Governing infrastructure networks for a low carbon economy

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GOVERNING INFRASTRUCTURE NETWORKS FOR A LOW CARBON ECONOMY: CO-EVOLUTION OF TECHNOLOGIES AND INSTITUTIONS IN UK ELECTRICITY DISTRIBUTION NETWORKS

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Abstract

This paper analyses efforts to promote innovation in the UK energy networks sector. Using a case study approach, we chart the co-evolution between technologies and institutions in electricity distribution networks since the introduction of privatization and market liberalization over twenty years ago. It is observed that as a result of macro level institutional dynamics, innovation has become an increasingly important policy and regulatory goal. However, efforts to promote radical and architectural innovation, such as the transition to a smart grid, face significant barriers at the firm and sector levels. It is argued that changes are required to the formal and informal institutions which govern the sector in order to promote a more coherent relationship between technological and institutional change, leading to a productive innovation system which allows firms to collaborate across the electricity value chain and develop inter-firm/cross sector innovation partnerships.

Keywords: co-evolution; electricity distribution; innovation systems; smart grid; socio-technical transitions

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1. INTRODUCTION

In recent years there has been a growing interest both within academic and policy arenas in the issue of how to restructure socio-technical systems, such as energy, water and transport, for the long term transition to a low carbon economy (Kern and Smith, 2008). As a consequence, efforts to understand the complex dynamics of socio-technical transitions has seen the emergence of a body of literature known as transitions theory which has attracted significant attention (Smith, Voß et al., 2010). However, as a recent special issue of the '*Technological Forecasting and Social Change*' journal points out, transitions research has paid little attention to the specific case of innovation processes in infrastructure networks and their relevance to broader transition processes (Loorbach, Frantzeskaki et al., 2010). It has also been argued that such systems and transitions perspectives adopt a structuralist conceptualisation of change and are thus poor at identifying specific causal mechanisms (Stenzel and Frenzel, 2008). By drawing from the literature on the co-evolution between technologies and institutions, this paper seeks to explore innovation processes specifically within electricity networks. Our primary focus is on the interplay between technical and institutional change in the UK electricity distribution networks, and what lessons can be learned for the overall transition to a 'Smart Grid'.

Like many developed countries, the UK electricity infrastructure, the transmission and distribution networks, were built in order to support post World War II economic growth and to accommodate large scale centralized generation technologies (Strbac, Ramsay et al., 2009). However, the demands placed on electricity infrastructures as we make the transition to a low carbon economy will be different. It is likely that more renewable forms of generation, whose output is less controllable, will be deployed on the networks both at the transmission and distribution levels, and that demand will become a more active part of the system e.g. by being more responsive to fluctuations in generation output. This therefore places attention on the need to adapt the existing electricity transmission and distribution infrastructure in order to facilitate a more diverse portfolio of low carbon generation and greater levels of demand side participation. In order to address many of these challenges facing electricity networks, the concept of the 'Smart Grid' has been proposed and is currently attracting much attention. Although the term has been applied flexibly, it typically refers to the utilization of information and communication technologies across the networks in order to actively manage a system with high penetration of decentralized and renewable generation, along with higher levels of demand side participation.

Reorienting established electricity networks and developing smarter grids is not only a significant technical challenge, it highlights the issue of how to coordinate change within complex socio-technical systems. In the past, this coordination would have been brought about through hierarchical institutions with state owned and operated public monopolies. However, the relatively recent trend towards privatization and liberalization has seen the progressive introduction of market based incentives and mechanisms, along with the fragmentation or unbundling of the value chain into competitive (generation and retail) and natural monopoly (transmission and distribution) segments. While the introduction of market incentives has seen rapid technological innovation in certain areas of the market, most notably in new generation technologies such as wind power (Garud and Karnøe, 2003) and CCGT plants (Winskel, 2002), other segments of the value chain, particularly electricity distribution, have seen little or no innovation (Scott and Evans, 2007; Voß and Bauknecht, 2008; Woodman and Baker, 2008). The aim of this paper is to examine the co-evolution of technological innovation and institutional change in relation to the recent history of UK electricity distribution networks, and to draw out lessons for current efforts to promote and accelerate a long term transition to a smart grid.

The paper proceeds by developing a framework for analyzing the co-evolution between technologies and institutions in infrastructures. It is argued that recent research on co-evolution, institutional theory and innovation systems provides a useful basis for the analysis of innovation processes within infrastructure sectors and a workable methodology for the identification of causal mechanisms which lead to inertia (lock-in) or change. Following this, using a case study approach and by employing qualitative research methods, we use the framework to explore how the governance of the electricity distribution sector in the UK has evolved since the introduction of privatization and liberalization in 1989. In particular, we analyze how efforts to promote technological innovation have become an increasingly important aspect of network governance, coming after a period in which economic objectives such as achieving short term operational efficiencies were given greater importance. Finally, we discuss the implications of the findings for the broader transition to a smart grid and draw conclusions.

2. ANALYZING ENERGY SYSTEMS: A CO-EVOLUTIONARY FRAMEWORK

Due to the technical complexity, scale, and public good characteristics of networks, the governance of infrastructures has traditionally involved a wide array of societal actors including private utility companies, economic and environmental regulators, national governments, local and regional authorities, amongst others. As a consequence, infrastructure sectors have been viewed as socio-technical systems (Hughes, 1983; Geels, 2004) i.e. technical systems which are embedded within a wider societal context; socio-technical systems constitute a 'seamless web' of interactions between technical and non-technical components. However, this systems perspective has been criticized for its structuralist framing of energy infrastructures and for forwarding a functionalist account of system change, often neglecting the role of agency (Smith, Stirling et al., 2005). For example; Stenzel and Frenzel (2008) discuss patterns of wind power technology diffusion in the UK, Germany and Spain. They argue that although the different institutional and regulatory environments had a significant role in shaping the initial stages of the industry, 'the subsequent reaction of the utilities and their strategic adaptation to the regulatory environment' was also a key feature in the three countries, particularly in the Spanish case where this led to 'virtuous cycles of the development of firm capabilities and regulatory change' (Stenzel and Frenzel, 2008). This example points to a need for greater analytical clarity in the study of energy systems – structures/institutions and actors/firms evolve with partial autonomy, and although there is a dynamic interplay between the two, their relative influence changes over time and they are not reducible to one another (Archer, 1995).

There is a growing body of literature which seeks to account for these co-evolutionary mechanisms that lead to long term change or dynamics within energy sectors. A recent contribution by one of the authors (Foxon, 2010) draws from the wider literature on the co-evolution between technological change and institutions in long term industrial dynamics (Nelson, 1998; Unruh, 2000; Perez, 2002; Murmann, 2003) and the socio-technical transitions literature (Geels, 2002), in order analyze the conditions necessary for the uptake of low carbon technologies, and to explore transition pathways to a low carbon economy.[1] For the specific case of infrastructure networks, the co-evolutionary framework has also proved to be a useful tool, in particular for the analysis of sector restructuring. Drawing from the work of Oliver Williamson (e.g. Williamson, 2000), Kunneke (2008) explores co-evolutionary processes in electricity networks. He argues that changes brought about by the unbundling and privatization of the industry have created a mismatch between the institutional arrangements governing electricity sectors and the prevailing technological practices, which have typically remained unchanged. It is proposed that this mismatch between a large scale centrally controlled technical system with highly complex and asset specific transactions, and a governance structure based on coordination through the introduction of market incentives, has created tensions within the socio-technical system resulting in 'an imbalance between institutions and technological practice' (Künneke, 2008). Künneke et al. (2010) develop this framework by identifying a number of 'critical transactions' which are essential to the functioning of infrastructures; they seek to align these transactions with 'critical technical functions' in order to find appropriate organizational models for reformed infrastructure sectors.

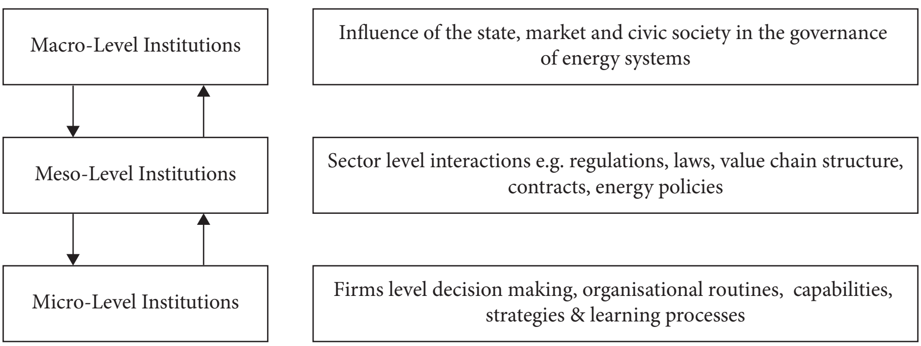
The above approaches to analyzing the co-evolution of technology and institutions provide a broad framework for examining processes of change, and also suggest the need for more detailed understandings of both technological innovation and institutional change, in relation to energy infrastructure networks. Thus, in the following sections, we draw on institutional and innovation approaches that complement the broader co-evolutionary framework, in order to be able to examine the specific interplay between institutional structures and innovation processes.

1 See also www.lowcarbonpathways.org.uk/.

2.1. INSTITUTIONAL CHANGE IN INFRASTRUCTURE NETWORKS

As we are proposing that technologies co-evolve with institutional change, an understanding of the institutional composition of network sectors is essential. For reasons outlined above (scale, technical complexity), institutional coordination is essential in network industries in order to safeguard system integrity and to promote efficiency and collective action (Finger, Groenewegen et al., 2005). A number of studies have proposed a layered approach to the analysis of institutions and institutional change within energy systems (Künneke, 2008; van der Steen, Groenewegen et al., 2008)[2]; here we draw from these studies and the literature on institutional theory (Scott, 2001) to delineate three levels of institutional analysis suitable for this study (see figure 1 below).

Figure 1. Levels of institutional analysis: Adapted from Scott (2001) and van der Steen et al. (2008)



At the *macro level* is the broader relationship between the state, the market and civil society in sector governance. In the UK, recent decades has seen the retreat of the state from direct intervention in the governance of energy systems and a shift towards market mechanisms via an independent regulatory authority (Moran, 2003). This contrasts with a country such as Denmark where civil society actors, e.g. municipal authorities and communities, have played a more active role in shaping energy systems (Lehtonen and Nye, 2009). This relationship strongly influences sector or field level interactions at the *meso level*; e.g. the privatization and unbundling of the electricity value chain along with the application of price-cap regulation in the UK has strongly incentivized network operators to reduce marginal costs and focus on operational efficiencies (Jamasb and Pollitt, 2007). At the *micro level* in our model, we focus on the firm. Within evolutionary based theories of economic change the business firm, e.g. a network operator, is designated as the fundamental decision making unit; i.e. 'the unit on which economic selection

[2] These studies draw from Oliver Williamson' s layered model of institutions (Williamson, 2000).

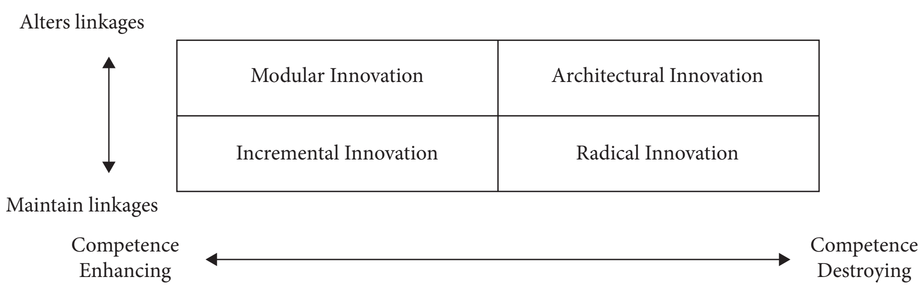
applies its grip' (Nooteboom, 1999). Decision making within the firm is bounded by its physical, financial, and human capital (Penrose, 1959), but also by its intangible assets, e.g. tacit knowledge stored in the form of behavioral routines (Nelson and Winter, 1982). Innovation therefore takes place as a result of firm level decisions taken in the context of a broader selection environment and bounded rationality. Section 3 of this paper analyses interactions between the three levels for the case of distribution networks in the UK. In the next sections we describe the different forms of technical change which take place in networks and how this is influenced by institutions.

2.2. TECHNICAL CHANGE IN INFRASTRUCTURE NETWORKS

Although there has been much debate in the literature on the creation of favorable selection environments for the uptake of various renewable generation technologies (Raven, 2005; Foxon and Pearson, 2007; Hekkert, Suurs et al., 2007; Stenzel and Frenzel, 2008; Verbong, Geels et al., 2008), there has been little discussion of low carbon innovation in the networks segments of the value chain (For exceptions see: Bauknecht, Leprich et al., 2007; Woodman and Baker, 2008). This may be due to the fact that, rather than having a direct impact on reducing emissions, 'network innovations' play a facilitating and enabling role which perhaps makes their immediate benefits less apparent. However, 'network innovations' such as HVDC links, smart metering, intelligent control devices etc. create more flexible and adaptive systems which in turn promotes the diffusion of low carbon conversion technologies (McDonald, 2008), and also can facilitate more efficient end use practices (Southerton, Chappells et al., 2004).

In order to begin to address this gap, we again draw from the literature on evolutionary economics, particularly the innovation typologies of Freeman and Perez (1988), Abernathy and Clark (1985), and Henderson and Clark (1990), to describe four generic types of innovation in infrastructure networks, see figure 2 and the description below.

Figure 2. Characterizing forms of innovation. Adapted from Henderson and Clark (1990)



- *Incremental innovation*: This type of innovation involves updating or improving existing network components which builds on existing practices and an established knowledge base e.g. like for like asset replacements and network reinforcement.
- *Modular innovation*: This involves changing or adding components to the system but maintaining the design philosophy and engineering principles which underpin the architecture of the network e.g. expanding the system through an interconnector. Often modular innovations are carried out in a piecemeal or niche basis and do not substantially affect the core competencies or practices of dominant market players.
- *Radical innovation*: Component level innovations involving technologies which typically would not be associated with existing networks e.g. deploying ICT based control systems. Christensen (1997) notes that, depending on whether radical innovations challenge the market dominance and competencies of incumbent players, radical innovations are often confined to market niches but periodically can benefit from dramatic performance improvements and overturn previously dominant systems.
- *Architectural innovation*: This occurs when radical innovations change the existing network architecture or value network (Christensen and Rosenbloom, 1995) i.e. the relationship between technical (nodes and links) and non-technical components of the system. For example, the invention of the AC transformer and the rotary converter in the 19th century prompted a move away from small urban DC systems towards large scale AC synchronous systems (Hughes, 1983). Such innovation is often controversial as it undermines sunk investments and embedded competencies. A dominant architectural innovation only emerges after a period of intense competition as in the transition from town gas systems to electric lighting in the late 19th century.

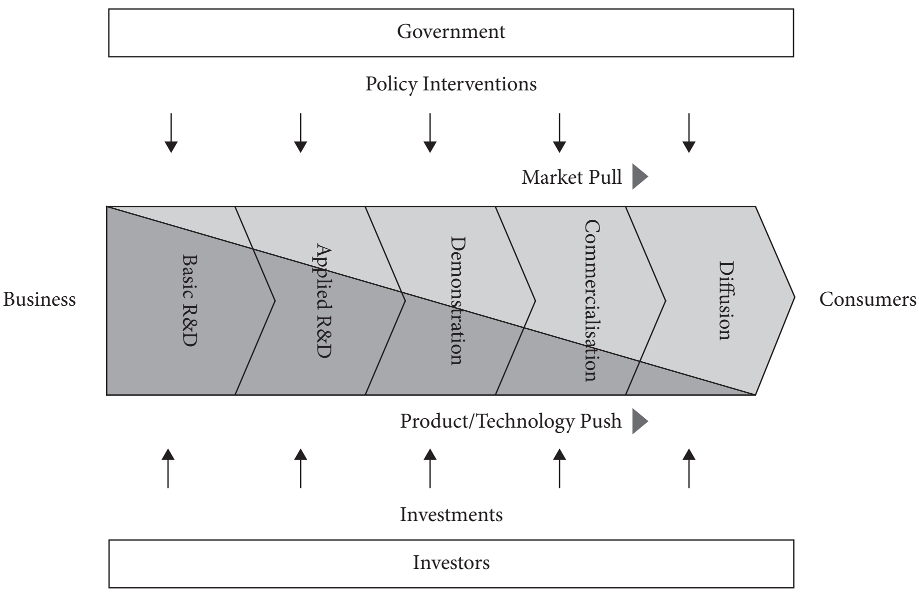
It is proposed here that 'institutions play an important role in creating incentives or barriers to the rate and direction of innovation' (Foxon, 2006); a key research task is to understand the specific forms of interplay which bring about different types of innovation in infrastructure networks. Taking a co-evolutionary approach we focus on the relationship between technical and institutional change, the governance challenge being to find an appropriate 'fit' or 'alignment' (Finger, Groenewegen et al., 2005; Künneke, 2008; Künneke, Groenewegen et al., 2010) in order to achieve desired policy outcomes (e.g. low carbon innovation). Below we briefly introduce the innovation systems literature where the aim is to create the institutional conditions necessary for effective innovation.

2.3. ALIGNING TECHNOLOGIES AND INSTITUTIONS: A LOW CARBON INNOVATION SYSTEM

The task of developing an alignment or coherent relationship between technologies and institutions in order to promote low carbon innovation requires an understanding of the process of innovation itself – here we draw from the innovation systems (IS) literature. Lundvall (1992) defines an innovation system as; *"the elements and relationships which interact in the production, diffusion and use of new, and economically useful knowledge"*. The concept – to create the conditions necessary for knowledge diffusion and innovation to occur – has been applied at the national (Lundvall, 1992; Nelson, 1993), sectoral (Malerba, 2002), and technological levels (Stankiewicz and Carlsson, 1991). This body of literature is quite extensive so we do not offer a comprehensive review here, however, there are two key concepts which are relevant to the creation of an infrastructure network innovation system.

Firstly, the IS literature expands earlier innovation models, which viewed innovation as a linear flow from basic scientific R&D to commercialization, to consider the wider systemic interactions that take place between a range of actors – as described by the innovation chain (figure 3).

Figure 3. The Innovation Chain



Source: Foxon, 2003

The traditional neo-classical economic approach to innovation argues that due to knowledge spillovers and the ability to appropriate new technologies, investment in R&D is a market failure warranting public support – individual actors such as private firms lack sufficient incentives to invest (Foxon, 2006). The systems approach expands upon this argument and argues that as innovation systems are highly dynamic and complex institutional environments, in many circumstances successful R&D does not necessarily lead to commercialization, often due to an institutional selection environment which favors incumbent technologies. This provides a rationale for continued support for new technologies along the innovation chain, particularly for the case of technologies which offer a potential benefit to the wider society e.g. by contributing to emissions reductions targets (Foxon, 2003).

The second relevant insight is the functions approach to innovation systems. A number of studies have identified the characteristics of successful innovation systems – how innovations move along the chain effectively. Within this field of research, scholars have identified mutually dependent system functions which, within successful innovation systems, interact to create the conditions necessary for new technologies to move along the innovation chain from R&D to commercialization. In a 2004 paper by Jacobsson and Bergek (Jacobsson and Bergek, 2004) it was proposed that the successful uptake of renewable technologies in Germany can be attributed to interactions between five functions which created the conditions necessary for mass diffusion:

- '*The creation and diffusion of 'new' knowledge*'
- To '*Guide the direction of the search process among users and suppliers of technology*' i.e. influencing how firms and users make decisions regarding new technologies
- To '*Supply Resources*' e.g. capital and competencies
- To '*create positive external economies*' across an industry by creating linkages, exchanging information and knowledge through networks; thus reducing uncertainty, risk and creating synergies.
- The '*formation of markets*' for new technologies

The IS framework allows us to evaluate the innovation characteristics of network sectors and to explore the causal links between institutions and technical change. The next section of this paper evaluates efforts to promote radical and architectural innovation within an established infrastructure – the electricity distribution networks in the UK.

3. CASE STUDY: CO-EVOLUTION OF TECHNOLOGIES AND INSTITUTIONS IN UK ELECTRICITY DISTRIBUTION NETWORKS

3.1. INTRODUCTION

Utilizing the co-evolutionary framework outlined above, we now discuss the specific challenges of aligning technical and institutional change to promote network innovation for the case of the electricity distribution networks in the UK. We do this in the context of recent efforts to promote a transition to a 'smart grid', as part of a broader low-carbon transition. We analyze the recent history of the co-evolution of technologies and institutions for UK electricity distribution networks, as this provides useful insights into how the prevalence of different political and economic priorities influences these co-evolutionary processes.

Although there are numerous definitions of what a smart grid is, it broadly refers to the deployment of intelligent control technologies in order to optimize the flow of electricity through the system from generation, transmission, distribution and through to end use – a definition which is often cited is that of the EU Smart Grids Technology Platform[3]:

> "A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver a sustainable, efficient and secure supply of energy."

The development of smart grids implies a shift from a largely centralized/large scale/ supply side dominated system, towards a more decentralized, flexible and responsive one; and depending on the degree of penetration of decentralized technologies, this could necessitate radical and perhaps architectural innovations. Within this context we place a greater emphasis on the distribution networks due to the fact that they will likely play a more prominent role in future energy systems. However, in the past, they have received less attention than other segments of the value chain in terms of investment and innovation. In centralized electricity systems, infrastructure planning and operation has typically been supply side led with much of the system management taking place at the national level via wholesale electricity trading enabled by an actively managed high voltage transmission network. Consequently, distribution networks (and the demand side) have essentially been passive elements within the system. However, as increasing levels of low carbon and renewable distributed generation (e.g. CHP and microgeneration) is incentivized[4] and as demand side participation in the management of systems increases[5], the role of distribution networks in overall system management will become more important. However, there remains a great degree of uncertainty as to the role that distribution networks may play in the energy system of the future. In order to give an illustration of the potential range of possibilities, we refer to a recent set of scenarios produced for the UK energy regulator, OFGEM, which propose potential long term futures (2050) for the structure of the electricity networks in the UK (see table 1).

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3 Www.smartgrids.eu/.

4 The main incentives for low carbon generation in the UK are the Renewables Obligation, a market based incentive, and the new feed-in tariff scheme which provides a fixed subsidy for every kilowatt hour of electricity produced by small scale, low carbon generators (under 5MW).

5 A key driver for demand side participation, such as load shifting at peak times, is the fact that the output of many renewable generators e.g. wind and solar power is uncontrollable and variable.

Table 1. Summary of LENS Scenarios (Ault, Frame et al., 2008): Table taken from Pollitt (2010)

Big Transmission and Distribution (T&D) – in which transmission system operators (TSOs) are at the centre of networks activity. Network infrastructure development and management continues as expected from today's patterns, while expanding to meet growing demand and the deployment of renewable generation.
Energy Service Companies (ESCOs) – in which energy services companies are at the centre of developments in networks, doing all the work at the customer side. Networks contract with such companies to supply network services.
Distribution System Operators (DSOs) – in which distribution system operators take on a central role in managing the electricity system. Compared to today, distribution companies take much more responsibility for system management including generation and demand management, quality and security of supply, and system reliability, with much more distributed generation.
Micro-grids – in which consumers are at the centre of activity in networks. The self-sufficiency concept has developed very strongly in power and energy supplies. Electricity consumers take much more responsibility for managing their own energy supplies and demands. As a consequence, microgrid system operators (MSOs) emerge to provide the system management capability to enable customers to achieve this with the new technologies.
Multi-purpose Networks – in which network companies at all levels respond to emerging policy and market requirements. TSOs still retain the central role in developing and managing networks but distribution companies also have a more significant role to play. The network is characterized by diversity in network development and management approaches.

A number of these scenarios, particularly where the locus of change is at the demand side of the value chain (DSOs, ESCOs, and micro-grids), envision significant changes to the structure and role of the distribution networks. With these more radical scenarios in mind, it is proposed that the promotion of innovation in distribution networks will become an increasingly important strategy to deal with an uncertain future and a more prominent aspect of electricity network governance in the UK and beyond. In order to explore this relatively under-researched area, the remainder of this section deploys the analytical framework outlined in section two to chart the evolving relationship between innovation and institutional structure in the distribution segment of the market; following this we draw some lessons for future regulatory strategies and policy making. We focus on the UK in particular as in recent years the regulator has been at the forefront of efforts to incorporate incentives for the deployment of new technologies into the broader regulatory framework (this has been a key feature of its recent review of the RPI-x regulatory framework[6]), however, outcomes and lessons learnt may have relevance for other countries. Also, as this is a rapidly evolving policy area, our main focus is on how regulatory incentives to promote innovation have been implemented along with the associated outcomes, although we do discuss the design of specific regulatory incentives.

6 The RPI-x@20 review: www.ofgem.gov.uk/Networks/rpix20/Pages/RPIX20.aspx.

The study draws from over 20 semi-structured interviews with key stakeholders within the sector including distribution network operators (DNOs), equipment manufacturers, academics, regulators and consultants. Interviews were recorded and transcribed, then coded according to three analytical categories outlined in figure 1 and subsequently according to the functions of innovation systems identified in the literature (Jacobsson and Bergek, 2004). We begin by discussing the evolving relationship between institutional and technical change since the process of electricity sector reform was initiated by the Electricity Act, 1989, and following this we discuss some specific issues facing the commercialization of low carbon network innovations using the IS framework.

3.2. CO-EVOLUTION OF TECHNOLOGIES AND INSTITUTIONS SINCE PRIVATIZATION IN THE UK

3.2.1. Innovation off the Agenda (1989–2002)

Since the privatization of the electricity supply industry in the UK, networks have been operated by private entities under license and regulated by an independent sector specific energy regulator. The Electricity act, 1989, established 12 licensed regional electricity companies (RECs) in England and Wales[7], similar to the nationalized Area Boards. In 1990 they were privatized, and along with owning proportionate shares in the transmission network, their role was to distribute and supply electricity in their respective areas. However, rather than accepting bulk power from a monopoly generator (the CEGB[8]), they were to transact in the wholesale trading market, then known as the electricity pool. Although not clearly specified in the 1989 act, the distribution (and transmission) networks were regulated by an independent entity, then known as the Office of Electricity Regulation (OFFER) and subsequently merged with the gas regulator to form the Office of Gas and Electricity Markets (OFGEM). Informed by the work of the academic economist, Stephen Littlechild (Littlechild, 1983), a form of price–cap regulation was introduced were the prices a company could charge for network services were index linked rather than tied to a specified rate of return on investments.[9] Beesley and Littlechild (1989) summarize the RPI-x regulatory approach.

> "…for a predescribed period of four to five years, the company can make any changes it wishes to process, provided that the average price of a specified basket of its goods and services does not increase faster than RPI-x, where RPI is the retail

7 The Scottish systems were retained as two vertically integrated entities.

8 Central Electricity Generating Board.

9 Price-cap regulation is generally preferred to rate-of-return approaches on the grounds that there is less incentive to over-invest in capital assets (Averch-Johnson, 1962).

> Price Index (i.e. the rate of inflation) and X is a number specified by the government…" (Beesley and Littlechild, 1989: 455)

Prices were set ex-ante each five year price control period and linked to the RPI, then outputs based incentives (the x factor), e.g. improving response times and reducing losses, were set by the regulator. From a macro level perspective it is not surprising that this approach to sector level governance was adopted. These reforms took place in a relatively benign energy policy environment, the job of regulation was to 'mimic the market' (Helm, 2004: 277) and RPI-x was viewed as an apolitical method of achieving this policy goal; this was particularly conducive with the broader neo-liberal ideology the then Conservative Government (Moran, 2003).

In terms of innovation, the theoretical underpinning of the approach was derived from the Schumpeterian view of the temporary nature of monopoly – monopoly power and above normal profits would act as an incentive to innovation and new entrants to the market (Helm, 2004). Innovation would take care of itself and the job of the regulator was relatively simple; to *'act as a surrogate for competition'* whilst ensuring that network operators had the ability to finance their activities (Owen, 2006). Quoting from Shaw et al. (2010) the Electricity Act, 1989, describes the role of regulation to:

> "..develop and maintain an efficient, co-ordinated and economical system of electricity distribution… and facilitate competition in the supply and generation of electricity"

Therefore, the role of regulation was not to promote innovation or favor particular technologies or methods; the focus was on reducing costs and promoting short run efficiencies. One interviewee from a distribution company comments on effect that the change of ownership and the introduction of incentive regulation had on R&D and innovation:

> "What happened is when the companies were privatised in 1990, not so much when they were first privatised but certainly in the first price review when there were huge cuts in income with the RPI-x mechanism, companies who were now of course owned by shareholders did what they could only do, which was to find ways of reducing costs. There were several ways you could do that; the trouble is of course one of the things that suffered from that was to be fair R&D"

…and on the effect of the changing ownership structure in the sector:

> "..in the past we have been owned by American owners who weren't interested, they just wanted money, in fact they were asset strippers really to be honest…make a quick buck and get out"

Compounding this, the fact that the privatized sector inherited a system which had benefited from a number of decades of over-investment under the nationalized Area Boards, meant that the newly privatized entities simply did not need to innovate to any great degree in order to deliver on performance targets set by the regulator. It must be said that during this period firms did innovate by improving operational efficiencies, however, while the institutional changes had been dramatic, interestingly this had little effect on the technologies chosen. This can be attributed to two effects; firstly, privatized firms had inherited an over-engineered system and could easily 'sweat the assets' without the need to innovate. Secondly, the cultural inheritance of the nationalized industries remained embedded to some degree within the newly privatized companies. One interviewee from an equipment manufacturer comments on both the physical and cultural legacy of nationalization:

> "The CEGB had this fantastic control of what happened to the network and it was very conservative and everything had plenty of margin built in… we've lived off all of those good things in the last 20 years and we've basically worked our way through all those margins…(but) there's a lot of corporate memory there about conservativism, a lot of that is still there so things are very conservative in how it's approached …"

This situation broadly continued following the 2000 Utilities Act; distribution networks were separated or unbundled from other areas of the value chain in order to enable the introduction of retail competition. This led to the formation of specialized Distribution Network Operators (DNOs). Not surprisingly, the key areas where innovation took place were in the newly competitive generation and retail segments of the market. For example, liberalization prompted what became known as the 'dash for gas', which saw a dramatic increase in investment in combined cycle gas turbine technology (Winskel, 2002), and at the retail end, new ways of segmenting the market and developing customer offerings were devised (Summerton, 2004). These innovations had little effect on the planning and operation of the distribution networks, and apart from limited incremental innovations in SCADA[10] IT systems at higher voltage levels, RPI-x seemed to have buttressed and reinforced prevailing practices that were present during nationalization i.e.'*the legacy of past management perceptions meant that more efficient control of distribution networks was neither required nor a worthwhile investment..*' (Northcote-Green and Wilson, 2006). Institutional change did not prompt any significant technical developments, and as a result, distribution networks in the UK became firmly rooted in a stagnation phase.

10 Supervisory Control and Data Acquisition.

3.2.2. The Emergence of Innovation as an issue (2003–2010)

As outlined above, the bulk of sector reform in the UK took place within a benign energy policy environment. This changed in the early part of the 2000s where, coming in the wake of an influential review of energy policy (PIU, 2002) and a policy white paper (DTI, 2003), growing concern over energy security and climate change have seen emphasis gradually move away from reducing costs and promoting competition, towards environmental and sustainability goals (Helm, 2004; Mitchell, 2007; MacKerron, 2009). In the area of network governance, the traditional role of the regulator under the original 1989 Act had been to *'protect the interests of consumers, present and future, wherever appropriate by promoting effective competition'*; however, due to the wider dynamics in national energy policy described above, this has been altered. The Energy Act, 2004, introduced a secondary duty beyond the protection of the customer's interests; to consider sustainable development in its decision making. In retrospect, this marked a significant shift from Littlechild's vision; an apolitical and formulaic application of RPI-x regulation. Although the implications that this policy shift has had on the governance of electricity distribution networks has been quite ambiguous (Owen, 2006), one area where it has had an effect is in the connection of smaller scale distributed generators to the networks. Schemes such as the Renewables Obligation, introduced in 2002, have incentivized investment in smaller scale renewable generators which tend to be connected to the distribution networks, rather than the higher voltage transmission network. This presents challenges for the DNOs as distribution networks have not been engineered to accommodate large numbers of DGs.[11] The traditional approach to DG taken by the DNOs to deal with these connections has been on an ad-hoc basis, and to push DG towards the higher voltage levels; as one interviewee from a distribution company describes:

> "Anything that's sizeable in the way of DG we can deal with on an ad-hoc basis if somebody wants to put 5MW or 30MW of DG on the network, it's a bespoke design study and we do what we need to do to accommodate that, and usually that involves some conventional network reinforcement or at least an extension to the networks"

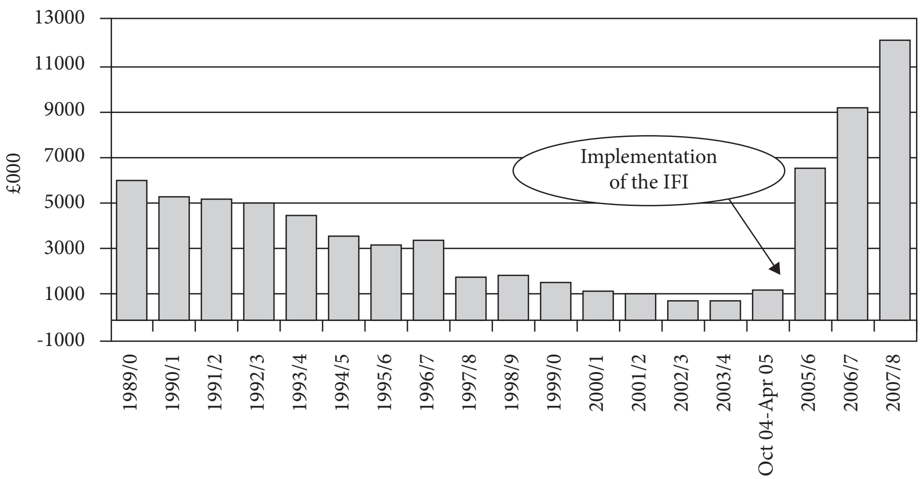
However, a number of influential studies, particularly from the ENSG[12] criticized this approach, terming it 'fit and forget', and argued that dealing with DG connections on a piecemeal basis would be inefficient due to the cost of reinforcing the network, particularly in areas with high potential for renewables e.g. north of Scotland. The alternative; optimizing a distribution system with large penetration of DG through the adoption of Active Network Management technologies (McDonald, 2008), has

11 DG connected to distribution networks changes voltage profiles, causing problems particularly in rural areas, and also by increasing fault levels on urban systems.

12 The Electricity Networks Strategy Group – Reports from the Distributed Generation Coordinating Group: www.ensg.gov.uk/index.php?article=28.

been proposed as an innovative solution to these problems (Djapic, Ramsay et al., 2007; Strbac, Ramsay et al., 2009; Ochoa, Dent et al., 2010). Prompted by these drivers and under the umbrella of its altered remit, Ofgem recognized the general lack of investment in R&D and innovation as a barrier to the development of a sustainable networks sector (Scott and Evans, 2007) and, more by accident than design, innovation in distribution became an issue; in particular the need to find alternative solutions to the connection of renewables at lower voltage levels. In response to this, for the fourth price control review (DPCR4) in 2005, Ofgem introduced a number of measures: firstly, an R&D funding mechanism: the Innovation Funding Incentive (IFI) – DNOs were permitted to spend up to 0.5% of its revenue on R&D – and a measure to promote trials of network innovations; Registered Power Zones (RPZ) – a DNO could spend up to £500,000/year and earn enhanced revenues for the connection of DGs. As Figure 4 below shows, the IFI did have a significant positive impact on R&D spending in the sector. It was a clear incentive where the risks to the DNOs were low.

Figure 4. UK electricity distribution R&D spending



Source: OFGEM

The RPZ scheme on the other hand was not so successful; only three projects[13] were undertaken by the companies throughout the five years of the price control period. Although the projects were relatively successful in trialing new technologies, as one academic interviewee suggests, they were modular innovations which were not of the radical or architectural type.

13 A project on Orkney operated by Scottish and Southern Energy island deploying active network management technologies. Central Networks Boston/Skegness project uses dynamic line rating techniques, and EDF Networks Martham scheme uses enhanced voltage control transformers to increase DG penetration.

> "…it didn't really come into that space. It was still very traditional but innovative way of operating a distribution network, I would argue, it doesn't really address the market opportunities"

While another describes the scheme as;

> "..a failure, there are only 3 schemes after 4 or 5 years. There's no incentive for the network to try something why may undermine its business model"

Meanwhile, during this price control period (2005–2010), the broader governance of energy and climate change in the UK saw a number of interesting developments, particularly at the state level. Most significantly, the Climate Change Act in 2008 set a legally binding commitment to reduce greenhouse gas emissions from 1990 levels by 80% by 2050 and 26% by 2020. Also established under the act was the Committee on Climate Change whose task is to formulate five year carbon budgets and report on progress, 2008 also saw the establishment of the Department for Energy and Climate Change. These broader institutional changes, along with the emergence of the smart grid agenda and an increasing focus on the role that the demand side can play in improving system efficiency (predominantly through a planned smart metering roll out), placed the focus on more radical and architectural forms of innovation. As a response to these developments and the poor take up of the RPZ scheme, in 2010 the scheme has been replaced by the Low Carbon Networks Fund (LNCF). The LNCF is more ambitions than the previous RPZ scheme, with the fund containing £500m and a greater emphasis being placed on more visible trials which engage with customers. The LCNF is about experimenting with new technical and commercial arrangements, and an interesting development is the recognition of the significance of collaboration and knowledge sharing:

> "We expect DNOs to collaborate with each other and non-DNO parties (External Collaborators) on many of the projects supported by the LCN Fund. DNOs are likely to have to work closely with other parties in the electricity supply chain (from generators to suppliers) to explore what technology or commercial arrangements best address changes in network use and what role they can play in facilitating low carbon and energy saving initiatives such as DSM and DG" (OFGEM, 2010: 4)

This brief review of the co-evolution of institutional and technical change has shown how the issue of network innovation has increasingly become part of the governance agenda for distribution networks, and this has been as a result of macro level institutional dynamics rather than strategic decision making by firms. Overall, the experience up to 2010 shows efforts to promote innovation beyond R&D have resulted in minor successes and modular rather than radical change. The next section discusses this in more detail.

4. LESSONS FOR CO-EVOLUTION TOWARDS A SMART GRID

In order to identify the reasons for the mixed success in promoting low carbon innovation in the UK's electricity distribution sector, we return to the functions of innovation systems introduced in section 2.3. For a competitive sector, these functions would be fulfilled through the interactions of market actors, but, for a regulated sector such as electricity distribution, there is a role for the regulator, such as OFGEM, to ensure that these functions are fulfilled. It is clear that, prompted by significant macro level governance dynamics, OFGEM have created regulatory incentives for R&D and trials, thereby fulfilling the *supplying resources* function. They have also been quite clear in creating incentives aimed at *guiding the direction of the search*, as the RPZ program funded DG connection solutions, and the LCNF expands this to demand side issues. However, although R&D is increasing and there have been some isolated pockets of innovation, there has been an undoubted failure to diffuse *new knowledge* within the sector and *create positive external economies* via a productive innovation system. There are several reasons for this; for example, a number of interviewees pointed towards cultural barriers within the network companies themselves. Over the years, the DNO business model has been built on reducing operational expenditure and achieving short run efficiencies, the longest time horizon being five years. A large body of the strategic management literature (Dosi, Faillo et al., 2008) argues that in such instances firms develop highly structured organizational routines based on tacit knowledge; where routines define a firm's capabilities and are difficult to alter in the short term. As one interviewee points out, this seems to be the case for DNOs:

> "… the network companies who are relatively averse to risk because they do not want to disrupt customers or do not want to spend money… they spend money on things which are quite well tried and tested. So that's a bit of a cultural and business thing as well"

One specific example of this is in the procurement policies of DNOs in purchasing network components, which as one interviewee points out have tended to be quite conservative and least cost:

> "(they) have this strong incentive to push down capital costs so they've put a lot of emphasis on negotiating at the procurement stage which basically means the just keep pushing down prices for buying basic standardised, well specified pieces of equipment"

Relating back to the three levels of institutional analysis outlined in figure 1, it can be observed that significant dynamics at the macro level have occurred during the period discussed, thus altering the broader institutional structures governing activity within the sector. In the light of concerns over energy security and climate change, national energy policy goals have become significantly more complex and diverse than previously was the case, prompting a more active role for the state in sector governance e.g. the formation of DECC.[14] This is placing a greater emphasis on long term policy goals and the low carbon transition, thus leading to an institutional mis-alignment at the meso/micro levels where the traditional emphasis has been on achieving static efficiencies. In the particular case of governing distribution networks, this lack of institutional coherence has manifested itself in a constricted innovation system for smarter grids due to short term time horizons, a lack of engagement with entrepreneurs, and disincentives to collaborate. Although the LNCF is seeking to address some of these problems at the demonstration phase, key barriers to the commercialisation (*formation of markets*) of smart grid technologies will remain as long as the sector is tightly unbundled i.e. the different activities along the electricity value chain are carried out in separate business units. A systems failure exists due to the fact that individual firms, such as DNOs, lack the incentive to invest in technologies which may benefit parties across the value chain. New governance structures will need to be developed which take into account the distribution of risks and benefits of investment in innovation across the value chain. This will require new institutional arrangements which are more amenable to productive collaborations within the sector, across the electricity value chain, and with other technology sectors e.g. telecoms. In this respect, key lessons can be learned from the telecoms industry where, as the sector made the transition into a more customer-centric service based provision, linear value chains quickly evolved into value networks (Li and Whalley, 2002), as defined by de Reuver as:

> "..a dynamic network of actors working together to generate customer value and network value by means of a specific service offering, in which tangible and intangible value is exchanged between the actors involved" (de Reuver, 2009: 12).

It is likely that as smart grids emerge and sector boundaries become less ridged, similar processes will take place in the electricity case. Such a collaborative approach could help to spread the risks of innovation and to develop inter-firm networks for the sharing of information and knowledge. This will require radical changes to the current institutional framework, both in terms of formal rules and regulations which govern the sector, and also informal institutions such as the prevailing business culture within firms and attitudes towards risk taking.

[14] Department of Energy and Climate Change.

5. SUMMARY AND CONCLUSION

This paper has outlined and applied a co-evolutionary framework for the analysis of innovation processes in network sectors. Incorporating concepts from evolutionary economics, innovation systems and socio-technical approaches, the framework focuses on a specific issue in the governance of energy networks – the need to create the institutional conditions necessary for the adaptation of low carbon network innovations. We highlight the dynamic interplay between technical change and institutional structures at the firm, sector and macro levels and how this enables or acts as a barrier to low carbon innovation. Following an introduction to the smart grid concept and its potential implications for distribution networks, the paper documented this interplay for the case of electricity distribution networks in the UK since the introduction of sector reforms in the late 1980s. It found that the initial stages of sector reform did not prompt any significant levels of technological innovation. However, in the early part of this decade, macro level institutional changes, particularly in relation to climate change, have highlighted a misalignment between the technological and institutional trajectories within the sector.

From our analysis of efforts to promote innovation in the UK electricity distribution sector, we identify two specific issues that are relevant to policy makers and regulators which might address this misalignment and bring about a more coherent techno-institutional arrangement. Firstly, the need for innovation incentives to take a broader view of innovation systems and value networks. Until the introduction of the LCNF, innovation incentives in the UK were directed at the individual firm level. The outcome of the RPZ scheme in particular highlighted the inadequacy of this approach both in terms of providing incentives to invest in technologies where the risks and benefits are spread unevenly across the value chain, and overcoming cultural barriers within a sector which is at the early stages of developing a capability to innovate. The LCNF's focus on collaboration provides the potential to overcome some of these systemic barriers by helping to reduce risk and uncertainty and facilitating the diffusion of knowledge between parties.

Secondly, the need to address the question of how to govern for long term transitions in the face of an uncertain future. The Ofgem scenarios outlined in table 1 show that there are multiple transition pathways for the evolution of electricity networks, with some pathways based on incremental or modular improvements to the existing system, whilst other pathways would necessitate more radical and architectural forms of innovation. Our analysis highlights a number of significant difficulties in achieving these forms of structural change within a regulated sector such as electricity distribution. In order to avoid lock-in to an incrementalist path, the development of coherent visions and transition pathways, along with a clear commitment to the long term promotion of innovation and systemic change, is required on the part of regulators and policy makers. Focus needs to shift from the promotion of short run efficiencies towards alternative policy goals, and this calls into question many of the underlying rationalities behind network regulation. Effective smart grid governance will thus require a great degree of institutional reflexivity and institutional learning on the part of regulators and provides scope for a redefinition of the relationship between policy and regulation.

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