS (see annex for a brief biography). The one-day workshop attracted a diverse international community of colleagues who had worked with Stewart and had been influenced by his activities and his ideas. Some of the papers published in this special issue were originally presented at this event; others have arisen from a wider call for papers. The theme reflects Stewart Russell's theoretical contributions to STS with their stress on a distinctive political approach which recognises structural constraints while exploring opportunities for action. It also reflects something of his broad empirical focus on environmental sustainability (including studies on cogeneration and district heating; renewable energy and electricity markets; water recycling and management and local energy planning). His work was also political in sense of having a deep concern for how a transition to more sustainable systems of production and consumption might be achieved.

Stewart Russell was one of a generation of scholars who moved from science and engineering to the newly emerging field of science, technology and innovation studies at the beginning of the 1980s. He

undertook postgraduate study at one of the early UK STS centres, the Technology Policy Unit (TPU) at Aston University. It was there he completed a MSc dissertation on *Autonomy, Determinism, Imperatives: A Review of thought on the loss of social control of technology* in 1980 and a doctorate on *The Political Shaping of Energy Technology* in 1986, followed by his first post-doctoral appointment.

The core concerns of his agenda for the politics of technology were shaped by a combination of research and political action which was a distinguishing feature of 1960s and '70s radicalism. This elicited an unusually broad interest in the social role of ideas on technology, progress and risk ranging from contributions to academic debates around elaborated and explicit theory through to engagement with everyday discourse and public debates. The ambition of this was further magnified by an acute awareness that relevant theories spilled over conventional boundaries and embraced not only the emerging field of STS, but also wider swathes of social and historical knowledge. The field of interest therefore had a breadth of engagement across

> explicit theoretical writing on the social effects of technology, the way technology is treated in social science disciplines like economics and sociology, the way it is presented in history books, numerous prophecies of our future way of life, the way it is depicted in the media, the general attitude into which people are conditioned to think of it (Russell, 1981: 2).

The motivation for such an endeavour was "not only for the intrinsic value of understanding how technologies are developed" but to reveal how prevailing theories of technology "can legitimate decisions, policies, actions and [...] obscure the real workings behind them" (Russell, 1981: 2). Political writings from the 1970s and studies from the 'alternative' and 'appropriate' technology movements (e.g. Illich, 1973; Dickson, 1974; Boyle & Harper, 1976) were also important to this project in showing potential different paths for technology.

Structure and Agency – Interest in Multi-Level Approaches

Thus the first broad element of Russell's approach to the politics of innovation was to stress a need to be interested in patterns of power and influence across society as a whole, as well as to explore how individual and collective actors sustain or seek to change such power relations. This involved engagement with a wide range of social theorists concerned with structure / agency debates and with analysing power. Russell (1986a) develops principles which give considerable weight to structural features, while paying attention to the ways in which these are maintained by and potentially disrupted by actors. This leads him to "to view social systems as in a continuous process of construction, maintenance and change, even though specific institutions may be deeply rooted and relatively stable" and "to explore the connections between levels of social structure and areas of activity as parts of a total social formation, even though each has partial autonomy" (Russell, 1986a: 58).

These analytical concerns put Russell at the heart of debates as the field of technology studies became established as a domain of systematic study in the early 1980s. Here, he engaged critically with colleagues from the self-proclaimed 'new sociology of technology' who sought to apply tools from the sociology of science to the analysis of technological change (Pinch

& Bijker, 1984; Bijker et al., 1987). Their analysis focuses upon readily observable interaction between directly and recently involved actors or 'Relevant Social Groups' (Pinch & Bijker, 1984). Russell criticises the individualistic paradigm that "leads them to treat actors as if they come to the interactions studied somehow free from their past histories, free from preconceived objectives, free from constraints other than those imposed by other groups involved" (Russell & Williams, 1988: 4). Such a perspective (as amply exemplified by Latour's [1988] concept of *Sartrean engineers*) has difficulties in addressing the constraining effects of pre-existing structures, and, for example, overlooks the differences between individual and collective actors (Russell & Williams, 1988: 4). Early Actor Network Theory writings were remorselessly sceptical towards existing social science theory (which is sometimes portrayed as presuming that outcomes can simply be read off from structural influences/interests) (e.g. Callon & Latour, 1981; Latour, 1988). Though expressing opposition to such mechanistic readings of structural influences, as we see below, Russell argued that this analytical move exposed them to well-rehearsed social scientific criticisms of empiricism and behaviourist approaches to power – leaving researchers poorly equipped to address absences, marginalisation and the suppression of alternatives and other "socially constructed constraints on choice" (Russell & Williams, 1988: 2). Russell particularly highlighted the risks that actor-centred and other 'micro-sociological' approaches, which focused upon local interaction and its role in constituting social relations and technologies, tended to overlook differences between groups of actors in access to knowledge and resources – differences which were rooted in broader social and economic structures – that conditioned their ability to be actors (Russell, 1986b; Russell & Williams, 1988). The 'flat ontologies' and simple methodologies of these approaches, with simple nostrums such as 'follow the actor' (Latour, 1987), left unanswered methodological questions about the choice of which actors to follow. Rather than counterpose local action and structural constraints, Russell's distinctive position argued that different modes of analysis were needed to examine immediate settings of action and the longer term patterning across multiple sites arising, for example, from entrenched institutional relations.

Russell later consolidated this theoretical contribution to what became known as the social shaping of technology as part of a European study group coordinated at the University of Edinburgh. This sought to systematise scholarship in the field and review what achievements had been made in the first decades of technology studies. Through a systematic review of analytical developments, Russell and Williams (2002a) drew attention to the extraordinary conceptual dynamism of the field, alongside a rich and growing body of empirical studies.

From this viewpoint, the 1980s controversies seemed indeed to have been a source of 'subsequent creative tension', as Williams and Edge (1996) had anticipated. There were various attempts to find resolutions to conceptual dichotomies that had surfaced in those debates around a number of key axes, including: agency and structural influences, and fluidity and stability in sociotechnical forms. This led to some elements of convergence in the field between approaches that sought to integrate explanation across different timeframes and levels and between short-term local and broader long-term shaping processes (Russell & Williams, 2002a). In the course of this collective endeavour, a

more complex and intricate understanding had emerged of an innovation process characterised not only by potential speed and global reach but also by enormous uncertainty and unpredictability (Russell & Williams, 2002b).

This more intricate understanding of the dynamics of sociotechnical development also helped to identify a wider range of possible sites and mechanisms for public and policy intervention. This included recognition of the wider range of sites and actors involved in innovation including, for example, contexts of consumption and appropriation as well as of technology supply. Particularly in the area of information technology, but increasingly elsewhere (and today including energy, see Silvast et al., 2013), he noted the emergence of different forms of technology, differing in arrangements for its production and consumption (as exemplified then by Fleck's [1993] distinction between configurational and systems technologies, but now widely evidenced e.g. by various forms of 'open' innovation). Today, we find increasingly elaborate innovation processes, distributed across an ever-widening range of settings and players. This draws our attention to mechanisms for inter-mediation – enabling more reflexive mutual governance and knowledge exchange – between chains of heterogeneous actors who differ in their knowledge, expectations and commitments (Russell & Williams, 2002a). In such situations other kinds of intervention strategies may come to the fore, involving "modulation and orchestration of the existing dynamics of innovation or technology management" (Russell & Williams, 2002b: 145) in addition to/in place of traditional top-down public intervention strategies.

One of the most significant developments has been the tradition of work that has subsequently achieved wide recognition as the Multi-Level Perspective (Rip & Schot, 2002). This work has had a dual role in both enabling effective analysis and also in highlighting opportunities for political intervention – most immediately in relation to managing the transition to environmental sustainability (Geels, 2011). Russell saw this as exemplifying a broader set of analytical moves that would be needed to produce an adequate understanding of technological change. What was at stake was first a broader view of technology as a heterogeneous assemblage involving visions and practices and a dispersed array of actors as well as artefacts. Studying this in turn called for methodologies and frameworks for engaging with "a wider conception of relevant actors and of the terrain of transformation" not necessarily centred around particular artefacts or actors, but allowing "examination of multiple related strands of development" and activities (Russell & Williams, 2002a: 71). This call can be seen as a precursor of current discussions of the benefits of multi-local, longitudinal 'biographies' of artefacts and practices. Finally Russell pointed to the benefits of integrating historical and sociological/anthropological enquiry, and also drawing upon a broader range of analytical traditions, including studies on innovation and on technology policy and regulation arising from innovation studies, evolutionary economics and policy studies.

A Commitment to a Diversity and Plurality of Approaches

A second element of Russell's approach, which flows from the first, was a commitment to a diversity and plurality of inputs. His sympathies in the 1980s were with Marxist approaches but he was very critical of the direction that many accounts from this perspective had taken.

Technology studies emerged initially through a critical engagement with the 'technological determinism' of prevalent accounts of technological change. These accounts took the trajectory of technical advance as a self-evident process, not amenable to social scientific enquiry, but instead imputed to the technical or commercial superiority of a new technology over its predecessors. Here Russell made a distinctive contribution. Thus an early object of attention was the "single-path idea of progress , a prevalent and influential assumption" (Russell, 1980: 93), which might more commonly be described today as the 'linear model of innovation'. The 'single path' concept was located as a specific and politically influential manifestation of a diverse body of thought proposing the autonomy, determinism or imperatives of technology (Russell, 1980). This prevailing view of technology, which Russell labelled as 'technicism', was one in which technology was seen as "self generating, self directing, and the main determinant of social patterns and change" (Russell, 1981: 6). Under this 'technology-out-of-control' thesis, technology is regarded as

> autonomous, independent, the product of a sphere of activity outside social influence. It develops according to its own logic; it has its own internal dynamic. Human choice plays a limited role; we can at best perhaps speed it up or slow it down. [...] Metaphor somehow assumes the role of explanation: momentum, acceleration, force, speed, inertia, thrust. Technology takes on its own plausible dynamics. (Russell, 1981: 3.)

Russell had no doubt that this was "an inherently conservative view" primarily because it "rules out significant intervention and conscious redirection". Apart from this political essence it was also inadequate analytically in that it obscured both the 'process' of technological development and its 'purposes' regarding motives and interests (Russell, 1981: 6). In his response he contributed to the general critique, through which the field of technology studies emerged in the 1980s, of the technological determinism of prevailing accounts of technological change.

Russell's STS starting point was Langdon Winner's *Autonomous Technology* (1977) which introduced the notion of a specific form of 'technological politics'. While finding this 'conceptually appealing' he was critical of two particular aspects: first the reliance on "technical imperatives" which led to a lack of attention to "differing expectations" and social conflicts, and second the emphasis on large "megatechnical systems" which he felt was too limited in its scope and oversimplified the continuing diversity of technologies (Russell, 1980: 83–84). While he was persuaded of the need for specific attention to the 'technological' dimension of politics, he continued to hold the view that human agency and social action, with different interests and intentions, remained fundamental (Russell, 1980: 84). Rather than treating the technological system as an "inseparable whole" it was "difficult but essential to disentangle social and technical components" (Russell, 1980: 83, 95).

This also led him to question the limitations of both a very narrow "simplistic attention to hardware" or an overbroad "danger of including so much as to render technology useless as a working concept". His sympathies were with a middle range approach of "fairly discrete, if interconnected and mutually reliant, technical systems, of the hardware, information, organisation and techniques associated with a specific product or purpose" (Russell, 1980: 12). Technology

was not an "indivisible package" and included "knowledge" abilities and potentials, as well "manifestations" through application (Russell, 1980: 12).

He argued therefore that a useful framework was required to focus on the relationship between both the social and technical. If one dimension was given priority then the outcome would be unsatisfactory:

> [A]ny theory which takes technology as its starting point is in danger of obscuring the human intention behind it. The very act of conceptually abstracting technology tends to sever social links or mask its social content. (Russell, 1980: 97.)

Here and in his later work, Russell sought to address both the forces leading to the entrenchment of particular technologies and the suppression of alternatives, and also the factors that might open up the scope for choice and for political intervention. At that time the tools for analysing these challenges were not well developed (whether the pessimism of the technology-out-of-control thesis, or the naïve voluntarism of critical projects for appropriate or human-centred technologies). He sought a more nuanced understanding drawing upon a range of intellectual traditions including neo-institutional theories, Gramsci's theories of alliances and work on routines and practices to propose a broadly Marxist approach that seeks to explain both stability and dynamism, and how these are shaped by local contingencies and broader historical settings. From this, his work offers a set of principles and guidelines for analysing change as unfolding at various partially autonomous levels, and proposes theoretical tools for analysing specific arrangements/outcomes and the linkages between different levels of analysis.

Here Russell had embarked upon an ambitious intellectual project. He wrote that his goal was

> to eschew the notion of a general theory and instead provide the theoretical tools with which specific social arrangements and phenomena can be analysed (Russell, 1986a: 58).

To provide scope for exploring his interests in structure and agency in understanding both change and continuity, he developed a methodology whose aim was to

> identify, locate and characterise the collective actors in the sector, trace the network of relations between them and their connections outside, and situate the sector, all with reference to a general substantive model of the whole social formation (Russell, 1986a: 103).

This often required a historical analysis since the aim was to understand how structures had been stabilised or disrupted by actions of various parties. He stressed the need to "trace the historical development [...] in terms of internal dynamics and effects of change in the wider society" (Russell, 1986a: 103). He argued that change was more likely to happen in some historical moments than others, and hence that such an analysis could provide the opportunity to

> acknowledge the presence of contradictions – the more or less temporary coexistence of incompatible or inconsistent features of various types – throughout social systems, within and between levels of structure and spheres of activity, and created, recreated, transcended or exacerbated by action [...] [and] to view change as produced by these contradictions, providing incentive, scope and

> constraints for action against the existing order; and to expect that change rather than forming a smooth process, to be punctuated by crises. (Russell, 1986a: 58.)

Focus of Empirical Work on Contestation

Russell's commitment to the social goal of environmental sustainability, and his concern to understand the politics through which this had been progressed or frustrated led him to argue that empirical work in STS should focus on contestations over the direction of technological developments. Through his emphasis on the interplay between structural constraints and the actions of actors he argued that there were particular moments when the opportunities for change were greater than others. Through his doctoral work on the limited take up of combined heat and power and district heating in the UK, he was as interested not only in those trying to achieve change, but also in the power of established interests to frustrate change. As such he mapped out a methodology for studying specific interactions, involving tracing the historical trajectory leading the parties to interact, and understanding their interests as derived from their location in relation to the potential outcomes. These interests could then be considered in terms of how they were represented in objectives and policies, and through the internal and inter-organisational procedures by which they are generated (Russell, 1986a). He then argued it would be possible to

> identify the structural elements drawn on by actors in the process of interaction, looking for economic, political and ideological components, and considering the different modes of their mobilisation: in devising conscious strategies and tactics, in following accepted procedures, in acting within existing constraints, in attempting to challenge them (Russell, 1986a: 103).

He stressed that this was an analytical device rather than a 'formula' which could generate outcomes from interests and structures. He wrote,

> there is no simple correspondence between interests, objectives, strategies, actions and outcomes. Each process whereby outcomes are produced in interaction needs to be *reconstructed* and *argued*. There can be no 'reading off' and comparison of capabilities and resources from social structure to arrive at a predictable outcome. (Russell, 1986a: 105, his emphasis.)

In his work on the limited take-up of combined heat and power and district heating in the UK from the interwar period up to the mid-1970s, he stressed the extent to which many aspects of the energy system were 'black boxed' by most commentators – that is their structure and approach had a taken-for-granted character. In particular his strong commitment to historically and institutionally informed analysis of energy led him to stress the extent to which producer interests and perspectives dominated the debates. He wrote:

> the energy sector [...] must be situated in the organisational and technical development of the key institutions [...]. These characteristics and relations must in turn be linked to the specific character of the [...] economy and state. (Russell, 1993: 43.)

Such an analysis, he argued, showed that

> much energy politics [...] [consists of] interests organised around production

> [...] and relations between these as regulated by the state [...]. Producer interests have generally sought to consolidate and maintain the structure of the sector. (Russell, 1993: 43.)

This overall argument about 'black boxing' energy analysis might seem less true today. We now have a more detailed body of empirical research (including in this journal) – engaging in far more depth than early studies were able to achieve with various settings of innovation and decision in the energy sector. This arguably allows better understanding of the dynamics of the sector as well as of opportunities to modulate these dynamics. The energy system has by no means stood still in this period – indeed, in the UK and beyond it has been radically reworked. This includes, notably, the turn towards the creation of novel market mechanisms as a means of governing investment, generation and (with the recent shifts towards 'smart' meters and grids) consumption – a move in which unpredicted outcomes have stimulated further reflection and reworking.

Some of these issues were discussed in the recent Special Edition of Science & Technology Studies on 'Energy Systems and Infrastructures in Society' (Silvast et al., 2013). That this special edition needed to be published as three parts [26(3), 27 (1 and 2)] is indicative of the rich vein of studies as STS provides tools for analysing energy and environment challenges. Energy policy continues to be the subject of extensive debate and the issue of what parts of the system are being opened up is still very relevant. It could still however be argued that the 'black box' is only being selectively opened up with some parts left unexamined, or being given only secondary consideration. In reflecting on this it is also worth considering whether our current dominant theories for understanding sustainable innovation (most notably transitions theory and technological innovations systems theory) provide only selective and partial readings of energy innovation (Winskel & Radcliffe, 2014).

Articles in This First Part of the Special Edition

A focus on heat provides a very distinct perspective on energy issues and, in particular, highlights consumer interests in a way absent from many debates. After moving away from the study of combined heat and power and district heating for many years, Russell had returned to this problem shortly before he became ill as part of a research project *Heat and the City* (www.heatandthecity.org.uk). It is fitting therefore that the first part of this special issue has three papers on this topic, including two arising from this empirical project.

We start with an article by Weber that includes a substantive analysis of Russell's theoretical approach to understanding sociotechnical change. Weber focuses on Russell's rich theoretical approach and its distinctive position from the, then, more accepted micro-sociological approaches. Since this was never fully articulated as an integrated theoretical approach, Weber brings together its strands and, through this, argues that Russell's approach can be seen as a precursor of much recent interest by science and technology studies in multi-level approaches. Weber goes on to assess the utility of this perspective to understanding the finding that three countries, apparently in similar situations for example in relation to their climates and historical and political trajectories, have very different levels and types of combined heat and power (CHP) adoption, and that this adoption occurred during different historical periods. This problem

is in the spirit of Russell's approach, with its analysis of the reasons for stasis as well as change, and in particular how certain policy options become excluded. But, as importantly, the analysis highlights the significance of historical moments when it appeared there were opportunities to break with existing path dependencies and other structural factors, and considers the role of political interventions which were more or less effective in allowing such opportunities to be realised. Weber provides a nuanced analysis of both the reasons why change in complex systems is so difficult to achieve, and a non-deterministic account of the way in which combinations of 'structural' change and political interventions can provide opportunities to disrupt path dependencies.

The other two papers focus on the situation in the UK and on the current and future prospects for forms of district heating in the UK. They both draw on detailed work with local authorities currently attempting to implement urban heat networks. As such, both papers move from the country level account of Weber's analysis to explore in greater detail the ways in which policy, cultural and organisational issues shape the opportunities for changing heating system. Most significantly this level of analysis allows an exploration of the ways in which practitioners attempt to counter dominant heating approaches and find their projects shaped by them. Webb's paper focuses on the ways in which innovative financial models, through which new urban heating projects have to be justified, make it difficult to make a 'business case,' despite a favourable environmental assessment. Weber highlights the liberalisation of energy markets as one of the disruptive movements when the case for CHP / district heating might be remade, and when indeed a rapid uptake was seen in the Netherlands. But as well as disrupting embedded institutional structures, liberalisation and privatisation were associated with changes in the way in which financial risks and benefits were assessed and, in some cases, particular technical choices were encouraged. Drawing on the sociology of markets and social studies of finance, Webb's paper explains why the financial innovations that emerged in the UK have been hostile to urban heat networks. However, through detailed work with practitioners she is also able to point to ways in which some individuals find ways to challenge these constraints through, for example, novel ownership or governance models.

Hawkey's paper starts from a recent UK policy commitment to achieve a radical change in heating provision in favour of district heating. Noting that such attempts to change direction had been made in the past (as analysed by Russell) he asks whether the current policy is being pursued in a way that addresses the reasons for past failures. His particular concerns are with governance issues and regulatory approaches which seem likely to undermine the intentions of national level policy yet again. The paper details the ways in which local government bodies attempting to implement national policy commitments are frustrated by continuing restrictions on their competencies, and by the ways in which the ending of a monopoly nationalised industry has failed to disrupt a centralised system of generation or a separation of producer and consumer interests. Thus a vicious circle is again apparent, consisting of attempted projects constrained in scope or by assessment criteria which are only able to achieve a limited impact, which is then used to undermine the policy ambitions which promoted them. He looks to devolved powers to the constituent parts of the UK as potentially able to provide the political leadership to break this cycle.

Thus all three papers in their distinctive ways take forward the theoretical and analytical approaches which were initiated by Stewart Russell, and in particular his concern to understand the difficulties in adopting a technology which, though environmentally beneficial, proved challenging for a number of linked reasons – the scale and capital costs of a large-scale fixed infrastructure, and its compatibility with wider sets of assessment criteria and institutional arrangements.

The next part of this special issue, to appear in 2015, will explore some of the wider challenges posed by Stewart Russell's work, particularly regarding the transition to an environmentally sustainable society.

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Guest Editors

Robin Williams
Director, Institute for the Study of Science, Technology and Innovation
Science, Technology and Innovation Studies Subject Group,
School of Social and Political Sciences
The University of Edinburgh
Old Surgeon's Hall, Edinburgh EH1 1LZ
UK
R.Williams@ed.ac.uk

Sonia Liff
Dr., Independent Researcher
Appleby Research
14 Top Street
Appleby Magna
Swadlincote DE12 7AH
UK
sonia.liff@appleby.ltd.uk

Mark Winskel
Dr., Chancellor's Research Fellow on Energy Innovation
Science, Technology and Innovation Studies Group
School of Social and Political Sciences
The University of Edinburgh
Old Surgeon's Hall, Edinburgh EH1 1LZ
UK
mark.winskel@ed.ac.uk

Editorial written by the guest editors with Fred Steward, professor of Innovation and Sustainability Policy Studies Institute, Westminster University, and President of the European Association for the Study of Science and Technology (EASST).

Appendix:

Brief biography of Stewart Russell (6th August 1955–17th September 2011)

After completing a Natural Sciences degree at the University of Cambridge (UK), Stewart Russell moved to the Technology Policy Unit, Aston University (1980–1986) for his postgraduate studies and some post-doctoral work.

From 1988 to 2006, he was Lecturer and later Senior Lecturer in Science, Technology and Society at the University of Wollongong, New South Wales, Australia. There he was a member at various times of UoW's Research Programme in Science and Technology Analysis, Science and Technology Policy Research Group, Technology and Environmental Strategies Group, Environment Research Institute, Institute for Social Change and Critical Inquiry, Centre for Research Policy and Innovation Studies, and the Centre for Asia Pacific Transformation Studies.

Stewart Russell joined the University of Edinburgh in 2006 as Deputy Director of the Research Centre for Social Sciences. He helped to build the interdisciplinary research programmes of the Institute for the Study of Science, Technology and Innovation. His sustained efforts, particularly in developing joint postgraduate programmes with the Science Studies Unit, paved the way for the establishment of the Science, Technology and Innovation Studies subject group.

As well as his important contribution to the development of the field of Science and Technology Studies (STS) over many years, outlined above, Stewart was tireless in his support for colleagues in their work – always available for students wanting to explore some knotty analytical question. He was keen to build links between STS and other scholarly communities and with wider audiences. At Edinburgh, for example, he developed an innovative *Understanding Technology* public lecture series with the National Museum of Scotland.

The Institute for the Study of Science, Technology and Innovation has established a fund to create a studentship to commemorate Stewart's commitment and passion in helping students achieve their full potential and to carry forward scholarship in this area. Further details can be found at: www.stis.ed.ac.uk/news/2013/the_dr_stewart_russell_student_award_fund.

The Success and Failure of Combined Heat and Power (CHP) in the UK, Germany and the Netherlands: Revisiting Stewart Russell's Perspective on Technology Choices in Society

K Matthias Weber

Stewart Russell's research work on combined heat and power / district heating (CHP/DH) in the UK was among the first empirical contributions to demonstrate that technological change is not just determined by seemingly objective technical and economic performance characteristics, but rather the result of social choices. His rich conceptual thinking is reconstructed in a coherent framework, and its explanatory power explored by analysing the innovation diffusion paradox of CHP/DH: in spite of very similar technical and economic characteristics, the patterns of innovation and diffusion differ significantly across countries. To this end, the evolution of CHP/DH in the UK, Germany and the Netherlands is compared. Russell's ideas can be regarded as a predecessor of recent multi-level approaches to the analysis of socio-technical change. He put much emphasis on studying power relations for explaining the (non-) occurrence of socio-technical change; an issue that is still debated today.

Keywords: technology choices in society, power and conflict, combined heat and power

Introduction: Characteristics and Diffusion Patterns of CHP/DH

Science and technology studies have their roots in a range of research strands in economics, sociology, political sciences and history that converge on the conviction that technologies do not just emerge as a result of their objective superiority in terms of technological or economic performance, but as a result of the social shaping of mental and conceptual frameworks as well as organisational, institutional and political conditions in which they are embedded.[1] This debate started in the 1980s, based on selected evidence from historical studies, but it took several years to take coherent shape.

One of the first thorough empirical studies of a technology that was guided and inspired by a focus on social relations, in the analysis of technology addressed the case of combined heat and power, and specifically its application to district heating, in the UK (Russell, 1986a). Drawing upon a thorough empirical foundation, it integrated many

of the – then current – debates about the socially and politically shaped nature of technology, and can thus be regarded as a pioneering piece of research.

The underlying principles of Combined Heat and Power (CHP) are rather simple. CHP means the simultaneous generation of electric power and useful forms of heat in the same process. It is an established technology that has been used since the beginning of the twentieth century, but has undergone several changes and improvements over past decades, for instance in relation to prime movers (engines, turbines, fuel cells, etc.) or the control systems to optimize the operation of CHP systems (load management, remote monitoring, etc.). Two main application areas of CHP can be distinguished. First of all, district heating, i.e. the centralised supply of hot water or steam, which represents a very efficient way of providing heating to residents. Large-scale local plants tend to be used for this purpose because heat cannot be transported without major losses over long distances. Secondly, industrial sites often need large amounts of high-grade heat, and if heat production can be coupled to power generation, either for their own use or for export to the power grid, the internal energy of the fuel can be exploited more efficiently than in separate processes. Sometimes, low temperature heating networks can even use the residual heat from high-temperature industrial applications. Until the early 1990s, these two types of CHP applications were mainly based on comparatively large-scale industrial and district heating plants. More recently, small-scale CHP systems have been developed that can be used for heating (and also cooling) purposes in large individual buildings such as hospitals, schools, public administration or residential areas down to the level of individual households, as well as for smaller industrial plants.

The compelling advantage of CHP is that it allows a much more efficient use of the internal energy of the fuel than in power-only production. Heat-only plants can also be highly efficient, but generating electric power as a particularly valuable form of energy entails major energy losses, dispersed as waste heat. In other words, the key argument in favour of CHP is that it allows high-value electricity to be produced in a way that avoids wasting at least 50% of the internal energy of the fuel, and instead uses it for heating or industrial purposes.

CHP thus seems to be an obvious example of a superior technology from an environmental and potentially also from an economic point of view, in comparison to power-only or heat-only plants. However, since it was first developed in the early decades of the twentieth century it has played a marginal role only in several European countries, whereas it flourished in others.

The diffusion patterns of CHP in Europe show some striking differences across countries (Raven & Verbong, 2007). For a comparative analysis, the UK, the Netherlands and Germany are chosen here as country cases. The developments over the past thirty years in the Netherlands and the UK are particularly interesting, because both countries had a quite low level of CHP capacity on the 1980s. The Netherlands managed to increase its CHP capacity by a factor of almost four in about fifteen years, the UK saw a much more modest growth of CHP, though also mainly in industrial applications. The situation in Germany is different in that CHP has a quite long-standing history of both industrial and district heating applications, with slow, but continuous growth over the past decades.

How to Explain the Innovation Diffusion Paradox of CHP/DH?

This diverse picture raises the question of why such a seemingly promising technology is highly successful in some countries, but not in others. Explaining the differences between countries requires explanations that go beyond traditional technological or economic frameworks. In increasingly open energy and energy technology markets in Europe, the technology used in the UK does not really differ from that in the Netherlands or Denmark. In fact Dutch companies started exporting their small-scale CHP technology to the UK in the mid-1990s, showing that the technical systems used do not differ significantly between countries.[2]

How can this paradox be explained? From an STS perspective, the immediate answer is rather straightforward and stresses the influence of social, organisational, cultural and institutional factors. The basic tenets of the STS perspective were already recognised when Stewart Russell (1986a) reconstructed in his PhD research the changing history of CHP and district heating in the UK since the 1930s as a process of social and political shaping. His research work raised in a thorough and empirically grounded way, many of the issues that have subsequently been debated by STS scholars. With his empirical work, he contributed to sharpening the understanding of the social shaping of technological trajectories, with a particular emphasis on the role of the *political* shaping of CHP and the influence of structural factors shaping innovation. His particular concern was with the ways in which particular possibilities failed to become expressed. In contrast to micro-sociological approaches this was seen not as a result of explicit conflict, but rather of historically grown structures and path-dependencies that systematically excluded certain options. While he derived clear methodological guidelines for his empirical work from the theoretical building blocks he used, he was less explicit in terms of formulating his conceptual framework.

Against this backdrop, a first objective of this paper is to revisit and reconstruct Stewart Russell's theoretical perspective on socio-technical change. Secondly, the aim is to explore the explanatory power of his framework by applying it to the aforementioned paradox, i.e. to explain the differences that can be observed between different countries in their adoption of particular forms of CHP.

The paper is structured as follows. In the next section, Russell's perspective is revisited and re-constructed by extracting his main lines of reasoning from his major publications. By relating his thoughts to later STS work on CHP/DH, his perspective will be embedded in the context of the wider STS debate. Section 3 uses this framework to look comparatively at the empirical examples of three countries (UK, the Netherlands, and Germany) with their very distinct innovation and diffusion patterns of CHP/DH. The aim is to explain the CHP paradox on the basis of Russell's main theoretical lines of reasoning. The final section draws some conclusions on the positioning of Stewart Russell's scientific contribution, and gives an outlook on a research agenda that flows from it.

STS Perspectives – Russell's Conceptual Framework

Russell's main interest was in the way choices are made about technologies in society, and in particular the political nature of these choices. As he argues that if technology is seen as socially shaped, then it is essential to understand how technology choices are made (Russell & Williams, 2002: 39). He understands technology as a social product, but admits that there are a number of constraints imposed on the choices to

be made – constraints which should not be ignored in the sociological analysis of technology. These limits to social choice are due to several different factors, including available skills, materials and tools, scientific and other forms of understanding technology and its unforeseen consequences, the physical reality around us and the constraints imposed by existing systems (Russell, 1986a: 21–23). Most of these constraints, however, are the result of previous choices made in society. Russell's key point in this regard is that social divisions are decisive for the choices made in the past and the present, and they point to the question of who is ultimately in control of these technology choices. Matters of power and control are a central element of Russell's thinking.

In his early work, Russell (1986a: 16) was not intending to develop a comprehensive theory of technology choices in society, but several of his guiding ideas were innovative at the time and influenced later debates. He also formulated the kinds of requirements that a theory of technological choice in society should meet, namely

> to provide a structured, historical and dynamic account of a social formation; explain the specificity of social phenomena; and allow engagement with the general forms and changes in technological ensembles and the detailed content of specific artefacts and techniques[…]. Russell, 1986a: 18.

In his later work, his theoretical approach and framework became more explicit and coherent in the sense that he was seeking to resolve some of the tensions in the prevailing STS debates (Russell & Williams, 2002).

In what follows, an attempt is made to identify the key arguments around which Russell's conceptual thinking was built. These will then be integrated into a multi-level conceptual framework that picks up levels of analysis proposed by Russell himself to guide his empirical analysis and interpretation. This conceptual framework provides a blueprint to analyse and understand how technology choices in society are made, and how ultimately the dynamics of socio-technical change come about.

The first of the seven subsequent key arguments is the most fundamental one in that it focuses on the overarching logic driving socio-technical change, whereas the six other arguments refer to specific features and determinants of that change process.

Socio-Technical Change as Complex Process of Creation and Destruction

Russell's perspective is rooted in a broadly Marxist analytical approach and substantive social model. The Marxist perspective on social transformation, focusing on the realm of production and the role of labour, had to be adapted to the issue of technology choice. Russell (1986a: 19) argues that

> cutting labour costs is only one of the uses to which technology can be put. It may also be used to reduce the cost of production plant; to economise on raw materials, component stocks of energy; in devising radically new techniques to supersede traditional production routes; in creating new products, improving existing ones incrementally or making superficially different products, to compete; and in reducing the time taken to get revenue through improvements in communications and transport.

Technology choices are thus seen as part of a broader process of socio-technical change and transformation; a process, in

which differences in power and interests are the key driving forces. Russell broadens the Marxist perspective by stressing that technology can be put to work for ends other than cutting labour costs and employment. Socio-technical change, in this sense, is about both the creation of the new and the (partial) destruction of the old.[3] Or to put it in Russell's (1986a: 26) words:

> Each option will to a differing extent require the destruction, replacement, enhancement or modification of already entrenched structures necessary for production, maintenance and options in the system of which it is to be a part.

Russell acknowledges that the observable dynamics of change are the result of complex mechanisms, resulting from the interdependence of social change and technological change, and from the path-dependencies, lock-ins and network externalities inherent to the socio-technical system in question (Russell & Williams, 2002: 55–60). This kind of reasoning is in line with similar arguments raised at about the same time by evolutionary and neo-Schumpeterian economists, as well as by later proponents of the multi-level perspective on socio-technical change (Geels, 2002).

Bridging Between Structure and Agency – Structures as Frames for Technology Choices

The duality of structuralist and behaviouralist perspectives on social change has a long tradition, and trying to reconcile both perspectives has been a recurrent struggle in the STS literature. Russell (1986a: 61) recognizes the limitations of established structuralist and action-oriented approaches to the study of social change and suggests relating the two levels of analysis by arguing that

> if it is accepted that social systems are in some sense structures of relations involving human action, an adequate framework must explain the role of action in creating, reproducing or changing these structures.

Building in particular on Jessop (1982), Benton (1981) and Giddens (1979), he favours a dialectical approach in which

> to take structures as imposing limits within which agents act, still essentially free-willed but with restricted scope. (Russell, 1986a: 61)

In seeking to understand his empirical material Russell (1993: 51) noted:

> I find it necessary [...] to argue the need for several different levels of analysis in the social systems within which technological development is situated [...].

With this statement, he is stressing that it is not enough to just trace actors and their networks, but that one needs to take into account also the social structures and contextual developments in which they are embedded. He argues against the then very influential micro-sociological perspectives on the social shaping of technology (Pinch & Bijker, 1984) which he criticizes for being mainly descriptive and not providing "an adequate explanation of why we have particular technologies and not others" (Russell, 1993: 50), for transferring naively categories from the sociology of science to the social analysis of technology (Russell & Williams, 1988), and for ignoring the need to embed specific social groups in their wider historical and structural context

(Russell, 1986b).[4] In particular, the partial emphasis on the micro-level is criticized

> in response to the action paradigm of the micro-sociologists, we find ourselves in the position of having to reassert the importance of the macro, and to argue the need for several different levels of analysis of the social systems within which technological development is situated[...]. (Russell & Williams, 1988: 2)

Patterns of centralisation and decentralisation, the existence of large incumbent players and the absence of smaller ones, or the formal competencies assigned to certain actors may be traced back to earlier choices and path-dependencies in society, but they cannot be ignored in the analysis of current choices. According to Russell, it is only within the confines of what structural and institutional contexts allow that behavioural forces can unfold to create and establish new technologies. Or, as Russell (1993: 52) puts it with regard to CHP:

> A contextual analysis [...] is necessary if we are to understand whether the exclusion of this technology has been accidental [...] or systematic [...].

In his work, Russell stresses the importance of the wider structural and institutional context in which micro-level interactions take place. His arguments foreshadow lines of reasoning that were later on proposed by other scholars studying the emergence of technology who also see structural conditions as enabling or preventing new types of behavioural and technological options. This view has become particularly prominent in the STS literature since the turn of the millennium, with the research strand on transitions using a multi-level perspective on long-term processes of socio-technical change. Here, the emphasis on the interplay between context, structures, institutions, organisations and behaviour is presented as a novel type of multi-level perspective (Geels, 2002), using the concepts of socio-technical landscape, technological regime and niches to denote three distinct levels, with the latter being essential for enabling experimentation and learning in protected spaces.

Interestingly, the multi-level perspective as introduced by Geels has also been used recently to analyse the emergence of CHP in the Netherlands (Raven & Verbong, 2007; Raven, 2007). Other attempts to bridge between structure and agency recur to a systems language, such as the TIS (Technological Innovation Systems) approach, which has been adopted by Hawkey (2012) to revisit the situation of CHP in the UK. There are without a doubt important differences between Russell's perspective and the new multi-level and TIS perspectives, in particular with regard to the understanding of how change comes about. However Russell's lines of reasoning can nevertheless be regarded as a precursor for the resurgence of interest in addressing different layers of determinants of socio-technical change.

Organisational, Institutional and Cultural Embedding of Technology

Russell recognises the particular importance of the organisational, institutional and cultural characteristics of the 'terrain' – as he puts it – in which a particular technology is embedded. This terrain refers to the sectoral context, but also to national level features, of relevance to the technology under study.[5] Large socio-technical systems can be organised in a more centralised or a more decentralised manner, thus favouring certain kinds of technologies over others. The balance

between the operation of market forces and regulation is another feature that frames and guides technology choices. Finally, the level of integration or separation of service supply streams characterises the terrain, and it is an aspect of particular importance for CHP. According to his empirical analysis, the institutional and organisational environment of the energy sector in the UK, was highly detrimental to the uptake of CHP/DH.

> The second aspect is the necessity of understanding the institutional structure of the sector. The key absence has been an organization with national responsibility for heat supply or even conservation, so that CHP and DH have been left to organizations with other major responsibilities, for which they would be additional and marginal activities with precarious financial and political support. (Russell, 1993: 52.)

Now, more than thirty years after the introduction of institutionalist perspectives and innovation systems approaches, paying tribute to the importance of institutional and organisational determinants of technological change seems almost trivial. At the time Russell published his work however, these kinds of arguments were controversial and counter to prevailing lines of debate in the energy sector and in energy policy in particular. He argues that without a 'carrier organisation,' that bundles interests associated with a specific technology, it is unlikely that this technology will succeed in a context of incumbent technologies and organisations. This argument went clearly beyond the usual technical and economic arguments used in the debates.

Interests and Power in Relation to Technology Choices

The structural, institutional and organisational determinants define the configurations in which the interests and power positions of the different organisations can be brought to bear. The ability of individual organisations to behave strategically, to pursue their specific interests, and to use their power positions to enforce them is key to understanding actor behaviour and change in socio-technical systems. This was a central conviction of Russell's (1980: 97) argument from his very early works:

> Any theory which takes technology as a starting point is in danger of obscuring the human intention behind it. The very act of conceptually abstracting technology tends to sever social links or mask its social content.

The notion of interests is in itself a complicated one. According to Russell (1986a: 75, 80–81), it is important to distinguish objective from subjective interests, i.e. those that are located in the structure of social life from those that are the result of interpretation by an observer. Moreover, interests depend on the structural location of actors, as well as on the specific circumstances of interaction. Interests usually refer also to potential outcomes and identities, and by referring to the future are inevitably contradictory. Power, against this background, is then the ability to secure these 'fuzzy' interests.

It is not a trivial task to identify 'interests' in practice. Interests must be understood as being related to existing arrangements as well as potential changes at different levels. They need to refer to subjective expectations as much as to seemingly objective organisational concerns. A typical strategy to safeguard an organisation's particular

interests is to channel them through seemingly technical debates. Russell (1993: 52) had identified this mechanism very clearly in his work:

> The terms of appraisal were clearly dependent on the performing institutions and the precise constraints on it. It is not sufficient to ask whether the option was 'economic'. We need to ask for whom its economics was assessed, and why narrowly defined economic criteria were used and whether they were appropriate.

With the help of these and other mechanisms, alternative options can be systematically excluded, if they challenge established interests of the incumbents. In order to understand their interests, it is necessary to take a broader perspective on organisational objectives and strategies as embedded in a sectoral context:

> The electricity industry was not always actively opposed to CHP; but nor was it ever a strong supporter. We need first a broad picture of the major objectives and programmes it had defined for itself, and its evolving relation as a nationalized industry with government and with the rest of the sector. (Russell, 1993: 52.)

On such a broader basis it is possible to understand better why certain organisations oppose or support a new technology, and why certain selection criteria have been introduced, while others have been excluded.

The importance of organisational interests and power structures has been confirmed by later authors, and also specifically with regard to CHP in different countries (Summerton, 1992; Hard & Olsson, 1995; Weber, 1999). They all stress that in order to reap the benefits from synergies between different socio-technical systems it is essential to integrate them under the roof of a single organisation, as a way to overcome major conflicts of interests.

Knowledge Dynamics and the Assessment of Technology

An important role is assigned by Russell to the use that can be made of knowledge in its various forms in political debates about technology choices. In fact, knowledge, and the control over knowledge, is a key element for understanding how power is exercised and interests defended. Power and knowledge are regarded as the two facets of social action, which is why it is essential to consider how "content" is produced under the influence of interests and power:

> It is clear [...] that debate is a significant component of struggle; that knowledge in some form informs all practices and actions; that the dominance of certain views cannot be explained by the 'facts'; that knowledge is an important resource in interactions; and that its possession, deployment or withholding is significant in determining outcomes. In disputes over scientific and technological issues in particular, ostensibly technical arguments are widely recognised to be aligned to institutional interests in terms of optimism, interpretation of evidence, and so on, though protagonists generally deny such a connection. Thus the problem in explanation is: what status should be attributed to technical arguments and their resolution in explaining outcomes, and what should the disposition of the analysis be towards the content of contending positions? (Russell, 1986a: 87.)

Russell pursues a middle way of neither following positivism (i.e. the belief in the objective quality of knowledge) nor relativism (i.e. the rejection of entering into a substantive debate about the pros and cons of technical arguments). According to Russell (1986a: 95), it is important to be aware of the social, normative and sometimes even ideological influence on decisions, but it still matters to understand the substance of debates:

> [...] the role of an argument is to be analysed specifically and with reference to its content [...], showing in particular how elements of knowledge – scope, form and substance – are drawn on as resources in the process of formation and deployment.

At the same time, knowledge in relation to new technology is always uncertain in many regards (e.g. in technological and economic terms, but also with regard to the context of technology use), and this uncertainty raises a further complication, also known as the Collingridge dilemma (Collingridge, 1980).[6] In brief, it states that any attempt to actively influence and shape the unfolding of a specific technology is confronted with a fundamental dilemma: early on in the process of a technology unfolding, we know and understand too little about it to assess its potential impacts and influence its trajectory, but later on in the process, once we know and understand enough about it to be able to influence it in an informed manner, the trajectory has already become so entrenched that it can hardly be influenced any more. The recognition of this dilemma calls for a continuous interaction and learning process between the actual realization process of a technology and the social and political decision-making around it. It implies that any assessment of a technology in the making must accept uncertainty as an undeniable condition of decision-making. In fact, Russell and Williams (2002: 54) go even further in arguing that this inherent uncertainty requires new forms of policy learning and monitoring:

> Our understanding of the co-evolution of technologies and social forms shows that treating technological development and the occurrence of 'impacts' as separate processes is severely limiting. It highlights the need to integrate policies and programmes for innovation with those for evaluation and regulation. The emergent and unpredictable nature of sociotechnical transformations points again to the value of flexibility and constant monitoring, maintaining channels of communication and arenas of debate, and avoiding disincentives to open appraisal.

Russell's understanding of how seemingly technical debates influence and even dominate the shaping of evaluations and assessments of new technology is pertinent here. Institutional structures matter a lot, but so do professional communities and their role in influencing economic and political groups. Their claimed monopoly on technical expertise may easily lead to a reinforcement of prevailing technological paradigms (Dosi, 1982) and thus reinforce their path-dependency, to the detriment of other non-conventional alternatives.

According to Russell (1986a: 91), assessing the merits or not of a technology thus calls for a critical position with regard to any claim of 'rational' evaluation; any evaluation needs to be related to context and interests, and to the question of how debates are structured:

> [T]he construction of technical knowledge is particularly important here. It depends on the relation of technical experts to political arenas, and the process of negotiation between them over the objectives of their work, affecting not only the adaptation or transformation of knowledge but its very content.

Embedding in Broader Debates and Expectations

Russell recognized the importance of looking at a broader frame of reference than just the concrete choices about particular technologies. The specific issues associated with CHP were embedded in wider debates about future policy objectives in a range of adjacent policy areas. In his writings, he points out that

> [before liberalisation] CHP found itself at the intersection of a number of debates in Britain: on energy strategies, the environment, conservation, and alternatives to nuclear power; on the role of coal, the maintenance of markets for it, and the defence of the industry against run-down; on fuel poverty, living conditions and degenerating housing stock; on problems of the nationalised industries, alternative forms of public ownership and [...] the devolution of centralised state functions to regional and city levels; and on criticism of the electricity supply industry over its nuclear programme, over-forecasting and excess capacity[...]. (Russell, 1994: 19)

Reducing the debate about CHP to one single arena is thus not appropriate. With the broadening of the range of actors having a say with regard to a technology, the range of arenas and arguments in which an issue is embedded is equally broadening. The notion of 'terrain' as used by Russell reflects this multiplicity of co-existing arenas in which an issue is dealt with. Some of these arenas may at first glance appear entirely disconnected from the issue at stake, but they nevertheless touch upon a range of debates, arguments and expectations that matter. One of the biggest challenges in this regard is how to manage and coordinate the arenas on this terrain, with their fragmented responsibilities and lines of reasoning.

Russell already recognised the importance of taking views and expectations about the future of the terrain into account, even if these expectations are subject to a great deal of uncertainty. This implies that the question how well a technology is embedded in future expectations (for instance about broader energy issues such as oil prices or institutional frameworks), which are often determined at national, European or even global level, needs to be considered when assessing its future perspectives.

In the STS literature, the importance of the role of future expectations for the shaping and diffusing of new technology has been re-discovered in recent years (Borup et al., 2006; van Lente & Rip, 1998). In fact, expectations at different levels of abstraction can reinforce each other, showing that the embedding of expectations with regard to a specific technology in wider expectations, for instance related to energy supply or climate change, can strengthen the potential of a technology to diffuse (Budde & Konrad, forthcoming). In other words, a technology's future prospects not only depend on the expected performance of that technology, but on how well it fits into broader future visions and debates around energy supply, and the expectations associated with them.

The Role of the State in the Governance of Technology

The history of energy supply is also a history of energy policy. Energy supply has been dominated for decades by public sector and state-owned organisations at national, regional and local level, and technology development was strongly influenced by government policy as well. This kind of political shaping of technology is a central element in Russell's thinking and it has been taken up in STS debates as well.

By rejecting linear thinking and acknowledging complexity, Russell calls for a more modest conception to what government policy can actually do and achieve, and how under these conditions "strategic social objectives can be formulated, pursued and maintained" (Russell & Williams, 2002: 145). He calls for a process-oriented perspective on the governance of technology; a perspective that is interactive (i.e. mediating between use and supply) and reflexive in order to handle unanticipated and undesirable consequences, and that stresses the importance of modulation and orchestration as the main roles of government policy in order to ensure continuous learning to take place:

> Thus technology steering will look much less like the traditional picture of omnipotent and omniscient central direction. It will be much more like modulation and orchestration of the existing dynamics of innovation or technology management. (Russell & Williams, 2002: 139.)

Russell's argument about the need to embed specific technology debates in a broader frame of reference extended to a range of policy areas and levels. In the case of energy supply and CHP/DH, the role of local authorities is particularly noteworthy because their range of autonomous competencies is decisive for their ability to make local energy choices and thus create opportunities for CHP.

The recognition of the complexity of energy choices in a multi-level, multi-policy setting implies that there is no one single point of intervention for policy instruments to "push" CHP, but a range of policy instruments needs to be considered simultaneously:

> The analysis makes clear that no one point of level of intervention will be adequate – particularly and exclusive focus on the design and development phase of innovation. It opens up a wider range of points of influence, and draws attention both to tensions between different means of intervention and to opportunities for synergy and reinforcement. (Russell & Williams, 2002: 144.)

Finally, Russell recognises the importance of the timing of policy interventions. His arguments in favour of a more modest approach to technology policy do not mean that the influence of policy is insignificant, but that the effectiveness of interventions strongly depends on the right timing of a major initiative. If this is judged correctly, a regime changing impact can be achieved, as in the case of the deregulation and privatisation policy after 1989, which provided an opportunity to change course in the energy sector of the UK. This could have changed the role of CHP, but it would have required an active and sustained policy to remove obstacles and provide incentives to stimulate investment into CHP. This is reflected in Russell's assessment of an active and supportive government policy to induce change in socio-technical systems. He argues with regard to the British situation:

> At privatisation it was widely assumed that the chances of a significant introduction of CHP would improve, but the structure of the new electricity market is providing a new and perhaps more daunting set of obstacles (Russell, 1996: 1).

However, a pro-active enforcement strategy of government to overcome entrenched interests and associated path-dependencies is unlikely to be pursued if it is not in line with the prevailing political culture. It requires the willingness and ability to give multiple and sustained policy impulses, and ultimately on the political culture of a country.[7]

A Multi-Level Framework

The integration of these main building blocks of Russell's thinking about technology choices in society into a consistent framework was partly done by Russell himself. Inspired by the conviction that the structure – action dichotomy needs to be overcome, he proposed three interdependent levels of analysis (Russell, 1986a):

1. *Context* in which a specific debate about a technology is embedded;
2. *Interactions* in organisations and arenas, which are dealing with the technology in questions;
3. *Knowledge* in terms of issues, evaluations and arguments, which are constructed and used in the interactions, arenas and organisations.

Six of Russell's key arguments can be assigned to these three levels, in the sense that they provide the main lines of reasoning for explaining technology choices and socio-technical change. The interactions between these three levels, and thus the interplay between the six main lines of reasoning, are embedded in Russell's guiding argument about the emergence socio-technical change processes, which is inspired by Marxist and complexity thinking.

The two context-related lines of argumentation ensure that the specific issue of technology choices is not seen in isolation, but as embedded in a wider range of structural, institutional

Table 1. Russell's multi-level framework

Layers of analysis	**Key argument**
Context	• Structures as frames for technology choices (e.g. societal or energy system) • Organisational, institutional and cultural embedding of technology
Interactions	• Interests and power in relation to technology choices • The role of the state in the governance of technology
Knowledge	• Knowledge dynamics and the assessment of technology • Embedding in broader debates and expectations
Dynamics	**Key argument**
	Socio-technical change as complex process of creation and destruction

organisational and cultures conditions, which tend to impose major path-dependent constraints on technology choices in society. Interactions associated with interests and power are at the core of Russell's framework, and they extend to the shaping of the arguments and knowledge claims that underpin interests and power positions. In this regard, the ability to manage and negotiate the knowledge claims is seen as crucial by Russell for understanding how interests and power can actually be used to determine technology choices. The knowledge claims are nurtured by a range of wider debates from which arguments and expectations can be drawn in order to underpin the assessments in favour or against the choices under debate. Government agents, either local or national, are just some of the players in that game and, depending on their specific role, they can influence context as well as specific choices and knowledge dynamics. Government policy can, exert a major influence on the future course to be taken, if time windows of opportunity are targeted in a coherent manner at the different policy levels and in a range of policy domains of relevance to the choices in question. Overall, a government-induced process of changing course in a complex system like energy supply will require destabilizing historically grown structures, institutions and practices, together with their underlying stabilizing mechanisms, while in parallel triggering the emergence and growth of the elements of an alternative by establishing corresponding self-reinforcing mechanisms at a suitable moment in time.

Explaining the Paradox – Comparing CHP in the UK, Germany and the Netherlands

If Stewart Russell's framework for explaining technology choices in society is a powerful analytical instrument, then it should provide a basis for an explanation of the innovation diffusion paradox of CHP. This is that while CHP technology and applications do not really differ significantly across countries, the patterns of innovation diffusion diverge significantly, with diffusion rates very high in some countries and very low in others. Denmark, the Netherlands and Finland generate between one third and half of their electricity from CHP. Other countries such as the UK or Sweden, while having similar climatic conditions, are well below 10%. The low level of CHP diffusion in France is also remarkable, but among several other factors the important role of nuclear power generation needs to be taken into account here. Other countries show intermediate levels of CHP diffusion. Germany and Austria, but also some Mediterranean countries, have quite significant CHP capacities installed.[8]

The UK, Germany and the Netherlands have been selected for detailed investigation and comparison, each showing distinct patterns of innovation and uptake of CHP. In the UK, the level of diffusion of CHP and district heating has remained very low, even if some growth in industrial CHP has been observed since liberalisation of gas and electricity supply markets in the second half in the 1980s. The Netherlands are characterized by very rapid growth of small-scale and industrial CHP applications since the late 1980s and a moderate uptake of district heating schemes, which was equally enabled by liberalisation of energy markets. In Germany, both industrial CHP and district heating have played quite a significant role over a much longer period

of time. This was further enhanced and complemented by small-scale applications during the 1990s, a development that was at least partly facilitated by the slowly liberalising energy sector in Germany. As major external conditions for the uptake of energy technologies, such as the climate conditions or the level of industrial development, are similar in all three countries they can be excluded as important explanatory factors for the differences in patterns of innovation and uptake.

The focus of this comparative analysis will be on the past forty years starting with the growing interest in energy efficiency after the oil crises of the 1970s, and covering, in particular, the period before and after liberalisation of energy supply markets. This period is very suitable for comparative analysis because it allows for the study of

Table 2. Phases of evolution and uptake of CHP in the UK, Netherlands and Germany

Phase	Disruptive event	Relation to interest in CHP	Change in use of CHP
1	Early industrial applications	First examples of industrial CHP and DH demonstrate feasibility and stimulated interest in efficient energy solutions	• Isolated cases of CHP development was the norm across all three European countries • Led by individual engineers
2	Post-war reconstruction following destroyed infrastructure	Rebuilding of cities and industry presented opportunities to consider CHP for heat and power supply	• In UK and the Netherlands evidence of active consideration of district heating, but limited realisation • In Germany CHP application to both housing and industry
3	Oil crisis of early 1970s	More expensive energy stimulated interest in exploring more efficient alternative technologies	• Some further development and retrofitting of CHP in Germany • Growing attention, but little change in the UK and the Netherlands
4	Liberalisation / privatisation of heat and energy supply markets	Presumed economic efficiency of open markets expected to provide opportunities for new approaches	• Rapid increase in CHP in the Netherlands • Slow, but steady further expansion of CHP in Germany • Little change in the UK
5	Support for decentralised renewable energy	Increases economic viability of alternatives to existing generation	• Expansion of CHP continues in Germany • Stagnation of CHP at low level in the UK, and at high level in the Netherlands

responses and patterns after an external shock. However, as highlighted by Russell, history matters, and a brief look at previous decades of CHP/DH history is needed. There were some 'windows of opportunity' for CHP/DH in earlier times, such as after the Second World War, and some of the structural, organizational, institutional and cultural aspects can even be traced back to developments in earlier decades of the twentieth century.

The main categories of Russell's framework, i.e. context, interactions, knowledge and overall dynamics, will then be applied to structure the discussion of the three cases in a comparative way with a view to explaining the differences in the innovation diffusion dynamics. The empirical material presented draws mainly on secondary sources from the three countries.[9]

The Historical Patterns of CHP Development

In the course of the twentieth century a number of main phases can be differentiated which were significant for the evolution of CHP. These phases provide a historical perspective on contextual developments that opened up new opportunities and/or specific challenges for CHP, but to which different countries reacted in distinct ways. In other words, these phases provide a common historical framing for the three countries under study, and, as such, may help understand the cultural and institutional contexts that are still influential.

Five phases are identified which are marked by major external (e.g. war, oil crisis) or political (i.e. policy reform) disruptive events. These phases are common to all the countries under discussion here (and were observed by Russell in relation to the UK) but, as sketched in Table 2, the outcomes for CHP development vary between them.

This longer-term historical picture shows that even if strong organisational path-dependencies exist, there are distinct moments in time when these patterns can be shifted. Disruptions, such as the Second World War, the oil crisis, or liberalisation of energy supply, seem to open up opportunities for major changes to occur. Whether these opportunities are exploited depends on the strategies pursued within national systems to overcome the full spectrum of barriers and constraints; strategies for which government policy can be the main trigger.

Context

Structures as frames for technology choices

The autonomy and competencies assigned to local authorities are important structural features framing technology choices, particularly with regard to district heating applications of CHP. Whereas in the UK local authorities have traditionally been endowed with weak competencies, the opposite is true in Germany. This British picture has not really changed, in spite of the 'devolution' policy to decentralize certain political competencies. German local authorities have in principle many different levers of change at their disposal, ranging from ownership of utility companies, special subsidies and regulations, through to planning and coordination. They are often responsible for the supply of a range of utility services, including water, transport, electricity and heat, allowing for both decentralization and horizontal integration of electricity and supply under one roof. In the Netherlands, local authorities also have a significant degree of autonomy, but are endowed with less resources for pursuing independent energy supply strategies than in Germany.

With regard to industrial applications of CHP, all three countries are home to energy-intensive sectors and thus offer

– in principle – a significant potential for CHP. In practice, only Germany has seen a significant amount of CHP installed since the 1960s, with the Netherlands catching up very quickly since the 1980s. Whether industrial CHP could flourish or not was thus a matter of regulatory conditions rather than of structural constraints on the demand side. Another industrial characteristic to consider in the context of CHP is the role of oil- or gas-extracting industries, which are still quite important in both the UK and the Netherlands. In contrast to the UK, the Netherlands have always been very concerned to exploit their natural gas resources in as efficient and sustainable way as possible.

The supply side of CHP systems is also of relevance here. With major technology supply companies in the energy sector operating increasingly at global level, their investment priorities have been slowly adapted to the standards of international financial markets. Less attention is paid to local specificities. This is an issue of particular importance for the UK (Hawkey, 2012: 20), where private investors play a more prominent role in the energy sector than in Germany or the Netherlands.

Most of these structural conditions remained in place even after the destructive shock created by the liberalisation and (partial) privatisation of the energy sectors. Against this backdrop, it is important to consider whether new CHP-friendly players outside the energy sector emerged in this transition phase or not. In Germany, there were influential supporters of CHP already active before liberalisation, and they emerged in the Netherlands quite quickly. In the UK, however, they remained marginal. Taking these changes in actor configurations into account is important to understand the evolution of CHP in the post-liberalisation phase. The arguments in favour of CHP could be made much more forcefully in the Netherlands and Germany, and this influenced the shaping of new regulatory frameworks in the broader national debates on the liberalisation of energy markets.

Organisational, institutional and cultural embedding of CHP

The organizational settings of the energy sector, in terms of the degree of centralization of the electricity supply industry (ESI), the infrastructure backbone, or the separation of heat and power supply, represent key elements of the terrain in which CHP is embedded. As described in his detailed historical account, Russell (1986a, 1993, 1994, 1996) shows that in spite of several serious attempts over the decades to establish CHP more firmly as part of the British energy system, it never really fitted the structure of vertically integrated, but horizontally separated chains of heat and of power supply, and thus fell in-between the interests of the main industrial players. And as pointed out above, local authorities were not in a sufficiently powerful position to establish CHP major district heating schemes either. Although the German ESI has also relied for several decades on large-scale regional monopoly suppliers, there has always been a lot of room for local and industrial CHP initiatives. Local energy companies and industrial power producers had sufficient resources and competencies to run their own local low-voltage grid infrastructures, pursue their own energy strategies, and thus ensure a diversity of technology solutions, including CHP.

Linked to the organisational structure of the electricity supply industry is the specific institutional and regulatory context in which the ESI is embedded. Liberalisation and privatisation of energy supply changed the rules of the game allowing the emergence of new players who could build and operate CHP plants. In both the UK

and the Netherlands, this period of policy changes and liberalisation of electricity supply went hand in hand with a phase of renewed interest in CHP. With the market entry of private energy service suppliers, industrial and small-scale CHP started to diffuse more widely, but ultimately the specific rules and regulations defined by the regulating authorities imposed limits on the economic viability of many CHP projects. In the UK, CHP had fallen for decades into the gap between electricity companies and heat suppliers, which both had a marginal interest only in a technology that was bridging between the two energy systems. With liberalisation, there was at least the possibility of better connecting the two systems through the setting up of specialised energy service companies. These companies considered it their main business to provide in particular industrial heat and power users with advantageous services that were not part of the core business of the firms in question. However, in spite of these improvements, CHP still had to fit into a regulatory context that was not conducive to its uptake (Russell, 1994). The opposite was true in the Netherlands where the liberalisation process was designed in a way which enabled the fast and widespread emergence of new players on the energy supply market, with the clear and explicit intention of government to facilitate the uptake of CHP and make it a major pillar of its energy supply system. Liberalisation in Germany may have been less forcefully implemented than in the other two countries, but it built on an already existing population of CHP plants of various types. As local grid infrastructures for providing citizens with heat and energy services were in the hands of municipal energy companies, they had much better opportunities to bridge the technical boundaries between heat supply and electricity supply.

The ways of handling the change process of institutional and organizational settings for energy supply are a matter of political culture and governance, and it is instructive to look at the political cultures of managing change during liberalisation in the three countries. The British liberalisation and privatisation debate of the 1980s and 1990s was characterized by strong ideological positions over the respective pros and cons, with little room for pragmatic solutions. Differentiated arguments about the need for targeted enabling measures to support specific technologies like CHP found no more than a limited place in these debates. Concerns about institutional and organisational barriers were largely ignored, driven by a strong belief in the benefits of the operation of market forces. In the Netherlands, a much broader consensus was sought in relation to the radical reforms of the energy systems, including major support measures for CHP that were put in place from the mid-1980s onwards. The German political context left much more room for diversity, due to the federal system which allowed the emergence of differences in regulatory and support structures between States, with some pursuing more active CHP promotion policies than others. This diversity offered opportunities to experiment with novel technical and regulatory solutions to a much greater extent than in the two other countries.

An important role was played by support organizations that contribute to the promotion of CHP from energy producers and users as well as in the policy-making context. In Germany, several different organizations were already in place and active in making the case for CHP-friendly rules and regulations, including the Association of Local Authorities, the Association of Industrial Power Producers and various engineering associations.

The Dutch PWK (Projektbureau Warmte Kracht), later called COGEN Netherlands, was set up explicitly with government support in order to serve as a network node for users, suppliers and authorities with regard to all matters relating to CHP, and it played an important facilitating role for CHP during the 1990s in particular. The British CHPA (Combined Heat and Power Association) never acquired the same level of influence as its German and Dutch counterparts, due to its narrower membership and resource base.

Interactions

Interests and power in relation to technology choices

For Russell, technology choices need to be seen against the backdrop of the interests of the main actors and their power relations. In other words, organizational structures in the sector are so important because they determine whether or not there is any institutional voice with an interest in the joint production of heat and power or not. In some of the countries studied, such organizations were in place, in others, this did not exist to the extent needed to support a wider uptake of CHP.

The British situation is very telling in this regard. Given the weak position of local authorities and the separation of the electricity and heat supply, which remained largely in place even after liberalisation, the only organizations with a serious interest in CHP were industrial users, in particular in heat-intensive industries. This is reflected in the growth of industrial CHP after liberalisation, be it on the basis of small-scale applications or by adding power production to established industrial production processes. After liberalisation, private energy service companies discovered the potential of CHP, as did some subsidiaries of the Regional Electricity Companies. However overall, the role of industrial CHP remained marginal due to the regulations and financial conditions regarding power exports to the grid. Other key actors in the ESI may have shown some temporary interest in CHP, but without sustained commitment. (Russell, 1996.)

In the Netherlands, it was also primarily the industrial application domain that saw a boost in the post-liberalisation period; a boost that drove the share of CHP-generated power up to almost half of Dutch power production. The subsidies and feed-in tariffs provided strong incentives to invest in CHP plants. Even if the level of incentives remained lower than in the Netherlands, similar arguments apply to Germany, in particular after feed-in tariffs for renewables were also applied in modified form to CHP. However, as a consequence of the more limited incentives and the existence of an already significant industrial CHP capacity, the growth of the industrial CHP was more moderate.

All three countries saw the emergence of a new type of company which made the provision of useful forms of energy, i.e. both power and heat, to industrial and public sector customers their business. The extent to which these integrated energy supply companies could flourish was quite different though. Given the limited market opportunities for industrial CHP and the difficulties in creating suitable public-private arrangements in the UK for district heating, their influence remained quite limited. In Germany, both public and private integrated energy supply companies emerged, with some local utilities explicitly moving into the business of providing, or at least facilitating, integrated energy services.

Germany serves as proof that this model also works at the level of municipalities. Local grid infrastructures for providing citizens with heat and energy services are in the hands of municipal energy companies that had much better opportunities to

bridge the technical boundaries between heat supply and electricity supply. In the British context, the weak role of local authorities and lack of organisational integration of different types of energy services made the realisation of this kind of approach much more difficult (Hawkey, 2012).

In contrast to both the UK and the Netherlands, German cities also continued to be strong supporters and carrier organizations of CHP for district heating purposes. However, the growing public deficits and tighter competition policy rules imposed on cities increasingly limited their room for manoeuver. Since the mid-2000s, several local authorities have sold their power supply divisions to one of the large scale power producers and with this gave up control over their joint heat and power supply activities.

The positions of the main types of actor relating to CHP are embedded in the public debates about energy supply issues, and need to respond to the political claims raised. The strong support for a CHP-friendly policy in all its facets in the Netherlands was hardly contested. Even if power supply companies in the Netherlands had initially only a limited interest in CHP, they were not in a position to oppose that development. The consensus on the expected societal benefits of CHP was strong enough to lend legitimacy to a pro-active government policy. The German situation was more diverse, but ultimately a moderately positive stance towards CHP was part of the political consensus on the principles of energy policy, even while opinions differed about the means to achieve that end, as reflected in the controversies about the electricity feed-in tariffs for CHP or about the potential impact of these tariffs on a more generalized decentralization of power supply. The British situation was again different in that no generalized consensus on the long-term societal benefits of CHP was reached. Strict economic assessment criteria continued to prevail and determined investment decisions; a policy that was in line with the interests of the main incumbents in the sector.

The role of the state

Prior to liberalisation the possibilities for autonomous power generation were very limited in strict legal terms. With liberalisation a new window of opportunity was thus opened up by public policy. The Dutch case shows that a change in the energy supply trajectory can be achieved, if complementary policies are adopted alongside a liberalised framework. It shows the importance of clear and sustained political commitments and the definition of ambitious targets to orientate policy, coupled with strong financial incentives. Various kinds of incentives were created both to stimulate investment and R&D in CHP. The success of the support measures was so overwhelming that the Dutch government had to reduce the incentives to dampen the diffusion of CHP, because it had reached a level at which the technical stability of the power grid could no longer be ensured.

In Germany, other instruments were used, but the impulse was equally strong. The strongest impact was achieved through special feed-in tariffs, which were applied not only to solar and wind power, but also to CHP. This provided a major incentive for renewable power generation as well as for CHP. Various generations of this feed-in law, including earlier voluntary agreements, gave a sustained impulse in favour of CHP. This was supported by the diversity of energy policy settings in Germany, itself a consequence of the high level of autonomy of federal states and strong local authorities. This case shows how a diversified political

system can help trigger experimentation with a range of energy policy instruments and their impact on technology options.

In the UK, liberalisation opened up the possibility of autonomous power generation, and thus opportunities for CHP, because deregulation opened up the electricity market to competition and gave new power generators access to the grid. However, many structural, organisational, cultural and institutional barriers remained in place and new ones were introduced, so that the conditions were not sufficiently conducive to enable a significant uptake of CHP. Ultimately, "CHP still has to fit somehow into a (deregulated) system that has not been designed to suit it" (Russell, 1994: 31).

In line with the limited incentives, capacity targets were also far less ambitious than in the Netherlands. Much was left to individual initiative, both at local level and industrial firms. Recent efforts to initiate district heating schemes moved ahead only through the initiatives of some key individuals, and in spite of scarce technical skills and knowledge (Hawkey 2012: 20).

Liberalisation is usually regarded as a potentially powerful trigger for CHP diffusion, but it can also have unintended detrimental effects. In combination with a tighter application of competition policy principles, for instance, it obliged local authorities to maintain a more transparent separation between the different utility services in Germany. Competition at local level also obliged them to pay more attention to cost-benefit ratios of their investment. Ultimately, this development in conjunction with the budgetary problems of several local authorities led to a take-over of many local energy utilities by the large power suppliers like RWE, EON or Vattenfall, and thus to a loss of local power in defining energy solutions.[10]

Knowledge

Knowledge dynamics and assessment of technology

It is a well-known phenomenon in innovation research that the production and diffusion of knowledge can give rise to self-reinforcing mechanisms and path-dependencies. In the case of CHP, for instance, knowledge and expertise need to be available locally, because CHP systems are embedded in industrial production or urban heat and power systems. As pointed out by Hawkey et al. (2013) for the UK, the lack of local knowledge and access to local social capital continues to pose a major challenge for cities interested in district heating applications of CHP. The ability to build up this knowledge is dependent on the access to other actors' knowledge, and thus on the embedding in networks of suppliers and other users. Industrial and local authorities associations can play an important role in this regard, as does the direct mutual knowledge exchange support among cities and firms. In the UK, this kind of local social capital has never been very well developed, not least due to the very limited diffusion of CHP in general. There were simply not many cases to learn from. The situation is very different in Germany, where associations of engineers, industrial associations as well as associations of local energy producers have been in place for many years, facilitating the exchange of knowledge and the specification of standards regarding CHP. Some of these associations have either dedicated sections dealing with CHP or were even set up explicitly for that purpose. Moreover, due to the number and diversity of specific local situations for CHP, there was quite a lot of diversity and experimentation taking place in Germany, thus offering wide scope for learning. In the Netherlands, the access and distribution of knowledge and experiences was one of the key tasks of

PWK (Projektbureau Warmte-Kracht), later on renamed Cogen Netherlands, which was built up with government support during the 1980s. It effectively played the role of a knowledge hub for CHP in the Netherlands.

Knowledge of CHP is also crucial for various kinds of assessments of the technology, ranging from techno-economic assessments at the plant level to wider socio-economic considerations regarding its risks and opportunities. As shown by Russell (1986a, 1994), in the absence of more supportive structures and regulatory conditions, the economic benefits and potentials of CHP were under-rated in debates about specific plants. This was partly due to a lack of knowledge, but also the result of the separation of heat and power supply utility services, which made it more difficult to exploit the synergies within the organisational frame of a single company. This problem of finding appropriate organizational governance models for district heating continues to be relevant even today (Hawkey et al., 2013).

Similar problems can be observed at national level, where the emphasis was put on a narrowly defined economic assessment dimension only. In the UK, other arguments which might have been expected to be supportive of CHP and district heating entered the debates at various moments in time, such as those relating to energy poverty and energy efficiency. Although in part dating back to the 1950s, these lines of reasoning never acquired a sufficiently strong and sustained role in the public and policy debates, even in the post-liberalisation phase. As a consequence, liberalisation had only a comparatively limited impact in unblocking potential for CHP, and then only in the industrial sphere. Public debates about energy policy and CHP at national level were not only constrained by a lack of knowledge and experience, but also by a lack of a sufficient diversity of informed voices. In the absence of positive experiences with district heating, for instance, it was hard to make a case in favour of it. And due to the almost complete absence of informed supporters of CHP in the debates, the arguments of incumbent players, usually opposed to CHP, had a dominant influence on policy and regulatory decisions. In Germany, on the contrary, both local authorities and industrial firms were in a position to reap the economic benefits of joint production of heat and power. Their respective industrial associations could make themselves forcefully heard in energy policy debates. As a result, CHP has been recognized as a desirable option since the 1990s in a number of important pieces of regulation. Most important in this regard were the feed-in tariffs for decentralised power production, which made the economics of CHP very promising. Similarly, the regulatory framework conditions and incentives introduced in the Netherlands led to positive economic assessments of CHP plants. These supportive conditions were embedded in corresponding debates at national level about the long-term economic and non-economic benefits of CHP and other renewable or highly efficient energy technologies.

Knowledge dynamics are not only driven from the demand side, but also from the supply side. In view of the CHP-friendly developments on the demand-side of energy supply in the Netherlands and Germany, it is of little surprise that significant public and private investments were made in R&D. As it was perceived as a growing market in both countries, private firms developed new generations of remote control systems, efficiency-enhancing prime-mover technology, in particular for small-scale applications (e.g. Stirling engines and fuel cells). Few comparable developments can be observed in the UK,

where instead Dutch producers of CHP systems successfully entered the market for small-scale CHP. As a consequence, the virtuous cycle resulting from the interplay of positive expectations on both the supply and demand side of the new technology has never worked effectively in the UK. This stands in contrast to the situation in the Netherlands and Germany, where conducive conditions led to positive expectations about future investments in CHP, and thus also to investments in R&D. This, in turn, helped improve the economic and other performance characteristics of the technology as compared to other alternatives.

Embedding in broader debates and expectations

CHP plants need to fulfil economic criteria, but the assessment criteria applied, the organisational and institutional framework, and specific regulatory or financial policy measures may shift the balance for or against specific plant projects. These determinants are framed and legitimized by reference to wider policy objectives, and embedded in broader debates and expectations about the future of energy supply.

In the Netherlands and Germany, proponents of CHP were very successful in generating legitimacy for CHP by embedding it in such broader debates, and could thus generate dedicated support for the technology. The British situation was different, because in spite of other broader debates about the social and environmental benefits of CHP at different moments in time (e.g. energy poverty, resource efficiency, long-term security of gas supply), there was never a sustained period of support during which, for instance, a significant number of district heating plants could be built, which subsequently could have served as positive exemplars.

It is also interesting to observe that these broader legitimacy-enhancing debates change their reference points in the course of time, for instance from energy security and efficiency gains to CO2 reduction, climate change and renewables. This is important to consider, because a technology like CHP requires sustained support over longer periods of time to become established, to build the support networks around it, and in order to reduce uncertainty for potential investors. In Germany, the policy support lent to CHP in the 1980s and 1990s was mainly driven by energy efficiency arguments and arguments about the autonomy of industry in securing its heat and power supply, but in the course of the 2000s the framing debate to provide support for CHP shifted towards climate change issues and renewables, which were then strongly supported by government. CHP-promoters managed to position the technology under that roof and thus ensured sustained support, e.g. with regard to R&D funding and the application of a new generation of feed-in tariffs. The Dutch situation is similar in many regards, but in addition concerns about the long-term security of national gas reserves played an important role. They were used initially to justify support to a highly energy efficient technology, and later on to limit the support to CHP in favour of 'real' renewables.

Socio-Technical Change as Complex Process of Creation and Destruction

Interpreting the dynamics of socio-technical change

This section brings us back to the initial research question, namely whether Russell's conceptual thinking provides an adequate explanation of the paradox of significant differences in the patterns of socio-technical change associated with CHP innovation and diffusion in

different countries. For Russell socio-technical change needs to be understood as a complex process of creation and destruction, resulting from the interplay of organisational and institutional conditions with social behaviour.

From a very simple comparative perspective, it could be argued that after liberalisation, the majority of the building blocks discussed remained hostile to CHP in the UK, while many of them became supportive in the Netherlands. The rapid shift in the structure of heat and power supply towards CHP-based systems observed in the Netherlands and the conservation of its rather marginal role in the UK can in principle be related to this generic observation. The German case also fits this picture. CHP had already been much more established a technology, be it for industrial or district heating purposes. Therefore the influence of liberalisation on the further uptake of CHP was more limited.

However, such a static interpretation is too superficial. In line with Russell, a historical view on socio-technical change needs to be adopted that is characterized by the operation of complex mechanisms leading to path-dependent developments (Weber, 2002; Russell, 1993); mechanisms that stem from the interplay between the six building blocks considered to be his framework.

Historically grown structures and cultural pre-dispositions (e.g. in terms of the role and influence of incumbent players, the degree of centralisation of political competencies and of energy supply, or the strict separation of heat and power supply) constrain the opportunities to break with past trajectories and realize organisational and institutional changes, but they should nevertheless not be regarded as fixed. Even within the confines of these structural constraints, there is still some, albeit limited, room for manoeuver, to change the self-reinforcing mechanisms at play that stabilise the prevailing path. Structures and institutions shape and influence the interests, options and power positions of the actors involved in decision-making about heat and power supply options, but at the same time the decisions and strategies of key players tend to shape the structures and institutions that are supportive for their interests and power positions. The degree of flexibility and dynamism of the system then depends on the balance between the stabilising influence of incumbent players and the opportunities for alternative voices to be heard.

While this interpretation of the relationship between path-dependencies and flexibility may be appropriate at times of incremental change, the situation is different at times of disruptive change such as in the post-liberalisation period, or after the Second World War. Major changes are only likely to happen once inherent contradictions and tensions become so strong that alternative structural and institutional settings need to be established. This kind of development can be observed in all three countries prior to liberalisation, but there were major differences in what was actually done to shape the subsequent process of change. Germany and, in particular the Netherlands, used these 'windows of opportunity' for CHP in a very different way than the UK. Liberalisation, as a policy-induced change process, opened up new opportunities that could trigger very different pathways of structural and institutional change in the energy system. The choice of specific mechanisms and incentives affected the extent to which a departure from the established structures and institutions was realised or not.

This interpretation suggests a co-evolutionary understanding of change processes in energy systems, where phases of incremental change can be interrupted

by periods of transformative change. To unleash the potential of CHP in a context that is not conducive to its application requires a break with historically grown path-dependencies and associated blocking mechanisms, while creating new self-reinforcing mechanisms that stabilise a process of structural change which supports CHP. Such a change process cannot be steered in a top-down manner by government, but it requires mechanisms to be put in place to guide the self-organisation of the actors in a CHP-friendly direction. This is in fact what happened in the Netherlands, but never took place in the UK.

The success story of Dutch CHP

The Dutch case shows what can be achieved with substantive and sustained changes to institutional framework conditions and targeted support measures. Regulatory changes facilitated the emergence of new players at the interface between heat and power supply, and major subsidies over a longer period of time provided sufficient incentives to make CHP economically viable. The establishment of a carrier organisation that served as knowledge hub and support organisations for both suppliers and users of CHP fulfilled an important caretaker function, and R&D funding helped foster the development of next-generation CHP technology.

While liberalisation as the main institutional trigger of the change process opened up the legal possibilities for self-generation of power, it was accompanied by a clear political commitment in favour of CHP, reflected in the well-timed introduction of a range of sustained support initiatives.

Reliable and supportive planning conditions for investing in CHP were thus offered to industry as well as to cities. These initiatives set positive self-reinforcing mechanisms in motion, which were particularly effective in industry. Cities did not have the same level of autonomy and competence in public utility services as their German counterparts, but they were able to make use of the fast growing energy service industry. This offered integrated solutions that allowed a bridge between heat and power supply, or between the gas regime and the electricity regime.

The strong incentives for CHP were maintained in spite of criticism raised by incumbent power generators. By embedding CHP in the long-term gas policy and later on in climate policy objectives, public and political debates remained supportive of the pro-active CHP policy. Other criteria than just narrowly defined economic ones were taken seriously in the decision-making processes.

Apart from the financial drivers, the creation of a carrier organisation for CHP must be regarded as giving rise to several self-reinforcing mechanisms. PWK not only served as an information and knowledge hub for suppliers and potential users of CHP, it also fuelled the public and policy debates with arguments and experiences that lent support to the pro-CHP policy of the Netherlands. It facilitated the fast replication of CHP experiences in different industrial areas in particular, and also helped to counteract efforts to discredit CHP.

Due to the fast growing market expectations, serious R&D efforts were made in the Netherlands as well. After a few years, Dutch CHP companies were among the leading players in small-scale CHP technology, with great success not only on the Dutch, but also on foreign markets (including the UK). Arguments regarding the creation of a competitive industrial activity thus contributed to enhancing the political support lent to CHP.

In other words, the time window of opportunity offered by liberalisation was actively seized and supported by targeted government action. The fast diffusion of CHP marked the beginning of a process of structural change in the energy system, which affected the actor constellations, the degree of decentralization of energy supply, the integration between heat and electricity supply, and the specialisation patterns of the energy industries.

Structural continuity and the neglect of CHP in the UK

The British case is an example of a quite radical liberalisation and privatisation effort that nevertheless preserved several structural path-dependencies. These path-dependencies continued to exclude systematically several technological options like CHP. Even despite incentives for individual energy end-users, structural features of the sector may thus act systematically against energy saving investments (Russell, 1994: 50).

The institutional and regulatory framework in the UK never offered effective enabling conditions for CHP, with the consequence that the kinds of self-reinforcing mechanisms observed in the Netherlands never acquired the same level of significance. The unleashing of the dormant CHP potential which could be observed so forcefully in the Netherlands, was only present in the UK for a small fraction of industrial plants and some larger public buildings. Even today cities do not have the power, the resources and the competencies to engage effectively in a local energy policy, and continue to struggle with a framework that requires difficult PPP models for CHP to be realized to bridge between separate systems of heat and electricity supply (Hawkey et al., 2013). Under these circumstances, CHP-based district heating has little likelihood of being realized, even in new residential areas.

Due to the absence of a clear commitment in British energy policy to CHP as a serious option, linked to a lack of dedicated support measures for CHP, investment in the advancement of CHP technology remained limited, even while some companies specialized in the provision of standardized small-scale CHP systems.

The role of the Combined Heat and Power Association (CHPA) as a caretaker and carrier organisation was also less influential than that of its Dutch and German counterparts. In fact, given the comparatively small number of CHP plants in the UK, the number of members and thus the scope for learning and knowledge exchange remained limited. In the absence of other influential proponents of CHP, the influence of CHPA on public and policy debates remained very limited, their arguments often overridden by other players. Without influential support, it is no surprise that hardly any dedicated incentives and regulatory provisions for CHP were taken up, apart from a rather modest CHP capacity target.

In spite of these detrimental conditions, some efforts were made in recent years to realise CHP at city level. However it required engaged individuals to push such new initiatives. Both in the private sector and in the public sector examples of this kind of entrepreneurship can be found. As shown by Hawkey et al. (2013) the situation in the UK is still characterized by major difficulties for local authorities to come up with workable solutions for district heating in a context of limited competencies, resources and networks.

Overall, one can argue that the UK missed the opportunity to change course towards a more decentralised, horizontally integrated energy system based on a

significant share of CHP. In the meantime, new path-dependencies have been created and, as a latecomer technology, CHP continues to struggle with an institutional and regulatory framework that is not made to suit this technology (Russell 1994).

Strengthening the existing pathway of CHP in Germany

The German case is different from the UK and the Netherlands because at the same time as introducing a liberalised framework for electricity supply in the 1990s, Germany was able to build on an already significant capacity of, and experiences with, both industrial CHP and district heating. There were already several decentralised and autonomous power production units in place. With the introduction of a system of feed-in tariffs the economic and legal conditions for CHP became more reliable and attractive. This was achieved in part due to the influence of some strong supporters of self-generation in general and of CHP in particular, in both industrial and municipalities associations.

This policy was not uncontested. Critical positions were expressed on the side of the large incumbents in the electricity sector, but political support for CHP was maintained by linking to energy efficiency, security of supply and, later on, climate change debates.

Given the comparative large number of existing CHP plants in cities and in industry, a large body of knowledge and experiences was available on which the newcomers to CHP could draw though various professional and industrial associations that were active in knowledge diffusion and standardisation. Due to the diversity of the specificities of regulation and support measures across Federal States, there was also room for experimentation with and learning from novel approaches.

Apart from the possibility to draw on an existing path and on strong and competent local utility companies, the willingness of national policy to provide active and targeted support to CHP applications in industry and public sector turned out to be decisive for strengthening the role of CHP in the liberalised German framework. Overall, the impact of liberalisation in Germany may have been less radical and influential from a CHP perspective, but it shows that it was possible to sustain the continuation of a growth path of decentralised and combined heat and power supply within a liberalised framework.

Lessons learned

Several lessons can be learned from this comparison of the evolution of CHP in the three countries, interpreted on the basis of Stewart Russell's reconstructed conceptual framework. In a nutshell, the three country cases show that in order to overcome the path-dependencies and trigger a process of 'creative destruction' after liberalisation, three strategic ingredients were of major importance, namely a) sustained effort to break structural and institutional settings and withdraw support for their stabilizing mechanisms, b) establishment of self-reinforcing mechanisms that help experiment with and promote the uptake of new options like CHP, and c) responding to a window of opportunity to trigger the change process in the desired direction.

Firstly, after a major shock like liberalisation, sustained efforts are needed to break with prevailing path-dependencies and create new self-reinforcing mechanisms that allow change in historically grown structures and institutions of energy supply. Although different tools and instruments were used, the German and in particular the Dutch experiences show that a sustained political commitment in combination with strong financial incentives and

regulatory provisions can be effective in establishing an alternative trajectory. This is in line with the argument by Hard and Olsson (1995: 201) who call for a stable and persistent energy policy and "for governments that are not afraid of taking on the roles of a 'guiding actor' and a 'creative regulator' ". In their view, deregulation and privatisation are enabling factors for the uptake of CHP, but should not be driven too far in order to avoid negative side effects. Instead complementary support measures need to be installed to overcome path-dependencies. In the UK there have been several historic moments when CHP received quite a lot of rhetoric support but, in view of the long lead times of energy investments, the efforts to support CHP were not sustained long enough to lead to the implementation of major CHP plants and of DH plants in particular.

Secondly, efforts to break with the past need to be complemented by efforts to create, reinforce and stabilise an alternative path. Government cannot control this change process in a top-down manner, but in the course of the turbulent phase following a major shock such as the liberalisation and part privatisation of energy supply, there is an opportunity to trigger and nurture new self-reinforcing mechanisms that help establishing an alternative pathway. Obviously it is not possible to fully anticipate how these new mechanisms will work, or whether they will be sufficiently effective and lead to desired outcomes and impact. Experimentation, monitoring and learning are thus required to accompany the change process. It is not easy to establish the financial support and regulatory changes necessary for such a major change, in particular if some incumbent actors' economic interests could be negatively affected. To pave the way towards a significant change, it is necessary to embed the rationales for the change process in wider political and public debates, i.e. to connect them to higher-order and longer-term goals (Budde & Konrad, forthcoming). In the UK, contrary to the Netherlands and Germany, neither of these mechanisms could be observed. A structural change of a different sort took place, based on a 'dash for gas', still reliant on a separation of heat and power supply.

Thirdly, even a powerful and intelligent change strategy can easily fail, if the initiatives and measures do not fit the right windows of opportunity. Liberalisation and privatisation offered such a window of opportunity to change the rules of the game and trigger a transformative change towards a new pathway of energy supply. That window of opportunity was clearly seized in the Netherlands, it was used to strengthen a pre-existing path in the Germany, but it was missed in the UK. As a consequence, a different direction was taken in the UK. This is not the place to judge the merits and problems of the British choice, but it is clear that CHP is still struggling today to find an appropriate place in a system that still does not suit it.

Overall, the paradox thus results not only from historically grown structural path-dependencies, but also from the willingness, or failure, to take the opportunities offered at certain moments in time in order to change course. Whether the changes in framework conditions turned out to trigger change or not was then determined by the emergence (or not) of self-reinforcing mechanisms of various sorts: good examples, structural changes conducive to CHP that met with the local initiatives taken by various entrepreneurs, the empowerment of local players, either private or public, conducive regulation, financial incentives. And this alone would not be enough, if efforts are not sustained for long enough or sufficiently broadly. Bringing these changes about is a matter of

supportive influences and interests in the debates about the pros and cons of different approaches, and thus also of the ability to connect with wider debates in order to ensure sustained support for CHP.

Conclusions

Stewart Russell's work on CHP/DH in the UK is recognised as a pioneering empirical contribution to the shaping of the emerging field of science and technology studies, but his conceptual thinking has thus far been under-exploited. This paper has made an attempt to revive this part of his legacy by re-constructing his main lines of reasoning about how technology choices in society come about and give rise (or not!) to processes of socio-technical change. The ambition was also to assess whether his framework provides an useful approach for explaining the significant differences in socio-technical patterns between countries.

Russell rejects any notion of technological determinism and stresses the socially and politically shaped character of technology choices in society, but he also acknowledges that social behaviour and choice must be seen as embedded in structural and institutional contexts. Innovative social behaviour can only exert its shaping power to the extent that it is enabled by structural and institutional conditions. Historically grown structural arrangements support and strengthen certain economic and political interests to the detriment of others, and thus affect the choices made and the decisions taken. In this way, some technological options may be more or less systematically excluded or even actively resisted. Similarly, knowledge about prevailing and novel options is neither objective nor neutral but constructed and deployed in line with the interests of the different players involved, for instance with regard to the economic assessment of energy technology choices and the criteria underpinning these choices.

Russell recognizes that structural and institutional conditions should not be taken as given. They are equally open to change but, being the result of historically and culturally framed processes, they tend to change rather slowly. However, as evidenced by liberalisation, if inherent contradictions have become so strong that alternative structural and institutional settings need to be established, the corresponding changes can happen at an accelerated pace. If appropriately guided by policy, these windows of opportunity allow a break with established path-dependencies and a change in course to a qualitatively different direction. It is this kind of theoretical principles (rather than any grand single theory) that need to be used as building blocks to explain specific arrangements (Russell, 1986a). Government policy has a key role to play in guiding and framing these long-term processes of socio-technical change in response to emerging tensions. With the help of these lines of reasoning, Russell demonstrates that it is possible to reconcile the macro and the micro to explain technology choices in society, without collapsing one into the other (Russell, 1994: 51).

With his focus on the (non-)occurrence of transformative change and on the interplay between three levels of analysis – context, interactions and knowledge – Russell's conceptual perspective is a pre-cursor of other more recent multi-level and systemic perspective on technology choice and socio-technical transitions (Geels, 2002; Hekkert et al., 2007). His emphasis on tensions as the origins of the destruction of the old and the creation of the new is still topical today, because it is increasingly recognized that transitions are not necessarily consensual processes, but

involve conflict and power (Smith et al., 2005).

With the reconstruction of Russell's conceptual framework, his guiding ideas have been given a clearer shape and can now be used systematically to guide empirical analysis. As shown by the comparative analysis of CHP in the UK, Germany and the Netherlands, his framework delivers a plausible explanation of the innovation diffusion paradox of CHP. It is sufficiently comprehensive to deal not only with the British CHP case, which represented Russell's main empirical basis, but also to handle the peculiarities of the two other countries. With the help of his framework, what seems to be a paradox at first glance, turns out to be a coherent story of social choices in times of major external shocks. The case of CHP has thus been productive in demonstrating the explanatory power of Russell's perspectives on socio-technical change.

The potential of Russell's ideas still remains to be further exploited, both in terms of conceptual refinements and empirical applications. His framework could be further developed, for instance with regard to the rationales suggested for explaining transformative change, which stress the importance of tensions, conflicts of interest and power struggles. In this regard, it represents a promising addition to prevailing transition theories.

In empirical terms, many of the insights generated in the context of the CHP case could be transferred to other technologies with similar characteristics. Given the high political interest in future energy transitions towards a more decentralised and renewables-based regime, applying Russell's framework could be helpful in informing technology choices ahead of us. In fact, there are several other emerging technology developments in the energy field that could be faced with similar blocking and reinforcing mechanisms as the ones at work in the case of CHP.

Stewart Russell's work is still highly topical in several regards. His pioneering research on the social and political shaping of CHP can be interpreted as a pilot case for later debates about decentralised and renewable energy technologies. His conceptual insights point to lines of reasoning that are under-represented in today's debates about energy transitions and should be brought more prominently to the fore. It remains to be seen whether we have learnt something from past insights as those so thoroughly elaborated by Russell.

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Notes

1 There are several seemingly separate strands within the STS literature such as the Social Shaping of Technology (SST), Social Construction of Technology (SCOT), Actor-Network Theory (ANT), Large Technical Systems (LTS) and others, which nevertheless share the criticism of technological determinism. For a thorough review see Russell and Williams (2002).

2 The Dutch company Nedalo BV, for instance, had a quite successful subsidiary operating in the UK since the early 1990s.

3 Understanding innovation and socio-technical change as "creative destruction", to use Schumpeter's words (Schumpeter, 1942), has gained ground in other disciplines as well, in particular in economics, where evolutionary and Neo-Schumpeterian innovation economics revived the interest in Schumpeter's arguments.

4 This is not the place to enter into the details of the debates between the different schools of thought addressing the social shaping of technology in the late 1980s and early 1990s. There is an extensive literature on these differences, which, in the meantime, have given way to a more pluralist stance on the appropriate frameworks to be used.

5 The use of the term 'terrain' by Russell reflects the difficulties of delimiting the range of actors to be considered in an analysis of socio-technical change, and thus of 'cutting' the appropriate terrain. Russell has broadened the range of actors considered 'relevant' for a terrain beyond what is usually considered in a sectoral analysis. (Russell & Williams, 2002: 43, 77.)

6 David Collingridge's influence on Stewart Russell's thinking is not a coincidence because he was one of Russell's doctoral supervisors.

7 Russell thus draws similar conclusions on the role of the state as Hard and Olsson (1995), who also looked at the fate of CHP/DH in the context of debates about liberalisation and sustainability, and the political strategies for dealing with the tension between these two guiding principles. In their analysis, they draw on experiences made in Sweden, Austria, Denmark, the Netherlands, Germany and the UK.

8 Geographical and climatic conditions have always played an important role in defining the potential for district heating, but in recent years, CHP has also been expanded to district heating *and* cooling applications, which now makes the Southern European countries more attractive markets for CHP.

9 In addition to the comprehensive empirical material published by Stewart Russell, the British case draws on other studies and scientific articles published over the past three decades, including Weber (1999, 2002), Weber et al. (2000), Alcock and Marvin (1988), Marvin (1991) and for the more recent developments Bolton (2011), Hawkey (2012), and Hawkey et al. (2013). The German case was investigated in depth by Weber (1999, 2002) and Walz (1994). The situation in the Netherlands was studied among others by Blok (1993), Weber et al. (2000), Raven (2007), Raven and Verbong (2007), Meijer et al. (2007).

10 Interestingly enough, a shift to re-localisation of energy supply can be observed, with local authorities buying back their local grids and power generation units from the large operators. The most prominent of these cases is the City of Hamburg which decided in referendum in 2014 to buy back its grid from Vattenfall.

Matthias Weber
AIT Austrian Institute of Technology
Innovation Systems Department, Vienna
matthias.weber@ait.ac.at

Evaluating Urban Energy Systems in the UK – the Implications for Financing Heat Networks

Janette Webb

UK energy policies position urban heat networks as components of a resilient low carbon, affordable system, but, as Stewart Russell's work showed, such technologies have never been integrated into UK provision. This paper takes Russell's legacy forward by examining prospects for urban district heating and combined heat and power development in the context of the *financial*, rather than technological, innovations shaped by liberalised energy and financial markets. Drawing on sociology of markets and social studies of finance, the paper examines the resulting evaluation practices. Findings indicate that such district energy infrastructure does not conform to the investment calculus, making a business case hard to establish. Bridging the value gap between liberalised finance and district energy requires actors willing to devise improvised solutions. In spite of the established sustainability credentials of the technology therefore, significant deployment in the UK (and similar countries) will depend on political leadership and new fiscal policy.

Keywords: energy, financial markets, sociology

Introduction

> ...our goal is to make sure that investable projects across our priority sectors can obtain finance in the market place (quote from research interview with UK Government Officer, Low Carbon Investment Team, 2012).

Contemporary energy policies and scenarios project a future of low energy consumption in a secure, affordable low carbon system (UK Government Department of Energy and Climate Change (UK DECC), 2011a; 2011b; European Commission (EC), 2011). Behind the aspirations however lie contested, and uncertain, models for how any transformation may be brought about, by whom, using what resources and with what implications for shares of costs and benefits. Such uncertainty and contestation are for example embedded in the terms of UK Green Investments, which received £3bn capitalisation from the UK Treasury in 2012 to address the lack of investment in low carbon technologies, on the condition that it operates on the same market terms identified as responsible for the current failure to invest.

This paper focuses on prospects for investment in meso-scale district energy[1]

and heat network infrastructures, which are defined in UK Government strategy as a key aspect of sustainable energy (UK DECC, 2013), and are targeted in UK Green Investment Bank (GIB) energy efficiency strategy (UK GIB, 2014). Investment in district energy in the UK remains, however, very limited (UK DECC, 2013). The paper uses a sociological perspective on markets and social studies of finance (Beckert, 2009; Callon, 1998; Carruthers & Kim, 2011; MacKenzie, 2009) to explore the reasons for apparent mismatch between the sustainability value attributed to such technologies in policy and their low valuation as an investment proposition in practice. It uses ethnographic research to assess the strategies of public and private sector organisations engaged in 'making the finances stack up' to secure 'the investable project'. Rather than treating market valuations of energy technologies as economic objects subject to universal laws of supply and demand which exist outside societal processes, the sociological perspective used here examines the socially-embedded production of value. The perspective is derived from classical sociological theory exemplified in Max Weber's (2000 [1894]) analysis of the centrality of politics and power relationships in financial markets, and Karl Polanyi's (1957 [1944]) appraisal of the embedding of economic exchange in social networks where political beliefs and ideologies inform value attribution. Recent scholarship has extended these foundations through examination of the processes of producing and reinforcing, or sometimes undermining, market facts, which are critical to market operation and attributions of value (Callon, 1998; MacKenzie, 2009). Such facts and metrics, such as rates of return on invested capital, are interpreted as a socio-technical accomplishment which brings particular kinds of economy, economic actors, and material outcomes into being (Caliskan & Callon, 2009). The sociology of markets and social studies of finance have however been relatively neglected in analyses of transitions to sustainable energy, where most attention has focused on the study of innovations in technology 'hardware'. This paper suggests that recent innovations in finance, using economic theory and mathematical knowledge, are reshaping market facts and the production of value (MacKenzie, 2009), with significant consequences for energy infrastructure and the characteristics of transition to a low carbon energy system.

The UK is a significant case study for questions relating to the evaluation and financing of low carbon energy infrastructure. On the one hand UK and Scottish Government climate change legislation has set ambitious targets and timetables for energy decarbonisation and demand reduction. On the other hand, in the liberalised energy system, solutions are expected to derive less from co-ordinated planning than from financial markets, where the discovery of viable commercial returns on private investment governs the prioritising and configuring of any low carbon provision. UK energy policy has recognised the failures of current market structures to deliver investment in secure and affordable low carbon energy, but envisages adjustments to the existing regulatory frame, rather than systemic reform (UK DECC, 2011a). Rather than holistic appraisal of optimal routes to energy systems decarbonisation, policy development has focused on electricity. Heat has remained marginal until very recently, even though more energy is used for heating than for the generation of electricity. For example in the UK, almost half (46 per cent) of the final energy used is for heat; a further 41 per cent is used for transport, while only 8 per cent

is used to provide electricity (UK DECC, 2012: 10). Around three quarters of the heat is used in domestic, commercial and public buildings; the remainder is used in industrial processes. In 2012, the UK government published a heat strategy, which concluded that climate change mitigation targets necessitate radical change to reduce energy used for heating, and to use low carbon or renewable sources to meet remaining requirements. Policy frameworks (UK DECC, 2013; Scottish Government, 2013) envisage a combination of solutions, including building insulation, electrification of heat and changes to the content of the gas grid. They also attribute value to low carbon heat networks in circumstances where development is justified by density and diversity of heat demand, and by the likely availability of local heat sources which would otherwise be wasted. These documents begin to incorporate a systemic model of energy, identifying the potential of heat networks to reduce the total costs, and improve the resilience, of a low carbon energy system, over and above their local value: 'the capacity of networks to store heat helps to tackle system balancing issues, and diverse heat sources will also reduce pressure on peak grid demand' (UK DECC, 2013: 45). By virtue of their territorial powers, knowledge and resources, local authorities are expected to be critical intermediaries in such developments.

The UK Historical Trajectory of Heat Networks and their Contested Value

Energy generated close to its point of use, at the meso scale, is recognised as having social, economic and environmental value in relation to carbon saving and affordable heat, and having potential to re-localise inter-relations of use, ownership and control (Kelly and Pollitt, 2010; UK Committee on Climate Change, 2010). Such district energy technologies, delivering heat, hot water and sometimes cooling, via an area-based network of underground pipes, or thermal grids, are well-established in Europe, but provide only around 2% of UK space and water heating. Stewart Russell's (1986; 1993; 1996; 2010) work examined the failure to integrate district energy (combined heat and power (CHP) and district heating (DH) or heat networks) into UK energy provisions, despite periodic policy advocacy and on-going improvements in technology. His work, examining CHP/DH up to the period following energy privatisation, concluded that such developments that have occurred have always required some form of state intervention to counteract the short-term economics of the energy sector. This was the case under both state and private ownership of energy generation and supply, indicating that limited development is not the result of system ownership *per se*. Russell argued instead that it is the result of the wider UK economy and polity, which have produced an energy sector geared to commercial economies of scale, and avoidance of social obligations. An increasingly specialised and segmented energy supply chain has limited capability to capture the integrated energy productivity of district energy which requires coordinated, predictable long-term planning. Post-privatisation, the more complex regulatory structure of the industry made the prospects for CHP/DH more unpredictable:

> To the extent that CHP did show an upturn in the early 1990s ... particularly in large industrial installations and in packaged mini-cogeneration units, it could not be argued convincingly that this came about because of the form of the restructured sector, but still rather in most respects in spite of it; in many ways the fundamental problems were

> reinforced and exacerbated, it still had to fit as best it could into a system that has not been designed to suit it, and there were no evident incentives or commitment towards energy efficiency built into the new arrangements. (Russell, 2010: 6.)

The historical absence of a focus on heat (as opposed to gas and electricity) provision resulted in the lack of a directly responsible UK policy-making and regulatory authority. Investment decisions were framed by short-term cost logics, even when the initial objectives of periodic investigation were long-term social and environmental benefits. Russell concluded that the economics of meso-scale CHP and DH have been constituted as marginal not because of their inherent lack of societal value, but because their evaluation was always embedded in the political-economic institutions, and physical infrastructures, of an energy sector increasingly modelled on the scale economies of centralised, large scale, generation of electricity, and gas grids.

The potential of district energy and heat networks to contribute to energy productivity and to reduce the total costs of a resilient low carbon energy system has again been raised in the context of climate change risks. The feasibility of an all-electric solution to decarbonisation of heat, with very large seasonal variation in demand and consequent need for (probably high carbon) expensive stand-by plant and grid reinforcement, is subject to scrutiny (Spiers et al., 2010). The low source fuel conversion efficiencies of large scale thermal power generation without heat capture, and with energy lost through long distance transmission, have also returned to the agenda. The costs and benefits of district energy, as a component of a low carbon system, are however contested, given the sunk investment in centralised electricity and gas grids. Risk assessment centres on the capital cost of heat grid infrastructure, and the lag between initial investment and revenues, combined with the lack of an existing regulatory framework for heat and the associated difficulty of securing a long-term revenue stream in the absence of an existing customer base. The UK also lacks supply chains, skills and business models. All of these factors tend to increase attributed risk, and hence the cost, of development, relative to European countries with established heat networks (Pöyry, 2009), militating against straightforward demonstration of *financial* value of investment.

A number of local authorities have however proceeded to develop district energy projects, using criteria of value derived from energy and carbon saving, provision of affordable heating and regeneration of urban centres; raising the necessary finance is however a key area of difficulty (BRE et al., 2013). The conventional principles used in configuring project finance are exemplified in Appendix 1. This is extracted from an Ernst and Young presentation to a district energy finance workshop[2], and shows a financial model devised from various combinations of debt and equity. Debt is considered to be cheaper than equity, so debt finance is expected to form the largest proportion. Public sector debt can usually be raised at lower cost than private finance; some local authorities may therefore borrow to finance investment, managing the risks through a variety of governance and contractual structures, including arms length organisations and joint ventures. Other authorities may be reluctant, or unable, to accept the risk of borrowing in order to finance energy infrastructure, when they have no statutory duty to do so, and they may regard themselves as lacking

the required knowledge and capacity. A claimed lack of capacity may stem from the underlying financial position of certain local authorities, where existing Private Finance or Public Private Partnership projects result in a high proportion of revenues being committed to servicing existing debt. In the absence of any change in financial regulations, such authorities may have little option but to pursue a commercial model, transferring risk to private contractors to develop, own and operate the system, under a long-term concession contract for heat and power supply. The costs of such an energy services contract are set against revenue rather than capital budgets; over the long term the total financial cost is likely to be higher, but there is no immediate addition to total borrowing. Urban heat network development is hence challenging, not only because of the physical disruption entailed in embedding new infrastructure in a densely populated place, but also because of the demands of assembling a locally feasible and legitimate financial calculus which is acceptable to local authority political leaders and executive officers, as well as other parties.

The Sociological Perspective on Evaluation Practices in Financial Markets

What is little publicly debated, however, and indeed is frequently 'naturalised', is why, when evidence of the wider environmental, social and energy saving value of district energy technologies is accepted, their measured financial value remains low, and the risk calculus is generally unfavourable to investment. Social science research on innovations in financial engineering suggests that these instruments have significantly reshaped financial markets, with material impacts on value creation (Knorr-Cetina & Preda, 2012; MacKenzie, 2009). Contemporary political-economic commitment to the attributed efficiency of liberalised markets shapes the field of possibilities, situating finance as a significant dimension of socio-technical innovation. Questions about the non-financialised public value to be derived from different forms of, and routes to, sustainable energy for urban settings, become marginalised.

The powerful neo-liberal discourse of the last 30 years has claimed that financial innovation, particularly complex instruments for securitisation of assets and accelerated capital recycling, is a major contributor to risk management for socio-technical innovation and market expansion in advanced capitalist economies (Engelen et al., 2010). The resulting financialisation of advanced economies (Erturk et al., 2008) is visible in corporate restructuring to prioritise financial value as the core performance indicator, and in the widespread legitimising of discourses of shareholder value (Crouch, 2011; Preda, 2009). Value is framed within a techno-economic policy model, which asserts that markets are rational-instrumental means of resource allocation, generating economic value by allocating capital efficiently according to its calculated productivity. The role of government in this model is restricted to removal of 'market barriers' by for example using restricted public finance to mobilise significant private capital investment. An efficient market is expected to allocate resources to technological development, because its value will be captured in financial returns to investors. The problems of creating an investable project are conceived as amenable to financial engineering, which is constituted as a means of de-risking investment. Financial metrics are increasingly applied to decisions governing investment in essential infrastructures, resulting in the treatment

of infrastructure as a standardised component of an asset portfolio, tradeable in a global market to maximise returns to private shareholders (Torrance, 2008). The underlying epistemology informing such evaluation methodologies, and what is included or excluded as a relevant factor in investment decisions, remains outside the frame and largely unexamined. There are however critical questions about whether such instruments are fit for purpose in relation to the long-term public interest in, and wider social value of, a sustainable, affordable and resilient energy system.

Sociology problematises this naturalising of financial evaluation, and argues that financial market instruments can instead be studied as a problem in the sociology of knowledge, an area of research which investigates empirically the social production of scientific, or expert, knowledge in the context of its institutional structures and cultural and political processes (Bloor, 2004; Shapin, 1995). Knowledge is understood as a form of shared belief, which may or may not be justified in practice, but which has attained the status of factual knowledge through the technologically mediated work of expert practitioner communities. Recent research has brought concepts from the sociology of scientific knowledge to the analysis of knowledge claims and processes in financial markets, where the facticity of market numbers is typically a prerequisite for a functioning market (Carruthers & Stinchcombe, 1999; MacKenzie, 2006; 2009). In the related tradition of actor network theory, the economy is treated not as an independent object, but as a societal phenomenon itself constituted by theories of economics and finance, which become enmeshed in practices of market formation (Callon, 1998; 2007). Associated questions about authority, power relations, and knowledge are the subject of renewed sociological focus through the analysis of *evaluation* techniques as a means of understanding the social production of material value (Beckert, 2009), and of different 'orders of worth' (Boltanski & Thevenot, 2007), which are central to the coordinated production of markets, including energy markets. The boundaries, differential qualities, and the relative value of resources to be transacted all have to be negotiated in order to constitute a market. Such structured power relations are amenable to analysis through study of the distributed knowledge of complex corporate and government actors, and the rules and instruments of markets. Knowledge formations, and their embodiment in 'soft' as well as 'hard' technologies, are conceptualised as the, at least partial, fixing of outcomes of struggles for power. Economic models in these terms are not derived from empirical observation of a fixed economic reality, but contribute to bringing the attributed phenomena of a particular market rationality into being, through the provision of behavioural scripts and algorithms (Callon, 1998; MacKenzie, 2006). Social studies of finance and the sociology of markets seek to avoid a functionalist analysis of market mechanisms of risk and value calculation in order to reveal the underlying contests and conflicts of interest, and the ultimately precarious qualities of market facts (MacKenzie, 2009). In the context of energy markets, the sociology of knowledge offers insights into the processes of evaluation which inform business investment. The following discussion examines such processes and their implications for assessments of value in district energy projects.

Methodology and Data

Drawn from a larger research project, qualitative data are used to explore the perspectives applied by finance practitioners and energy utilities to the evaluation of meso-scale energy project developments. These data focus on the context-bound, interaction-oriented aspects of financial practices. The aim is to gain insight into the actor's perspective, while seeking to avoid assumptions about the pre-given, normal or taken for granted qualities of the processes explored.

Analysis is based on the following data:

- Semi-structured interviews with nine finance experts (two representatives of a UK government low carbon investment team; three environmental finance specialists - two employed by a transnational finance and accounting corporation and one partner in an independent consultancy; two finance consultants with long-term expertise in UK privatisation of public infrastructure, development of Private Finance Initiative and Public Private Partnership instruments, private equity fund management and infrastructure procurement; two representatives of corporate banking with responsibility for lending to renewable energy and energy efficiency sectors); and five community energy market managers from two of the six large scale gas and electricity utilities which supply the UK[3].
- Presentations and discussions from a one-day workshop on financing district energy, organised by the research team in collaboration with a district energy practitioner. The Workshop was attended by 25 local authority representatives and a mix of finance experts, consulting engineers and district energy suppliers.
- Interaction with the UK government Department of Energy and Climate Change (UK DECC) through analysis of heat policy documents and attendance at a workshop on market barriers to district heating.
- A data set of forty-four case studies of district heating projects developed in the last ten years (BRE et al., 2013[4]). Interviews included a key section on finance. The research findings were a component of evidence used in formulation of heat policy (UK DECC, 2013).
- Interaction with the Scottish government energy team to investigate policy instruments to accelerate delivery of low carbon and renewable heat[5].
- Interaction with the trade association, UK CHPA, to gain insight into their strategic position on urban heat network policy instruments and financing.
- Interaction with senior managers and non-executive chair of a large-scale energy utility at an invited meeting of a stakeholder forum to consider city scale low carbon investment strategy.

Evaluating Urban Energy Investment

The Dominant Frame: 'Constrained Public Finances' and Risk in a Centralised, Regulated Energy Market

> ...and we all recognise that there's a finite pool of public funding out there. So if we are limited to that sort of funding to invest in the green space, that is

> going to severely constrain the base investment (Quote from research interview with UK government officer, Low Carbon Investment team, 2012).

Two interlocking narratives stemming from neo-liberal political-economy provide the dominant frame for evaluating the viability of urban energy developments. The first is illustrated in the above quote, which situates constrained public sector finance for low carbon investment as unavoidable, rather than as a matter of political decision. The second narrative, which is the necessary counterpart to the first, denotes the continuing commitment, post-financial crash, to financial market innovation to stimulate new private investment in energy infrastructure particularly in the unfamiliar urban scale energy efficiency technologies:

> ... the sort of ultimate, if you could create a model where public sector sort of stands behind investment, and then the business model is proven, that can then be refinanced by private capital, and then that capital can be recycled (UK government officer, Low Carbon Investments team).

Investment in energy infrastructure has been progressively redirected away from the financial logics of national systems of energy production, and innovation, to those of internationalising capital markets, technology and fuel supply chains (Winskel, 2002). In a market context structured by large corporations, where the main performance indicator is shareholder value, long-term investment programmes have been displaced by an emphasis on 'asset sweating' and short-term investment horizons. The major utilities built strong balance sheets, with 'deep pools of capital for utility type risk' (UK government officer, Low Carbon Investments team). The UK energy market regulatory framework has also guaranteed predictable returns on large-scale investment in generation and transmission, and in electricity and gas distribution networks. Available capital has been deployed by the utilities in line with the established procurement models for centralised energy infrastructure, enabling them to 'satisfy their investors on the basis that they can provide predictable returns... through a regulatory environment...' (UK government officer, Low Carbon Investment team). For energy infrastructure, high value is therefore placed on large-scale decontextualised, standardised technologies suited to the economics of liberalised markets. In this framework, the utilities 'know exactly what they're building; they know exactly how to do it... The actual projects themselves are large scale, economically viable, generation schemes' (Asset Management Consultant), and they are able to use their 'strong lobbying ability with government' (Asset Management Consultant) to protect incumbent interests:

> 'Frankly we have a cartel within the electricity supply, and the government is unwilling to break it until it's solved the generation problem, because the big six suppliers, oops they're the big six generators... By and large the generators and suppliers are the same people... But the real problem is that the market has not in fact been opened' (Financial Investment Consultant).

External investors similarly rely on the application of standardised risk assessment instruments to identify easily replicable investment opportunities, producing reliable returns:

> A: If you're a bank ... you want the lowest risk, the best return that can be churned out like a sausage machine.

> B: And it's systematised; they've done it before and they'll carry on doing it again… Cookie cutter.
> A: It was. That's a good phrase: cookie cutter. This [district energy] is exactly the opposite of that.
> (Environmental Finance Specialists A and B).

In standardising evaluation around the criteria of maximising predictable financial returns, such templates de-contextualise and delocalise investment decisions, obscuring any local benefits. For example the energy utility stakeholder forum observed by the author addressed the topic of future energy investments at city scale. The post-privatisation withdrawal of the business from customised locality-based energy planning, despite its public benefit, was acknowledged:

> '[Utility] has for a long time ignored its cities and turned to the international agenda. We used to have DH in [X City] because it was proved that it reduced the maintenance costs of buildings' (Utility Senior Manager, energy networks).

The main business of the meeting examined the socio-economic rationale for re-engagement and collaboration between the utility and urban authorities. Joint benefits derived from synergies between political, economic and social goals of localities, and utility business goals were identified. Business benefits were cited as: reduced costs of electricity network investment associated with distributed generation, delivering mandated carbon savings and new revenues from innovation in energy services. The projected UK market for such developments was estimated as in excess of £100 billion, with near-term opportunities of around £2 billion, as well as potential to meet energy company obligations for carbon reduction and affordable warmth. Two thirds of the value of decentralised energy opportunities was expected to derive from CHP/DH.

Liberalised financial markets, however, have resulted in corporate structures geared to a central performance metric of share price, and the maximising of shareholder value, in relation to a global asset portfolio. Finance experts have progressively displaced engineers as chief executives (Fligstein & Dauter, 2007; Krippner, 2005; Zorn et al., 2005), as in this case where the corporate director of the utility's UK operations joined the company from a career in investment finance. He in turn must recommend any proposed UK investment to a transnational parent company board, and in this instance concluded that there was no business case which could succeed at board level, given the availability of secure, regulated returns through other routes. An idealised market model asserts that limited resources are rationally allocated according to laws of capital productivity. In advanced capitalist economies however the rules of resource allocation, and even the scale of resources available, are contingent on politically-informed negotiation between state and market actors, with results embodied in regulatory frames governing property rights and rules of trade (Fligstein & Dauter, 2007). In relation to electricity and gas transmission and distribution, for example, the UK's regulated asset base model guarantees a secure, predictable return on capital investment in networks through a periodically reviewed price control formula (Ofgem, 2013). This logic of value marginalises localised spatial and energy planning for integrated heat and power, however, despite policy recognition of likely benefits to system efficiencies and reduced network reinforcement costs.

The economics of locally customised meso-scale CHP and urban heat networks are hence constituted as marginal in the context of a state regulatory framework which rewards investment in a centralised system, where incumbent corporations are oriented to short-term financial performance in global markets. The initial capital investment and the long-term uncertainties of payback associated with particularities of place result in perceived risk to capital, increasing the cost of loans, and limiting the financial viability of projects:

> '…go and talk to Drax and they'll say 'we're very happy to talk about… replacing a big power station, but what on earth would we want to go and invest what would be ten times the amount of staff to do probably a hundred times as many, little, individual CHP schemes dotted around. Where on earth is the economics behind that?'… And you compare everything there is opposite to CHP: small scale, relatively ad-hoc procurement, disparate interested parties. They've got to get through all the planning bureaucracies of doing development in the middle of big cities; regulatory risk; policy uncertainty; lack of clarity over revenue risks and who is taking which risks; promoted by small industry players, who, you know, you can't blame them for trying, but they just don't have the same lobbying ear that the big six have. And that's really the conundrum isn't it?' (Asset Management Consultant)

Standardised risk assessment tools put a correspondingly high cost on alternatives to business as usual: 'The issue is risk, perceived risk' (Finance Investment Consultant). In relation to urban heat networks:

> 'Unfortunately with heat, the key risk and the key downside is… you haven't got a heat grid, so you come back to, again and again, [to] the bankability of that heat and the credit worthiness of the heat off-takers' (Environmental Finance Specialist B).

> 'The big challenge is how do you de-risk them [heat networks] in such a way that you can attract the pools of low cost finance' (UK Government Officer, Low Carbon Investment Team).

During periods of policy uncertainty, such as those relating to electricity market reform, however, all energy investments were regarded by market actors contributing to this research as risky. The state, rather than business, was considered responsible for 'the investment fundamentals' of stable, secure and predictable cash flows: the 'private sector won't invest speculatively… Large industrial players … will invest once policy certainty and detail are established… CHP requires industrial and political sponsors' (Asset Management Consultant). The constitution of market reform, including guaranteed strike prices for electricity, is for example under development between government and utilities in relation to a proposed new generation of nuclear power stations:

> 'They're saying that they'll only be funded if the power companies are prepared to actually take the risks of producing and generating the electricity off them. But that is disingenuous, because the disposal of the nuclear waste, they're saying 'don't worry about that, we'll sort that out.' Well hang on a minute, you know, the infrastructure involved in disposing of nuclear waste is going to be enormous, not just in terms of engineering, but in terms of cost…

> But… there are very strong backers within government for nuclear power' (Asset Management Consultant).

Conversely district energy was perceived as lacking the government sponsorship and covenants embodied in the financial innovations introduced through the Private Finance Initiative and Public Private Partnerships. The main 'risk' in investment in local energy systems stems therefore not so much from its *price* per se, or lack of capital for investment, as from the constitution of its economic value relative to established markets and the interests of incumbents, where 'developers are developers, councils are councils, utility companies are utility companies, and district heating doesn't fit any of them' (Finance Investment Consultant). The lack of fit for meso-scale CHP and DH with the established high value placed on centralised energy markets, and large-scale, decontextualised technology investment structured around guaranteed rates of return on capital, means that their substantive benefits remain elusive in the financial calculus.

Making the Market Work for Low Carbon Investment

> 'The holy grail is this model which enables both to be done in an intelligent manner, combining both public and private finance' (Quote from research interview with UK Government Officer, Low Carbon Investment Team, 2012)

A powerful theme in the evolving narrative of a liberalised energy market is that the role of government is to address attributed 'market failure' in areas where private investment is lacking, despite other dimensions of value such as carbon saving or local economic regeneration. A key instrument of government policy is the quasi-autonomous UK Green Investment Bank, which is required to apply market rules for allocation of public finance to projects. In relation to financial innovation oriented to formatting an energy efficiency market, its remit is confined to debt financing in what is construed as the 'narrow space' between projects which already attract private capital, and those which are substantively uneconomic. It is charged with 'crowding capital in' by deploying public funds into the private sector in order to 'help the market to generate deal flows' (UK Government Officer, Low Carbon Investment Team) in targeted areas. It is not allowed to provide start-up equity, low cost loans or financial guarantees. The model thus relies on use of bounded public finance to invest on commercial terms, and to incentivise the rapid recycling of capital through for example the creation of a new energy efficiency asset class which can be securitised:

> 'We have to focus on commercially viable investments and we're about leveraging private capital into the market… Additionality and leverage is really important to our mission… If we can demonstrate to the market that you can make good money in these sectors, then private capital will follow in large volumes' (UK Government Officer, Low Carbon Investment Team).

Addressing the need to constitute a market where investors perceive little or no value entails building legitimacy to create and sustain shared belief that financial returns can be reliably achieved in such disregarded sectors. Legitimacy is consciously courted through the selection of officers who 'understand how the City works' (Finance Investment Consultant). Fund manager partners must not only

have a track record for efficiency and reliability in allocating and managing funds and project portfolios, but also pass 'the reputation smell-test' or 'the Sunday Mail test' (UK Government Officer, Low Carbon Investment Team), indicating that cultural dimensions of evaluation practices are expected to be a significant factor in making low carbon energy and energy efficiency markets work. The UK GIB is positioned as a market intermediary channelling information about the trustworthiness of trading partners through social networks; the resulting reputational capital, anchored in shared beliefs about reliability and trustworthiness, is expected to resolve uncertainties over the value of the products traded (Granovetter, 1985; Podolny, 2001; White, 2002).

The stance taken by the UK Government in specifying that UK green investment lending must be solely on commercial terms is contested by other market actors, who suggest that 'rethinking the problem, and doing it a different way' (Finance Investment Consultant) might be more productive in achieving the overall objectives of a low carbon energy system. One informant noted that the model was likely to have the perverse result of increasing the overall cost of local energy infrastructure finance:

> 'And one of the problems… rather than moving commercial debt to prudential rates, which is the French model, UK GI is saying: well we're going to move prudential rates on to commercial levels, because we're not prepared to lend unless the banks do… because it's not on market terms' (Asset Management Consultant).

Such rules are in practice however expected to evolve in operation, and in negotiation over European sanctions against state aid:

> 'It would be interesting to see when they've got a throughput of projects how many of them have been on true market terms… I mean they're under immense pressure to push capital into the market place… I don't think they've had a great deal of success on that front to date' (Investment Manager, corporate banking).

The market finance model is thus more precariously established, less singular and more susceptible to contestation than its formalistic definition as a mechanism of efficient resource allocation implies. Making the market work for low carbon investment may consequently have more scope for improvisation than acknowledged in public statements of policy.

The Risk to Public Value?

That there is public value in district energy investments, both in terms of cost and carbon savings, seems little disputed:

> 'What I would say for district heating is almost the nice thing about it is it stacks up from a pure economics perspective…so particularly within a landscape where you have such a poor state of energy structure within the local authority and public sector user, the introduction of a retrofit gas fired CHP, plus pipework, plus boilers, plus the associated energy efficiency measures to provide guaranteed savings, would reduce carbon emissions by 20 per cent. It would save the local authority or NHS or a public sector user X hundred thousand pounds per annum' (Investment Manager, corporate banking).

As this manager went on to comment, such investments in 'non-core' energy services would also return finance to core public services by reducing energy costs over

the life cycle, thus creating further public benefit.

Contemporary evaluation frameworks have however limited the pace and scale of urban CHP and DH projects: 'It's very much sort of only the gold plated, de-risked projects that are actually going forward with private sector funding in them' (Environmental Finance Specialist B). Development has taken place mainly where profitability for private investors is secured by some form of public guarantee or risk underwriting; this may include more than long term contracts with secure revenues, and extend to factors such as the anticipated reputational or 'brand' value of investment in prestige developments. In relation to Olympic Park district energy investment for example, 'I think they're banking on the fact that it's probably the highest profile development site in the country, and if it turns into a white elephant it'll be a national embarrassment' (Environmental Finance Specialist B). Such projects may however function primarily as a showcase for capital (Hodson & Marvin, 2010), without ensuring commensurate public benefits. Long term private finance contracts governing prestige projects are positive in demonstrating the potential structures for private public partnerships, and access to private finance, but such long term concession contracts for energy supply should theoretically show the added public benefits resulting from increased total project cost of private finance. In practice, private sector operators exercise significant control over their future direction, making long-term public value creation uncertain: 'effectively the public sector needs to package something up, hand it over and keep their fingers crossed that they will be able to somehow influence the private sector going forward' (Environmental Finance Specialist B).

Most urban areas also lack 'that sort of brand' (Environmental Finance Specialist A) associated with public investment in high profile developments such as the Olympic Park 'where we know it's going to happen' (Environmental Finance Specialist A). Hence to attract investment at sufficiently low cost of capital for a project to proceed, 'somebody within that circle has got to absorb a higher degree of risk. Now in the deals that we've done to date that has … been predominantly the public sector end user that, because of lack of capital, has commercially taken the view that they'll accept that risk provision' (Investment Manager, Corporate Banking). The ultimate risk, and its cost, remains with the public sector. This may mean that other towns and cities will be experimental sites for market testing a privately-financed 'green development' model, where standard risk instruments do not adequately incorporate the future substantive risks to the locality of their contribution to guaranteeing private returns. Private finance is legally accountable to shareholders; local accountability and wider public value may prove difficult to secure.

Bricolage and Alternative Hierarchies of Value

When technical devices such as those of liberalised finance are legitimised by government regulation, and established as authoritative in evaluating energy investments, then interpretative flexibility has been restricted, and the value of some technological trajectories has been given relatively fixed, durable meaning (Clegg, 1989). But such configurations of power are not monolithic. During periods of major political economic uncertainty, as at present, any model of a singular stable and self-regulating market under-recognises the tensions within and among institutions, or the potential for a plurality of 'partial' market and non-market investment schema to be in operation, with different

goals and assumptions. Such tensions may work as catalysts to innovation and change, as suggested by sociological analyses of the productivity of intra- and inter-organisational dissonance, and discrepancy in assumptions and understandings between different groups (Boltanski & Thevenot, 2007; Stark, 2009). Research interviews and ethnographic data provide evidence of such dissonances and of the recognised need for new variants of situated financial innovation. This is innovation of an improvisatory kind, characteristic of the bricolage responses of financial actors to changing circumstances (Beunza & Stark, 2003), but guided by a continuing dominant theory (MacKenzie, 2013) of the laws of private finance:

> 'I guess what you have to try and do is work with what you have inside the system, and then tweak it rather than require a fundamental new idea to introduce, because the more dramatic the change, then the longer it's going to take, the more painful it's going to be for it to happen' (UK Government Officer, Low Carbon Investment Team).

> B: It would be interesting if someone carved out three or four hundred million, and they said 'okay, London, with parts of Birmingham, Manchester, Glasgow, Edinburgh, here we go, thirty/forty million pounds each; go and develop your scheme.' But that's very much going back to the nineteen thirties; it's New Deal, it goes against the culture of where we are… and I don't see that happening.
>
> …
>
> Interviewer: Do you think that will be forthcoming though?
> A: Probably not, because … it's not in the ethos or the culture of how the government wants to deal with energy. It doesn't really want to step in and be a big planner.
> B: Yes, you could float the argument really: leaving it all to the market, actually, what are you doing? You're really just abdicating your responsibilities and side-stepping.
> (Environmental Finance Specialists A and B).

Such bricolage, Engelen et al. (2010: 56) argue, may work to reformat markets by turning the 'nodal possibility into a profitable position by using whatever instruments are to hand to create a business model'. This seems to characterise the position of UK GI, charged by UK government with discovery of profit-making potential in low carbon energy and energy efficiency investments, while remaining conscious of the need to demonstrate public benefits from the higher costs of private capital. This does not however recognise that bricolage may also embody subordinated knowledge of alternative social and cultural hierarchies of value which could be brought into play:

The speculation by finance experts on the tenets of contemporary financial models echoes the sociology of knowledge argument that knowledge is a matter of shared belief which may or may not be true (Bloor, 2004). A core tenet of the current energy project finance model for example is that debt is cheaper than equity (Appendix 1). This may have increased the risk aversion of urban authorities to equity investment in heat network development. In private enterprise, state regulation allows interest paid on debt financing to be set against tax, making equity more expensive in the short term. Given the different tax status of local authorities, however, an equity stake in energy infrastructure confers

some advantages; equity overcomes the problem of the time lag between infrastructure investment and revenues, and confers control over strategic direction. Even in private enterprise, the belief that debt finance is always preferable because of its lower cost has been challenged by formal financial economics; the Modigliani-Miller theorem shows that, over the long term, the balance between equity and debt in an enterprise makes no difference to the overall cost of capital (MacKenzie, 2013). There is controversy over the conditions under which this may apply, but the point to be highlighted here is that current financial models are not inviolable. The financial innovations characterising the contemporary mode of capital accumulation, which prioritise debt financing through market instruments, may be working to the detriment of a more sustainable, secure and affordable energy system. Bricolage activity identifies the dissonances which limit current investment in sustainable urban energy, but has not yet resulted in coherent development of alternatives suited to the creation of a sequence of viable projects.

Conclusions

> We keep using the phrase 'the best is the enemy of the good', and you've got to go out there and make some of it happen, because if nothing happens because we're all paranoid about doing something, then that's the worst outcome of all I think. (Quote from research interview with UK Government Officer, Low Carbon Investment Team, 2012).

Attempts to reconfigure financial evaluations of urban energy infrastructure represent a moment where large-scale energy and financial market interests encounter questions about their future trajectory, and the future qualities, costs and control of energy provision. What is observable in these interviews, in policy meetings and trade forums are the attempts of actors to discover potential solutions, while securing relative socio-economic advantage from such improvised means. The current neo-liberal economic orthodoxy, which prioritises use of financial mechanisms to incentivise private investment in energy infrastructure, shapes decision-making to rule in, and rule out, options. Expert practitioners engage in critical deconstruction of the orthodoxy, but they are unlikely to pursue radically different models, given their judgement that, in the present political-economic settlement, adjustment to mainstream finance models is more likely to prove productive. The 'sunk investment' in knowledge of financial instruments and markets, as well as in material infrastructure, the lobbying power of large corporations and the disempowerment of local levels of government mean that the search for solutions centres on minor adaptations to the dominant private finance model, referred to by one practitioner as 'son of PFI' and by another as 'taking the things that worked from PFI, and applying it here'.

At the level of localities, bridging the gap between liberalised finance and local political and economic interests in urban energy projects requires considerable governance capacity, and has high transaction costs for the local authorities who are positioned as critical intermediaries. Faced with declining resources, local authority politicians and directors of housing, finance and economic regeneration perceive few benefits from the struggle to assemble finances for low carbon energy projects. Centralised state control over their finances and reduced budgets are shrinking their role, as well

as the material assets they have available in negotiating with private developers. Significant urban leadership for meso-scale CHP and DH as a component of a low carbon energy system would require greater budgetary autonomy for local government in a regulatory framework which re-values social and environmental benefits of local economic regeneration. These conclusions are in line with the work of Stewart Russell which found that earlier district energy projects were stalled by a UK economy and polity oriented to commercial economies of scale and weak social obligations. The paper extends his legacy by adding a new dimension, derived from the inter-related work on the sociology of knowledge, markets and social studies of finance, to his theoretical account. This work demonstrates the potential for critical insight into the restructuring of energy systems to be gained from a focus on the financial innovations which have dominated political economy for the last three decades. It suggests the societal value of a research agenda to develop social studies of energy markets and energy economics. Such research would in turn strengthen the conceptual basis of the sociology of markets through new insight into the interaction of the economic sciences with political struggle over definitions of legitimate value, interests and market rules. This paper has sought to contribute to such a programme of work.

In relation to policy, there is scope for alternative district energy evaluation models to counter-balance technical-economic assessments of risk and value with questions of substantive risk and value in relation to public goods of ecology, economy and society. For the first time in the UK, there is an indication that new valuation models may be taking shape, at least in elementary form, through embryonic development of institutional authorities directly responsible for heat. The 2013 Heat Policy (UK DECC) established a Heat Networks Delivery Unit to contribute to early stage project development; government is also working with the industry to develop consumer protection and technical standards. The Scottish Government District Heating action plan and heat network partnership is also oriented to increasing development, with funding under the Renewable Energy Investment, Warm Homes and District Heating Loan funds, in a regional development model.

It may be that financial innovation through the mainstream of de-risked investable projects and structured asset classes is the eventual trajectory for low carbon heat developments, but this can be achieved under a variety of governance structures, some providing more public accountability, transparency and checks on unearned profit than others. There are also alternatives to the current private sector energy utility model, which prioritises short-term maximisation of shareholder value in a global energy market. These are the many subordinated variants of public or community ownership, mutual enterprises, partnerships or consumer cooperatives in a less centralised, distributed energy system. One alternative to the complex financial engineering and costs of the private finance model is the non-profit model, where energy provision is governed by a community interest company, mutual enterprise or company limited by guarantee: 'The not for profit model is more suited for where there is in effect a demand guarantee, which was the Aberdeen context. And was indeed the Wembley context as well effectively, okay, because the projects have got to be developed anyway. So there wasn't this risk problem to be solved. So retrofit … the, sort of, community interest company approach does fit that very well' (Finance Investment Consultant). Around 30% of UK municipal authorities are developing a variety of ownership

and governance models for urban energy projects. In the most advanced projects, these include consideration of mutual enterprise structures, where heat supply is owned and controlled by its users, as well as non-profit generation and supply companies, for-profit companies, and joint ventures between energy utilities and public bodies. In the current political-economic settlement, these are typically projects developed through the determination of 'wilful individuals'[6] (Local Authority Officer) who continue to believe that local government has a broadly specified responsibility for public welfare, and who persist in finding resourceful means to work within technical, financial and political constraints. A democratic commitment to reasoned consideration of routes to affordable, sustainable energy provisions in urban centres requires such options to be explicitly and actively maintained on the public agenda. Such a shift in the political framing of the energy debate would require changes in fiscal policy to direct long-term affordable investment into low carbon infrastructure responsive to regional social and economic benefits.

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Janette Webb
Institute of Governance, School of Social and Political Science
University of Edinburgh
High School Yards
Edinburgh EH1 1LZ
Jan.Webb@ed.ac.uk

Appendix 1

Figure 1 Financing principles – urban heat networks

- Financing made up of Debt, Equity, or a combination.
- Debt is traditionally cheaper, so idea is to include as much as possible, traditionally project financed waste or social infrastructure projects made up of c.80% debt, c.20% equity, based on project risk profile.
- Equity normally provided by shareholders in equal proportions to shareholding. Public sector needs to fund its equity requirement, from reserves, PWLB[7], grants etc. Drivers may be more than financial returns, so social and economic outcomes.
- Financial model takes account of funding approach and costs, project revenues need to support cost inputs – IRR (return requirement) will decide the funding route taken.
- Private sector return requirements (10%+) higher than public sector (5-6%).
- Reducing risk will increase IRR – robust electricity and heat off takes, easier with electricity, heat often seen as not bankable.

Source: Extract from Ernst and Young Presentation to Financing District Heating Workshop, London, April 2012.

Note

There is ambiguity in the final point of the extract, which states that reducing risk will increase IRR (or the rate of return required on project lending). Reducing risk should reduce costs of lending. The point is that secure long-term heat and electricity supply contracts improve cash flow and business revenues, reducing risk of investment in CHP/DH.

Appendix 2 – Interviewees Cited in Text

1. Finance Investment Consultant - former civil service economist with responsibility for development of UK government privatisation instruments; former Director of a firm of Consulting Engineers; currently independent.
2. Officer of UK government green investment team and former Director of a firm of Consulting Engineers.
3. Environmental Finance Specialist A, Transnational Finance and Accounting Corporation.
4. Environmental Finance Specialist B, Transnational Finance and Accounting Corporation.
5. Asset Management Consultant and former consulting engineer; construction industry specialist; former director of private equity fund in a major bank; currently independent.
6. Corporate Banking Investment Manager, responsible for investments in energy efficiency in the built environment, including district energy infrastructure.
7. Utility Senior Manager, energy networks - professional engineer with leadership and operational expertise in gas and electricity infrastructure. International experience of energy market restructuring.
8. Local Authority Officer – team leader in sustainable development and energy in an English Borough Council; developer of a financial model to analyse options for local energy investments, and participant in the UK District Energy Vanguards network.

Notes

1 Defined here as ranging from a Combined Heat and Power (CHP) engine, or heat-only boiler, to supply a small number of inter-connected buildings, such as housing estates &/ or public and commercial buildings, up to inner city scale with an area-wide network connecting multiple heat producers and mixed public, commercial and residential users.

2 The Workshop is one of a series of knowledge exchange events organised as a collaborative venture between the research team and a district energy practitioner. Details from www.heatandthecity.org.uk

3 See Appendix 2 for description of interviewees directly quoted

4 The author was a member of the research consortium led by BRE and reporting to UK DECC

5 The author is a member of the Scottish Government Expert Commission on District Heating

6 In English, the term *wilful* has ambiguous connotations, signalling intentional, determined and stubborn action, which defies established rules of conduct. For public sector officers or politicians, this risks reputational damage, and harm to career prospects or re-election. In this context, it also has connotations of the initiative, enterprise and determinism required by the minority of local officers and politicians who advocate development of urban energy services, against conventional beliefs and practice.

7 Public Works Loan Board

District Heating in the UK: Prospects for a Third National Programme

David J C Hawkey

The UK has seen periodic attempts to develop large district heating (DH) networks to make use of residual heat from industry and power generation. Under concerns about climate change and energy security, DH has recently re-emerged in policy visions for future heat systems with small decentralised combined heat and power (CHP) generators playing a key role in the establishment of such networks. This paper draws on Stewart Russell's accounts of earlier DH programmes, asking to what extent the reasons he concluded CHP and DH were systematically excluded continue to marginalise the technologies. In spite of governance changes which ostensibly open new opportunities for experimentation, key structural issues challenge the development of decentralised energy, particularly the alignment of the electricity sector to a centralised system and the dependency of local governments with limited capacity on central government. The reluctance of central government to engage in system planning and the failure to integrate policies related to energy production and energy consumption limit the effectiveness of support for DH.

Keywords: district heating, combined heat and power, energy policy

Introduction

On page 78 of its 2013 policy paper, *The Future of Heating: Meeting the challenge*, the UK Department of Energy and Climate Change (DECC) illustrates its strategic framework for low carbon heat in buildings in a figure showing a "pincer movement" involving different energy networks. New district heating (DH) networks would be established in dense urban areas, in time expanding outwards to lower density suburbs. Electricity networks would be upgraded to support building-scale electric heat pumps in rural areas, with reinforcement progressively extending to higher density areas. The currently ubiquitous gas network (which serves around 80% of building heat demand) would eventually be scaled back dramatically (DECC, 2013).

The figure, as a summary of the Government's proposed strategy, is remarkable for a number of reasons. First, the scale of the change envisaged is unprecedented: while there are countries where district heating and/or electric heating are ubiquitous (particularly in Scandinavia) there is no precedent for a transition away from widespread network gas heating (International Energy Agency, 2009). Second, the "pincer movement"

is presented as a shift in thinking about heating, away from an emphasis on the technologies connected to networks, to consideration of system wide configurations of network infrastructure. Third, the strategy is clear that decisions between heating technologies and infrastructure will be driven by informed consumers, and not by government-led planning (of the sort which underpinned development of most widespread energy distribution networks in the past) (Graham & Marvin, 2001; Grohnheit & Gram Mortensen, 2003). And fourthly, because the UK Government has twice before tried to establish major programmes of district heating, neither of which succeeded.

The Ministerial foreword to DECC's Heat Strategy states, "We have [...] inherited a big hole where there should be policy for finding alternatives to fossil fuel for the supply of heat," (DECC, 2013: 1). To the extent that this "big hole" relates to district heating, Stewart Russell's pioneering work on the social shaping of technology (Russell, 1993, 1994, 1996), which sought to explain the neglect of combined heat and power (CHP) and district heating (DH), provides a valuable basis on which to understand the roots of this inheritance. Russell's account rejected the notion that technological development and deployment were driven by an internal logic of improvement, and sought instead to reveal "the complex interaction of economic, political and social forces that shape development and adoption of technologies in particular forms" (Russell, 1993: 50).

Russell argued that the neglect of CHP/DH in spite of attempts to introduce it was *systematic* (in the sense of being characteristic of a social formation) rather than *accidental* (in the sense that a different outcome could have been realised without significant changes to the energy sector or wider society). This paper examines the prospects for DH to become more widely used in the UK as envisaged in DECC's (2013) heat strategy, drawing on Russell's historical analysis to ask to what extent the forces he identified as systematically marginalising CHP and DH have parallels today, and whether emerging policy approaches address these issues in an effective way.

The paper is organised as follows. The next section introduces the concepts used in the paper, drawing out central social shaping of technology themes in Russell's writing on CHP/DH in the UK. This section frames the later discussion by drawing on energy policy and governance literatures to present some of the contemporary contextual aspects of the UK relevant to the investigation. After that I describe the empirical material used in the two sections that follow, which explore issues confronting the development of DH networks and CHP systems providing heat to them respectively. The final section concludes.

DH, CHP and the Political Economy of the UK

History of CHP and DH Programmes

Although experiments with CHP and DH can be traced back to the late 19th Century, the first significant attempt at a national DH programme in the UK followed the Second World War. Central government initially saw significant opportunities for rationalising energy use in a context of limited supply by coordinating the newly nationalised energy industries with the reconstruction and regeneration of British cities. However, the organisational challenges implied by widespread district heating, resistance within the nationalised electricity supply industry to operate (or accept electricity from) CHP, restrictions on the powers of local authorities and resource

shortages affecting the housing programme contributed to the failure of these plans (Russell, 1993, 1994, 1996).

National visions of widespread city-scale DH systems were revived in the second attempted major programme, the "Lead Cities" programme, which arose in the context of concerns around resource availability prompted by the 1970s oil crises. The programme was caught up in, and ultimately fell victim to, widespread changes in government policy which eventually led to the liberalisation and privatisation of most nationalised industries, including the energy industries. In this context, DH and CHP were seen as something of a test case for the new approach, with Government scaling back its proposed investment in favour of private capital. The shrinking number of cities included in the programme found they were unable to make schemes attractive to private investors who sought higher and shorter-term returns, and whose perceptions of investment risk were likely heightened by the Government's apparently waning commitment (Russell, 1993, 1994, 1996).

Stewart Russell's historical analysis of DH programmes was inherently sociotechnical, emphasising that the development of technology and social arrangements are part of the same process (Russell & Williams, 2002b). Key STS features of Russell's account include alignment of interests around a centralised electricity system supported by co-production of that system and its social organisation, the distributed nature of change that widespread use of CHP and DH would imply, and a balance between the apparently idiosyncratic issues that held back particular schemes and the systemic issues which kept the technologies in a precarious and marginal position (c.f. Russell & Williams, 2002b).

The twin products of CHP, heat and power, underpin the division which runs through Russell's account between the integration of the technology with the electricity system, and the development of DH infrastructure. Issues in the former domain focused on the centralised character of the electricity system, both in its organisational form as a national-scale state owned company and the corresponding technical configuration the industry pursued with large centralised stations and electricity cascading down through transmission networks to distribution networks to consumers. Incompatibilities between this centralised sociotechnical system and the use of CHP as a smaller scale electricity generating technology embedded in distribution networks, both in terms of a capital investment programme and in relation to network control, led to the marginalisation of the technology from the electricity supply industry under both programmes. This marginalisation took the form both of decisions within the nationalised industry not to develop its own CHP systems, and of an unsupportive (and at times actively hostile) response of the industry to other organisations feeding CHP electricity into the public system.

The latter domain, the development of DH infrastructure networks, was also frustrated by capacities and interests influenced by organisational structures and relationships. While some organisations (such as universities) developed heat networks to serve a small number of buildings, local authorities, in the main, were the central actors in plans for larger scale, multi-organisation heat networks (Russell, 1993). UK local authorities are limited by the *ultra vires* principle which prevents them from engaging in activities not expressly sanctioned from the centre (Wilson & Game, 2002). In the post-war period, no general dispensation for local government to develop or operate DH networks existed. When the UK parliament

granted individual local authorities powers, they were often restricted to fragmented areas of their city. By the second CHP/DH programme local authorities had general powers to develop heat networks, but their capacity to shape the spatial relationships between sources of, and demand for, heat was limited by constraints on their spatial planning powers. Dependence on central government was manifest during the second period in the arrangements for financing DH systems: initially central government support was planned, but this was withdrawn in favour of private capital which proved difficult to mobilise at a cost which systems could cover (Russell, 1996).

Russell (1993: 48) argued that the split between organisations involved in heat and power reflected not only the twin products of CHP, but also a characteristic split in energy debates in the UK between interests organised around energy production (viz. the electricity industry) and interests organised around consumption (as mediated or expressed by local authorities seeking to achieve social goals through development of heat networks). Contrasting the UK with other Western European countries where extensive DH systems have developed is instructive. During DH development, these countries had relatively autonomous local government, often able to coordinate heat network development with municipally operated electricity systems, other local infrastructure, and development of the built environment, particularly housing (Ericson, 2009; Grohnheit & Gram Mortensen, 2003; Raven & Verbong, 2007; Rutherford, 2008; Summerton, 1992).

In Russell's account, the dependence of DH/CHP development on UK central government can be seen in the effects of its withdrawal from an active role in planning at the times of both programmes. While nationalisation of the energy industries was justified in terms of rationalising a dysfunctional sector, the UK government's plan for CHP and DH was not embedded in a strategic vision of the configuration, components or integration of the energy industries. When the electricity industry sought to establish its autonomy from central government control (indeed using CHP as a test case for this relationship), central government acquiesced, choosing rather to use the nationalised industries only expediently as a component of its Keynesian management of the economy (Russell, 1996). The explicit goal of freeing the energy industries from political control through privatisation contributed to the destabilisation and failure of the second programme.

Complementing these structural issues, Russell also described some of the mechanisms by which organisational interests were expressed and translated into action, or more commonly inaction. While a wide range of social issues motivated interest in CHP and DH (raising standards of living, cheap warmth for low income households, efficient use of resources, regeneration of local industry, local employment and regeneration of housing stock), terms of appraisal imposed on CHP/DH schemes were progressively narrowed to cost benefit analyses and ultimately (in the run-up to privatisation) whether schemes could offer returns attractive to private investors (Russell, 1993). Russell argued that the 'technical' character of debate this led to did not undermine his analysis of organisational interests. Indeed, the fact that a variety of different methods and criteria for appraising CHP/DH were deployed in these debates supports the view that judgements whether the option was 'economic' or not could not be reduced to some internal technical characteristics. Instead, Russell argued, appraisal reflected the priorities of, and constraints on, the performing institution. For example, the

nationalised electricity company concluded that in only in a limited number of cases would DH be 'practicable and economic', ignoring its own role in weakening the financial case for DH by offering poor terms and low prices for electricity from CHP. The failure to consider CHP as an integral part of the UK's energy systems, instead holding it as an adjunct to a centralised system, meant schemes struggled to find a viable position in a system not designed for them. The marginal performance of the fragmented schemes which struggled to exist in this context itself became part of the marginalisation of the option, negatively shaping visions and understandings of what CHP and DH would mean in the UK, visions which were weakly articulated and not widely shared in the first place (Russell, 1993; Weber, 2003).

This presentation does not exhaust the themes and detail of Russell's account (for example, the association of CHP and DH with a range of issues and support from unusual political coalitions). However, it is these themes — the shaping of interests and capacities through organisational structures and relationships, and mechanisms by which those interests are expressed — that I focus on in exploring the contemporary prospects for CHP and DH.

Contemporary UK Energy Policy and Politics

While Russell's account revealed striking parallels between the failure of both the CHP/DH programmes of the 1940s/50s and the 1970s/80s, they failed at different times and under different conditions. In the post-war period, industry and government coalesced around a model of centralised command-and-control decision making oriented to rational infrastructure development as a component of economic expansion (Helm, 2005). The second programme was caught up in the 1979 government's moves to redefine the boundaries of the state, with liberalisation and privatisation of energy an iconic example of a widespread shift in governance arrangements to the use of competitive markets (and, where such markets were not feasible, market-mimicking mechanisms) with the aim of driving up economic efficiency through lower costs and stimulation of innovation (Fudge et al., 2011; Helm, 2005).

The character of energy policy (and the corresponding industry structure) in these periods was reflective of what Russell and Williams (2002a) identified as more widespread developments in technology policy, from nationally organised infrastructure, industrial and military programmes up to the 1970s, to policies inaugurated in the 1980s designed to create supportive conditions for a wider range of actors to innovate. Russell and Williams (2002a) detected a further shift in technology policy from the end of the 1990s towards an approach which maintains an orientation to distributed processes (indeed national governments have largely retreated from planning), while accommodating a more complex view of the development of technologies and a corresponding broadening of the sites for policy intervention.

In UK energy policy, the extent of such a shift is the subject of academic debate. Helm (2005) argues that contrary to political expectation, liberalisation did not result in de-regulation of energy, and that the enduring role of government in setting the framework for the (increased range of) actors in the energy system has become more pressing through mounting energy security and environmental problems. These pressures became so acute at the end of the 1990s that government was led to explore a wider range of policy interventions to purposively reshape UK energy systems

(Helm, 2004, 2005). Others disagree with the contention that this represents a new 'paradigm' in energy policy, arguing that significant continuities with the 1990s exist in commitments to market and market-mimicking approaches to resource allocation (including investment decisions), technology neutrality of policy, independence of regulation and linking of growth-based indicators of prosperity with analyses of energy economics (Fudge et al., 2011; Mitchell, 2008). These authors argue these continuities render policy interventions ineffective, and marginalise visions of an energy system radically different to the current fossil fuel-dependent centralised system.

Shifts (to whatever extent) in energy policy are embedded in broader political and policy programmes and assumptions. Moran (2003) argues that the form in which the energy sector was reconfigured in the 1990s is part of a more general transition in UK governance (covering sectors as diverse as financial services, medicine and sport), from systems of 'club government' to systems of enforced self-regulation which Mitchell (2008) groups under the Regulatory State Paradigm (RSP). Where club government was oriented to closed networks, personal contacts, tacit understandings and autonomy of sectors from state oversight, its replacement, the RSP, is characterised by codified, juridified and institutionalised systems of regulation. An important aspect of RSP governance is an emphasis on the autonomy of multiple actors' decision making in regulated areas, on grounds that distributed actors have better access to information than a central actor. However, this emphasis sits uneasily with the state's on-going modernist ambitions, such as to radically reduce territorial greenhouse gas emissions. In combination, these features of the RSP imply complex policies and programmes which aim to shape distributed actors' decisions (for example, by altering relative prices). The demands of calibration and monitoring of these interventions has led central government to seek more information in pursuit of what Moran (2003) calls synoptic legibility. The relationship between local and central government has undergone changes in line with these broader developments, seeing an increase in the use of indicators and audit of performance alongside moves towards greater freedom of action from central control (Martin, 2011; Nutley et al., 2012).

Details of how these broad shifts in governance in the UK are manifest in the domains of local government and energy are examined in later sections of the paper. However, this high level view of governance changes in the UK sets the context for the investigation: to what extent do attempts by central government to distribute decision making in energy and local government across other actors support or impede the contemporary development of CHP and DH?

CHP, DH and Low Carbon Energy

DH networks are 'source agnostic' and heat from CHP can be used in a variety of applications, so a coupling between CHP and DH is not inevitable. Indeed, the development of DH networks in Sweden included very little CHP, and much of the CHP developed in the Netherlands in the 1990s did not feed DH networks (Ericson, 2009; Hekkert et al., 2007). In the UK, DH development commonly draws on gas-fired megawatt-scale CHP. Gas CHP offers desirable characteristics to DH developers and operators: as a mature technology with well established fuel supply, heat source risks are reduced. In addition, electricity prices in the UK are largely determined by gas prices and the main competitor for heat supply is gas, meaning changes in input and

output prices for gas CHP move together, giving the technology a 'natural hedge'. The proportion of homes with central heating has increased steadily from less than a third in 1970 to over 95% (Palmer & Cooper, 2011). Fuel poverty measurement varies between parts of the UK, but in broad terms was at a low point of around 5% of households in 2004 and has consistently risen to around 15% in 2011 (Hills, 2012). CHP and DH can make heating more affordable particularly when replacing electric heating, making retrofit of CHP/DH to alleviate fuel poverty in electrically heated high-rise dwellings a particular target for the technology (DECC, 2013).

The link between DH and CHP in what follows is, therefore, justified by this link existing in contemporary practice, though over the longer term this relationship may evolve into something different. While (unabated) fossil-fuelled CHP can achieve short-term greenhouse gas emissions reductions, it nonetheless produces CO_2, and may in future be more carbon intensive than alternative forms of heat and power generation, such as renewable electricity and electric heat pumps (DECC, 2013). The role of CHP and DH in possible trajectories of decarbonisation of energy systems is, however, complicated by the possible dynamics of future energy systems including the role of CHP in efficient balancing of an electricity system with inflexible generation such as nuclear and renewables (Lehtonen & Nye, 2009; Toke & Fragaki, 2008) and the use of CHP as a bridge to lower carbon heat sources (DECC, 2013; Rotheray, 2011). Large scale DH networks could have a variety of relationships with other energy systems depending on future outcomes (in patterns of generation and resource availability) that are currently highly uncertain. Considering these relationships is beyond the scope of this paper, but is noted as one source of uncertainty and complexity confronting development of DH and CHP in the UK.

Data Sources

This paper draws on the first three years of a four year research project into the prospects for sustainable heat in cities, *Heat and the City* (www.heatandthecity.org.uk). The project explores the prospects for development of sustainable heat in UK cities and has gathered a range of original empirical material through surveys, interviews, workshops and observation at meetings. This dataset concerns household experiences with DH, the organisation, development and financing of local DH initiatives, and policy making at local authority, Scottish Government and UK Government levels. In this paper I draw on a subset of this empirical material as it relates to the development of heat network infrastructure (next section) and the relationship between CHP and DH with the incumbent energy system (subsequent section). Original data is combined with analysis of policy documents, practitioner guides and research reports, and relevant academic literature as indicated in the text.

The material used in the section on the development of DH networks focuses primarily on the role of local government. The perspectives of local authority officers on the challenges of developing heat networks are drawn from 49 interviews with officers across 5 city case studies, along with a series of 4 workshops, organised as part of *Heat and the City*, with members of a network of 65 local authorities and 12 housing associations actively engaged in developing district energy initiatives. This material is combined with observations from academic literature on local government and documentary analysis of UK policies concerning the powers of local authorities and support for DH, to situate

the reported immediate concerns of these individuals in a broader context of local governance.

The exploration, in the subsequent section, of the integration of CHP/DH with the incumbent energy system is guided by challenges reported by project developers, consultants and industry, and draws parallels between these and issues Russell highlighted in his historical account. This material is combined with interview data and engagement at meetings and workshops with government energy policy makers. Again, rather than take the perspective of these individuals as objective sources of information, this primary data is supplemented by analysis of the evolution of UK energy policy through documentary analysis and relevant issues identified in the literature on UK energy governance.

Contemporary Development of Heat Networks in the UK

Local government has historically played a central role in attempts to develop DH networks, both in the UK and elsewhere (Russell, 1993; Ericson, 2009; Grohnheit & Gram Mortensen, 2003). The breadth of its estate (including housing development) means it can anchor local heat networks, its role in spatial planning and building control enables it (in principle) to strategically coordinate infrastructure development, it is able to broker relationships between organisations with local presence, and its potential to make long term investment is underpinned by its commitment to the locality, low borrowing costs and its role in securing local social objectives. While other organisations can (and do) develop heat networks (particularly campus-based organisations such as universities and hospital complexes, or social landlords), local government nonetheless is looked to by both policy-makers and practitioners in the UK as playing a crucial role in the possibility for city-wide DH systems able to achieve greater economies of scale (International Energy Agency, 2005).

Fragmented Local Governance

Recent UK reforms to relationships between central (and devolved) government and local government ostensibly empower local authorities to act innovatively (Martin, 2011). The *ultra vires* principal has been relaxed somewhat by new powers of "wellbeing" (introduced in 2000) which allow local authorities to undertake activities judged to improve the social, economic or environmental wellbeing of their areas. The financial liability local authorities can incur is no longer capped by central government. Instead borrowing is regulated by a set of rules (the Prudential Code) administered by an independent professional institute (the Chartered Institute of Public Finance and Accountancy).

However, limited capacities of local government to develop DH networks, and the dependence of local authorities on support from central government remain striking features of UK DH development. While borrowing powers have been extended, financial autonomy from central government is limited in comparison with other European countries, with a relatively low proportion of local government funding coming from local taxes and fees (Wilson & Game, 2002). The introduction of the wellbeing powers was accompanied by new forms of performance management structured around performance indicators and ring-fencing of central government grants to specific local activities, which led many local government departments to be more responsive to their central government equivalent than their local counterparts (Leach & Percy-Smith, 2001; Wilson & Game, 2002).

A parallel trend in local governance in the UK has been the fragmentation of local service delivery. In pursuit of performance improvement through competition, various powers and responsibilities have been transferred from local government to other providers. For example, the 1988 Housing Act removed local government's monopoly on state-subsidised social housing, allowing numerous Housing Associations to compete for this function, limiting local government's capacity to coordinate social housing development (Wilson & Game, 2002). In addition local authorities, under obligations to secure "best value", have been increasingly tendered services for which they have statutory responsibility (such as refuse collection and ground maintenance) to commercial providers (Leach & Percy-Smith, 2001).

The consequences of local fragmentation and entrenched central control for local government's capacity and willingness to develop DH systems are various. Local government activities are oriented towards exemplifying good practice (e.g. reducing its own estate's carbon footprint) and enabling others to act, rather than direct provision of services (Bulkeley & Kern, 2006). Our case-study research across different local authorities indicates an uncomfortable fit between DH and organisational structures, with different departments taking the lead on heat networks in different authorities (for example, housing, regeneration or environmental departments). Departmental fragmentation can frustrate attempts to develop schemes: for example in one case we have examined a lack of cooperation among neighbouring departments has undermined implementation of a pilot scheme, particularly its designed use of existing revenue and accounting systems to manage customer billing.

The capacity within local government to develop technically and financially viable energy systems is limited not only by their lack of experience with energy (having had the power to operate gas and electricity systems removed under the nationalisations in the 1940s), but also by the orientation of in-house skills to managing relationships with external service providers. Where local government has developed DH systems, this has often relied on costly consultancy services, and where officers lack technical knowledge to adequately specify consultancy requirements the quality of work delivered is variable: for example, in one case we have researched in depth, an initial feasibility study indicated the proposed scheme would require under £10m investment, while a second study doubled the capital cost, reduced the payback period by over a year and indicated the scheme's internal rate of return would be twice that initially estimated. Furthermore, local government officers in district energy workshops have raised concerns about the impartiality of advice (which is cheaper from companies able to also construct DH systems) and the outsourcing of knowledge development (see also King & Shaw, 2010). Those local authorities which have developed DH systems follow different routes (Hawkey et al., 2013) but a common theme emerging from interviews and workshops with local authority officers is that project success relies on the persistence of a small number of dedicated individuals, often just one or two, whose struggles to coordinate resources within their organisation are neatly captured in the epithets they apply to themselves, such as "sheepdog," "wilful individual," or "lone nutter."

Thus while local government potentially plays important roles in the development of strategic, city-wide heat networks, their limited capacity coupled with fragmented

internal structure and dispersal of service delivery across numerous other organisations often limits the scope of planned systems. While enthusiastic local authority officers participating in district energy workshops try to "think big but start small" (Lovell et al., 2011) the challenges of designing and funding future-proofed systems (for example, with oversized pipework to ensure capacity for future connections) coupled with uncertainty in whether additional heat load will be available in future mean implementation of a strategic approach is rare. DECC has recently created a Heat Networks Delivery Unit, one function of which is to help local authorities navigate the development of schemes, particularly supporting them in negotiation with the private sector for consultancy services (DECC, 2013). Whether this process is also able to help local authorities broker relationships across multiple subscriber organisations will be crucial to whether heat networks continue to be predominantly small and fragmented, or develop as more strategic local energy systems.

Central Government Capital Funding for Heat Networks

Where DH schemes have developed over the past decade, funding programmes directed by central government have often been instrumental. The Community Energy Programme (CEP), initiated in 2002 with a budget of £50m, illustrates aspects of how DH is appraised by government, and challenges in the development of an ongoing development programme. CEP was sponsored by the Department for the Environment, Food and Rural Affairs (Defra). It had social objectives (reducing carbon emissions and fuel poverty), but used a cost-benefit analysis model for appraisal of individual schemes rooted in the financial transactions schemes engaged in (rather than externalised or non-transactional objectives). Future transactional costs and benefits were discounted for comparison with current costs and benefits using a social discount rate of 3.5% per year (HM Treasury, 2003) which (in theory) weighed equally the preferences of people now and in future. Projects that satisfied the programme's criteria were eligible for up to 40% capital funding.

The programme imposed demanding timescales on project development, meaning only relatively simple, smaller schemes were able to complete. As heat networks exhibit increasing returns to scale (International Energy Agency, 2005) the performance of the small networks that went ahead under the programme was consequently disappointing. In addition to this, Defra identified difficulties produced by the spike in demand for consultancy and contractor services created by the programme, which exacerbated its poor outcomes (relative to its objectives) by raising prices for these services and lengthening lead times (Hawkey, 2012). In the 2006 review of the UK's Climate Change Programme, the CEP was abruptly ended, with UK Government citing "other programmes that can more cost-effectively deliver carbon savings" (Defra, 2006: 88).

The decision to end the Community Energy Programme echoes Russell's observation both of the narrowing of appraisal metrics, and the role of earlier disappointing schemes in shaping visions and understanding of how DH performs in a UK context. In both programmes Russell examined and the CEP, contextual factors shaping the poor performance of those systems were ignored (including, in the 2006 case, the terms of the funding programme itself, and the broader context of energy systems discussed in the following section). It also illustrates continuity in the

dependence of local authorities engaged with DH on central government, and the uncertainties generated for the former by shifts in the position of the latter.

Since the CEP, more grant funding has been made available to local authorities for DH: a £25m 'green stimulus' in 2009 (Homes and Communities Agency, 2011), and funding under climate change obligations imposed on energy companies (DECC, 2012a). Tight timescales for grant spending are still, however, difficult to reconcile with strategic local energy development.

Planning Policy and Building Control

Powers and guidance issued to local government on spatial planning and building control provide another example of challenging central-local government relationships. Planning guidance issued in England in 2007 required local authorities to develop targets for new development to use renewable and decentralised energy, with funding available to support creation of local evidence bases (Department of Communities and Local Government, 2007). Planning guidance did not, however, indicate how support for decentralised energy should be balanced against other goals set out in the planning system, such as provision of affordable housing or speedy processing of planning applications (Williams, 2010). In spite of this drawback, some local authorities did use the guidance both to create local requirements for new developments (such as housing or commercial buildings) to adopt DH, and to rejuvenate legacy networks on the grounds that new planning guidance opened opportunities to extend these systems (Hawkey, 2013). Following the election of a new UK government in 2010, the planning system underwent a major overhaul through the Localism Act 2011, under which regional planning strategies were abandoned, central government guidance was simplified to remove "top-down" policies (such as those set out around decentralised energy) and local groups were given powers to develop neighbourhood plans within the planning system. Officers from local authorities which had aligned their DH planning approach around planning guidance and support from regional bodies report these reforms undermined their capacity to develop robust local policy with some describing the new arrangements as a 'shipwreck' in workshop discussions (Hawkey, 2013).

Building standards have passed through a parallel evolution, with a 2006 policy to ensure all new homes built after 2016 were net zero carbon. The policy allowed for onsite emissions to be offset by savings elsewhere, with developers investing in 'allowable solutions' including DH networks. However, the scale of investment the mechanism was expected to produce was significantly reduced in 2011 when central government restricted the definition of 'zero carbon' to cover only emissions associated with heating and lighting (Zero Carbon Hub, 2011), and further uncertainty surrounds the mechanism by which funds generated by the policy will be distributed.

Under these changeable conditions, local government officers participating in a DH workshop on central government policy (see Hawkey, 2013) raised the question of whether local government has a 'mandate' to develop heat networks, and what central government's view is as to who is the 'rightful owner of district energy' (e.g. local authorities or commercial developers). Thus in spite of a rhetoric of releasing local government from central control, in relation to district heating this has not led to perceptions of local authority empowerment among officers, due both to authorities' ongoing dependency on inconstant central government policy, and a tendency among local authorities to look

to central government to sanction their DH activities.

Energy Policy and the Co-production of Heat and Power

The nationalised electricity supply industry, structured as a central generating organisation providing bulk supply to regional distribution boards, played a crucial role in Russell's account of the marginalisation of CHP. Privatisation and liberalisation of the sector has resulted in significant restructuring of the industry, now based around six companies integrating generation and retail activities, supplying 99% of domestic customers (Ofgem, 2008). While the principle of de-integration was not sustained with respect to electricity generation and retail (Thomas, 2006), distribution and transmission networks are separated as regulated monopolies. While two of the six integrated companies do operate distribution networks, they are required to keep these separate from generation and retail activities behind "Chinese Walls". Activities of the companies are overseen by an independent regulator, Ofgem, and European directives play an increasing role in governance of the sector. Thus the range of actors involved in the sector (either as direct participants or in governance) has increased, and monopoly power has been mitigated by a mixture of competition and independent regulation. To what extent has this opened opportunities for CHP and DH?

Participation in Energy Markets

During both CHP/DH programmes, the nationalised electricity supply industry perceived small CHP systems embedded in distribution networks as contrary to its interests in centralised generation, and offered poor terms for connection to the network and low tariffs (Russell, 1993). The current regulatory split between Distribution Network Operators (DNOs) and generators in principle alleviates this conflict. However, while DNOs formally do not have an interest in generation, the UK regulatory model, a form of price-cap regulation, still creates misalignment between DNO interests and distributed generation. The intended impact of price cap regulation was to drive cost reduction (Bolton & Foxon, 2011). The nationalised industry had left a legacy of networks with significant capacity margins built in, and DNOs have faced little need to invest in network innovation. Consequently, they have profitably operated by cutting R&D spending in network development, and have done little to reconfigure networks to better accommodate decentralised generation (for example, through active power management), instead treating proposals to connect generation in a piecemeal fashion, leading to high connection charges (Bolton & Foxon, 2011). In its 2005 Price Control Review, the regulator introduced financial incentives for DNOs to invest in R&D and to trial network innovations to connect distributed generation. While R&D spending did increase, only three network innovation projects were undertaken (Bolton & Foxon, 2011). Distributed generators continue to complain that DNOs impose opaque conditions and high charges for connection (Ofgem, 2011a).

Where CHP operators have connected to the public system, they have found participation in the UK's wholesale market challenging. Credit and administrative requirements are high, and penalties for failing to generate the quantity of electricity forecast can be relatively more severe for CHP operators than for large companies able to respond to imbalances within their own portfolios (Toke & Fragaki, 2008). Long term planning for CHP developers

is made challenging by poor visibility of future electricity prices as wholesale market liquidity is low, because wholesale electricity transactions are dominated by self-supply within vertically integrated supplier/generators (Ofgem, 2011b).

Small CHP generators therefore usually avoid the wholesale market. Some sell to a consolidator, an energy supplier which effectively treats a generator's output as negative demand but at tariffs considerably lower than wholesale prices (Toke & Fragaki, 2008). Sale over a 'private wire' network (i.e. a distributed generator's own network outside the public distribution system) can generate income comparable with retail electricity prices, and exemptions from the electricity generation licensing regime limit costs, albeit while also limiting permissible scale (London Energy Partnership, 2007). Private wire networks also give small generators the advantage of a relatively stable market as users face a barrier to switching suppliers in the form of the cost of a new connection to the public system. However, in 2008 the European Court of Justice[1] found against this form of supply monopoly, ruling that private wire networks must grant access to third party suppliers to allow subscribers access to competitive markets, undermining the long-term business models for CHP/DH systems with private wire. For example, an interviewee from a municipally owned energy services company (ESCo) indicated fears that larger companies would offer 'silly prices' to poach the lucrative customers connected to the ESCo's private wire (office developments, supermarkets, shopping centres, etc.). These market conditions for CHP electricity, therefore, favour more restricted situations where long term agreements for power supply to large users can be brokered. Our research on specific cases in the UK indicates such agreements tend to rely on organisational relationships, for example campus-based CHP/DH systems where heat and power are used by a single organisation such as a university, or municipally-led schemes where electricity can be used by municipal facilities such as leisure centres and schools (e.g. Webb & Hawkey, 2014).

Several recent regulatory changes and incentive mechanisms have been introduced or are in development to tackle both network access and access to power markets: a new regulatory regime for DNOs (Ofgem, 2010); a mechanism for small generators to use the resources of licensed suppliers who would voluntarily give them access to the retail market, 'License Light' (Ofgem, 2009); proposals to increase wholesale market liquidity (Ofgem, 2012); and proposals to subsidise gas CHP (DECC, 2013). What the outcome of these combined changes will be is difficult to predict, and indeed this difficulty of knowing how what the outcome of interventions and regulatory changes will be is, as Mitchell (2008) argues, a characteristic of the RSP. That outcomes may not cohere with intentions is demonstrated by the failure of the 2005 attempt to incentivise DNOs to accommodate more distributed generation.

Preferences of the Incumbent Energy Companies

Several of the six dominant energy companies in the UK have small business units focused on CHP and DH. These units undertake a variety of development, construction and operational roles in DH systems, some appearing to invest defensively, others seeking more constructive local engagement. However, the overarching financial models and investment preferences of the incumbents are difficult to reconcile with the locally specific, incremental and social-capital oriented characteristics of much DH development (Hawkey et al., 2013). The

reorientation of the industry in the wake of liberalisation, away from national systems of energy production, towards international ownership and associated flows of capital and technologies result in preferences for delocalised, scalable, replicable and predictable investment opportunities (Winskel, 2002). The mismatch is particularly stark in terms of investment scale. DH initiatives, limited by the difficulties in coordinating subscribers, rarely exceed around ten million pounds of investment. While there has been some participation among the incumbents in a handful of projects at this scale, they are small in comparison with other energy investments. For example, an officer from one of the Big Six energy companies indicated at practitioner and research workshops that his company would see half a billion pounds as a minimum investment in a scheme.

Analysis of policy documents since 2003 suggests the incumbent companies are resistant to interventions designed to encourage co-generation of heat and power from their large thermal power stations. In 2003, UK government committed to alter the procedures for power station consents, requiring generators to demonstrate they had considered options for heat off-take (DTI, 2003). However, as the distance heat can be transmitted via pipes is limited (by financial, rather than technical constraints, Roberts, 2008), these considerations would only conclude in favour of cogeneration if plant were located close to sites of considerable heat demand. The change to the consent procedures did not require consideration of alternative locations for their plant when appraising CHP opportunities, and consequently were ineffective as developers selected sites too far from demand centres for the option to be viable (DECC, 2009: 96). Early drafts of the 2012 EU Energy Efficiency Directive proposed stronger regulation that new and refurbished thermal generation plant above 20MW be *required* to operate in CHP mode. In research interviews and discussions, commercial and policy officers indicate that UK industry and government actively resisted this proposal which was eventually watered down to a requirement to conduct a cost/benefit analysis of CHP operation, reducing the estimated energy savings impact of the measure by 70% from 25 Mtoe to 8 Mtoe (Services of the European Commission, 2012).

Influences on UK Government Energy Policy

Following the programme to privatise and liberalise the energy sector in the 1990s, UK government did not produce a formal energy policy until 2003. The re-emergence of energy policy, driven by energy security and climate change concerns, was formulated in a White Paper. CHP was set alongside renewables as being central to a vision of future low carbon generation (DTI, 2003), and both forms of generation were exempted from the new Climate Change Levy. DH was also directly supported under the UK's *Community Energy Programme* described above.

In the CHP/DH programmes of the 1940/50s and 1970/80s, CHP struggled to find a place in an electricity system not designed for it (Russell, 1993). Parallel difficulties were acknowledged in the 2003 White Paper: "nationwide and local electricity grids, metering systems and regulatory arrangements [...] were created for a world of large-scale, centralised power stations." It argued that these would all need to be restructured to accommodate renewable and decentralised energy (DTI, 2003: para.1.40). The paper identified several barriers to greater deployment of CHP and DH, namely terms of access to distribution networks, difficulties

participating in wholesale markets, and the failure of the planning system to direct new power stations to be located sufficiently close to areas of high heat demand that large scale heat off-take would be possible.

As discussed above, a decade later these issues still challenge widespread development of DH and CHP. While the 2003 White Paper envisaged an energy system re-oriented to distributed generation, its successor in 2007 was more ambivalent, seeing decentralised generation as "a complement rather than an alternative to centralised generation" (DTI, 2007: para.3.8). By the 2009 Energy White Paper, mention of decentralised generation and its challenges was completely dropped (DECC, 2009). When decentralised energy has appeared in recent policy documents, its role has been presented as marginal: "the Government does not believe that decentralised and community energy systems are likely to lead to significant replacement of larger-scale infrastructure" (DECC, 2011b: para.3.3.29).

A number of factors may be adduced to explain this return to decentralised energy being considered as adjunct rather than alternative to the centralised system, including the forms of analysis used in policy development, the influence of incumbent interests on policy visions, and divisions within government between producer and consumer oriented policy making.

Russell (1993) argued that appraisal methods disguised organisational interests in apparently technical debates, pointing particularly to the way CHP and DH were appraised by the nationalised electricity industry. Computational models informing policy are predominantly commissioned by government from either commercial consultancies or academic institutions, suggesting the interests of electricity generators do not have the same direct influence over selection of appraisal methods. However, UK policy has reoriented towards visions of centralised energy systems, and Rogers-Hayden et al. (2011) argue that industry interests have played a crucial role in shaping those visions. They describe how energy security and climate change discourses were reshaped between 2003 and 2005 by an intensive lobbying campaign by nuclear power interests. Climate change shifted from being a "symptom of unsustainability" to an "environmental issue", and energy security shifted from a "lack of diversity" to a "gas-gap". Both changes marginalising arguments in favour of decentralised energy and supporting visions of electrification (of heat and transport) which emerged as core solutions to energy problems (e.g. UK Committee on Climate Change, 2008).

Mitchell (2008) argues that the UK government was receptive to this reframing in part because a centralised approach is more familiar and hence more attractive: appearing to require less intervention in the daily lives of millions of UK citizens; implying continuity in the retail market and supplier business models; and requiring construction of a small number of large plants rather than a large number of smaller interventions. This orientation to producer interests was, before 2008, reflected in the departmental structure of UK government, with the Department for Trade and Industry assuming responsibility for production side policy, and the Department for Environment, Food and Rural Affairs responsible for climate change and energy consumption policies areas such as fuel poverty. The Department of Energy and Climate Change (DECC), created in 2008, was designed to overcome these divisions, but after five years the internal structure of DECC maintains a high level division between production and consumption (DECC, 2012b), officers acknowledge in

research interviews that this structural division is reflected in the work of the department, and outsiders complain that these policy silos lead to outcomes which frustrate development of CHP and DH (Meeks, 2013).

Conclusions

In a striking formulation, Russell (1993: 50) concluded that "some basic features of our social and economic organisation mean it is intrinsically incapable of promoting efficient use of resources." The evidence reviewed above indicates that, while there have been many changes to the social and economic organisation of the UK, particularly attempts to disperse decision making away from central government in both energy and local government, key features underpinning the frustration of previous attempts to develop widespread CHP/DH programmes remain and challenge the prospects for contemporary development. In the electricity sector, while the UK model of liberalisation and privatisation has ended the monopoly of the nationalised industry, the new regulatory structures and organisational interests are aligned around the centralised system of generation which they inherited. This alignment contributes to the marginal economics of CHP through connection terms and tariffs available to CHP operators. In local government, while authorities have greater formal freedom to develop DH schemes, limits to their capacity and ongoing dependence on changeable central government policy mean projects are developed in unusual circumstances and are often small, fragmented systems rather than the comprehensive strategic networks able to achieve economies of scale and scope.

In addition to these broad systemic continuities, some of the detailed reasons for the marginalisation of CHP and DH identified by Russell have contemporary parallels. While a range of social goals are often acknowledged in policy documents, appraisal of support programmes and future scenarios (through modelling) adopt narrow financial criteria. Schemes which do manage to find a place in the interstices of unfavourable energy and local governance conditions perform poorly against such criteria, contributing to the marginalisation of DH and CHP from visions of future energy systems which can worsen the already unfavourable conditions (as, for example, happened with the decision to withdraw funding under the CEP).

While the retreat of central government from active planning was a component of the failure of both national programmes Russell studied, the inappropriateness of government planning (as opposed to competitive market allocation) is virtually axiomatic in contemporary policy development under the RSP, including in relation to heat infrastructure (e.g. DECC, 2011c: para.25; DECC, 2013: para.3.55). As Mitchell (2008) argues, government determination to maintain technology neutrality and market efficiency leads to ineffective policies, whose impacts are difficult to predict, and which can achieve change only slowly. While central government recognised systematic barriers to deployment of decentralised energy a decade ago (DTI, 2003), policy responses have not managed to overcome these issues, suggesting Russell and Williams' (2002a: 145) concerns that technology policies could "resign [themselves] to minor tinkering with agendas and directions of development set by powerful interests" were well founded.

The division in the energy sector between producer interests and consumer interests (as meditated by local government) is still present in the UK, both

in the autonomy of the companies which dominate the production and supply of energy from local government, and in the enduring split between production and consumption issues in energy policy. However, there are some countervailing pressures in the UK which merit further attention for understanding the prospects for district energy. Devolved government (in Scotland, Wales, Northern Ireland and London) created at the end of the 1990s has responsibility for local government, and restricted competence in governance of the centralised energy system. Under these conditions, support for local government in developing DH networks is one way devolved government can intervene in energy issues confronting its domain, and London in particular has pursued relatively clear decentralised energy policies (Greater London Authority, 2008, 2009; Williams, 2010). Tensions between the form of market liberalisation in the UK and the objectives of energy security, affordability and climate change mitigation are increasingly recognised in UK energy policy and underpin current efforts to reform the electricity market (DECC, 2011a). The UK opposition Labour Party announced in 2013 its intention, should it form the next government, to freeze energy prices for twenty months during which it would 'reset' the energy market, though details remain vague (Milliband, 2013). The UK may therefore be entering a new phase of upheaval in the energy sector, though it remains to be seen whether this creates conditions which mitigate or resolve the tensions between producer and consumer interests which Russell argued lay behind much of the marginalisation of CHP and DH.

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David J. C. Hawkey
Institute of Governance, School of Social and Political Science,
University of Edinburgh
Chisholm House, High School Yards, Edinburgh EH1 1LZ, UK.
Dave.Hawkey@ed.ac.uk

Notes

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Knowing and Loving: Public Engagement beyond Discourse

Sarah R Davies

This article builds on STS scholarship on public engagement with science to reflect on the role of the non-discursive, arguing that this has been under-studied in analyses of engagement. I make this point in three stages: I review literature that has analysed public engagement, suggesting that it can be understood as focusing on *process*, *effects*, *framing* or *context*, and has therefore largely ignored features such as site, materiality and affect; I draw on recent work in political theory to emphasise the importance of the emotional and creative within deliberation; and I present an example of what it might look like to be attentive to emotion in public participation by exploring the role of pleasure in engagement activities. As a whole this discussion is used to point to a lacuna in studies of public engagement, and to suggest some implications for both practice and empirical research.

Keywords: public engagement, deliberation, non-discursive, emotion

Introduction

I want, in this paper, to reflect on a single, but I believe important, point, which is that STS-informed practice and analysis of public engagement with science has tended to focus on the discursive to the exclusion of other features, such as embodiment, materiality, affect and place.[1] Thus we – as scholars of public participation – have planned engagement events and deliberative activities that focus on enabling the equitable exchange of reasoned arguments, and have analysed these events with an eye to the talk that appears within them – looking at the ways that science, publics or citizenship are constituted, for instance, or at the subject roles that participants take up. My argument here is that in doing so we are missing important aspects of the practice of public participation. We should understand public engagement with science – of all types and varieties[2] – as not only spaces in which language is at play, but as processes constituted by embodied experience, objects, and emotions. We should be attentive to both the material 'stuff' of public engagement activities and to their affective content – for instance as expressed in disruptive rationalities and emotional tone.

In arguing thus I am building on Matthew Harvey's 2009 paper, 'Drama, Talk, and Emotion: Omitted Aspects of Public Participation', as well as on a much larger body of work which has analysed

burgeoning European moves towards public engagement with science and technology. But I want also to draw on recent work from deliberative theory which has similarly argued for a move away from 'reasoned argument' to an openness to other modes of interaction. I develop my argument in three parts. I start by reviewing the significant corpus of STS literature which has emerged around the analysis of public participation and engagement, suggesting that such analysis has tended to focus on one of four different concerns, none of which is particularly attentive to the material practices and affective repertoires of engagement. In the second section I draw on thinking from deliberative theory to argue that there is (and indeed should be) more going on within public participation than can be captured by stimulation of and attention to discourse, and suggest some implications of this for our thinking on the practice of public engagement. And in the final section I focus on how our analyses might focus on the non-discursive by discussing one under-studied aspect of engagement: emotions of pleasure and delight. Drawing on theoretical and empirical studies in STS, I outline some of the reasons we may be hesitant to make such emotions the focus of our studies of engagement, and some ways in which we might start to take them seriously as components of public participation in science. In a brief conclusion, I draw these strands together. I start, then, by turning to some of the key ways in which public engagement has been analysed and critiqued in the STS literature.

Analysing Public Engagement

The turn to public engagement, participation and dialogue on science that has taken place over the last two decades has been widely discussed (see, for instance, Elam & Bertilsson, 2003; Irwin & Michael, 2003; Jasanoff, 2003). While identifying the triggers and outcomes of this turn remains problematic (Delgado et al., 2010; Gregory & Lock, 2008; Irwin, 2006; Lengwiler, 2008), it seems clear that, in European science policy and communication at least,[3] there has been a shift towards the language – and to some extent the practice – of "the involvement of nonscientists, laypeople, or citizens in science and technology" (Lengwiler, 2008: 187). Scholars have sketched out frameworks for what such involvement should look like (PytlikZillig and Tomkins 2011), and have written about the tensions inherent in seeking to put these into practice (Delgado et al 2010). I am, however, concerned here with the way in which activities and processes that fall under the rubric of public engagement have been analysed and assessed: what those in STS have said, in other words, about what public engagement looks like as it is carried out. My argument is that analysis so far has focused on four different areas – or, better, has emphasised one of four different (though overlapping) concerns. These are, briefly: the *process, effects, framing,* and *contexts* of public engagement with science. I will sketch out the literature on each of these below.

Most work has been done on the first of these concerns, in examining *process* – exploring what happens within public engagement processes. Here the paradigmatic work is that on evaluation of participatory events or structures (e.g. Rowe & Frewer, 2000; Rowe et al., 2004; Horlick-Jones et al., 2006; 2007; Neresini & Bucchi, 2010), which tends to take a normative perspective by outlining what should have happened in any particular process, and then to describe what actually did. Rowe and colleagues, for instance, outline nine evaluation criteria ('representativeness, independence, early

involvement, influence, transparency, resource accessibility, task definition, structured decision making, and cost-effectiveness'; 2004: 93) before assessing how one process – a Food Standards Agency-run stakeholder consultation – matched up to these. Similarly, Horlick-Jones et al. (2006) sketch out the aims and objectives of the UK's *GMNation?* public debate before considering its success or otherwise (it was, they say, "flawed in a number of important ways", Horlick-Jones et al., 2006: 283). Evaluation criteria and reports also emerge from outside of the STS community, including in practitioner literature (see Bonney et al., 2009; Gammon & Burch, 2003; McCallie et al., 2007).

Similar issues emerge from more general analyses of engagement-as-process. Procedural issues, such as the representativeness of participants, are a consistent theme: participant motivations (Kleinman et al., 2011), the knowledges and deliberative behaviours at play within engagement (Burri, 2007; 2009; Endres, 2009), and the discursive strategies participants use (Besley et al., 2008; Davies et al., 2006; Walmsley, 2010) have also all been discussed. The tracings of power and of expertise within public engagement (Blok, 2007; Davies, 2013; Felt et al., 2009; Kerr et al., 2007) are a key emphasis. Other scholars have examined how the practice of public engagement matches up not to particular evaluation frameworks but to different conceptualisations of participation (Carolan, 2008; Kerr et al., 2007) or to deliberative theory as a whole (Davies et al., 2006). Many of these assessments are pessimistic. The gist of work on process has been to de-mythologise and complicate the very notion of public participation in science, showing – whether through the failure to meet stated aims, the presence of enduring inequities, or simply the complexity of moment by moment interaction – that the practice of participation is by no means as straightforward as has occasionally been implied. As Delgado et al. (2010) write, "while our mentors presented us with the idea that public participation was *the solution*, we increasingly feel that we have inherited it as *the problem*" (Delgado, 2010: 826; emphasis in original).

Out of research on process as a whole, two further concerns have emerged as particularly important. There has, first, been an enduring – and often critical – interest in the *effects* of participatory activities. Work in this area has sought to examine the efficacy of policy-oriented engagement and the relationship between such activities and the institutional structures they are embedded within: many accounts have, for instance, noted the limitations of deliberative processes as a means of publics influencing or shaping government or scientific policy (Hagendijk & Irwin, 2006; Katz et al., 2009; Lyons & Whelan, 2010; Schibeci et al., 2006). In the case of the much-studied *GM Nation?*, for instance, it was suggested that key decisions had been made in advance by the UK government and could in no way be affected by the outcomes of the public debate (Horlick-Jones et al., 2006; Irwin, 2006; Mayer, 2003). Summing up the work of the STAGE ('Science, Technology and Governance in Europe') project, which reviewed case studies of public engagement in 26 countries, Hagendijk and Irwin (2006: 176) write that:

> ...in most countries, and in most cases, engagement initiatives are kept at arm's length from formal decision-making. Understandably, governments will not guarantee in advance their response to deliberative recommendations. ... However, a refusal to take outcomes seriously risks undermining public trust.

While more recent work has tended to take a broader perspective in defining efficacy – suggesting, for instance, that impacts on citizens and citizenship may be as important as those on policy (Powell & Kleinman, 2008) – the sense that, without definite outcomes, current interest in participation is a smokescreen for increasing public trust without increasing public accountability remains a pervasive one (Dryzek et al., 2009; Wynne, 2006).

A third and related analytical focus has been the *framings* embedded within engagement processes, and in particular the ways in which different actors and concepts have been constituted through public participation. A key emphasis, derived particularly from the work of British 'critical PUS' scholars (Irwin & Michael, 2003), has been the ways in which "scientific knowledge unwittingly *performs* its imagined publics in normative ways" in and through engagement (Wynne, 2006: 219, emphasis in original). Such performances often continue to frame lay publics as deficient or lacking in some way. Irwin has written about lingering 'deficit model' perspectives within one public consultation, which meant that citizens were framed as ignorant (Irwin, 2001), while other work has repeatedly identified cases in which scientific knowledge was *a priori* assumed to be more valuable than 'lay' or 'local' knowledges and perspectives (Goven, 2003; Kurian & Wright, 2010; Martin, 2007; Schibeci & Harwood, 2007). Indeed, shifting constructions of the publics of participation – as pure, partisan, mobile, engaged or distinctively 'non-scientific' – have been something of a theme in recent literature (Braun & Schultz, 2010; Gottweiss, 2008; Kurath & Kisler, 2009; Lezaun & Soneryd, 2007). As with interest in the effects of participation, the concern here is not merely how different actors are framed within public engagement, but what the impacts of these framings are. Lassen et al. (2011), for instance, are able to trace the ways in which agency is subtly removed from citizens and focused on other actors (such as policy makers) through their discourse analysis of two participatory fora around climate change. For Wynne, the limits and constraints placed upon publics by scientific imaginations of them – as embedded within calls for and practices of public engagement – are a central challenge to the science and society relationship. The problem, he writes, is technoscience's tendency to:

> impose its own tendentious and debatable definitions of public meanings onto the public, then misreading the reasons for negative or sceptical public reactions from within the same unquestioned (science- or risk-centred) premises about public meaning, rather than recognizing that the original premises may be worth revising – such as the premise that publics are concerned only about 'risk' and not, for example, about upstream (usually unaccountable) driving human visions, interests and purposes in the science and innovation itself. (Wynne, 2006: 217)

It is not necessarily science that is being rejected, in other words, within public controversies or debates – but rather the limited versions of public concern and citizenship that are presented within public participation.

Finally, recent research has begun to explore the broader *contexts* within which participation occurs, and to discuss the ways in public engagement is inflected by the cultures – political, national, scientific, local – which surround it. There is a growing awareness, for instance, of the importance of national culture in the imagination and practice of engagement activities (Horst &

Irwin, 2010; Macnaghten & Guivant, 2010), and of the different models of participation and citizenship which are at play within deliberative activities (Felt et al., 2008). The political economies of participation are also starting to be unpicked through attention to both the linear models of technological development which are implicit in talk of 'upstream engagement' (Joly & Kaufmann, 2008) and wider economic and political cultures. Joanne Goven's analysis (2006) of New Zealand's Royal Commission on Genetic Modification emphasises the need for researchers of such processes to look beyond immediate concerns of 'success' or 'failure' to the broader framing impacts of the surrounding political-economic culture and, in particular, neoliberalisation. Goven argues that the concepts – such as 'scientific citizenship' – mobilised in public participation are profoundly influenced by wider political dynamics; similarly, Charles Thorpe has traced the interplay between the turn to public engagement with science in the UK and the co-option of publics within post-Fordist markets (Thorpe, 2010; also Horlick-Jones et al., 2007; Thorpe & Gregory, 2010). Such scholarship is increasingly locating public participation within pervasive, but largely invisible, political dynamics. Noting, as have others, the connections between discourses of public participation and those of the commercialisation of science (Irwin, 2006; Pestre, 2008), Thorpe (2010: 404) writes that:

> public engagement with science and technology should be understood as an aspect of this broader Third Way movement toward 'democratization' as a strategy of governance of, and through, culture. … In particular, public engagement gains its policy rationale from the idea that it is a 'new politics' appropriate to the 'new economy.'

Such work thus continues the task of de-mythologising engagement and of emphasising its contingency. Just as studies of 'process' indicate the fragile, moment by moment construction of deliberative talk (Davies et al., 2006), analyses of the contexts of participation show just how tightly any event or process is entangled with the cultures in which it is situated.

Public Engagement beyond Discourse

While such de-mythologisation is vital in a context which can too often cleave to unrealisable ideals of deliberation (Delgado et al., 2010), what the research described above does *not* do is pay much attention to the non-discursive – to the role of, for instance, the emotional, material or creative within public engagement. It is striking, for instance, that the concerns I have identified in the public engagement literature (of process, effects, framings, and context) are essentially immaterial. They are grounded in the analysis of discourse – of policy documents, interview transcripts, and the talk of public engagement events; and they are concerned with rather abstract entities: institutions, policies, consensus, "institutional body language" (Wynne, 1992). While the accounts they give of the power dynamics of deliberation, or of its entanglement with neoliberal assumptions, are pressing (not least because they are too often ignored or misheard), we are, I think, justified in asking: is there anything else at play within these processes?

My answer to this is yes: as Harvey has outlined (2009), dialogue events are "dramatic and emotional", and their reduction to a series of evaluation criteria (or, we might add, a consensus report or discourse analysis) misses the fact that they are "sites of intense emotion, argument, tension, and humor" (Harvey, 2009: 146) – and, indeed, that these dynamics will shape

their progress and outcomes.[4] Equally, they are *sites*, full of objects and bodies, and they deal with experiences and knowledges (both 'lay' and 'scientific') which are similarly embodied and ordered through material practices. Thus, for instance, they take place in particular kinds of sites and spaces (a shopping centre, conference venue, venerable scientific institution, or café), produce different emotions (indifference, enthusiasm, annoyance, embarrassment, boredom), and deal with very different forms of embodied knowledge (the expertise of the lab scientist, the self-awareness of the patient in pain, the mundane rituals of everyday life in a technological society). These features will surely shape the practice of public participation, and are thereby also worthy of attention.

I want to expand on this point by discussing some recent work in deliberative theory. Before I do this, however, I need to clarify my terms somewhat. I have been using notions such as 'affect' and 'emotion' disingenuously, lumping all non-discursive aspects of interaction together in, more or less, the same pot. My central point is certainly that *all* such non-discursive features and modes are interesting for us as analysts, whether sites, bodies, emotions, aesthetics, or objects. But the disadvantage of this one-pot approach is twofold: it sets up an distinction between 'discourse' and 'the non-discursive' which is too simplistic (Wetherell, 2012); and it occludes very real differences between notions such as affect and emotion (Tomkins, 1962). Many theorists of affect view affect and emotion as fundamentally different processes, with affect the primary, more basic 'pull' between bodies and objects and emotion a more sociologically loaded experience (Massumi, 1995; Sedgewick & Frank, 1995). However, in practice it is often not easy to draw the line between notions such as materiality, embodiment and affect: for Massumi, for example, affect is "irreducibly bodily" (Massumi, 1995: 89), such that the study of affect – what Seigworth and Gregg have described as an 'inventory of shimmers', a discussion of "intensities that pass body to body" (Seigworth & Gregg, 2010: 1) – cannot be separated from the weight of the material world.[5] There are, then, good reasons for accepting that focusing on one of these 'non-discursive' aspects will involve some attention to the others. For the purposes of this discussion I have therefore largely ignored differences between, say, embodiment and materiality, as well as the distinction between affect and emotion, to operate within an deliberately simplified framework which gives scope for my wider point: that practice and analysis in public engagement should go beyond discourse.[6]

It is also important to note that much of this thinking is not new to STS, which as a discipline has been influential in both the material and affective turns in recent social theory (see Bennett, 2009; Bryant et al., 2011; Ingold, 2010; Miller, 2005; Gregg & Seigworth, 2010). STS scholarship has drilled home the importance of materiality in the production of scientific knowledge, and indeed in sociality more generally (Latour, 2000), and has paid attention to the materialities of 'everyday publics' and politics (Braun & Whatmore, 2010; Marres, 2012) and of public engagement with mundane technologies (Michael, 2011). It is therefore surprising that this attention has, by and large, not been further brought to bear on recent moves towards dialogue and deliberation on science[7] – and particularly so when one realises to what extent these concerns have risen to the fore in recent work in deliberative theory.

This literature is relevant because much of the 'deficit to dialogue' move within STS and engagement practice ultimately draws

upon theories of deliberative democracy (see Davies et al., 2006; Elam & Bertilsson, 2003; Hamlett, 2003). Thus Elam and Bertilsson (2003: 241) write, in discussing the turn from PUS to public engagement, that:

> Deliberative democracy also appeals to the scientific community for its commitment to building political decision-making on 'rational consensus' rather than 'mere agreement'. The civilized vision of democratic politics that deliberative democracy supports is one of the unhurried exchange of arguments between reasonable persons guided by the principle of impartiality.

Deliberative theory has, indeed, traditionally espoused the "exchange of arguments between reasonable persons" (ibid). At its most basic it presents a model of democracy which is tied to "accountability and discussion" (Chambers, 2003: 308): it emphasises deliberation over processes of representation and voting (and is thereby readily linked to calls for participatory or direct democracy; see Fiorino, 1990; Hamlett, 2003). Deliberative processes are those in which participants "are amenable to changing their judgments, preferences, and views during the course of their interactions, which involve persuasion rather than coercion, manipulation, or deception" (Dryzek, 2000: 1; see also Cohen, 1989). It therefore brings different – and differing – actors together around a central problem, which they explore and seek consensus (or at least some kind of outcome-oriented endpoint) upon (Chambers, 2003). Deliberative theorists argue that such open, multi-vocal public debate will enable better decision making (Chambers, 2003; Cooke, 2000) and is a more authentic form of democracy (Dryzek, 2000).

There are therefore clear parallels with the way in which public engagement with science has been conceptualised (see, for instance, Rowe & Frewer, 2004). There is, however, one difference. Within deliberative theory this 'ideal type' deliberation has been criticised and, through such critique, taken in a number of new directions. As yet, these later developments have been less well applied within thinking on public participation with science. For scholars such as Iris Marion Young and Lynne Sanders, for instance, deliberative theory's emphasis on reasoned argument is itself anti-democratic. Calls to deliberate, Sanders writes, imply the primacy of "rationality, reserve, cautiousness, quietude, community, selflessness, and universalism" (Sanders, 1997: 348) – connotations "which in fact probably undermine deliberation's democratic claims" (ibid). Young (2001) is similarly concerned with deliberation's hidden entanglements with power, in the shape of its assumption that the power dynamics of wider society can be 'bracketed' within a deliberative process such that equitable argument leads to just, reasonable, and consensus-based decisions. She uses the character of the activist – one who self-consciously rejects the opportunity to participate in deliberative processes, and instead acts on the margins of such processes in order to disrupt and problematise them – as a means of exploring the limitations of deliberation and the constraints in which it is enmeshed. Such limits include the need to operate within established political structures and the inevitable reproduction, within deliberative engagement, of hegemonic discourses. Ultimately, she writes, other modes of interaction are required in order to disrupt these taken-for-granted assumptions about the world:

> Because he [sic] suspects some agreements of masking unjust power relations, the activist believes it is important to continue to challenge these discourses and the deliberative processes that rely on them, and often he must do so by nondiscursive means – pictures, song, poetic imagery, and expressions of mockery and longing performed in rowdy and even playful ways aimed not at commanding assent but disturbing complacency. One of the activist's goals is to make us *wonder* about what we are doing, to rupture a stream of thought rather than weave an argument. (Young, 2001: 687.)

While for Sanders the model of quiet, considered argument implied by deliberative theory unjustly privileges those citizens adept in such interactional techniques (citizens who, as Elam and Bertilsson point out, also fit the model of the good scientist; 2003: 242), Young is more concerned with the limitations of such interaction in exposing hidden ideological commitments. The nondiscursive formats of creative intervention or street theatre, she suggests, are more effective at breaking into "a stream of thought" (Young, 2001). Both Young and Sanders ultimately suggest the value of going beyond reasoned argument to open deliberation up to more diverse forms of interaction: storytelling, for example, or polemic, or Young's "pictures, song, poetic imagery". Reasoned argument, in other words, is *not enough*. Good deliberation should incorporate space for emotional, creative – even disorderly – modes of communication.

Such critiques have been influential, and are increasingly being taken on board by those concerned with the practice of deliberation. John Dryzek's (2000) discussion of deliberative democracy – tellingly titled *Deliberative Democracy and Beyond* – explicitly widens deliberative interactions to include *any* form of communication which is non-coercive[8] and which can connect the particular to the general, while Bächtiger et al. (2010), in a summary of deliberative theory and practice, separate the field into two by distinguishing between that which "embodies the idea of rational discourse" and newer forms which "involve[s] more flexible forms of discourse" (p.33). And in more applied fields, such as urban planning, expectations of what deliberative engagement does and should look like have been radically widened to incorporate not only different forms of discourse but also artistic, dramatic or musical expressions of opinion or perspective (Sandercock, 2003). Within political theory the expectation is thus no longer that deliberation is necessarily the calm, strictly rational activity so attractive to scientists (Elam & Bertilsson, 2003), but a process which is at once more open and more equitable – though perhaps also more chaotic.

These developments have clear implications for public engagement with science. If STS has emphasised that science is inextricably intertwined with the material world and its affective powers (Latour and Weibel, 2005), recent deliberative theory indicates that these dimensions must and should play a key role in public participation. My argument here, then, becomes both normative and practice-oriented as well as analytical. We should not only be *attentive* to non-discursive features of public engagement within our analyses but, as practitioners, actively seek to design participatory processes which enable the expression of knowledges and perspectives in modes which go beyond the discursive. The importance of affect and materiality thus has implications for both the design and analysis of public participation.

I want, in the next section, to briefly treat some of these implications for analysis by considering how we might become attentive to the role of interest and enthusiasm in public engagement with science. Before doing so, however, what might it mean to incorporate knowledges and modes of interaction that go beyond discourse into the *design* of participation and dialogue? While I cannot discuss this question in any detail (see Davies in press for a fuller treatment), there are a number of avenues that we might follow. We could take inspiration, for instance, from the existing work that has been done within deliberative theory. Iris Marion Young's emphasis on the power of the activist and the need for creative disruption (2001), for instance, might lead us to develop an openness to groups and individuals 'breaking in' and messing with our tidy, carefully designed deliberative processes (cf. Michael, 2012; Wehling, 2012). From traditional, public understanding of science-oriented science communication we might search out new formats – such as art-science collaborations (Webster, 2005), object-oriented engagement events (Birchall, 2011), or university and lab open days (Ward et al., 2008) – and explore how these different material and affective configurations might be incorporated into more straightforwardly discursive processes, such as consensus conferences. Or we could build on existing work within STS which has sought to emphasise or communicate affective or aesthetic dimensions of emerging science and technology – projects such as Maja Horst's *Stem Cell NetWork – a Social Science Lab*,[9] which developed an immersive installation within which visitors could reflect on the contingency of scientific knowledge in activities such as game-playing or making themselves 'at home' in a model bedroom; or the UK project *Synthetic Aesthetics*, which investigates "shared and new territory between synthetic biology, art and design" through collaborations between social scientists, biologists, and artist-designers.[10] All of these examples seem likely to help introduce different kinds of knowledge and experience into public participation, or to highlight aspects of science or everyday experience that are often occluded in deliberation. But this is, of course, a topic that requires further thought, experiment, and assessment.

Knowing and Loving: Pleasure in Public Engagement

Thus far I have summarised STS analysis of public engagement with science, arguing that the literature's emphases on process, framings, effects and contexts have tended to focus on the discursive aspects of these practices. I have also suggested, from recent thinking in deliberative theory and the material turn in STS, that aspects such as emotion, site, embodiment and creative intervention will and should be important features of public engagement. If this is the case, how should we go about analysing these dimensions? How, in other words, do we become attentive to the role of materialities, affects, and place in encounters between publics and science?

Again, there is not scope within this article for a programmatic methodology.[11] Instead I want to present a case study of what it might look like to start to notice, and follow, these under-studied aspects of engagement. I will do this by focusing on the idea of pleasure – and, relatedly, enjoyment, delight, or interest – in public engagement with science. I want to make three points: that, firstly, STS scholarship has tended to be suspicious of anything that has emphasised pleasure within engagement, and as a result we have largely elided its expression from our data; that it is in fact

a key way that participants understand public engagement; and that there are at least a couple of lines of thought, drawn from more theoretical accounts of interest and wonder, that might help us think about what its expression means and does. This is, then, not a final analysis, but an exploration of the ways in which we might start to 'rehabilitate' one particular emotion within our analyses. In reflecting on these issues I draw both on a number of previous research studies on the practice of public engagement with science in the UK – work that has included attending formal and informal dialogue events as a participant observer, interviewing (lay and specialist) participants, and talking with practitioners and organisers of deliberative activities (Davies, 2009; 2013a; 2013b) – and on the wider STS literature on engagement.

My starting point is the near invisibility of pleasure or enjoyment as features of extended empirical analysis of public engagement – certainly as a focus of such analysis. This derives, I would suggest, from the affective work that has been done around scientific citizenship over the last decades, and perhaps especially from public engagement's creation narrative of 'deficit to dialogue', which tells of a move from naïve public understanding of science (PUS) to enlightened participatory approaches (Elam & Bertilsson, 2003; Gregory & Lock, 2008). It is possible to read this history in terms of the emotional relations between science and its publics: Jon Turney, for instance, assessed PUS as undergirded by the assumption that "to know science is to love it", writing that "[o]ne of the motives for trying to improve people's understanding of science has been to increase public sympathy for science and scientists, and perhaps give those trying to introduce certain new technologies an easier ride" (Turney, 1998: 3). Here the cognitive ("understanding") is intimately and immediately tied to the affective ("sympathy"). Knowing leads to loving. Good citizens know about science, but that knowledge is not, in itself, the point. Rather, it is viewed as able to mediate love – and thereby emotional ties to science. In the context of the deficit to dialogue narrative, these emotional ties play a particular role: it is this twinning of knowledge and affection that is disrupted by critical social research (for instance, Irwin & Wynne, 1996), leading, ultimately, to new models of science and society and to the contemporary emphasis on participation, dialogue and engagement.

It may seem, then, that the drive to inculcate love has been elided from scientific citizenship with the move to public participation and dialogue. But closer inspection reveals that new models of scientific citizenship also entail particular affective configurations. Indeed, I would suggest that modelling the good citizen as participant involves a simultaneous purging of emotion, through deliberative democracy's emphasis on reasoned argument, with an infusion of new affections, such as trust, confidence, and excitement. Thus on the one hand we have the influence (as discussed in the previous section) of theories of deliberation which view the good citizen as unbiased, reasoned, and measured. Elam and Bertilsson (2003: 244) write that:

> Just as passion and outrage were necessarily absent from science according to the traditional Enlightenment model of science and society relations, so they can end up being rendered alien to the exercise of scientific citizenship by the alliance of PES with deliberative democracy. In the latter context, passion and outrage become not only threats to Truth, but also to the achievement of a Fair and Just scientific democracy.

"Passion and outrage" are thereby excluded from scientific citizenship, which is framed as centring on participation in deliberative processes (the good citizen is now the one who participates, rather than the one who knows; the one who participates is cool, reasoned, unemotional). At the same time, however, it is clear that much of the flurry of interest in engagement which took place in the early 2000s in the UK was carried out with the expectation of increasing public trust (Wynne, 2006). Thorpe and Gregory, for instance, note:

> That the affective condition of confidence is the desired outcome of participatory activity is repeated throughout British government statements on the topic … Such statements, understood in the broader policy context in which they are situated, suggest that public engagement is being constructed as a technique for producing the public confidence regarded as essential to the stability of the 'innovation system'. (Thorpe & Gregory, 2010: 286)

Here, then, publics are instilled with trust and confidence in science through participation: as Thorpe and Gregory (2010) suggest, "participatory activity" is fundamentally about ensuring an "affective condition of confidence". We might therefore understand contemporary scientific citizenship, as it is produced within the drive for public engagement, as a hybrid of two configurations: the passionless deliberator and the passionate enthusiast. As such, we find citizens who participate in order to love, and a citizenship in which engagement inculcates the habits and desires of the scientific mind.

It is perhaps not surprising, then, that expressions of interest and pleasure within public engagement have been viewed with some suspicion within STS: are they simply a sign that lay participants are in some way complicit in the deficit model, and have capitulated to the cultural superiority of science? My second point is that this hesitation – this sense that public (and scientific) pleasure in science must be linked to uncritical submission to scientific hegemony – has led to a bracketing of these emotions within analyses of public engagement. This is despite the frequent citation of enjoyment or pleasure by those who participate in engagement activities as both motivation and reward for such participation (Besley et al., 2012; Martin-Sempere et al., 2008; Pearson, 1997; Rowe et al., 2010; Simonsson, 2006; Wilkinson et al., 2011). For instance, during my empirical research I have found that entertainment is implicit in the framing of informal public engagement, with organisers striving to design events which laypeople will, above all, *attend*, and ideally enjoy; that enjoyment is constantly cited by audiences and participants as a key feature of their experience (with interviews with these actors, at public engagement events or deliberative processes, almost invariably starting with some variation of: 'it's really good, I'm enjoying it'); and that the necessity of pleasurable affects is articulated with normative passion by communicators who argue not just that they know what their audiences want but that science-as-leisure can have profound effects on participants. Delight, interest, enthusiasm, and pleasure all leave their traces on the practice of public engagement (see also Pearson, 1997; Rowe et al., 2010; Simonsson, 2006; Wilkinson et al., 2011) – even those forms, such as consensus conferences, which are more formal, perhaps drier, in nature (Powell et al., 2011). It is worth, I think, running the risk of labouring this point. People (whether scientists or laypeople) generally participate in public engagement because they want to – because they find

some satisfaction or enjoyment in talking about nanotechnology at a museum forum event, experiencing the spectacle of the Body Worlds exhibitions, or participating in a policy-oriented discussion. There is, we might say, a hedonism of science as leisure and pleasure, and it is this latent and largely unacknowledged reservoir of emotion that powers many of the encounters between scientific knowledges and publics.

Certainly, the critical accounts outlined above describe one dynamic – the shaping of supportive, uncritical citizens – in which these positive affects are implicated (Thorpe & Gregory, 2010). The production of trust has been, and continues to be, an underlying (if not always acknowledged) motivation for some scientific and policy enthusiasm for engagement (Irwin et al., 2013; Wynne, 2006). Many scientists do think that interested publics will like science better, and become a more accepting market for its products (or perhaps be recruited into it; Besley et al., 2012; Davies, 2008). But is this dynamic the only one structuring expressions of interest, pleasure and delight? Can we understand them in any other terms?

I would suggest that pleasure in public engagement is indeed a more complex phenomenon – one that requires further attention in order to account for and understand its role and meaning within (different kinds of) engagement activity. I would like to briefly offer up two lines of thought which might help us start to do this – two potential vehicles for 'following' pleasure in public engagement, and which may act as thought-experiments with which to start to interrogate its affordances and effects. The first is taken from Isabelle Stengers' notion of the need to 'relearn' laughter (2000). In an essay concerned with how to criticise (or, better, *intervene* in) power – specifically, the power of "Science, Reason, Objectivity" (Stengers, 2000: 53) – without becoming ensnared within the very structures such power assumes, Stengers introduces the value of laughter. The injustices of power, she says, readily bring us to angry, serious denunciations – to critiques that run the risk that "one might accept the terms of the problem as they have been defined" (Stengers, 2000: 42). Laughter disrupts these relations: it stands outside, calling attention to the fictions which attend scientific truth claims (cf. Young, 2001). As such, she dreams of publics who will:

> recognize and laugh at those [scientific] productions whose aim is to fascinate, to subordinate, or to win us over. This would obviously not suppress power relations. But it would *complicate speculation*. It would impose new constraints and multiply the risks for speculative scientists. It would at least destroy the appearance of neutral rationality used as a blind whenever there is a question of addressing the "incompetents." (Stengers, 2000: 51; italics in original)

Importantly, this laughter, though "mocking", is not simply derisive. Stengers emphasises the value of the *interest* of scientists, and is appreciative of its productions – but she is concerned that we do not take these productions too seriously. It is vital, she writes, that "we cease to be easily impressed" (p.51).

For Stengers, then, interest twinned with laughter can disrupt power relations, complicating the claims technoscience makes for itself and for its products (its 'speculations'). It is precisely when science is *not* taken too seriously that engagement with it becomes powerful: the combination of appreciative interest and humour enables the unpicking of the work that goes into the production of facts or promises and allows fun to be poked at whatever is grandiose and

dictatorial (whether on the side of science or its "cohort of denunciators"; p.42). Perhaps, then, something along these lines may happen within public engagement – specifically that which emphasises entertainment, interest, and enjoyment. Perhaps – we might speculate – expressions of light-hearted pleasure open up space for an equally light-hearted negotiation of scientific claims. And in this regard we might draw a line to analysis of one experiment mentioned earlier: Maja Horst's dialogically-oriented public installation on stem cell research (Horst, 2011). A key outcome of this was exactly a public disregard for the solemnnities of dialogue, and a disruption of anticipated outcomes (Horst & Michael, 2011). As in this example, respect for the humour of engagement may help us identify unexpected patternings of power.

Jane Bennett (2001) is also interested in the effects of a disposition of light-heartedness. Specifically, she is concerned with the ethical potential of enchantment, arguing that, firstly, the grand, Weberian narrative of a disenchanted modernity ignores pockets and streams of enchantment within modern life; and, secondly, that such moments of enchantment can give rise to the ethical work of generosity and grace. It is important, she writes, to:

> heighten awareness of our profound – and empowering – attachment to life. For such attentiveness can help transform shock at tragedy into a political will to reform painful social structures. … My own sense is that the ethical and political potential within suffering is more likely to be realized if one's attention to suffering is infused by or remixed with the en-couraging [sic] experience of wonder. (Bennett, 2001: 160)

Thus, for Bennett, a state of enchantment can be a gateway to emancipatory action, providing "energy and inspiration" that enables individuals to, for instance, "enact ecological projects, or to contest ugly and unjust modes of commercialization" (Bennett, 2001: 174). She identifies a range of sites of such enchantment, including cross-species encounters, Thoreau's Nature, and advertising campaigns; of most relevance to this discussion, however, is her interest in both the natural world – as it is revealed by "scientific practices and instruments" (Bennett, 2001: 171) – and technological artefacts such as computers, which can similarly "provoke wonder, surprise, and disorientation". Here wonder and delight can in and of themselves be an ethical good, opening the possibility of generosity to others (both human and nonhuman). For Bennett, then, lay exploration of robot pets or nanotechnology may provoke broader results than those encapsulated in science policy decisions or consensus reports, instead acting – at least potentially – to cultivate dispositions of generosity and ethical action. In her view delight in technoscience need not be automatically harnessed to neoliberalism and the cultural authority of science. Wonder may develop, in its participants, new sensitivities to tragedy and suffering. Again, it is helpful to point to concrete examples where this (may) be happening. The artist and academic Oron Catts, for instance, who runs the SymbioticA laboratory,[12] has carried out a number of projects using tissue culture techniques, from creating a jacket of 'victimless leather' to collecting contemporary biological curiosities. These projects have the potential to fascinate and revolt in equal measure; they compel the viewer, but also force the opening up of new lines of ethical thought (what counts as life? How should we treat living stuff?). We might speculate that they induce wonder – but a

wonder that disrupts rather than pacifies taken-for-granted assumptions, and which thereby energises the possibility of new modes of action around contemporary biological citizenship.

The lines of thought suggested by the work of Stengers and Bennett are, in part at least, empirical questions, dependent on the exact contours of pleasure within science-in-engagement.[13] Once we have understood a little more of the pleasures of public participation – what is it, exactly, that provokes interest and enjoyment? How are these emotions expressed or suppressed? – we may be able to speak more of its powers and effects. My point has thus not been to offer a categorical analysis of pleasure and delight in public engagement, but to illustrate the kinds of directions that being attentive to such emotions may take us in. Nor is my emphasis on these positive affects the only direction possible: as Harvey (2009) has noted, public participation may also be marked by more negative dynamics, such as frustration, rage, and humiliation. Following these – and other non-discursive aspects such the 'heaviness' of public engagement, its loadedness with sites and objects and stuff – is just as important as the need for a better understanding of pleasure and delight that I have pointed to here.

Conclusion

My aim in this article has been to provoke thought around what I have identified as a lacuna in the literature on public engagement with science. I have argued that STS analysis of public participation and engagement has tended to construe these practices as fundamentally discursive, and thus to render invisible the role of non-discursive aspects, such as the material and affective, within them. In reflecting on this I have presented an overview of the literature on public engagement (noting that this has tended to explore the process, effects, framing or contexts of participation); discussed thinking from political theory which points to the importance of going beyond 'reasoned argument' within deliberation; and started to explore what it might look like to notice, and take seriously, public expressions of delight and interest in science within public engagement activities. While I inevitably have not done justice to the literatures on affect, materiality, and political theory that I have gestured to, and have used deliberately simplified outlines of their concepts, I hope I have shown that they offer productive lines of thought for the study of public engagement. My intention has been to build on the substantial body of knowledge STS has developed around public participation, and to suggest some new directions this scholarship might take. As such I have begun to outline, very sketchily, some possibilities for both empirical research and the practice of public engagement. Normatively – I have argued – we should try to incorporate the emotional, creative, aesthetic and embodied into our engagement practices; whilst empirically we need to be better at analysing these aspects of the processes we study.

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Sarah R. Davies
Institut for Medier, Erkendelse og Formidling
Det Humanistiske Fakultet
Københavns Universitet
Karen Blixens Vej 4, DK-2300, København S
dxq327@hum.ku.dk

Notes

1 In this article I use the terms 'discursive' and 'non-discursive' to refer to 'language in use' (or not). This is the sense in which they are used in linguistics and the types of discourse analysis primarily influenced by it (see Cameron 2001), and should be differentiated from other, broader understanding of the discursive, in which discourses are not necessarily tied to language (Fairclough 2003).

2 Throughout this paper I treat the terms public engagement with science, public participation, and dialogue as effective cognates. Though it is possible to parse out differences between them (and indeed between different practices which use the same nomenclature), there has been a *general* move towards the use of participatory and deliberative techniques which has impacted, for instance, science policy, STS, and science communication. See discussions in Delgado et al. (2010), Hagendijk and Irwin (2006), Lehr et al. (2007) and Lengwiler (2008).

3 I focus on the European – and more specifically the UK – context in this paper, though similar developments are occurring in the US (Bonney et al., 2009).

4 One of the reviewers pointed out that dialogue events are not neccessarily "dramatic and emotional", but may also be rather dry and mundane. While this is certainly the case, it is worth bearing in mind that the dryest event still has performative and dramaturgical aspects (Hilgartner, 2000) – and that boredom, *ennui* and the quotidien have affective as well as discursive dimensions.

5 In addition, the affect/emotion distinction is itself not unproblematic and has been subject to much debate. See Leys (2011) for one STS-inflected critique and Wetherell (2012) for a helpful overview.

6 Though, as the paper progresses, it will become clear that my interest in the case study of the role of pleasure in public engagement that I begin to

work through is primarily with emotion rather than with the more subtle workings of affect.

7 The key exception being Marres' work on 'material participation' (2009; 2012). However, Marres explicitly focuses on forms of participation that are overtly and deliberately oriented towards innovative material configurations, such as smart meters and other 'green living' experiments in the home; she is interested in efforts to "locate public engagement with environmental issues in everyday material practice" (Marres, 2012: 3). This is slightly different to the analysis of science communication and policy-oriented deliberation where materiality, both as explicit subject matter and implicit configuration, has been rendered invisible.

8 A position which can itself, of course, be critiqued: are any interactions truly free from coercion (Mouffe, 2002)?

9 See http://www.stamcellenetvaerket.dk/eng-installation1.htm

10 http://syntheticaesthetics.org/about

11 Though there are again some obvious avenues to follow, including asking: what different materialities are implicated in different forms of participation? What emotions do participants report? What role do nonhuman actants play in co-constructing the outcomes of deliberation? Methodological traditions from both STS (for instance, lab ethnographies) and social psychology (which is increasingly turning its attention to the study of 'affective practices'; Wetherell, 2012) offer additional lines of thought.

12 See http://www.symbiotica.uwa.edu.au and http://tcaproject.org

13 They also require further contextualisation and theorisation. Both lines of thought are sketches, only, and would benefit from further development. One reviewer made the point, for example, that both can be situated within longer traditions: of the 'idiot' or fool, in the case of Stenger's interest in laughter (cf Michael 2012); and of the sublime, in the case of Bennett's analysis (see Nye, 1996). We might also look to the long history of notions of beauty, elegance and love within scientific practice, from Poincaré's comments that "The scientist does not study nature because it is useful to do so. He studies it because he takes pleasure in it, and he takes pleasure in it because it is beautiful. If nature were not beautiful it would not be worth knowing, and life would not be worth living" to Graham Farmelo's book *It must be beautiful* (2003), which argues for the essential elegance of important scientific equations.

Trevor Pinch and Karin Bijsterveld. The Oxford Sound Studies Handbook. New York: Oxford University Press. 2012. 593 pages.

In recent years there has been a concerted effort to establish sound as an object of interdisciplinary concern. Trevor Pinch and Karin Bijstervelds' (2012) 'Oxford Sound Studies Handbook' finds good company among other contemporary, and similarly weighty, edited collections on the study of sound (Bull and Back, 2003; Bull, 2013; Sterne, 2012) but is distinctive for its attempt to stake a place for STS within this expanding field. The handbook demonstrates some of the ways in which STS can be 'applied' in another interdisciplinary field of research and also offers some interesting provocations about how sound studies can expand and open new horizons for the social study of science and technology. At the heart of the new directions for STS research offered in the handbook is a renewed focus on the study of the senses, specifically the role of listening in processes of knowledge production and the social-technical mediation of auditory perception.

Pinch and Bijstervelds' handbook is incredibly diverse in scope, bringing together fields as broad as musicology, the history of the senses, film studies, the anthropology of medicine, engineering studies and media arts to name a few. The chapters of the book take readers on a journey through some of the variety in contemporary sound studies, showcasing very different kinds of socio-technical relations that are produced through sonic phenomena. Some of the handbook's stand out chapters include an aural history of industrialisation centred on US female factory workers (Smith), an immersive anthropology of underwater music composition (Helmreich), a technical history of early scientific field recordings in ornithology (Bruyninckx), a cultural meeting between Kafka and Florence Nightingale in hospital sound design (Schwartz), and a discussion of sonification and media theory based on simulations of the 19th century phonautograph writer (Sterne and Akiyama). More a celebration at the carnival of sound than a sober stock-taking exercise, Pinch and Bijstervelds' handbook is bold for the sheer range of disciplinary and theoretical interests, methodological approaches and analytical lenses it offers on the study of sound. The handbook demonstrates both the interdisciplinary promise of sound studies to traverse social worlds and bring together varied socio-technical concerns, while also making an important statement of intent for new directions in STS research.

In the handbook's introduction Pinch and Bijsterveld outline what they consider to be STS's original contribution to sound studies. In a fast-moving and somewhat panoptic account of the field, the authors propose that science, technology and medicine provide the "keys to unlock the worlds of sound". The distinctive contribution of STS to the field, the authors claim, lies in accounting for the material mediations of sound. Sound is not simply experienced sensorially, Pinch and Bijsterveld argue, but is also materially mediated by machines and, as such, appears increasingly "thinglike".

Demonstrating their case, the authors' open their introduction with a discussion of the Sound Ear: an ear-shaped device used in Swedish classrooms designed to maintain discipline by visualising noise levels. Attempting to expand the dominant orientation in sound studies on the sensory experience of sound, Pinch and Bijsterveld's discussion of the Sound Ear demonstrates the argument they pursue throughout this introduction that the 'sensing' of sound is mediated and technical. If we are serious about sensing sound, they suggest, we need to be attentive to the things that mediate our sonic perceptions and the sonic "skills" required by different fields of practice. The authors draw attention to what they describe as the increasingly technical character of sound capture, storage and reproduction. Innovations in science, technology and medicine, Pinch and Bijsterveld argue, both create new kinds of sound and dramatically transform the ways in which societies relate to sound. The contemporary study of sound, then, has to confront the machines, devices and technical infrastructures through which sound is mediated and for this reason, they suggest, STS is well placed to bring its resources to bear on the field of sound studies.

In Pinch and Bijstervelds' account, sound studies does not simply provide a new arena into which STS can expand. Rather, they suggest, sound studies also offers the prospect of developing new forms of attentiveness to the ways in which the relations between science, technology and culture are negotiated and produced. Pinch and Bijsterveld propose that sound offers STS researchers the opportunity to examine some of their "visual" biases; empirical science studies, they suggest, has often focused on the visual practices of science at the expense of auditory and other sensory practices. Where empirical science studies have attempted to move beyond idealised notions of science, Pinch and Bijsterveld suggest that accounts of scientific practice that focus on modes of "representation", data visualisation, and in "inscription devices" have often unwittingly reproduced a visual-centric bias that is particular to Western culture. Through an engagement with sound studies, they argue, STS stands to gain an attentiveness to the multiple sensory modes of technical practice. A further theme of STS research that might be developed through sound studies, Pinch and Bijsterveld suggest, is its theories of materiality. By following the ways in which sound is "transduced" from one medium to another, STS has the potential to develop its accounts of the materiality of mediation. Being attentive to the often "unintentional" sounds of the technological developments in advanced industrial societies (Bijsterveld, 2008), STS can find new ways to approach the study of inventive practice and technological innovation. In the handbook, then, Pinch and Bijsterveld make the case for something of a mutual exchange between sound studies and STS in which the engagement of these two fields enhances and expands the outlooks of both.

In its stated ambitions to unsettle some of the concepts most often applied in the social study of science and technology, Pinch and Bijstervelds' handbook gestures beyond the conventions of a publication format which would typically introduce rather than invent. That said, STS readers are likely to find the authors' introductory claims, for instance that notions of "transduction" might fruitfully expand an STS repertoire, more as signposts for further exploration than decisive interventions. Nonetheless, such provocations make apparent that there is potentially a very large can of STS worms that Pinch and Bijsterveld's approach to the study of sound might open. Specifically, the authors'

decision to foreground sensory perception as the locus of engagement between sound studies and STS inevitably raises some of the latter's longstanding concerns, not least because the senses occupy a somewhat 'foundational' position in epistemological discourse. For the most part, the handbook largely sidesteps traditional philosophical treatments of the senses, and perhaps with good cause since dragging in such weighty baggage would somewhat narrow and dampen the wide-ranging scope of the volume. However, as some of the contributions (particularly Bruyninckx and Sterne and Akiyama's) suggest, such sidestepping also comes with some risks. First, the framing of the turn to sound through the critique of the dominance of the visual in Western culture, though popular in sound studies, can easily slide into a lazy form of sensory essentialism. As Tim Ingold (2000; see also Ihde, 2007; Sterne, 2003) persuasively demonstrates, the novelty of auditory studies has all too often been established by making a straw-man of 'the visual'; the study of sound, Ingold argues, has relied too heavily on contrasting a visual modality that "objectifies" and an auditory modality that "personifies"[1]. Second, and relatedly, foregrounding the senses treads a fine line between positioning sensation as the object of investigation in its distributed and socio-technical forms, and, conversely, slipping back into certain asymmetric human-centred approaches that STS research has long critiqued (Latour, 1993). However, such risks, Pinch and Bijstervelds' approach suggests, are not simply pitfalls to be avoided – the authors' careful discussion of the Sound Ear in Swedish classrooms is in this respect exemplary – but rather opportunities to explore the relations between sensory perception and technical mediation. The study of sound, the authors argue, holds the promise of reframing some of the longstanding problematics that have occupied the social study of science and technology.

To this end, Pinch and Bijsterveld's handbook demonstrates why an STS engagement with sound studies has the potential to be highly productive. The handbook presents a wealth of frontiers in the study of sound that offer STS new empirical objects of study and from which STS might expand on its existing stock of theories and concepts. Bringing a fresh approach to the study of the senses, Pinch and Bijstervelds' book is both important and provocative for those researching the relations between science, technology and culture.

Notes

1 As Ihde highlights, the turn to the auditory as a counterpoint to the visual is itself part of a long-standing tradition in Western culture rather than being antithetical to it.

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Laurie Waller
Sociology Department
Goldsmiths, University of London
New Cross, London, SE14 6NW, UK
l.waller@gold.ac.uk

Steve Woolgar and Daniel Neyland. Mundane Governance: Ontology and Accountability. Oxford University Press: Oxford, UK 2013. 282 pages.

How do processes and practices of governance and accountability operate in connection with mundane activities such as recycling, driving, and passing through airport security, and especially with the objects and technologies implicated in those mundane activities? This is the question addressed in this interesting book, which sets out to argue that 'STS inclined re-conceptualizations of objects and technology can offer new understandings of the nature and practice of governance' (p. 3). In particular, the book argues for the fruitfulness of a particular form of ontologically-focused and ethnomethodologically-informed STS. Both these aims are addressed through considering empirical material gathered between 2004 and 2006 at a remarkable number of field sites where the mundane domains of traffic, recycling/waste management, and airports are enacted. The rich descriptions of these varied field sites, which are satisfying and abundant, are a core pleasure of the book for the reader. It is fascinating to see inside sites with which we are thoroughly familiar but rarely think about: the work of authorities determining where to put speed cameras, and at what speed to issue infringement tickets; airport managers trying to figure out how to induce passengers to remove all sharp objects and liquids from their persons prior to security so that they have more time to spend in airport shops; and local government teams wondering about citizens' recycling practices.

Governance has attracted increasing analytic attention in recent years, notably accounting for an entire theme at EASST 2014 (governance in practice). Woolgar and Neyland stake their claims to novelty in focusing on governance in mundane settings, which are often overlooked, and in bringing to bear a number of classic and more recent ideas from STS. The focus here is on how governance is constituted in action, and they argue that a good way to investigate this question is to look for relations of accountability – who is accountable to whom, when, and how this relation is constituted in practice. Accountability is understood in an ethnomethodological sense, as a making available for mutual interrogation as part of a joint sense-making endeavour. This is an approach which emphasises meaning making's moment by moment achievement. The authors are particularly interested in how mundane objects and technologies might figure in these relations of accountability, and argue that most studies of governance tend to overlook this question. One term they introduce in their attempts to rectify this oversight is that of a 'governance pair', referring to a pair of entities (household/recycling box, car/driver, plane passenger/'sharp' objects) that are made to hold together in order to be accountable, or fail to hold together and hence prevent accountability relations and therefore governance (biometric data in an ID card trial/human body to which it should correspond).

In line with the authors' desire to demonstrate the usefulness of STS to a study of the practices of governance, a number of familiar STS themes are prominent. Demonstrating the labour required to achieve, or in their preferred term constitute, the world and its entities is emphasised throughout the book; the particular way in which they conceptualise constitution will be discussed in more detail later. A second familiar theme is that of messiness. The first five chapters are chiefly focused on demonstrating the messiness of governance-in-action through stories of their fieldwork, juxtaposed with narratives of governance as straightforward, provided by theorists of other persuasions (mostly management/organisation theorists and neo-Foucauldians such as Nikolas Rose) and also by certain actors in their field sites (the Handbook for speed camera partnerships, for example, and the management consultancy which produced it). The status of 'structure' or 'context' as requiring explanation, rather than being a mechanism of explanation, is also emphasised. Other STS themes that appear more briefly include the role of classification in constituting the world as it is (chapter 3), the role of evidence-making in constituting entities as-they-are (chapter 4) and the need for ongoing repair to these classifications (chapter 4). Spaces (of governance) as constituted in practice are also given a chapter, although the authors do not engage with other STS-influenced work on space, preferring instead to refer to Foucauldian and ethnomethodological influences.

The main theoretical point that the authors seek to make throughout the book, however, and key to their aim to evaluate different aspects of STS for their utility in understanding governance, is a focus on the 'ontological constitution' of the people and objects involved in relations of accountability and governance in their field sites. This focus is framed as a shift away from epistemology and 'traditional' ontology (such as in the natural sciences, studying what is), to studying 'when, where and how objects and technologies are 'achieved', that is, how they are apprehended and experienced' (p. 17). For Woolgar and Neyland, the process of ontological constitution is about how an entity comes to have and maintain a certain ontological status, how it (temporarily) comes 'to possess certain properties or characteristics' (p. 38). For them, the ontology of an object is about property-having, rather than about how it acts in a particular situation; it is not relational. Some entities are constituted as ontologically uncertain and may turn out not to be as they appear, such as a letter which may turn out to be a bomb, or a water bottle that turns out to be a terror object in virtue of its path through the airport.

This focus on ontological constitution provides a useful framework for a detailed analysis of the workings of their field sites, and draws attention to practices and their ephemeral constitutions of entities. The ontological constitution of entities is generally said to lead to the enactment of particular governance and accountability relations, but at times it is said to work the other way, and ontologies are constituted by governance relations; the authors comment that neither version quite captures what they mean to say.

A nice aspect of the term 'ontological constitution' is the insistence that moral order and what they call 'action-ability', the possibilities for action and appropriate actions that the entity supports, are all rendered as part of this process of constitution, rather than as occurring afterwards. The means by which constitution is described as occurring are, however, largely social, such as the decisions made by households about

what to put in their recycling box and by drivers about whether to slow down for a speed camera, the conversations and disagreements between council workers, and the leaflets and notice boards that attempt to induce a separation between air passengers and their water bottles and 'sharps'. In the stories these authors tell, the actions through which ontological constitution occurs are primarily human actions.

The authors note early on that an approach which has ontology as achieved implies that the distinction between human and non-human is itself constituted, and that this constitution enacts a profound politics (p. 52–3), a point also made by Donna Haraway (1997, for example) and Helen Verran (2001), among others. I would have liked this observation to have been taken further, but it seems to have 'gotten lost' in the work of studying ontological constitutions through the actions of humans, and as apprehension and sense-making. These concerns pull towards a divide between those entities which make sense (humans), and those which do not. Woolgar and Neyland reject 'material' approaches to analysis which *begin* with an assumption that agency in a given setting may lie with any of the entities, human or not. They argue that 'current emphases on materiality tend to bestow entities with a form of agency, which distracts from an investigation of how entities get to be material in the first place' (footnote 11, p. 37).

This book attempts to balance the interests of two rather distinct audiences: readers interested in governance and accountability who are assumed as in need of being convinced of the utility of STS analysis; and an STS audience whom they wish to convince of the fruitfulness of their particular conception of ontological constitution, and methodological and theoretical approaches. This is a difficult task and the needs of the first audience are more comprehensively met.

So what are the 'take home messages' for an STS audience? The authors are of the opinion that an analytic frame of ontological enactment requires further elaboration. An obvious response to this would be to ask why then did they not more fully engage with the work of other contemporary analysts working on this elaboration. Yet, readers must agree they have provided much food for thought. In particular I would recommend this book to junior STS scholars, because of its helpful reiteration of classic STS themes, the nice way that the authors weave together analysis and empirical material, and the methodologically interesting discussion in the final chapter of how they shaped their text.

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Alison Marlin
History and Philosophy of Science
University of Melbourne
amarlin@student.unimelb.edu.au

Hallam Stevens: Life Out of Sequence: A Data-Driven History of Bioinformatics. University of Chicago Press: Chicago, Illinois, 2013. 294 pages.

Life Out of Sequence investigates intersections of biology, physics, and computer science to offer an account of the historically recent emergence of bioinformatics as a scientific discipline. Stevens draws from his field work at the Broad Institute in Cambridge, Massachusetts as well as interviews and archival research to investigate the dynamic relationship between biology and computing technologies, both the epistemological space which computers responded to, and how knowledge paradigms shifted once computers began to be integrated in the laboratory. Stevens makes it clear from the outset that he is not offering a technologically determinist analysis of computers in biology. His argument, rather, focuses less on the machines that go "ding" and more on the types of research questions and knowledge production mechanisms that these machines both afford and constrain. He looks at how biology *shaped* and is *shaped by* computing technologies.

Life Out of Sequence is organised by a concern for the movements of different types of objects (including data, laboratory workers, "wet ware," and other laboratory technologies) and the spaces through which these objects move (physical and virtual). This creates an engaging organisation that mirrors how knowledge circulates and is produced and reproduced in these spaces. Oscillating between ethnographic accounts and archival research, we learn about the physical organisation of laboratories, especially at the Broad Institute. Readers see how this physical organisation of laboratory space reproduces divisions of labour, centralising and privileging some types of work as "real science" and casting others as more menial tasks. Similarly, we learn about ongoing difficulties in balancing the need for bigger experiments, bigger laboratories, more interdisciplinary teams, and the perceived need to defend traditional knowledge making forms. This physical organisation and growing needs of the biological laboratory translates into interdisciplinary tensions, where traditional biologists seem to carry a burden to defend their traditional forms of knowledge production as "real science." As a result, the "real scientists," we are told, tend to control knowledge production in these interdisciplinary laboratories. The tension within interdisciplinary teams goes beyond interpersonal communication; it stems from differences in what is viewed as legitimate means of knowledge production. To illustrate the stark differences in knowledge production, Stevens offers us a compelling direct comparison of two projects interested in alternative splicing: one conducted by a biologist, and the other a computer scientist. In two short anecdotes telling of the work of graduate students in these intersecting fields, and we learn how they would proceed with their investigations. The difference between the two visions of knowledge production lies in their approach to data: the biologist is more concerned with "wet ware" and specific

cases, whereas the computer scientist looks for ways to crunch as much data as possible, as quickly as possible.

In describing how spatial organisation relates to this restructuring of biological knowledge production, Stevens focuses on ethnographic field notes taken at the Broad Institute in Cambridge. He uses front/back and central/periphery orientations to describe how laboratory space at the Broad is organised in order to present an image of "real" biology. In addition, this configuration of scientific labour brings in issues of control and surveillance. Using before-and-after diagrams and scenarios, readers are shown how the laboratories at the Broad were run using notions of lean management, which was borrowed from industrial management. This type of management places values on speed and efficiency, much like factory production lines. In this model, teamwork and productivity are favoured over individual intelligence and innovation.

Following this description of the order of physical laboratory space, three chapters offer a description of the organisation of virtual spaces. Stevens' primary critique in this section focuses on the pipeline metaphor of computation, which presents the movement of information as passive flows from genome to hard drive. This pipeline metaphor, he argues, glosses over the effects of human choice in informational systems, tools, annotations, and gene ontologies, "flattening" messy data into "universal" data. More specifically, the movement of data into virtual spaces creates a linguistic problem; ontologies applied to this data create a particular way of viewing biology, and constraining ways of talking and acting within the biological sciences. A change in the language used to describe the data results in a change in what one can do with the data.

To historicise the development of genomic databases, Stevens offers a side-by-side discussion of Margaret O. Dayhoff's development of the *Atlas of Protein Sequence and Structure* (Dayhoff & Richard, 1968) and Walter Goad's collection efforts at Los Alamos. Dayhoff and Goad were the two primary candidates for the creating a genomic database for the National Institute of Health (NIH), with Goad ultimately receiving the funding. Stevens offers a compelling argument on how Dayhoff may have been less favoured than Goad because her efforts were understood as "mere collection and compilation" and not as a real contribution to the systematisation of biological thought. Goad's GenBank, on the other hand, proposed a "flat file" structure for the database that appealed greatly to the NIH. Using the GenBank flat file as an example, Stevens ultimately argues in these chapters that the flattening of biological information into easily transportable entities not only obscures human judgement that is part of the digitisation process, but also creates a particular landscape for particular kinds of biological action. In short, the movement of biological information pre-determines what is considered legitimate biological knowledge. Stevens does not, however, go as far as explaining exactly how gene ontologies and gene databases structure biological knowledge.

Using ethnographic and archival research of physical and virtual lab spaces, Stevens offers a way of seeing computers in the laboratory as they directly influence organisation, labour, surveillance, data collection, and knowledge production in the name of biology. Throughout this text, Stevens explains the technical concepts necessary to follow the arguments he puts forth, making the text very accessible for readers with different levels of familiarity with bioinformatics. However, despite

Stevens' clear and explicitly stated intentions of not following a technologically determinist thinking, Stevens seems to uncritically distinguish between "the digital" and "the biological," or "data" and "nature." To a certain degree, this distinction seems necessary in order to support Stevens' arguments, however he does not provide any lengthy account of how this distinction is made. This single criticism aside, Stevens follows in the tradition of Latour and Woolgar's (1979) *Laboratory Life* to bring an updated account of the circulation of knowledge in biological spaces. Stevens' work provides a compelling and insightful analysis of the changing role of data in biology, and shifting ways of knowing with increasingly interdisciplinary work centred around computing technologies. It is a crucial new read for STS researchers interested in engaging in interdisciplinary research on emerging science and technologies.

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Molly Hartzog
Communication, Rhetoric, and Digital Media
Genetic Engineering and Society
North Carolina State University
Ricks Hall, Box #7579
Raleigh, NC 27695
mshartzo@ncsu.edu

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