Socio-Technical Transitions and Infrastructure Networks: the cases of electricity and heat distribution in the UK

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The candidate confirms that the work submitted is his own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others

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In writing this paper I received direction and advice from the second author; however as the lead author its content largely draws from my own field work and literature review. Relevant sections are marked within the text.

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Abstract

There is a growing recognition that current energy systems are unsustainable and require fundamental restructuring. While this is a significant engineering challenge it is not a matter of replacing one set of technologies with another. Technologies are embedded in a wider set of political, social and economic institutions which means that the transition from one energy system to another also requires an understanding of the interactions between the technical and non-technical. This thesis contributes to knowledge in this area by paying specific attention to energy distribution networks; the pipes and wires which deliver our energy services.

It is argued that existing approaches to the study of transitions in energy systems have largely black-boxed the network components, tending to concentrate on production and demand. However, infrastructure networks have unique technical and institutional characteristics which require a more systematic treatment. Therefore the aim of the thesis is to make more visible the interplay between actors, institutions and technologies in reproducing and transforming energy distribution networks.

For this purpose a novel analytical framework is developed which draws from economics and science and technology studies and incorporates insights from the governance literature. The framework is applied to the cases of electricity and heat distribution in the UK. It is found that following the liberalisation of energy systems, the governance of distribution networks has been siloed from the mainstream energy regime which has focused on promoting competition in other segments of the value chain. Therefore efforts to decarbonise energy supply in the UK have tended to be market based with a short term focus, rather than integrated solutions which recognise the role that flexible distribution networks can play in this transition. A number of policy recommendations are made which inform debates surrounding the development of local heat infrastructures and the reconfiguration of electricity distribution systems.

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List of Acronyms and Abbreviations

ANM	Active Network Management
ANT	Actor Network Theory
BEA	British Electricity Authority
BETTA	British Electricity Trading and Transmission Arrangements
BSC	Balancing and Settlement Code
CAPEX	Capital Expenditure
CCC	Committee on Climate Change
CCGT	Combined Cycle Gas Turbine
CCL	Climate Change Levy
CEB	Central Electricity Board
CEF	Community Energy Fund
CEGB	Central Electricity Generating Board
CERT	Carbon Emissions Reduction Target
CESP	Community Energy Saving Programme
CGP-DH	Combined Heat and Power with District Heating
CHP	Combined Heat and Power
CHPA	Combined Heat and Power Association
CHPQA	Combined Heat and Power Quality Assurance
CRC	Carbon Reduction Commitment
CSH	Code for Sustainable Homes
DCLG	Department for Communities and Local Government
DE	Decentralised Energy
DECC	Department for Energy and Climate Change
DEKB	Decentralised Energy Knowledge Base
DG	Distributed Generation
DGI	Distributed Generation Incentive
DHN	District Heating Network
DNO	Distribution Network Operator
DPCR	Distribution Price Control Review
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
DTI	Department for Trade and Industry
DUKES	Digest of United Kingdom Energy Statistics
DUoS	Distribution Use of System
EfW	Energy from Waste
EGWG	Embedded Generation Working Group
ENSG	Electricity Networks Strategy Group
EPC	Energy Performance Certificate
ESCO	Energy Services Company

ESI	Electricity Supply Industry
EST	Energy Saving Trust
EUETS	European Union Emissions Trading Scheme
FIT	Feed-in tariff
HCA	Homes and Communities Agency
HV	High Voltage
IDNO	Independent Distribution Network Operator
IFI	Innovation Funding Incentive
IS	Innovation System
JEA	Joint Electricity Authority
LA	Local authority
LA21	Local Agenda 21
LCIF	Low Carbon Infrastructure Fund
LCNF	Low Carbon Networks Fund
LDA	London Development Agency
LDF	Local Development Framework
LEB	Local Electricity Board
LGA	Local Government Association
LTS	Large Technical System
LV	Low Voltage
MLP	Multi-level Perspective
NETA	New Electricity Trading Arrangements
NG	National Grid
NIE	New Institutional Economics
OPEX	Operational Expenditure
PCR	Price Control Review
PES	Public Electricity Supply
PHEV	Plug-in Hybrid Electric Vehicle
PPP	Pool Purchase Price
PPS	Planning Policy Statement
QOS	Quality of Service
RAB	Regulated Asset Base
RCEP	Royal Commission on Environmental Pollution
REC	Regional Electricity Company
RHI	Renewable Heat Incentive
RIIO	Revenue = Incentives + Innovation + Outputs
ROC	Renewable Obligation Certificate
RPI	Retail Price Index
RPZ	Registered Power Zone
RSP	Regulatory State Paradigm
SCOT	Social Construction of Technology
SMP	System Marginal Price

SO	System Operator
SRA	Strategic Relational Approach
SST	Social Shaping of Technology
STS	Science and Technology Studies
TCE	Transaction Cost Economics
TM	Transition Management
TSO	Transmission System Operator
VPP	Virtual Power Plant
WACC	Weighted Average Cost Of Capital
WPD	Western Power Distribution

1 Introduction

The objective of this thesis is to explore and explain the dynamics of contemporary energy systems with specific attention being paid to distribution networks - the pipes and wires which deliver our energy services. It is often the case that distribution networks are hidden from view beneath the streets of our cities or in out of the way places, often being treated as technical objects rather than socio-technical systems which are reproduced and transformed by ongoing interactions between actors, institutions and technologies. The central aim of this thesis is to uncover these complex socio-technical processes taking place in contemporary distribution networks and to explore implications for the long term transition to a low carbon energy system.

Currently in industrialised countries the infrastructures which deliver essential energy services to homes and businesses are highly carbon intensive and in need of significant reinvestment. In the UK for example, much of the energy infrastructure was designed and constructed in the decades following the Second World War in order to power a highly industrialised economy and the consumer boom of the 50s and 60s. During the 1970s a slowdown in economic growth and successive oil crises began to undermine this expansionary model and the discovery of fossil fuel reserves in the North Sea saw a trend towards the use of gas for heating and later electricity supply. Today the UK is no longer an industrialised economy and its gas reserves are in decline, having recently become a net importer. The rationales which underpinned the development of these large scale energy infrastructures are therefore no longer as salient and as a consequence flexibility, efficiency and decentralisation have been emphasised in recent decades.

The example of the UK shows that energy systems are never static but change and evolve, being influenced by such things as the relative prices and availability of different fuels, the social and political environment in which they operate, and technological innovation - this has been the case since the industrial revolution of the 18th and 19th centuries. However, contemporary energy systems face a unique challenge; the scientific consensus surrounding anthropogenic climate change means that there are growing calls for the rapid decarbonisation of energy production and end use in order to prevent dangerous levels of greenhouse gases from entering into the earth’s atmosphere. This creates a dilemma for the governance of energy systems because although relatively rapid technological transitions have taken place in the past, these have generally not been planned or predicted. There is therefore a need to develop a greater understanding not only of the technical and engineering challenges involved in decarbonising entire energy systems, but also how the social and technical interact in this process.

In recent years a body of literature known as socio-technical transitions theory (Verbong and Geels, 2007, Rotmans and Loorbach, 2008) has developed which seeks to do just that. The aim of the thesis is to contribute to this growing body of literature by emphasising the particular case of energy distribution networks. These pipes and wires are the arteries of the systems which transport energy, whether it is electricity, gas or heat, to end customers and therefore form a key link in the energy chain. However, analyses of energy transitions have tended to black-box the network components of infrastructures, focusing instead on the more visible areas of energy systems such as renewable generation technologies, nuclear power plants and the way energy is used. It is argued that, although having a less direct impact on carbon emissions, the development of flexible distribution systems will be crucially important in enabling and facilitating more sustainable production and consumption patterns.

In order to achieve this aim two in-depth cases of distribution networks in the UK are developed. The first looks at electricity distribution systems which have been in place for many years and are operated by incumbent energy companies; the second focuses on district heating networks which are a niche technology in the UK and are typically operated by local authorities who are not mainstream actors in the energy industry. It is proposed that these contrasting case studies can provide valuable insights into the nature of the interplay between actors, institutions and technologies in reproducing and transforming contemporary energy distribution systems. Theories from new institutionalism, evolutionary economics and science and technology studies are drawn upon in order to develop an analytical framework which can analyse the complex socio-technical interactions taking place. The framework pays particular attention to the changing governance patterns of socio-technical systems at a macro level and how this affects the structure of energy distribution sectors at the meso and micro levels.

The thesis makes two key contributions to the study of long term structural change in energy systems and the transition towards a secure and sustainable energy system. Firstly, as an empirical contribution the study focuses on the socio-technical dynamics of the electricity and heat distribution sectors in the UK which, as argued, have received less attention than other sectors such as energy generation and demand. In doing so a second, more theoretically orientated contribution is made where the study develops a novel analytical framework which uncovers the socio-technical and governance dynamics of the distribution pipes and wires which have unique technical and institutional characteristics.

1.1 Innovation, Industry and Environmental Sustainability

In order to situate this thesis and the transitions approach within a broader context it is useful to discuss the ways in which researchers have explored the nexus between technical change, industry and the environment.

Arthur Mol in his study of the ecological modernisation of the Dutch Chemical Industry (Mol, 1995) identifies three successive waves of environmental concern in industrialised societies. The first took place in the early twentieth century which ‘focused mainly on the degradation of ‘natural’ landscapes due to increasing industrialisation and the expansion of cities’ (*ibid*: p.1). This led to the conservationist movement and the creation of vast nature reserves and protected areas. It did not however see a fundamental questioning of the relationship between the environment and the rapid industrialisation which was underway at the time. In the 1960s and 1970s a new wave of environmental activism emerged which recognised more explicitly the need to redress this relationship. This led to the institutionalisation of environmental issues in government departments, planning laws and environmental regulations; however ‘the ecology-inspired demand for social change in the early seventies resounded only to a limited extent in the institutions of industrial society’ (Mol, 1995: p.1). In the late twentieth and early 21st centuries, a third wave of environmental concern has been identified. This is more explicit about the need for a fundamental restructuring of industrial society, or ‘transformations of the industrial order’, which are more structural in their nature (Mol, 1995: p.2). This widening of the scope of environmental concern and its effect on the structures of industrialised society are generally reflected in various strands of the technology and innovation studies literature (Smith et al., 2010).

For example, ecological modernisation theory, which has grown in prominence in the past number of decades, seeks to integrate economic and environmental goals by advancing the diffusion of cleaner technologies and reorienting macro-economic/sector structures to promote environmentally benign economic development (Mol, 1995, Hajer, 1995, Mol et al., 2009). Gouldson and Murphy (1998) summarise:

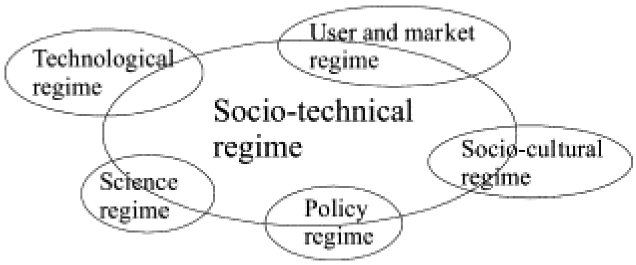
> *“…ecological modernisation seeks to shift the emphasis of the macro-economy away from energy and resource-intensive industries towards value and knowledge-intensive industries (…) ecological modernisation seeks to encourage structural change in the macro-economy and technological and organisational change in the micro-economy” (Gouldson and Murphy, 1998: p.3)*

In terms of its approach to technology and innovation it seeks to make productive links between the second and third waves of environmental concern by promoting the diffusion of clean technologies and techniques, as oppose to control technologies and end-of pipe solutions. This involves the integration and embedding of environmental concerns in the strategies of firms and decision making processes surrounding technological investments. In doing so, a key aim is to harness 'the forces of entrepreneurship for environmental gain' (Gouldson and Murphy, 1998) and to produce win-win solutions which improve competitiveness.

Similar efforts to promote a synergistic relationship between technical change, industry and the environment are present in the literature on industrial ecology (Ayres and Simmonis, 1994) and eco-innovation (Rennings, 2000, Freeman, 1992). A key argument that is made is that eco-innovations, or clean technologies, face a double externality problem (Rennings, 2000): The first is that, similar to conventional technologies, environmentally friendly innovation will be under-supplied by the market because the benefits of investment in R&D can be appropriated, and as a result there will not be adequate incentives in place for individual actors to engage in innovation (Foxon, 2006). The second externality is specific to eco-innovations; because the environmental costs of incumbent technologies and the positive external effects of eco-innovations are rarely priced, firms face an added disincentive to invest (Rennings, 2000).

The transitions approach broadens the analytical perspective from industrial production and markets to entire systems of production and consumption; termed socio-technical systems. These underpin basic societal services such as food, energy, hygiene etc., and as the figure below shows, markets are embedded within these wider regimes or sets of institutional relations.

Figure 1.1: Meta-coordination through socio-technical regimes



Source (Geels, 2004)

Transitions research moves beyond arguments which propose that a lack of innovation is a market failure which can be addressed through the pricing of externalities. Rather, it adopts a wider and more systemic approach to innovation (Edquist et al., 1998, Lundvall, 1988) where technical change is seen as an inherently evolutionary process whose outcomes cannot be predicted ex-ante. The process involves complex interactions taking place between a wide range actors and social groups, of which market and industrial actors (customers and firms) are a subset. The approach explicitly deals with persistent environmental problems whose urgency necessitate rapid and fundamental changes to the structures of a number of socio-technical systems which, it is argued, are locked-in to unsustainable trajectories and require a reorientation of their entire systems of production and consumption. Frank Geels, one of the key proponents of a transitions approach, refers to these as ‘New Environmental Problems’:

> *“New Environmental problems, such as climate change, biodiversity and resource depletion, gained prominence on the political agenda in the 1990s and early 2000s. These pervasive problems differ in scale and complexity from the environmental problems of the 1970s and 1980s, such as water pollution, acid rain, local air pollution and waste problems. While many of these problems could be addressed with end-of-pipe solutions (e.g. catalysts in cars, scrubbers on power stations) or clean technologies, new environmental problems such as climate change are more difficult to address and will require social as well as technical changes. Achieving cuts of 50-80 per cent in CO2 emissions will require shifts to new kinds of systems in transport, energy and agri-food domains. Such transitions entail not only new technologies but also changes in markets, user practices, infrastructures, cultural discourses, policies and governing institutions” (Geels, 2011: p.13)*

The literature on socio-technical transitions seeks to understand the process of transformation in industrial sectors of the economy and adopts an explicitly normative stance that radical innovation which produces more sustainable and environmentally benign outcomes can and should be encouraged. This ‘broadening of the problem framing’ has led to an associated ‘broadening of the analytical framework’ (Smith et al., 2010) to consider how structural transformations in sectors of the economy, and not just individual technologies, can be induced and rapidly accelerated:

> *‘Ecological restructuring of production and consumption patterns will require not so much a substitution of old technologies by new ones, but radical shifts in technological systems or technological regimes including a change in consumption patterns, user preferences, regulations, and artefacts’ (Hoogma et al., 2002: p.5)*

Due to the nature of modern energy systems as high polluting and highly interconnected configurations which are prone to inertia, the transitions approach has been widely drawn upon to analyse how long term structural transformations to renewable and low carbon energy systems can be governed (Raven, 2005, Verbong et al., 2008, van der Vleuten and Raven, 2006, Raven and Verbong, 2007, Foxon et al., 2010, Foxon and Pearson, 2008, Verbong and Geels, 2010). The following section will discuss in more detail socio-technical transitions in energy systems and the need to give more explicit consideration to the dynamics of infrastructure networks in these processes.

1.2 Socio-Technical Transitions and Infrastructure Networks

The main argument of this thesis is that infrastructure networks – pipes and wires – have unique characteristics which have been neglected or downplayed in analyses of socio-technical transition processes in energy systems. As the unit of analysis of transitions research has expanded to incorporate entire systems of production and consumption, it has often been the case that the technical and institutional characteristics of specific sub-systems, such as distribution networks, are treated as part of the wider system as a whole. As a result emphasis tends to be placed on either (or both) the supply (generation) and demand side (how energy is used), with the networks often being black-boxed. Although the structure of distribution systems have played a key role in shaping modern energy systems (Hughes, 1987) they tend to be neglected because they are often less visible than generation technologies such as nuclear plants and wind turbines, and have less direct impact on carbon emissions than energy use patterns. While the highly aggregated system level framing may have been appropriate when energy industries were integrated under public ownership, in a liberalised context there are both competitive and non-competitive parts of energy systems which have quite different institutional characteristics and therefore require separate treatments in analysis.

The distribution network component of energy systems have similar attributes to a number of other 'network industries' such as telecoms, water and transport which are infrastructure based (Groenewegen and Künneke, 2005). These industries have the following unique features:

- In many cases the services that these industries provide are essential to everyday life and are therefore classed as public utilities or social goods
- Due to the physical and economic characteristics of infrastructure networks they tend to be natural monopolies which means that they are non-competitive
- Parallel networks rarely compete against one another therefore the services they provide are not traded in markets but are subject to some form of state influence e.g. through economic regulation or public ownership
- Infrastructure networks are large scale technical systems which have a defined geographical scope
- Infrastructure networks are complex systems and their successful operation requires the mutual interaction between large numbers of individual components. In order to achieve

> this technical complementarity institutional arrangements which coordinate a range of both public and private actors are required

The aim of this thesis is to show that the dynamics of infrastructure networks require systematic attention in analyses of socio-technical transitions in energy systems. The study pays particular attention to electricity and heat distribution networks which have traditionally not been a particularly prominent part of centralised energy systems. However, it is likely that for different reasons – e.g. more flexible electricity distribution networks will be required and heat networks promote energy efficiency - they will become a much more important part of energy systems in the future (chapter 4 will explain this in greater detail). Thus, it is proposed that the thesis can contribute to a more nuanced understanding of transition processes in energy systems leading to policy recommendations for a low carbon energy transition in the UK and other industrialised countries.

1.3 Governance, the State and Energy Systems

As proposed in the introduction to this chapter, developing an understanding of transition processes - how they can be directed and accelerated - will necessitate an appreciation of the non-technical or social aspects of energy systems. In a number of recent contributions to research in this area it has been argued that there is a particular need to develop a greater understanding of the political and governance dimensions of energy sector transformation (Smith and Stirling, 2007, Kern, 2009, Shove and Walker, 2007, Meadowcroft, 2011, Scrase and Smith, 2009). Largely due to its roots in economics and innovation studies, there has been a tendency to present transitions as unproblematic and uncontested processes which are largely characterised in terms of technical change (Smith et al., 2005); however, in reality, energy systems are deeply embedded in wider political, economic and social institutions.

In her study of renewable energy policy in the UK, Catherine Mitchell (Mitchell, 2008) has argued that attempts to promote the transition to a low carbon energy system have largely been shaped by the changing nature of the state's involvement in the governance of the energy sector and the economy more broadly. It is proposed that the governance of the energy industry in the UK has been closely bound up with the state and its approach to economic regulation. Drawing on the work of Michael Moran (Moran, 2003), Mitchell argues that this nexus has been paradigmatically structured, with the post-war welfare state – characterised by managerialism and the socialisation of risk - being followed by a move towards liberalisation where state involvement is based on the promotion of economic efficiency thorough market mechanisms – this has been termed the Regulatory State Paradigm (RSP). Mitchell and others (Helm, 2004) have proposed that energy institutions and decision making in the UK has been shaped by changing political paradigms with a long period of public ownership being ended by the Thatcher government of the 1980s and the privatisation of a number of network industries including electricity and gas. In recent years efforts to promote decarbonisation of energy supply have been channelled through this paradigm with emphasis being placed on competition, incentives to promote marginal efficiency, and the use of prices to correct market failures (Mitchell, 2008). However, there remains a great degree of uncertainty regarding the appropriateness of the RSP and its application to an energy system which requires fundamental and rapid transformation. For the case of renewable energy, Mitchell argues that the existing energy institutional framework promotes incremental rather than radical structural changes; the RSP being similar to a ‘band of iron’ which constrains the agency of decision makers and favours existing technologies and incumbent actors. This points to an underlying paradox at the heart of UK energy policy where efforts to promote a transition to a low carbon energy system run parallel to the day to day practices and institutions of governance which often reinforce existing technologies and practices.

Therefore, in order to uncover these complex socio-technical processes, a central concern is the changing role of the state in the governance of energy systems. It is argued that an exploration of the socio-technical dynamics of energy distribution networks presents a particularly interesting and underexplored forum for these debates. As discussed in the section above, distribution networks are one of a number of network industries which have particular technical and institutional features – such as natural monopoly – which mean that they are not conventional market goods; rather they require an institutional architecture which is coherent with their unique technical characteristics and can deliver social as well as economic objectives. It will be argued in chapter two that the literatures which have dealt with the governance of network industries and energy systems in a liberalised context have tended to down-play or under-theorise the role of the state in shaping the institutions of distribution sectors. By drawing on various strands of the governance literature a theoretical contribution that this thesis makes is to pay particular attention the changing role of the state in economic governance and how this contextualises and shapes meso or sector level dynamics in energy systems.

1.4 Research Questions

The main argument of this thesis is that infrastructure networks, such as energy distribution systems, have specific technical and institutional characteristics which require more systematic analysis in the study of energy transitions. It is proposed that distribution networks will become an increasingly important part of energy systems in the future and that as the transition to a low carbon energy system unfolds it will reveal new forms of interplay between actors, institutions and technologies in these sectors which the thesis aims to explore. The guiding research question of the study is therefore as follows:

What is the nature of the interplay between actors, institutions and technologies in reproducing and transforming contemporary energy distribution systems?

It is proposed to use a qualitative case study methodology to address this research question. The rationale for taking this approach and choosing the electricity and heat distribution networks in the UK as case studies is outlined in chapter three.

The following sub-research questions address particular aspects of this interplay:

1. *How do the liberalisation and climate change agendas interact to influence this interplay?*

Over the past twenty to thirty years, the UK has been a leading proponent of the liberalisation and privatisation of network industries and this has shaped the current governance structure of energy distribution networks. In more recent years efforts to address climate change at a national level in the UK have increasingly begun to influence various aspects of energy policy. It has been argued elsewhere that there are incompatibilities between these two agendas, particularly in relation to accelerating the deployment of renewable generation technologies and more efficient demand side behaviours which have tended to be pursued through a market-led framework (Mitchell and Woodman, 2010, Mitchell, 2008, Woodman and Mitchell, 2011, Helm, 2005, Foxon and Pearson, 2008). The study explores the co-evolving relationship between these two agendas for the specific case of distribution pipes and wires in order to shed light on potential areas of coherence and conflict in the governance of energy networks.

2. *What is the role of the state in the governance of energy networks and how is this changing?*

As outlined above, a key contribution which this thesis aims to make is to uncover the changing role of the state in the governance of energy systems, paying particular attention to distribution networks. It is proposed that the technical and institutional characteristics of infrastructure networks can illuminate the nexus between public and private actors and can provide insights into the state's role in the governance of contemporary energy systems.

3. *How are socio-technical transition processes in energy systems likely to be affected by the specific dynamics of distribution networks?*

It was argued in the section above that analyses of socio-technical transition processes have not paid adequate attention to the characteristics of distribution systems and network industries more generally. By asking this question the aim is to explore in more explicit terms the particular dynamics of long term socio-technical change in network industries and to develop insights which are relevant to policy makers in the UK.

1.5 Outline of the Thesis

The thesis is structured as follows:

Chapter 2 investigates the interplay between actors, institutions and technologies in distribution sectors through the lens of a number of literatures which have been previously drawn upon to explain structural changes in infrastructure sectors. These are broadly divided into two main categories; economic approaches which stress the importance of institutions and socio-technical approaches which are more actor-centric. The chapter interrogates the literatures in terms of their framing of institutions and institutional change and the interplay between actors and their wider environment in shaping technical change. It is argued that while these existing literatures provide useful insights to address the main research question, they lack a satisfactory discussion of the role of the state in the governance of infrastructure sectors (research question 3). In order to fill this gap, the final section of the chapter introduces and discusses the governance literature which seeks to understand relationships between the state, the market and civil society. Two strands of this literature are explored in further detail - state theory and governmentality - which delve more deeply into the nature of the state and its changing form. Potential implications for the governance of distribution networks are discussed.

Chapter 3 draws on these insights and develops a novel analytical framework for the analysis of the socio-technical dynamics of energy distribution networks. The framework brings together insights from the previous chapter and draws more widely from sociological understandings of institutions in order to frame the interplay between actors, institutions and technologies as a process of governance involving interventions, interactions and outcomes taking place in the context of a national level governance regime. Governance outcomes are assessed in terms of three analytical dimensions – physical, relational and structural. The chapter also outlines the research design and methodology.

Chapter 4 outlines the contextual background to each of the two case studies. This covers the technical and institutional structure of the electricity and heat distribution sectors and a brief history of their evolution. It also outlines how the key concepts in the analytical framework can be operationalised for each of the cases.

Chapter 5 & 6 are the main empirical chapters of thesis. Chapter 5 applies the analytical framework to the electricity distribution sector in the UK and Chapter 6 looks at heat distribution. Each of the chapters outline the interplay between actors, institutions and technologies as an evolving process by exploring the outcomes of sector level interventions and interactions which are taking place within the context of national level structures, termed a governance regime. These chapters pay particular attention to the co-evolution between the liberalisation and climate change agendas during the 2000s and how this has influenced the uptake of various technologies and practices in each of the cases.

Chapter 7 is a cross-case analysis which is designed to extrapolate from the context specific knowledge which was developed in the empirical chapters to provide more generalizable insights regarding the socio-technical dynamics of energy distribution networks. A number of causal mechanisms which have influenced the interplay between actors, institutions and technologies in each of the cases are identified and discussed. This shows how the study can inform the existing literature but also how the analytical framework has uncovered a number of novel mechanisms which develop knowledge in this area.

Chapter 8 is the concluding chapter where each of the research questions which have been outlined above are addressed in turn. The policy implications of the research are discussed and a number of concrete policy recommendations are made. The chapter also reflects on the main contributions of the thesis, its limitations and potential avenues for future research.

2 Theoretical Perspectives on the Dynamics of Infrastructure Networks

The purpose of this chapter is to review the existing literatures which deal with the topic of infrastructure networks and their socio-technical dynamics, thus addressing the central research question regarding the interplay between technologies, actors and institutions. Due to the complex and multi-faceted nature of infrastructure systems, a large number of literatures have dealt with the topic from different perspectives ranging from engineering to sociology. In the interests of precision, literatures which broadly analyse structural changes in energy systems and the nature of the relationship between the technical and non-technical dynamics of infrastructures are discussed; these tend to take a multi-disciplinary approach.

The chapter is sub-divided into three main sections; the first two comprise a review of the existing literature on the dynamics of infrastructure networks while the third incorporates insights from a range of governance approaches to address the gap in the literature regarding the changing role of the state in the governance of energy systems. Section 2.1 explores economic and institutional approaches to infrastructures, focusing on new-institutional and evolutionary economics. What these approaches have in common is that they highlight the role of institutions in the dynamics of infrastructure networks; however they adopt different stances on the nature of institutional change with new-institutional economics stressing the importance of transaction costs while evolutionary economics places a greater degree of emphasis on technology and innovation as a source of institutional change. Section 2.2 is a discussion of a broad range of socio-technical approaches to the analysis of infrastructure networks which tend to be rooted in science and technology studies. These take a more actor-centric or constructivist stance, stressing the contested nature of technical change and the multiple framings and meanings that different actors and social groups attribute to technology. These literatures are not confined to one particular infrastructure sector and throughout the chapter the electricity, heat and other sectors will be referred to.

It is proposed that these two areas of theorising can provide useful insights into processes of change in distribution networks as they emphasise in different ways the relative importance of both structures (institutions) and agency (actors' framings, choices and motivations etc.). An understanding of both of these opposing forces (stability and change) is key to revealing the paradox which is at the heart of contemporary energy systems i.e. efforts to promote long term structural change running parallel to the ongoing interplay between actors, institutions and technologies which often reinforce existing structures. Section 2.3 of the chapter develops the argument which was introduced in the previous chapter regarding the changing role of the state in the governance of energy systems and how this is currently poorly conceptualised in the existing literatures. Various strands of the governance literature are discussed with a view to developing an analytical framework in chapter 3 which can reveal the underlying processes of governance which are influencing structural change in socio-technical systems and energy distribution networks in particular.

2.1 Economic and Institutional approaches

In this section approaches based on various strands of the economics literature which link institutions with infrastructure sectors are discussed; the focus being on dynamics at both the firm and industry sector levels. The study of institutions had been intermittently in vogue within various strands of the economics, sociology and political science literatures since the late 19th century with contributions from prominent authors as Thorstein Veblen, Max Weber and Alfred Marshall. As a result there are a wide range of definitions of institutions such as; '*general habits of action and thought'* (Thorstein Veblen), 'the *rules of the game'* (Douglas North), and '*modes of governance*' (Oliver Williamson) (Nelson and Nelson, 2002). Broadly however, institutions in the economic sphere generally refer to the formal and informal rules which constitute both market and non-market incentive structures. Economists who draw on institutional theory tend to share in common a critique of conventional neo-classical approaches which presume that actors are perfectly rational and that incentives in the market determine behaviour. This is particularly relevant to the study of infrastructure networks as they possess a number of attributes which make conventional micro-economic analysis less relevant and thus provide an interesting site of application for institutional theory.

Firstly, in the language of neo-classical economics, there are number of 'market failures' associated with infrastructure networks (Finger et al., 2005). *Network externalities* occur when the benefits to individual users of a network increase as the size of the network itself increases[1]; this means that infrastructures benefit from economies of scale. Also, because there tends to be large fixed cost investments with long asset lives in these sectors; over time they tend to display natural monopoly characteristics where one actor dominates the market place. Therefore, rather than being a price taker, as in an equilibrium market (i.e. 'where price equals the marginal production costs' (Vivet and Coppens, 2004)), in a monopoly situation the production costs fall as output increases thus making it more economical for one network to dominate (Vivet and

[1] Kunneke (1999) notes that 'a classical example of network externality is the telephone network, in which the benefit to end-users directly depends on the number of subscribers to the grid'

Coppens, 2004). There are also external effects associated with infrastructures because it is difficult to allocate the costs and benefits to individual parties of network services. As outlined in the introduction, infrastructures such as transport, energy and communications produce positive (e.g. economic growth) and negative (e.g. visual and noise pollution) effects which make it difficult to disaggregate costs and benefits into an appropriate pricing regime. These factors lead to a situation where;

> *"Traditional market organization is not possible or largely restricted. Often, strong governmental regulation is warranted to provide suitable economic conditions for the development of these sectors. It is very well known from textbook economics that under the circumstances of market failures private investments will not occur, or in the best case will be realized at an inferior level. Regulation or public funding is necessary to develop infrastructures under these conditions. As a consequence, traditionally the sector organization is characterized by monopolistic market structures and a high degree of vertical integration." (Finger et al., 2005)*

A second feature of infrastructure networks is that due to the fact that networks involve interactions between a vast array of technical components and actors, a wide range of both market and non-market coordinating mechanisms are required. This makes institutions a key explanatory factor in accounting for stability and change within these sectors. Two approaches which deal with the relationship between infrastructures and institutions are discussed below.

2.1.1 New Institutional Economics

One approach to institutions which has been applied to the analysis of various infrastructure sectors is a branch of New Institutional Economics (NIE) called Transaction Cost Economics (TCE). TCE focuses on 'how specific types of transactions can best be coordinated in specific types of governance structures' (Finger et al., 2005) and it has been applied to the analysis of the ways in which infrastructure sectors can be organised. The basic premise is that because the behaviour of economic actors cannot be predicted ex-ante due to information asymmetries between agents, there are various costs associated with market based transactions. Institutions, particularly formal institutions such as legal contracts which 'bind participants in economic exchanges' (Hamilton and Feenstra, 1998), become important as they can address these information asymmetries and reduce the uncertainties involved in market based transactions. Proponents of TCE argue that, depending on the nature of transactions taking place, there is an optimal mode of organisation or governance structure which can economize on or reduce the costs of transacting. If market based transactions prove to be too costly[2], a firm will tend to

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[2] The costs of enforcing contracts and exchanges between actors

carry out its activities 'in-house' through hierarchical governance structures, or alternatively it will transact with external actors where the price mechanism is relied upon to coordinate its activities.

TCE therefore recognises that markets are not alone in economic coordination and that there are a range of non-market based modes of governance based on alternative ways of organising transactions. A transaction in this sense may refer to 'the transfer of a physical good, a commodity, a legal right or a natural resource between actors' (Andrews-Speed, 2010: p.5/6) and the purpose of an institutional framework or governance structure is to maintain the integrity of the transactions taking place. Underlying this is a basic presumption that economic agents choose the most efficient governance structures i.e. they economize on transactions costs depending on the nature of those transactions. As will be discussed at the end of this section, this presumption has proved to be problematic, particularly in the analysis of long term dynamics in infrastructures, due to the implication that institutional change conforms to some abstract notion of efficiency in a functional manner. Despite this issue however, TCE has proved to be a useful tool for the analysis of network industries because it moves beyond notions of perfect rationality and provides an analytical tool to identify the heterogeneous ways in which coordination can be achieved within these sectors. The framework has been applied to the analysis of large scale technical systems such as energy networks, in particular regarding questions of how to most efficiently coordinate complex technical functions e.g. through a vertically integrated structure (hierarchy) or a more disaggregated one which relies on market based transactions to achieve the required coordination.

The origins of TCE stem from Ronald Coase's theories regarding the nature of the firm (Coase, 1937). Traditional classical approaches posited that firms operate in an economic environment where outcomes are determined by the price mechanism and can thus be treated as 'production units that result from demand for a product and from the economies of scale needed to produce that product efficiently' (Hamilton and Feenstra, 1998: p.107). Coase questioned why, if 'the price system perfectly coordinated the provision of goods and services, we would have units called firms and individuals called managers, supplying still more coordination' (Granovetter, 1998: p.67)? In the theory he distinguished as separate governance structures between markets – where the price mechanism organises activity - and firms – which are based on centralised hierarchical decision making. It was proposed that transacting in a market is not a costless activity, rather in involves frictions or transaction costs, as described above, and due to the presence of transaction costs firms exist as alternative modes of coordination to markets and the price mechanism, thus allowing economic agents to make efficient 'make or buy' decisions in the provision of goods and services. Succinctly put 'when it is costly to transact, institutions matter' (Coase, 1937).

In the following quote from his Nobel Prize winning speech, Coase points to costs associated with discovering prices and to the costs of negotiating and agreeing contracts.

> *"What the prices are need to be discovered. There are negotiations to be undertaken, contracts have to be drawn up, inspections have to be made (...) It was the avoidance of the costs of carrying out transactions through the market that could explain the existence of the firm in which the allocation of factors came about as the result of administrative decisions" (Coase, 1993: Quote from Granovetter, 1998)*

Since Coase's initial hypotheses regarding the firm as an alternative mode of governance to the market, Oliver Williamson's work has been key to advancing the transaction cost approach. His work is a key pillar of what has become known as New Institutional Economics (Williamson, 1985, Williamson, 1998, Williamson, 1979). Firstly, Williamson elucidated the behavioural assumptions which underpin transaction costs arguments. Drawing on the work of Herbert Simon (Simon, 1957) he argued that actors posses bounded rationality i.e. since 'the quantity of relevant information is great relative to the ability of humans to deal with information (…) humans often cannot deal with the entire set of relevant information, they have no alternative but to deal with only a subset' (Fransman, 1998: p.148/149). Also, Williamson stressed the fact that along with problems of asymmetric information, actors can behave opportunistically which he defines as 'self-interest seeking with guile' (Williamson, 1985). Therefore the source of transaction costs emerge from the 'imperfect subjective models of the players as they attempt to understand the complexities of the problems they confront' (North, 1990: p.8) and can lead to inefficient allocation in a market context. By drawing on a diverse set of literatures ranging from political science, law, sociology and cognitive science, Williamson has developed his approach to provide new insights into the dynamics of industrial organisation more broadly where '…the modern corporation is mainly to be understood as the product of a series of organizational innovations that have had the effect of economizing on transaction costs' (Williamson, 1985: p.275).

There are a number of characteristics of his approach (Williamson, 1985):

- The firm is a governance structure rather than a production function
- There are non-market interactions and complex forms of contracting
- Institutions economize on transaction costs and the unit of analysis is the transaction. 'Transaction costs are economized by assigning transactions (which differ in their

attributes) to governance structures (the adaptive capacities and associated costs of which differ) in a discriminating way' (ibid: p.18)

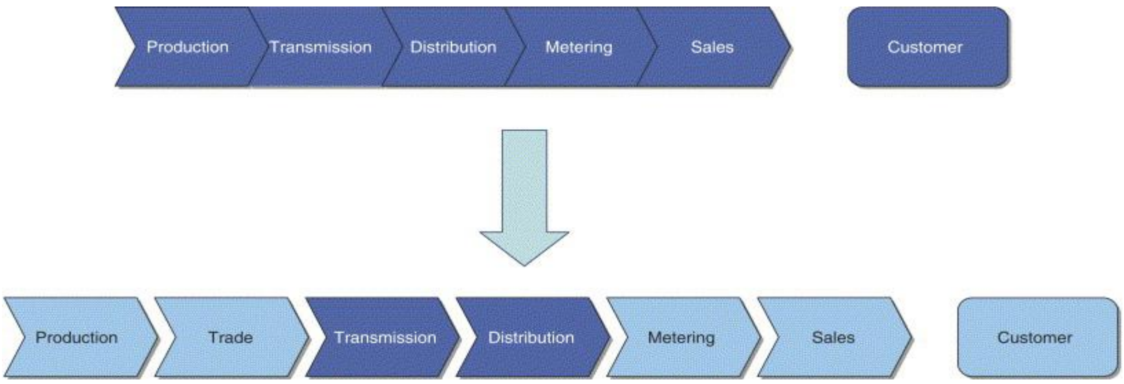
- Problems are reduced to contractual issues which involve prices, hazards (e.g. opportunism) and safeguards (e.g. legal contracts)

TCE insights regarding the distinction between markets and hierarchies and its emphasis on problems of governing transactions have been utilised in order to explain the dynamics of network industries in a number of ways which are described below.

Vertical Integration and Network Regulation

The concepts outlined above relating to the distinction between markets and hierarchies have been operationalised in order to account for structural dynamics in network industries. In particular this is in the context of the ongoing processes of liberalisation and privatization which has seen the unbundling of previously integrated value chains in sectors such as telecoms, water and electricity. The figure below shows this process for the case of the electricity industry:

Figure 2.1: The electricity value chain



Source: (Künneke and Fens, 2007)

Traditionally, network industries such as electricity were organised on a hierarchical basis where all of the technical functions were centrally coordinated. For example, in the case of the electricity industry in the UK, generation plants and the networks of transmission and distribution were all owned and operated by publicly owned organisations who then planned and operated the system in a coordinated and integrated fashion. This is known as vertical integration; 'where a single ownership entity spans both sides of the transaction' (Williamson, 1985: p.78). In more recent decades there has been a trend towards the privatisation and liberalisation of such industries and this has necessitated the unbundling or separation of the different technical functions in order to separate the natural monopoly segments (networks) from the areas where competition is possible (generation, metering and retail).

It is generally recognised that for the case of network segments of such value chains, typical market based transactions where prices can be revealed cannot occur. Viewed through the lens of TCE, the transactions which take place in these infrastructure sectors tend to be more complex than typical market based transactions. This is because they are characterised by asset specificity or 'investments actors make specifically for the transaction at hand' (Finger et al., 2005). Many transactions in infrastructure sectors are dependent on the presence and operation of a physical network e.g. a new electricity generator seeking connection to a distribution network or a potential customer seeking access to a heating network. This means that unlike market based transactions where actors can freely trade standardized goods and services, infrastructure sectors are characterised by what is known as the 'hold-up' problem i.e. parties to a transaction become reliant upon each other, thus increasing the likelihood of opportunistic behaviour. In order to illustrate the approach in more detail, the table below which was developed by Williamson, identifies governance arrangements which are best suited to different types of transaction based on their frequency (occasional or recurrent) and whether they are made more complex by asset specificity i.e. they are idiosyncratic.

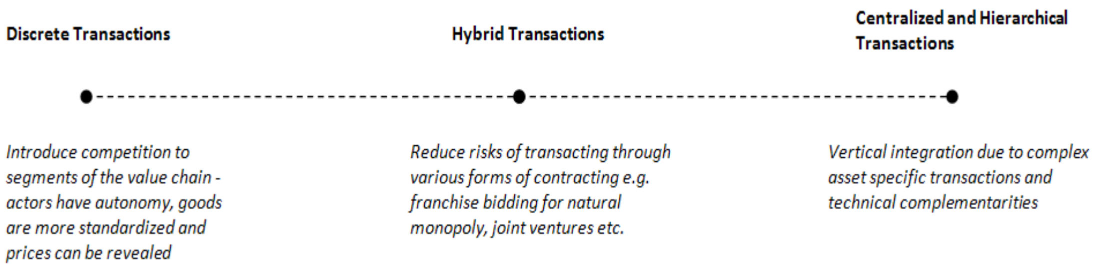
Table 2.1: Types of Transactions and governance structures

	Investment Characteristics		
Frequency	Non-specific	Mixed	Idiosyncratic
Occasional	Market governance	Trilateral governance (neoclassical contracting	
Recurrent	(classical contracting)	Bilateral governance (relational	Unified governance governance)

Source: (Oerlemans et al., 1993). Originally from Williamson (1985)

Some argue that due to the non-standardized nature of transactions taking place in infrastructure sectors and the need for technical complementarities in order to ensure the functioning of the system as a whole, vertical integration or unified governance is the most efficient mode of coordination in some infrastructure sectors (Michaels, 2006 for the case of electricity). On the other hand, proponents of liberalization would argue that exposing segments of the value chain where possible to competition promotes more efficient investment decisions and system operation. The figure below identifies some of these arguments for the case of infrastructure sectors.

Figure 2.2: Transactions and modes of coordination in infrastructures



There are a number of implications of taking a TCE perspective when analysing the governance and dynamics of network industries in a liberalized context. Firstly, prominent neo-classical economists had argued that it is possible to deal with the problems of natural monopoly through ex-ante measures such as franchise bidding, i.e. competition for monopoly, therefore avoiding the need to regulate such sectors (Demsetz, 1968). TCE suggests that because of asset specificity and the significant risks of opportunistic behaviour in infrastructure investments, 'Competitive pressure is important in both ex ante (before the contract is signed) and ex post (after the contract is signed) situations' and therefore 'Post-contractual competition is important to prevent the supplier from opportunism' (Finger et al., 2005). Using TCE arguments, Williamson (1976) notes that depending on the nature of transactions taking place, the regulation of natural monopoly may in fact be the least costly way of coordinating such industries due to the potential risks associated with market based transactions. These investment risks include the risks to private investors of government opportunism (the benefits of an investment may be passed on to customers in the form of lower prices rather than shareholders) and the risks to customers of monopoly pricing (as there is typically only one network) – the independence of a regulator is therefore often highlighted. Along with distributing economic rents, a second implication of TCE is that in some circumstances network regulation can help to reveal information and prices in a more effective way than market based arrangements. As we will see in the case of the governance of electricity distribution systems in the UK, these issues relating to investment risk, the role of an independent regulator and unbundling have become an important part of the regulatory landscape in a liberalized environment.

Assessing the performance of Infrastructures

A second operationalisation of NIE theory has been in assessing the technical performance of infrastructures, particularly in the light of a number of technical failures which have occurred in network industries e.g. electricity blackouts in Italy and the north eastern states in the US, and a number of rail accidents in the UK during the 1990s. While the application of TCE to issues of sector organisation which were discussed above concentrate on investment decisions, the following application of TCE is more focused on technical and operational issues.

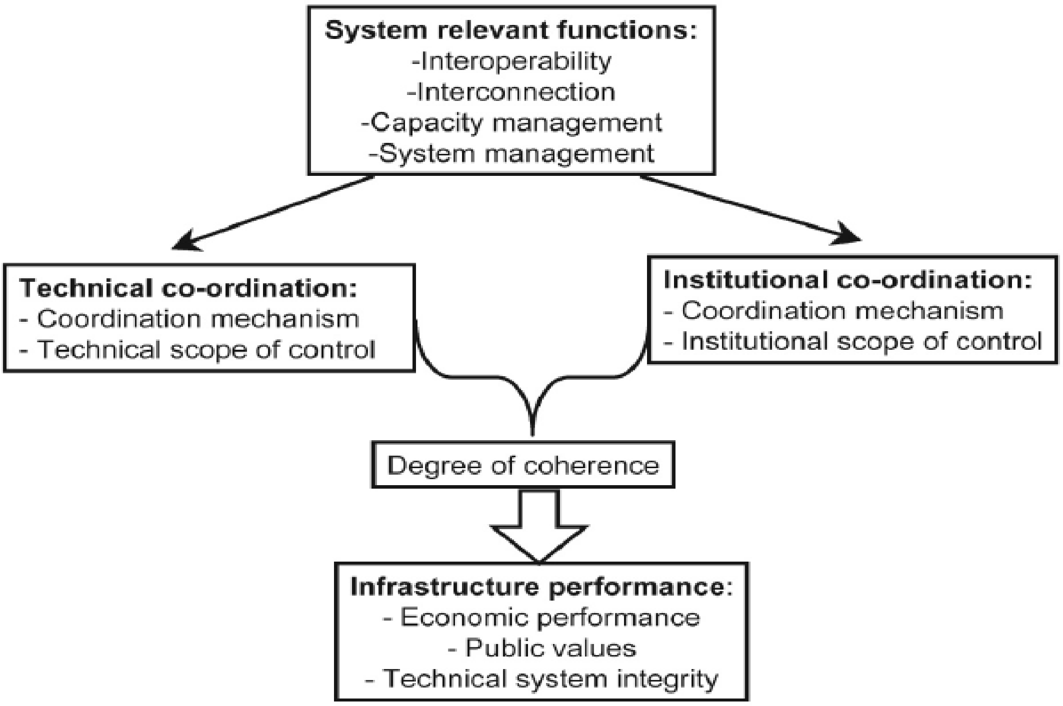
It has been noted within the literature that TCE approaches to infrastructures have tended to neglect the technical characteristics of the different networks under study:

> *"…this [TCE] is mostly a partial analysis, i.e., an analysis where the transactions are analyzed in isolation from the technological and socio-political system. Technology comes into the analysis mainly in terms of asset specificity, but not as a system element, which coevolves with the institutional governance structure (Finger et al., 2005)*

It is of course important for a comparative analysis of socio-technical dynamics in electricity and heat distribution networks to take into account the technical features of each of the systems. One important difference with electricity systems is that in order to retain system integrity there must be a real-time balance between supply and demand, and this is made more difficult as it is difficult and costly to store electricity. Heating systems do not have this technical requirement however there are complexities involved with CHP-DH systems as they serve both local heat markets and electricity markets which operate at a national scale in the UK – this makes the transactions involved more complex.

A number of researchers have proposed a co-evolutionary framework which looks in more detail at the interplays between technical functions of a system and the institutional arrangements which govern the system in question (Finger et al., 2005, Künneke et al., 2010, Künneke, 2008). The hypothesis is that 'the technical functioning of infrastructures needs to be supported by suitable institutional regimes in order to perform satisfactorily' (Finger et al., 2005: p.229) and that the restructuring of network industries has brought about 'a tension between the technical requirements for system coordination and the economic organization of liberalized infrastructures' (*ibid*: p.231). The focus is firmly on ensuring the technical integrity, service quality and safety of networked infrastructures and achieving a balance between the economic and social good outputs of networks in the context of a liberalised governance structure where networks are owned and operated by private actors. A framework based on achieving coherence between these requirements which is based on a number of critical technical transactions is outlined in the figure below:

Figure 2.3: Coherence Framework



Source: (Finger et al., 2005)

The critical technical transactions they outline can be summarised as follows (Finger et al., 2005):

- Interoperability: This is achieved ‘if mutual interactions between network elements are enabled in order to facilitate systems’ complementarity’. Standardization (e.g. of voltage and frequencies in an electricity system) is a key variable in this critical transaction as it ensures that the various individual components of the network can operate in a coherent manner.
- Interconnection: This deals with ‘the physical linkages of different networks that perform similar or complementary tasks’. A case in point is a CHP-DH system where a CHP plant inputs to both an electricity and heat network and often relies on a gas grid for energy input, in this case there needs to be adequate interfaces between a number of different networks.
- Capacity management: Capacity is the valuable economic commodity of a network. In a liberalised environment, capacity management, which refers to ‘the allocation of this

scarce network capacity to certain users or appliances', has become crucially important. There is often a mixture between market based allocation (e.g. wholesale electricity markets) and centralised management based on hierarchy (e.g. a system operator), depending on the technical requirements of the system and the governance regime.

- System management: This 'pertains to the question of how the overall system (e.g., the flow between the various nodes and links) is being managed and how the quality of service is safeguarded'. In the electricity system for example real-time balancing between supply and demand is required, while in the case of CHP-DH schemes, issues can arise where local systems need to operate in a coherent manner with national level electricity markets. Due to the large scale nature of infrastructure networks and the trend towards unbundling and fragmentation, coordination between a wide range of actors is crucially important.

These critical transactions 'are essential for guaranteeing the technical functioning of the system, thus imposing constraints on the mode of organization' (Künneke et al., 2010: p.499). Institutions need to be designed in order to fulfil these technical requirements, whether this is a centralised top-down design (vertical integration) or more reliant on bi-lateral contracts or market based real-time transactions. As Oliver Williamson notes, the aim is to align transactions and institutions 'in a discriminating way' (Williamson 1985: p.385).

Summary of the TCE approach

This TCE framework provides a useful analytical tool to uncover the specific micro-economic characteristics of network industries and provides insights into the range of governance models which can be adopted to coordinate activity in such sectors. The operationalisation of TCE for these purposes highlights the importance of recognising the technical characteristics of different infrastructure sectors and the specific nature of transactions taking place. In the next chapter, the analytical framework which is to be adopted for the comparative analysis draws on a number of these insights, particularly in relation to the need to achieve a necessary level of technical coordination. Also, as has been noted with regard to issues of environmental governance, NIE 'is based on the concept of interdependence rather than that of externality' (Paavola, 2007) and thus provides a useful analytical tool for the analysis of sectors involving technical complementarities and coordination between a range of actors.

However, because the purpose of this research is to analyse the long term dynamics of distribution networks, this framework alone cannot be relied upon. Firstly, as briefly outlined above, TCE assumes that institutional change occurs in a functional manner where actors choose the most efficient governance structure. As will be discussed below, a number of studies have shown that institutional and technical change in network industries, particularly when viewed from a longer term perspective, does not conform to some abstract notion of efficiency such as economizing on transaction costs. The following quote from Granovetter and McGuire's study of long run dynamics in the US electricity supply industry illustrates the difficulties in using theoretical models such as TCE in isolation to predict the outcomes of complex socio-technical processes:

> *"One implication of our approach is that at several historical junctures quite different outcomes might have emerged, and had this occurred it would likely have been argued, as it has for actual outcomes, that* those *were the most economically or technically efficient"(Granovetter and McGuire, 1998)*

Therefore, while TCE analysis is a useful micro-analytical tool to study short term dynamics in infrastructure sectors such as energy distribution, it loses some of its explanatory power as the time horizon lengthens. Also, because NIE tends to focus on short run static efficiencies, it does not incorporate the undoubted influence of technological innovation, particularly processes of radical innovation which characterise more fundamental transitions in broader socio-technical systems (Geels, 2004, Foxon, 2003). It is recognised however that a number of significant contributions to the NIE literature have sought to move away from this functional perspective and explore the embededness of economic institutions of broader socio-institutional environments (Williamson, 1998) and the influence of more informal institutions such as culture in processes of long term economic change (North, 1990). These more recent studies tend to take a more long term evolutionary perspective to processes of change – this perspective is outlined in the following section.

2.1.2 Evolutionary Approaches: Incorporating Technical Change

The central thesis behind the evolutionary economics perspective is that economies are 'complex adaptive systems' which operate out of equilibrium and are populated by agents with heterogeneous capabilities (Foxon, 2010). Markets are not seen as deterministic, rather they form part of a wider selection environment. Changes in industries or sectors are underpinned by an evolutionary logic which is characterised by generic processes of variation (across a population of agents or firms), selection and retention, and rather than being functional and predictable, economic change is characterised by periods of stability/inertia, and shorter periods of more radical change. The work of the Austrian economist Joseph Schumpeter (Schumpeter, 1939, Schumpeter, 1934) has informed much of this literature in a number of ways, in particular his insights into the innovation process. Schumpeter proposed that innovations, which can be 'new combinations' of technologies, materials, organisational models or processes, are the engine of growth in a capitalist system and he argued that technological competition between firms within a sector is as important as price based competition:

> *" ... in capitalist reality as distinguished from its textbook picture, it is not that kind of competition that counts but the competition from the new commodity, the new technology, the new source of supply, the new type of organization (...) - competition which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives" (Schumpeter, 1954: p.84. Quoted from (Fagerberg, 2009))*

Malerba (2002) distinguishes between two types of innovation in Schumpeter's writings: The first is brought about by entrepreneurs (individuals or new firms) who, rather than being inventors in a conventional sense, fulfil this function of combining existing knowledge with new ideas to bring about 'creative destruction' – Malerba terms this Schumpeter Mark I. The second, or Schumpeter Mark II, is characterised by a process of accumulation rather than creative destruction, with 'large established firms and the presence of relevant barriers to entry'(Malerba, 2002). Freeman and Perez (1988) have argued that over time the interplay between these two types of innovation - radical and incremental - characterise structural changes within economies, or technological revolutions such as the industrial revolution or the information age (See also: Freeman and Louçã, 2001, Perez, 2002). These two types of innovation are of course both relevant to distribution networks; for example, CHP-DH systems in the UK are not mainstream technologies and rely on a dispersed set of local actors who act in an entrepreneurial fashion. Electricity distribution sectors on the other hand are characterised by incumbent actors which are mainly large multi-national firms. It is therefore highly likely that the nature of innovation and the diffusion process across the two cases will differ along these lines as outlined by Franco Malerba.

This approach would argue therefore that dynamics in infrastructure sectors, such as changes to the value chains, should be considered in a more systemic way involving ongoing changes in the technological, organisational and institutional selection environment of such sectors - rather than solely focusing on changes to the nature of transactions taking place. Richard Langlois summarises this dynamic view of industrial change:

> *"Industrial structure is thus an evolutionary design problem. It is also a continually changing problem, one continually posed in new ways by factors like population, real income, and the changing technology of production and transaction" (Langlois, 2003)*

Another strand of evolutionary economics places the focus on the characteristics of the firm. Similar to NIE, evolutionary approaches reject notions of the firm existing solely as a production function (Nelson and Winter, 1982). However, rather than seeing the firm as a governance structure or a 'response to information-related problems' as in TCE, a firm is viewed as a 'repository of knowledge' (Fransman, 1998). Nelson and Winter (1982) proposed that firms are constituted by organisational routines or 'relatively simple decision rules and procedures' similar to search heuristics which are 'used to guide action' (*ibid*: p.139). Contrary to neo-classical approaches therefore, a firm's choice set is constrained, not only by limited ability process information, but also by its ability to develop and store knowledge.

Informed by a resource based view of the firm (Penrose, 1959), the concept of the routine has been forwarded (Nelson and Winter, 1982, Nelson and Sampat, 2001). Routines, or search heuristics, are developed by a firm through learning processes in order to enable them to engage in complex processes and to survive in a dynamic selection environment. Such cognitive processes define the capabilities of firms and act as a key source of variation within organisations and across sectors of the economy. These routines are stores of knowledge which allow firms to engage in complex processes and to 'render predictable…the response of a firm to its changing environment' (Fransman, 1998). For example, in the event of an electrical fault on an electricity distribution line, a network operator will have written procedures which will be followed in order to address the issue e.g. by rapidly dispatching a team of line workers and dealing with safety issues. Over time, as these procedures are refined they will most likely become less formal and eventually develop into rules of thumb based on tacit knowledge which allow an operator to carry out multiple such complex procedures. However, routines can also be a source of inertia if new technologies or processes cannot be incorporated into the existing organisation. It has been found that successful firms can gain competitive advantage by adapting their routines in increasingly dynamic environments where the pace of technical change is rapid (Teece and Pisano, 1998).

These concepts provide useful insights for the analysis of distribution networks because infrastructure sectors are characterised by complex technical processes and dynamic institutional environments. For example, although local actors who develop heat networks may be characterised as innovative entrepreneurs, in the long run they will need to develop their knowledge and routines through learning processes in order to operate and survive in a competitive and complex institutional environment. Also, the ongoing processes of the de-integration of infrastructure value chains could be viewed in terms of large multi-national energy corporations seeking to gain competitive advantage by specialising on one particular function rather than spreading their scarce resources across the whole value chain, resulting in an alternative form of division of labour in a more complex technical and selection environment (Langlois, 2003, Piore and Sabel, 1984).

Long Term Institutional Change in Infrastructures

One implication of taking this longer term or evolutionary view involving dynamic interactions between new technologies and organisational forms, is that institutional change is not viewed as an efficient or predictable process but in terms of 'the path-dependencies and unintended consequences that result from such historical development' (Schmidt, 2010). As noted above, institutions such as organisational routines within firms do not necessarily change in a rational objective manner; rather their options are constrained by their limited and unique capabilities and uncertainty regarding the external selection environment. Sector level structures are therefore fluid and continually being shaped and redefined by technical and organisational change. Evolutionary theorists propose that such ongoing and contemporary dynamics cannot be studied in isolation, this is because the historical chain of events tend to have a bearing on the future directions or paths of institutional change i.e. 'preceding steps in a particular direction induce further movement in the same direction' and where the 'probability of further steps along the same path increases with each move down that path' (Pierson, 2000). This perspective, known as path dependency (David, 1985) or historical institutionalism (Schmidt, 2010, Hall and Taylor, 1996), is summarised in the following quote from one of its originators, Paul David:

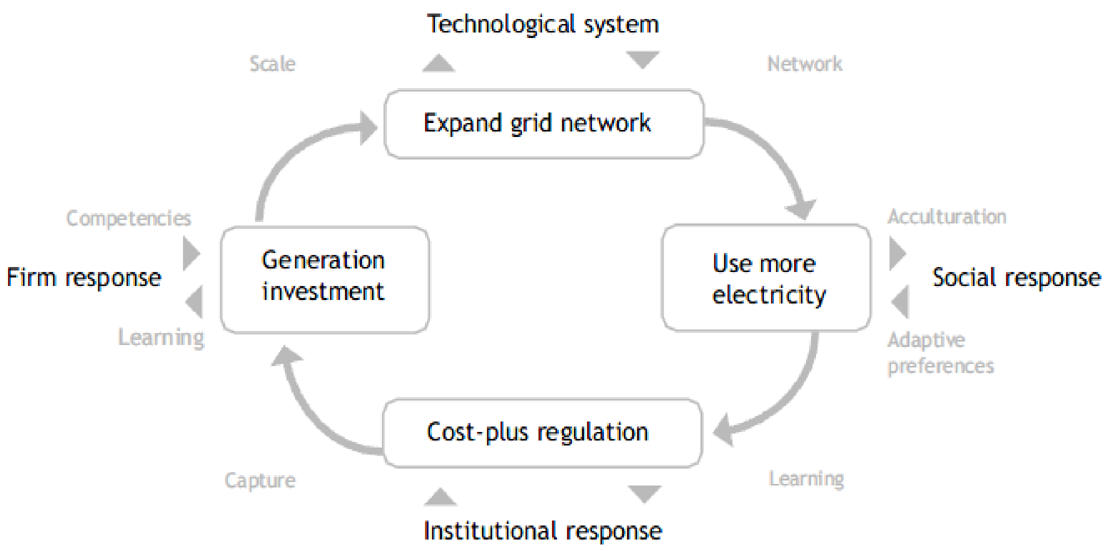
> *"A path-dependent sequence of economic changes is one of which important influences upon the eventual outcome can be exerted by temporally remote events, including happenings dominated by chance elements rather than systematic forces. Stochastic processes like that do not converge automatically to a fixed-point distribution of outcomes (...) 'Historical accidents' can neither be ignored, nor neatly quarantined for the purpose of economic analysis; the dynamic process itself takes on an essentially historical character" (David, 1985)*

This has important implications for the analysis of institutional change: First, actors cannot simply switch between alternatives in order to achieve an efficient outcome in the objective sense, as proposed in NIE or rational choice models, and second, that seemingly unimportant events along a chain can have 'unintended consequences' which can constrain future decision making and potentially lead to sub-optimal outcomes. The classic example of this is the QWERTY keyboard interface which David argues has persisted despite the presence of competition from more efficient alternatives (David, 1985). In a later paper, David and Bunn (1988) make similar arguments for the emergence of centralised electricity systems; they argue that the so called '*battle of the systems*' between d.c and a.c network standards during a short period during the 1880s had a large part to play in shaping the future structure of centralised electrical power systems which persist to this day.

In a number of influential contributions recently made by Gregory Unruh (Unruh, 2000, Unruh, 2002), the argument has been forwarded that due to processes of path dependency, modern industrial systems such as energy infrastructures have become locked in to a high carbon emitting trajectory or pathway. Unruh draws on the work of Brian Arthur[3] (Arthur, 1989, Arthur, 1994) to argue that contrary to conventional technical diffusion models, where due to the competitive process technologies experience decreasing returns over time, in certain cases technologies can benefit from increasing returns due to scale economies, learning effects, adaptive expectations and network economies which create positive feed-back loops between a technical system and its environment. It is argued that as a result of these processes a dominant design such as a fossil fuel based energy infrastructure emerges and over time is reinforced by organisational and institutional changes to create a stable system which perpetuates a lock-in to a carbon intensive trajectory. This process is explained in the figure below for the case of an electricity system:

[3] Arthur discusses the adaptation of technologies under competition. He proposes a model where, rather than an optimal process with a stable and predictable equilibrium (under a presumption of diminishing returns), technological change under competition can display multiple equilibria and the potential for multiple outcomes under increasing returns. In the model, random events, timing, and strategy can contribute to the uptake of a potentially inferior technology where 'the more they are adopted, the more experience is gained with them, and the more they are improved'. There are a number of contributory factors to the presence of such positive externalities including scale economies, learning economies, adaptive expectations and network economies (Arthur, 1994).

Figure 2.4: Lock-in to carbon intensive energy systems



Source: (Foxon, 2003); originally sourced from (Unruh, 2000)

This coevolutionary process resulting in carbon lock-in is termed a Techno-Institutional Complex (TIC) which is summarised as follows:

> *"TIC arise because large technological systems, like electricity generation, distribution and end-use, cannot be fully understood as a set of discrete technological artefacts but have to be seen as complex systems of technologies embedded in a powerful conditioning social context of public and private institutions" (Unruh, 2000: p.818)*

This concept of a TIC is important for the analysis of socio-technical dynamics of infrastructures as it shows how large scale technical systems such as distribution networks, if understood in this systemic fashion, tend to become paradigmatically structured (Dosi, 1982) along potentially technically and/or socially sub-optimal trajectories where choice or switching between alternatives is constrained.

Understanding Innovation Processes

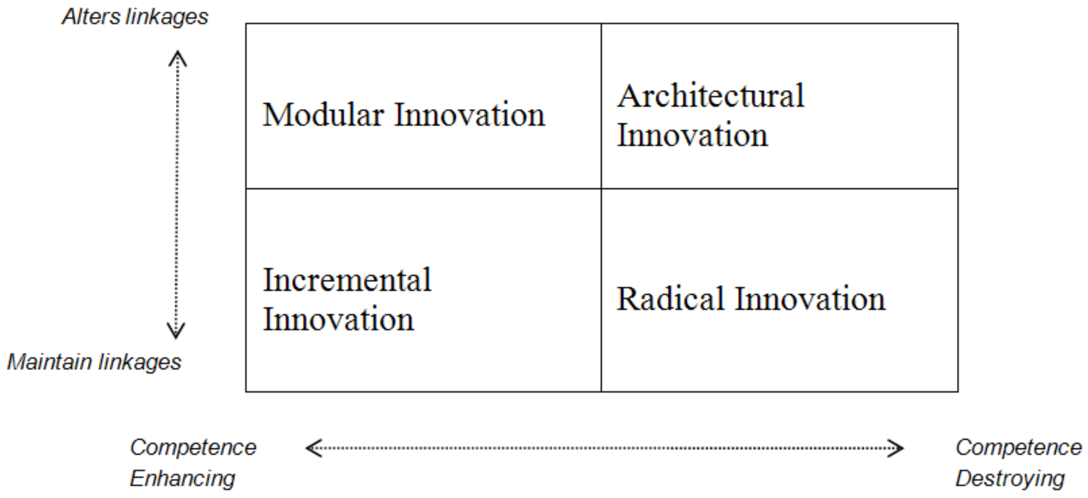
A second application of evolutionary thinking to infrastructures is developing a greater understanding of the nature of the innovation process itself. In order to understand the implications of different types of innovation various strands of the evolutionary based literature have developed early Schumpeterian hypotheses regarding the uncertainty of the innovation processes and uneven diffusion patterns to outline an industry lifecycle model (Klepper, 1997, Henderson and Clark, 1990, Abernathy and Clark, 1985). They propose that in the early stages of an industry lifecycle there are a large number of competing firms engaged in radical innovation processes which are typically involved in the development of new products. Over time however, as described in the literature on path dependency and lock-in, a dominant design emerges which becomes institutionalised as firms pursue a particular technological trajectory (Dosi, 1982) which is characterised by technical standards (Garud et al., 2002) and engineering practices (Nelson and Winter, 1977). The nature of innovation in this phase tends to be incremental and process orientated rather than product type innovations. As the process continues, an industry 'shakeout' occurs where the market becomes increasingly concentrated leading to the emergence of a small number of large firms.

These processes are particularly relevant to large scale technical systems such as energy distribution networks which involve a design hierarchy with components, sub-systems and systems (Murmann and Frenken, 2006). In this model 'incumbent firms are rarely the source of radical innovations…it is entrepreneurial entrants that challenge and overthrow an existing dominant design' (Unruh, 2000: p.822). This ongoing interplay between incumbents (associated with a dominant design) and entrepreneurial actors will be an important factor the long term dynamics of energy systems (Verbong and Geels, 2007). For example there will likely be a good deal variation in terms of technologies and practices adopted in different district heating schemes in the UK while it is more likely that electricity distribution companies will be more focused on exploiting an existing technical system using process innovations.

Interestingly, Christensen (1997) proposes that established firms and industries can become de-institutionalised following the emergence of 'disruptive technologies' which are similar to anomalies in changing scientific paradigms (Kuhn, 1962). In some cases these disruptive technologies can lead to the creation of new technical paradigms (Dosi, 1982); for example the development microprocessors has been central to the creation of new ICT based industries and has fundamentally changed the characteristics of infrastructure sectors such as telecommunications (Perez, 2002). The extent to which such disruptive technologies can affect incumbent firms in established industries is related to the impact they have at different levels of the design hierarchy (Murmann and Frenken, 2006). For example, in some cases incorporating a new technology may simply involve a reorientation of a small number of system components thus allowing a firm to reorientate its routines and adapt. On the other hand, if a new technology cannot be accommodated by existing systems and necessitates changes higher up on the design hierarchy, the core competencies and value networks of firms dominating an industry can be fundamentally undermined leading to structural changes (Christensen and Rosenbloom, 1995). A potential example of such a disruptive technology is decentralised energy generation which in many ways alters the systemic characterises of energy systems, but it is as yet unclear as to what impact their diffusion will have on the overall structure of energy sectors.

In order to utilise these insights for analysing the socio-technical dynamics of energy networks, Bolton and Foxon (2011) have proposed a typology of innovation types which occur in infrastructure networks – this draws from the innovation typology of Henderson and Clark (1990):

Figure 2.5: Characterising forms of innovation in infrastructures[4]



Source: (Bolton and Foxon, 2011); 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,

[4] This figure and the explanation below draw from Bolton and Foxon (2011)

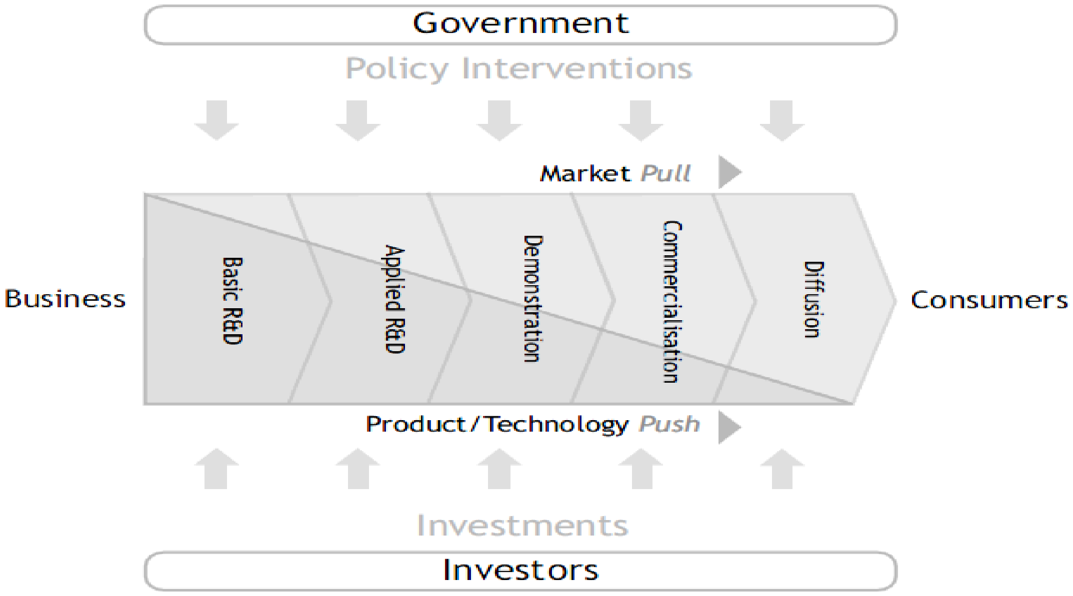
radical innovations are often confined to market niches but periodically can benefit from dramatic performance improvements and overturn previously dominant systems.

- 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 and non-technical components of the system. For example, as outlined by David and Bunn (1988), the invention of the AC transformer and the rotary converter in the 19th century prompted a move away from small urban DC electrical systems towards large scale AC synchronous systems (Hughes, 1983). Such innovation is often controversial as it undermines sunk investments in infrastructures 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.

In the case of infrastructures and energy systems in general, these types of innovation processes cannot be analysed solely in the context competitive forces between private actors as might be the case in conventional industrial sectors. The socio-economic characteristics of network industries mean that these innovation processes will be shaped by a wide array of both public (e.g. various government departments, regulatory bodies, local authorities etc.) and private (network operators, multi-national energy companies, sub-contractors, and engineering companies) actors.

The innovation systems strand of the evolutionary literature provides some insights into how these interactions might work and the types of relationships which emerge between these different innovation processes and institutions. Lundvall (1992) defines an innovation system (IS) 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 (Nelson, 1993, Lundvall, 1992), sectoral (Malerba, 2002), and individual technological levels (Stankiewicz and Carlsson, 1991). Firstly, the IS literature expands earlier innovation models which viewed innovation as a linear flow from basic scientific R&D to commercialisation, and broadened Schumpeter's earlier distinction between inventions, innovation and diffusion to consider the wider systemic interactions that take place between a range of actors - as described by the innovation chain:

Figure 2.6: The Innovation Chain



Source: (Foxon, 2003)

The traditional neo-classical economic approach to innovation had argued that due to knowledge spillovers and the ability to appropriate new technologies, investment in R&D is a market failure warranting public support as individual actors such as private firms lack sufficient incentives to invest (Foxon, 2006). The systems approach expands upon this argument and proposes that innovation systems are highly dynamic and complex institutional environments; thus in many circumstances successful R&D does not necessarily lead to commercialisation, often due to an institutional selection environment which favours incumbent technologies. It has been argued that for cases where innovation may be beneficial to society as a whole, e.g. low carbon technologies, this provides a rationale for expanding publically funded R&D programs to support new technologies along different stages the innovation chain (Foxon, 2003).

Hendry and Harbourne (2011) note that: 'These insights contribute much to the understanding of innovation as a complex uncertain non-linear process, and underline the deficiencies of R&D-led technology push'. Studies of the diffusion of renewable technologies in different countries (Jacobsson and Bergek, 2004, Foxon et al., 2005, Negro, 2007) have shown how the creation of an institutional context or a suitable selection environment for technical change is essential for the uptake of energy technologies and gives us some insight into the roles that different actors can play in this. 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 commercialisation. 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:

1. ‘The creation and diffusion of ‘new’ knowledge’
2. 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
3. To ‘Supply Resources’ e.g. capital and competencies
4. To ‘create positive external economies’ across an industry by creating linkages, exchanging information and knowledge through networks; thus reducing uncertainty, risk and creating synergies.
5. The ‘formation of markets’ for new technologies

The IS framework elucidates the innovation characteristics of energy systems and gives us some insight into the interactions between public and private actors and the causal links between institutions and technical change.

Summary of the Evolutionary Approach

The various strands of the evolutionary economics literature outlined above provide a number of insights which are relevant to the analysis of socio-technical dynamics in energy network contexts. By focusing on the dynamic interactions between technologies and organisations rather than solely on short-term responses to changes in transaction costs, the evolutionary approach draws attention to the path dependent nature of long run institutional change and the potential for lock-in and sub-optimal outcomes. This is in contrast to the TCE approach where institutional change is predictable and functional, in that it conforms to an objective efficiency criterion. It is proposed that the evolutionary account of institutional change provides a more realistic framework as it recognises that there are different types of actors or firms (incumbents and entrepreneurs) who engage in a range of innovation processes. An analysis of energy distribution networks should take into account these ongoing and dynamic interactions between actors, institutions and technologies and also outline the historical context within which they are occurring.

It is argued however, that evolutionary approaches tend to reify technology as a source of change and do not recognise sufficiently the fact that sources of variation often emerge from political and institutional dynamics; this is particularly the case for sectors such as energy networks which have social good characteristics. Within this framing, actors tend to be presented as being passive and subject to the inevitable forces of creative destruction where radical technical changes emerges from 'left-field' rather than being shaped by the strategic actions of both public and private actors. Also, there is often a tendency to present institutions in binary terms as either barriers or enablers to innovation or as neutral dependent variables which are subject to change by technologies e.g. institutions need to 'catch-up' with the increasingly rapid pace of technical change. This view is illustrated in the following quote which proposes that the organisational changes occurring in the 1950s and 60s which led to the development of large corporations[5] can be attributed to 'needs' of technology:

> *"The managerial revolution Chandler chronicles was the result of such an imbalance, in this case between the coordination needs of high-throughput technologies and the abilities of contemporary markets and contemporary technologies of coordination to meet those needs."* (Langlois, 2003)

This argument will be developed in the next chapter where, drawing on insights from science and technology studies and sociological approaches to institutions, a deeper and more comprehensive view of the dialectic between infrastructures and institutions is developed.

2.2 Socio-Technical Approaches

The second section of the review discusses a set of literatures which broadly stem from a branch of Science and Technology Studies (STS) termed the Social Shaping of Technology (SST) – this field of research can be categorised as socio-technical approaches. Although the NIE and evolutionary economics literatures outlined above provided valuable insights into processes of change and inertia in energy distribution sectors, the emphasis tended to be placed on structural and institutional mechanisms rather than the micro level conflicts and commonalities which will emerge between a wide array of both public and private stakeholders with individual perspectives and framings. While it is important to analyse overarching institutional dynamics such as the liberalisation of network industries and the ensuing technical changes which are occurring, this cannot be properly analysed in isolation from the various motivations and strategies of a diverse array of actors. Frank Geels outlines the basic premise behind a socio-technical approach which distinguishes it from economic or technology orientated treatments.

> *"Artefacts by themselves have no power, they do nothing. Only in association with human agency and social structures and organisations do artefacts fulfil*

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[5] This was documented in the work of the business historian Alfred Chandler (Chandler, 1990)

functions. In real-life situations (e.g. organisations, houses, cities) we never encounter artefacts 'per se', but artefacts-in-context. For the analysis of functioning artefacts, it is the combination of 'the social' and 'the technical' that is the appropriate unit of analysis" (Geels, 2005: p.365)

Although the evolutionary literature did highlight the fact that firms differ in their capabilities to innovative, it perhaps does not offer adequate insight into the contested nature of technical change and the roles of non-firm actors such as the state. It is undoubtable that due to the economic and social importance of infrastructure sectors, a process such as the liberalisation and privatisation of energy sectors is the emergent outcome of social processes and is an ongoing fluid processes - rather than a static outcome - which is continually being shaped and reshaped by the contested nature of socio-technical dynamics.

A central motivation behind the development of the socio-technical literature has been a rejection of technical determinism[6] i.e. where 'Technologies change, either because of scientific advance or following a logic of their own; and they then have effects on society' (Mackenzie and Wacjman, 1999: p.3); rather proponents seek to promote a more actor centric view. Following our discussion of evolutionary and NIE approaches to the analysis of the dynamics of infrastructures, it is proposed that while they cannot be accused of technological determinism in its purest sense per sae, socio-technical approaches can offer some valuable insights, particularly with respect to the emergence of infrastructures and the interface between the technological systems and wider society. For example, a number of studies have highlighted the ways in which infrastructure sectors have been shaped by social forces - the following quotes from two historical studies of the emergence of electricity systems highlight this:

"…most large, multi-component and multi-agent network systems did not emerge full-blown in the forms that they have come to assume. Only rarely will such systems be found to have fully and faithfully realized the initial integrated design concept of some single sponsoring agent. Rather, systems such as the railroads, electric-light and power utilities, and telephone networks should be regarded as both society-shaping and 'socially constructed'." (David and Bunn, 1988)

"We conclude that the electric utility industry was born not of Benthamite Equations or optimizing rationality, but longstanding friendships, similar experiences, common dependencies, corporate interlocks, and active creation of new social relations." (Granovetter and McGuire, 1998)

[6] This refers to conformity to a particular form of rationality e.g. technical or market. Technological determinism assumes that technology imposes itself in a linear manner on society according to some inherent inner logic.

And for the case of heating systems, Jane Summerton outlines how a small number of local actors interacted with the incumbent energy sector in developing a CHP-DH scheme in a Swedish town in the 1980s:

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

Although there are some similarities here with the evolutionary approach, in particular the notion of path dependency, the socio-technical approach tends to emphasise to a greater degree the importance of agency and the contextual development of a particular technology, rather than underlying processes of economic or institutional change. This is summarised by Edge and Williams:

> *"In contrast to traditional approaches which only addressed the outcomes or 'impacts' of technological change, this work examines the content of technology and the particular processes involved in innovation" (Edge and Williams, 1996)*

The socio-technical approach is not a single unified theory; rather it is a research agenda which seeks to present contextualised accounts of technical change where contingency and agency are central to the analysis. A number of strands of this literature have discussed the dynamics of infrastructures more explicitly.

2.2.1 Social Construction of Technology

There are quite a number of approaches in this strand of the literature (see Edge and Williams (1996) for a useful overview) however in common they reject technological determinism and argue that technical change tends to be the outcome of a political processes rather than simply a question of cost or efficiency advantages. One prominent approach to this is the social construction of technology (SCOT). This explicitly rejects notions of a directionality ascribed to processes of technical change e.g. trajectories or paradigms[7] (Bijker, 1995, Bijker and Law,

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[7] Notions of paradigms and trajectories proposed by evolutionary theorists are problematic within SST as they are 'predicated upon the maintenance of a stable set of social, economic and technical forces, which serve to generate the necessary uni-directionality of technological development'. The work of Chris Freeman and Carlota Perez on techno-economic paradigms has attracted criticism in this respect 'for its tendency to treat technology in an over-generalised way, and sometimes to see technological change, deterministically, as the motor of socio-economic change' (Edge and Williams, 1996). However later work by Freeman and Louçã (2001) has been more sensitive to interactions between technology, culture and society. It may also be noted that questions over the salience of trajectories or paradigms are

1992, Pinch and Bijker, 1987); rather they argue that technical change is a 'garden of forking paths' (Edge and Williams, 1996) with multiple alternatives. An example that is often cited is the emergence of the bicycle where Pinch and Bijker (1987) outline how the negotiation process which took place between different social groups who had shared meanings of a technology played an active part in shaping alternative designs. Each of these social groups possessed what is called *interpretive flexibility* in that there were different meanings attributed by social actors to a particular technology and its social function. These moments of ambiguity mark the branching points where 'one interpretation rather than another succeeded'; thus 'every stage in the generation and implementation of new technologies involves a set of choices between different technical options' (Edge and Williams, 1996).

For example, in the early stages of the evolution of the bicycle, influential actors placed a great degree of emphasis on speed as a function while later in the process of social construction concerns over safety emerged from different social groups. Joseph Murphy argues that interpretive flexibility has been a key factor in the shaping of sustainability issues surrounding GM crops; where 'some claim that this technology is a threat to sustainable agriculture, and others argue that it is a route to it' (Murphy, 2006b: p.9). Following a period of negotiation between social groups which involved an interactive process between sometimes conflicting interpretations, a degree of *closure* was achieved where there is convergence on a shared interpretation or meaning. This sense of closure is not a permanent one as over time issues and conflicts can resurface, one contemporary example of this is the debate over the safety of nuclear power (Murphy, 2006b). Similar processes are of course at play in energy networks, in particular due to the economic and social importance of these technical systems and presence of natural monopoly they will involve interactions between different public and private actors who will undoubtedly possess different goals which will come into conflict at different stages. It must be noted however that while taking a purely constructivist perspective may be appropriate for analysing how individual components of a system may change such as generation technologies, the characteristics of the overall system may be less amenable to these ongoing processes as over long periods of time they become institutionally embedded in power relations.

The work of Langdon Winner is a useful counter point to some of the relativist tendencies within SCOT. Winner (1977, 1980) proposes that technological artefacts can reflect power relations and certain inequalities within society itself i.e. 'technologies are not neutral, but are

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dependent on ones unit of analysis. For example if viewed at an industry level, the emergence of the bicycle – a much cited example of the social construction of technological artefacts - can be seen as part of a wider trend towards mechanization which took place in the 19th century (see Rosenberg, 1963).

fostered by groups to preserve or alter social relations' (Edge and Williams, 1996). Winner proposes that the material characteristics of artefacts 'can contain political properties' (Winner, 1980: p.123). He gives the example of how overhanging highway bypasses in Long Island were specifically designed in order to discourage use by busses which typically were used by the poor and black communities, thus limiting access to nearby Jones' Beach to a middle-class white community. Graham and Marvin (2001) make similar arguments regarding the ways in which 'the biased configuration of technology' (Graham, 2002) in infrastructures reflect deeply embedded social and economic inequalities in large third world cities.

2.2.2 Systems Approach

Since the early 1980s a body of literature has developed which seeks to understand the emergence and long term evolution of infrastructure systems which adopts a socio-technical approach - termed large technical systems (LTS). This emerged from the work of the historian of technology Thomas Hughes and in particular from his account of the development of electricity systems in the 19^{th} and early 20^{th} centuries (Hughes, 1983). Hughes' approach was unique in that rather than treating large scale technical systems as purely technical artefacts, his account of electricity systems in the first half of the twentieth century outlines the role that politics, geography, and particular individuals played in shaping the early emergence of these systems. The following quote summarises the contribution that Hughes made to the analysis of large scale infrastructure systems.

> *"For a long time, social studies of technology have focused on individual technologies (for example, the assembly line, the automobile), explaining their invention, diffusion, and political regulation and their impact on working conditions, individual lives, etc. Primarily historical studies of technology can take credit for partially reconciling this narrow focus by conceptualizing networked infrastructures as sociotechnical systems." (Monstadt, 2009: p.1927)*

The approach therefore differs from the evolutionary or institutional literatures because it takes an explicitly systemic approach where the components of the system 'can be both technical (e.g. power stations, transmission lines) and non-technical (distribution companies, environmental laws)' (Sauter and Watson, 2007) and constitute a 'seamless web' which 'embody a multitude of scientific, economic, political and institutional components' (Summerton, 1992: p.64). These components can mutually influence each other and cannot be considered in isolation i.e. 'changes in one component can often lead to changes in others' (Sauter and Watson, 2007: p.112). Hughes summarises the systems approach as follows:

> *"Large scale technology, such as electric light and power systems, incorporate not only technical and physical things such as generators, transformers and high-voltage transmission lines, but also utility companies, electrical manufacturers and reinforcing institutions such as regulatory agencies and laws" (Hughes 1983: p2. Quoted from: Sauter and Watson, 2007)*

Although Hughes' study is mainly a historical account of technological change in electrical power systems, he does seek to generalise some of his observations to develop hypotheses regarding the dynamics of large technical systems more generally and their (inter)relationship with societal change. This process of evolution is characterized by a number of concepts and themes that Hughes develops, these concepts characterize an LTS in its various stages:

System Builder: In its formative years an LTS is developed by what Hughes terms a 'system builder'. System builders are innovators, similar to Schumpeterian entrepreneurs, who build a bridge 'between resources and demand' (Hughes, 1983; p.20). In order to build systems they must overcome technical barriers but also face organisational, political, cultural and social challenges in their attempts to have their technologies adopted. They not only invent and commercialise individual technologies or components, but also develop the systems within which they are deployed. A prominent example is that of Thomas Edison who pioneered the development and commercialisation of DC electricity systems in the late 1870s and 1880s.

The System and its Environment: Hughes drew from systems theorists such as Talcott Parsons (1968) and Ludwig Von Bertalanffy (1968) to frame an LTS as an evolving system which interacts with its environment. In this way the LTS literature also seeks to link micro-level interactions between technical and non-technical components of a system with its macro environment (Mackenzie, 1987).

Technical Styles: The ways in which a particular system interacts with its environment produces technical styles which differ according to context. In his cross country/city comparison of London, Berlin and Chicago, Hughes (1983) showed how cultural, political and social differences between countries were reflected in the technologies that were adapted. For example, London's slow process in modernising its electricity network, compared to Berlin and Chicago, was attributed to the hegemony of the independent local authorities who saw centralisation as a threat to their power. Hughes noted that the different technical styles which emerged in each of his case studies were influenced by their individual contexts:

> *"The style of each system was found to be based on entrepreneurial drive and decisions, economic principles, legislative constraints or supports,*

> *institutional structures, historical contingencies, and geographical factors, both human and natural" (Hughes 1983, p.462)*

He also notes that once institutionalised, technology transfer takes place across national boundaries making systems more uniform in a trans-national sense.

Technological Momentum: As a system evolves and grows it becomes a more coherent set of technologies and institutions; system builders are replaced by managers and financiers and technical knowledge becomes codified with specific engineering tasks becoming routinized. Momentum within a system has a number of determinants e.g. sunk investments in fixed assets and the skills and knowledge base associated with a particular set of technologies. Hughes outlined that momentum in systems is characterised by a particular system goal e.g. a drive for achieving economies of scale in electricity generation and aggregating loads (load factor) [8]. This 'soft determinism' (Hughes, 1994) is an interesting aspect of the Hughesian systems approach which appears to contradict some of the central tenants of SCOT as it ascribes a directionality to technical change; however, this is most likely due to the more aggregated system level unit of analysis (Woodman, 2003).

Reverse Salient: A breakdown in system momentum is characterised by a reverse salient which focuses attention on one particular critical (technical) problem within the system e.g. high losses on electricity lines. For a period there can be conflict between different solutions to a critical problem e.g. alternating current and direct current[9]. A system regains its momentum once such conflicts have been resolved; Hughes gives the example of the mass diffusion of synchronous AC electrical systems and the development of the universal electricity system. These reverse salients are similar to the periods of interpretive flexibility described in the SCOT approach above where multiple outcomes are possible. It is often the case that these barriers to system expansion can be overcome by incremental changes at the components level, however, in some cases they can result in more architectural type innovations and become the 'nucleus of a new system' (Hughes, 1983: p.81, Sauter and Watson, 2007).

Since Hughes' study a number of academics have developed the LTS approach; for example, Coutard (1999) develops our understanding of the governance of large systems and introduces a number of empirical studies; McGowan (1999) discusses the regulatory implications of the internationalisation of telecommunications and energy infrastructures while Guy et al. (1999) discuss the liberalization of the UK utilities and the spatial implications for urban development;

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[8] Ratio of average and maximum system output

[9] See David and Bunn (1988) for a historical account of the 'Battle of the Systems'.

they argue that liberalisation will result in a move away from standardisation and homogeneity in service provision and to the emergence of a new logic of network management which focuses on the demand side. Summerton (1994) broadened the analysis of how systems which have become characterised by momentum and inertia can change. Using insights from the social shaping literature (e.g. Pinch and Bijker (1987)) Summerton argued that the 'undoing of closure' in systems can result from three sources; system expansion due to the internationalisation of infrastructure e.g. interconnection of electricity systems, the blurring of functional boundaries between infrastructures e.g. the convergence of electricity and heating systems in CHP-DH schemes, or radical institutional changes e.g. privatisation and liberalization. In addition to this, Davies (1996) and Nightingale et al. (2003) argue that a key factor in changing the momentum of LTSs has been innovations in ICT based control technologies which have changed the economic rationale behind system evolution, away from achieving economies of scale towards economies of system i.e. evolving towards a more efficient system rather than a 'bigger' one.

The LTS approach is particularly useful for the study of infrastructure sectors for a number of reasons; firstly because the unit of analysis is at the system level the analytical framework can be applied to all infrastructures thus serving as a useful tool for cross case analysis of such systems. Secondly, the framework stresses the socio-technical nature of LTSs and the co-dependency of technical and non-technical components whilst recognising the context dependent nature of their evolution. These aspects will be developed in the analytical section where it is proposed that greater analytical clarity with regards to the systems environment is needed; the Hughesian approach tends to lack clarity regarding the nature of a systems environment and the boundaries between it and the system. Also, the LTS perspective was primarily developed in order to explain the emergence and growth of systems; it is argued that contemporary sociotechnical dynamics involve more subtle processes such as decentralisation.

Insights from Actor Network Theory

One particular study in the Hughesian vein that is worthy of note is Jane Summerton's analysis of the development of a district heating network in a small town called Mjölby in Sweden (Summerton, 1992). Summerton adopts the LTS framework and incorporates insights from actor-network theory (ANT). ANT, which can be seen as a complementary approach to the LTS perspective, focuses the analytical lens on central actors, known as 'engineer-sociologists', who seek to enrol other actors using various strategies and tactics (Callon, 1986). These central actors have the capacity to 'construct a world (…) to define its constituent elements, and to provide for it a time, a space, and a history' (Callon, 1986: p.21). This is termed an actor-network; 'a highly interconnected set of entities that have been successfully linked to each other by an actor (…) who thereby is able to act with their support and on their behalf' (Summerton, 1992: p.69).

To illustrate the concept of an actor-network, Callon gives the example of the French energy company, EdF, who sought to enlist or enrol actors into their proposal for moving to electrified vehicles. EdF developed a futuristic vision of a post-industrial urban society within which conventional vehicles are framed as 'the offspring of an industrial civilisation that is behind us' thus being replaced by a new electric car which 'could lead to a new era in public transport in the hands of new social groups' (Callon, 1986: p.21). EdF, by seeking to construct the future in this way, sought to enrol and coordinate a heterogeneous set of actors such as component manufacturers, governments and transport users in order to shape a new actor-network. Rather than evolving with an external environment, as in the systems approach described above, by constructing these actor-worlds, engineer-sociologists seek to simplify a complex reality within which it is the central actor. Influential actors who construct these actor worlds use tactics and strategies such as *interessement*, whereby an engineer-sociologist intervenes in existing relationships thus 'interrupting competitive links and manipulating the interests of others in order to create new allies' (Summerton, 1992: p69). The composition of an actor-network not only consists of the relationships between entities in terms of standard sociological interactions such as legal contracts and power relationships, but also by the interactions between human and non-human entities e.g. 'electric currents or electromagnetic forces' (Callon, 1986). Callon notes that 'the solidity of the whole results from an architecture in which every point is at the intersection of two networks: one that it simplifies and another that simplifies it' (Callon, 1987).

By incorporating this approach to the analysis of a CHP-DH scheme in Mjölby, Summerton describes how a group of influential local actors constructed both a physical network but also an 'invisible grid' of institutions and organisations whereby stability and coherence was brought about within the actor-network. Also, to a greater degree than the systems approach, the analysis of CHP-DH in Mjölby emphasises the role of conflict in shaping socio-technical change[10]. However, in his review of Summerton's work, Russell (1994) points to some of the deficiencies of ANT when discussing such large scale infrastructures. He argues that because of the characteristics of infrastructure networks they typically involve a greater degree of interdependencies and systemness than conventional technologies; therefore the central role of

[10] The Hughesian view tends to emphasise problem solving to a greater extent (Summerton, 1994)

the engineer-sociologist tends to be downplayed. He also notes that the 'microsociological approach seems to have steered her [Summerton] away from connecting the detailed action to its context more effectively'. By jettisoning the concept of an environment external to the system[11] and taking the approach of 'follow the actors' (Geels, 2007), Summerton's analysis lacks a structural framing which makes it less amenable to generalisation – the following quote summaries:

> *"The tradition of participation and consultation in Sweden, and the major role that local government has in energy planning, are evident throughout the account, and provide a strong contrast with other countries. But again we are given no way of understanding the importance of these in explaining the widespread adoption of district heating" (Russell, 1994).*

This study is therefore worthy of note as it highlights some of the deficiencies of relying on actor-centric approaches (such as ANT and SCOT) for studies of infrastructures i.e. technical systems which are deeply embedded within societal structures and persist for long periods of time. Returning to Edge and Williams (1996), the following quote highlights the fact that ANT presents a flat ontology which, although providing some useful concepts, is an unsuitable overarching framework for the analysis of infrastructures which, as described in the previous section, develop in a path dependent manner:

> *"Thus actor-network theorists…are remorselessly sceptical about the nature and influence of pre-existing, large-scale social structures such as class and markets - and, in particular, in the prior attribution of social interests… And they, in turn, have been criticised for eschewing existing social theory, leaving them poorly equipped to explain particular developments, and open to criticism for 'empiricism' - offering mainly descriptive work and post-hoc explanations. To their critics, they run the risk of ceding too much power and autonomy to individual actors, rather than to existing structures of power and interests … (Edge and Williams, 1996)*

Drawing more from a Hughesian ontological perspective, presented below is an approach which seeks to provide a more structural account of socio-technical change using a multi-level approach.

2.2.3 The MLP and Transition Pathways

A strand in this literature which was briefly discussed in the previous chapter is known as socio-technical transitions research. This emphasises many of the aspects of SST but more explicitly incorporates ideas of structures and constraints on agency such as notions of paradigms and

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[11] It is worth noting here that in the systems perspective the environment predates the system; although as the system evolves it exerts a greater degree of influence over its environment.

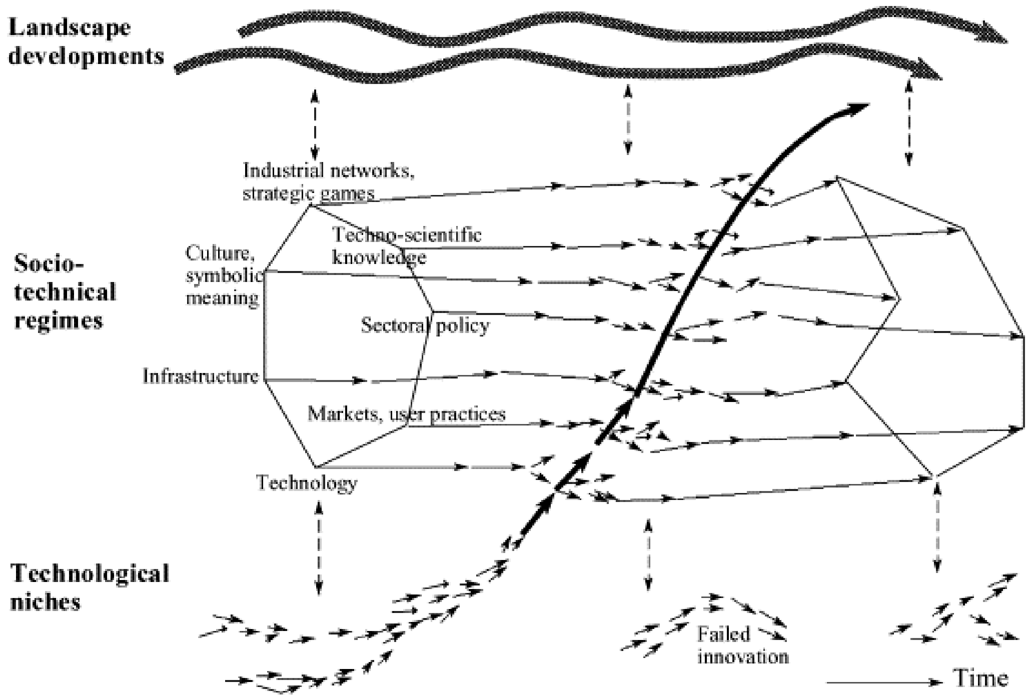
trajectories. Similar to the LTS approach, the emphasis is on longer term trends in technical change at the higher levels of the design hierarchy, rather than to individual components or artefacts. The aim of the approach is to describe structural changes or systemic innovations i.e. changes in sector level structures (or systems of production and consumption) ‘made up by a cluster of elements, involving technology, science, regulation, user practices, markets, cultural meaning, infrastructure, production and supply networks (…) This cluster of elements forms a sociotechnical system’ (Geels and Kemp, 2007: p.441). This group of researchers, mainly historians, have noted two important characteristics of socio-technical transition processes:

1. Socio-technical systems are embedded in a wider set of regimes e.g. technological, science, user and market, policy and socio-cultural regimes (Geels, 2004). These coalesce to form stable configurations, known as socio-technical regimes, to provide coordination to systems. These socio-technical regimes are prone to inertia and path dependency and thus tend to be obdurate.
2. Changes in socio-technical systems tend to emerge from practices which take place outside of this stable configuration. Transitions theorists characterise these spaces of change as niches, practices which take place within these niche spaces are less constrained that those within the regime. Niches are less structured spaces with more scope for agency and, using a biological analogy, they can foster more variations within a less deterministic selection environment. Experimentation and learning are the key processes within niches (Raven, 2005).

Developed by a group of Dutch researchers, it builds upon a number of historical studies of past transitions where it is argued that structural changes in sectors, or periods of systemic/architectural innovation, tend to stretch out over long periods of time, approximately 50 years, and are characterised by different patterns of transformation called transition pathways (Geels and Schot, 2007). Examples of their studies include the transition from sailing ships to steam ships (Geels, 2002), and the development of urban water infrastructures in the Netherlands (Geels, 2005).

These basic hypotheses regarding the nature of socio-technical transitions have been framed within a micro-meso-macro multi-level framework, which is commonly referred to as the Multi-Level Perspective (MLP), as displayed in the figure below:

Figure 2.7: The Multi-Level Perspective on Transitions



Source: (Geels, 2002)

The MLP, described as a 'nested hierarchy of structuring processes' (Smith et al., 2010), is constituted by three levels of increasing stability (Geels, 2004): The meso or *regime* level is a particular sector which provides a societal function e.g. the provision of energy services. Socio-technical regimes are heavily influenced by selection pressures and are a 'stable and dominant way of realising a particular societal function' (Smith et al., 2010: p.441). At the micro level are *niches* which are less dependent on selection pressures which influence the regime, there is therefore more scope for radical innovation to occur as 'the norms of the niche are different compared to the rules in the regime but tend to be less established and relatively stable' (Smith et al., 2010: p.441). Often niches require some form of protection, for example subsidies, but eventually need to interact with regime actors for resources and legitimacy. Finally, at the macro level is the *landscape* which is similar in its conception to a system's environment: 'The content of the sociotechnical landscape is heterogeneous and may include aspects such as economic growth, broad political coalitions, cultural and normative values, environmental problems and resource scarcities. The landscape metaphor is used to emphasise the large-scale material context of society, e.g. the material and spatial arrangements of cities, pervasive technologies that affect all of society (...)The material landscape is changing very slowly' (Geels and Kemp, 2007).

Unlike actor based approaches such as ANT or SCOT, the MLP outlines a ‘deep’ ontology where processes of innovation and transformation are analysed in the context of embedded structures at the regime and landscape levels (Geels, 2007). The MLP has been utilised to frame a wide range of energy sector transformations (van der Vleuten and Raven, 2006, Raven and Verbong, 2009, Coenen et al., 2010, Verbong et al., 2008) and a notable outcome of these studies is that the presence of a meso level as an analytical category provides scope to analyse how emerging practices confront and engage with incumbent regime structures. The framework also provides a platform by which useful insights from the evolutionary-institutionalist literatures, which were introduced earlier in the chapter, can be incorporated. Here change within the MLP is characterised by both an evolutionary and an enactment logic (Geels, 2011):

- An enactment logic – Within the niche and regime levels patterns of behaviour can be discerned from ‘social (inter)actions with semi-coherent rule structures that are recursively reproduced and incrementally adjusted by ongoing actions’ (Geels, 2011: p.16). This draws heavily from Giddens’ structuration theory (Giddens, 1984) where action and structure are co-constructed.
- An evolutionary logic – Between the levels, processes of strategic selection occur where the broader selection environment at the landscape and regime levels strategically select practices at the niche level which are the sources of variation. This ‘not only involves market processes, but also depends on the fit of niche innovations with regulations, infrastructure and cultural meaning’ (Geels, 2011: p.16).

Examining the framework from a SST perspective, it retains basic presumptions regarding contingency and agency in technical change whilst incorporating more structural processes such as institutional embededness and path dependency. A number of these studies have analysed process of structural change in terms of alternative pathways which involve different types of interaction between and within levels, these have been both generalised (Geels and Schot, 2007, Smith et al., 2005) and more contextualised for the specific case of the UK (Foxon et al., 2010).

In terms of analysing infrastructures, this pathways approach provides a means by which processes of change can be uncovered which expand upon the linear trajectory presented in the Hughesian approach where system building leads to system momentum. To illustrate the pathways approach, three patterns of transition are outlined by Geels and Kemp (2007):

- Reproduction: Dynamics are confined to the regime level leading to a process of incremental change where ‘the existing socio-technical system and regime form a stable context for (inter)action of social groups. Existing rules are reproduced by the incumbent actors, and elements in the socio-technical system are refined' (Geels and Kemp, 2007).

- Transformation: Due to pressure exerted from the landscape level regime level actors successful re-orientate their strategies and practices in the absence of niche level sources of more radical variation. This would result in modular type innovations.
- Transition: A transition or 'shift from one socio-technical system to another' occurs when, faced with landscape pressures, regime level actors fail to re-orientate their routines successfully. This creates a favourable selection environment and a window of opportunity for new sources of variation which emerge from niche level and become institutionalised (as shown in figure 2.7). For the case of an infrastructure sector this would involve processes of architectural innovation at the system level of the design hierarchy.

The MLP has been adopted by policy orientated researchers who propose that by providing temporary and targeted protection to niches (termed strategic niche management (Raven, 2005, Smith, 2006)), along with altering the broader landscape and selection environment at the meso-macro levels, novel technologies and practices can be diffused and transitions can be managed or governed in a particular normative direction e.g. sustainability (Rotmans and Loorbach, 2008). Unsurprisingly, the practical and political feasibility of managing such transitions in this way has been called into question. It has been argued that Transitions Managements (TM) often under-represents the political and contested nature of technical change (Shove and Walker, 2007, Kern and Smith, 2008) which is present in the ANT literature for example (Genus and Coles, 2008). Also, it is unclear how sources of variation emerge at the niche level; for example, Hughes' insights regarding the emergence of different technological styles depending on contextual factors such as geography and scale seems to be absent. However, the MLP does provide a useful framework which recognises the deep ontology of infrastructure sectors and the multiple ways in which processes of change can occur; this will be drawn upon in the next chapter.

2.2.4 Splintering Urbanism

As noted, the MLP provides a framework whereby the role of embedded institutions in shaping practices and innovation processes can be systematically analysed; however, it has been observed that the concept of the landscape in particular, which tends to encapsulate a wide range of external variables which influence regimes, tends to be under theorised. For the case of infrastructure networks, it is noted that structural changes within society such as the shift from a Keynesian welfare state towards liberalisation have often characterised the socio-technical dynamics of these sectors (Mitchell, 2008). A literature known as Splintering Urbanism, which draws from urban studies and critical perspectives on political economy, provides useful insights into the relationships between these broader social and economic structures and distribution networks – this is illustrated in the following quote:

> *"...from the late 1970s a quadruple movement of political, economic, technological and socio-spatial decentralizations, combined with a 'decollectivization' of certain societal functions and meanings, has increasingly challenged the traditional forms of organization and governance of large networked systems. This evolution has included the emergence of more polycentric and multilevel forms of political governance; the application of neo-liberal reforms, including privatization and liberalization; the technological 'stasis' (Hirsh 2003) of centralized infrastructure and the concurrent downscaling of systems of service provision…" (Coutard and Rutherford, 2011: p.108)*

In their 2001 book '*Splintering Urbanism*', Graham and Marvin (2001), from the perspective of urban studies, offer new insights into the relationship between the unbundling of infrastructure networks and the spatial evolution of large cities. Seeking to contribute to the urban studies literature they argue that 'treatments of the materialities of infrastructure and technology remain marginal within critical urban and social science' (Graham, 2002). They seek to explore the dialectic between changes in the nature of infrastructure provision and consumption, urban planning, and 'the restructuring of urban space' (Graham, 2002) .

Opening up the black box of the system's 'environment' or 'landscape', it is argued that infrastructures 'and the financial, engineering and governance practices that support them' are 'embedded within the broader power relations of global capitalism' (Graham and Marvin, 2001: p.190/1). Drawing on the work of political geographers (Harvey, 1985, Swyngedouw, 1993) they argue that in order to serve the needs of 'capital accumulation' networks are important in linking and coordinating 'widely dispersed sites of production, consumption and exchange' and to 'link spaces and times together' (Graham and Marvin, 2001: p.192/3). However, because infrastructure networks are embedded within space and require large amounts of capital to be invested, over long periods of time a disconnect can develop between this inherent inflexibility and the continuous cycle of capitalist dynamism i.e. 'Crises emerge where older infrastructure networks (…) become barriers to later rounds of capitalist accumulation' (Graham and Marvin, 2001: p.194). Similar to arguments proposed by Langdon Winner described above, they argue that social biases are deeply embedded in the material and spatial configuration of infrastructure networks.

Central to the splintering urbanism thesis is the shift away from what they term the 'integrated ideal' of nationally interconnected systems based on Fordist mass production and distribution principles and balanced by 'Keynesian models of state policy and demand management' (p.74 Book) and cross-subsidisation[12] - they describe this as follows:

> *"…democratically accessible and homogenous infrastructure grids, usually under public ownership or control…(to) help realise the social, economic and environmental benefits of mass production, distribution and consumption, integrated through the mediating powers of new infrastructure networks" (Graham and Marvin, 2001: p.52)*

The rationality behind this network logic, they argue, was to bring about cohesion and order to the urban form and was underpinned by notions of technical determinism, modernity and comprehensive urban planning. The provision of public goods[13] in this unified and integrated way has however undergone significant changes in the last number of decades. This has been prompted by a changing political economy where 'governments are easing restrictions on private entry into previously monopolistic infrastructure markets' (*ibid*: p.96). They argue that it is likely that such investment will 'focus on low-risk, lucrative projects with short-term, demonstratable profitability' leading to splintering or unbundling of the previous integrated monopolies, organisationally, geographically and technically. This is creating 'premium network spaces' (Graham, 2000) where more reliable and sophisticated network services are tailored to the needs of certain areas within the city, such as financial districts, resulting in new forms of 'territorial inequalities' (Offner, 2000). The resulting uneven development has implications for the spatial characteristics of cities as 'relationships between infrastructure networks and urban spaces, seem to embody powerfully the changing dynamics of global political economies and societies' (Graham and Marvin: p.16).

These developments have also prompted new technical innovations which in different ways have undermined traditional assumptions surrounding service provision through public monopolies e.g. technologies which further reduce economies of scale, promote decentralisation and flexibility. The underlying rationale behind these technologies is to reduce the barriers to market entry and 'facilitate the division of integrated networks into monopolistic and non-monopolistic segments'; examples include 'complex control, monitoring and data management

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[12] Where lower-income users and less profitable services are subsidised through generalised tariffs or taxation (Graham, 2000)

[13] They outline four characteristics of a public good (*ibid*: p.80): 1) Non-rivalrousness (provide for one or all at the same cost), 2) non-excludability (once supplied cannot prevent user from using), 3) spillovers/externalities (positive and negative externalities), 4) non-rejectibility (once supplied must be equally consumed by all).

systems' (Graham and Marvin, 2001: p.139). These changing technologies and network logics are also altering the relationship between the users and providers of network services –as illustrated by the following quotation:

> *"These technologies therefore challenge the assumption that relations between users and providers are standardised and homogenous. Instead the interface becomes much more complex: users may be enrolled by producers to shift the timing and level of demand; new pricing technologies can send real-time economic signals to shift consumption patterns; and new intermediaries such as logistics specialists, energy and water conservation agencies, and property developers, increasingly manage relations between network users and providers" (Graham and Marvin, 2001: p.140)*

This tendency towards disaggregation leads to the creation of niche markets for network services where private firms can '…selectively connect together the most favoured users and places' (*ibid*: p.15). The consequence of this 'infrastructural consumerism' (Graham, 2000) has been the construction of consumer identities and branding where 'differentiating among goods, services, and tariffs is a crucial tool for achieving managers' goals of targeting and satisfying privileged users' (Summerton, 2004: p.490). Guy et al. (1999) characterise this process of creating niche markets and targeting specific users as 'cherry picking' and 'social dumping' or 'the easing out of economically marginal domestic markets'.

In a number of respects the Splintering Urbanism thesis provides useful insights into the relationships between infrastructures and society. Firstly, it opens the black box of the system's environment (Hughes, 1983) where it is shown how infrastructure development is 'closely bound up with wider sociotechnical, political and cultural complexes' (Graham and Marvin, 2001: p.11) such as 'contemporary societal shifts towards globalisation, liberalisation, privatisation and general scepticism about centralised bureaucracies' (Graham and Marvin, 2001: p.183). This provides insights into the different *network logics* which underpin their material and spatial evolution and how these logics are closely connected to structural changes within society; e.g. how processes such as 'global-localisation' (Guy et al., 1999) explain changes in the capitalist accumulation regime and their effect on urban infrastructures.

This perspective provides useful insights into the changing role of the nation state in the governance of infrastructures[14]. Also, their critical stance provides a cautionary note to those who seek to promote innovation and technical change in infrastructure networks in order to

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[14] Although it will be argued in the next chapter that Splintering Urbanism tends to underplay the contemporary role of the state in the move away from the Keynesian 'Infrastructure Ideal' and it often neglects the day-to-day processes of governing which are heavily influenced by the state e.g. economic regulation.

achieve certain social objectives e.g. transitions to sustainability. Because of the essential importance of infrastructure networks to everyday life and to the functioning of economies, there are potential distributional and spatial consequences of innovation in these sectors which are often not recognised in the transitions literature (Coutard and Rutherford, 2011). Promoting innovation as a means to an end neglects the consequences of unbundling and decentralisation for 'urban cohesion and equality' and also that the sources of this emerging technological and organisational paradigm lie in 'the restless workings of global capitalism' (Coutard and Rutherford, 2011). For example, a recent contribution to this strand research has argued that the emergence of climate change and energy strategies in large 'World Cities' reflects 'a constant search for innovation to be and remain competitive predicated in the first instance on the ideology of mobile capital rather than more specific local priorities' (Hodson and Marvin, 2011: p.23). Efforts to steer or manage transitions in infrastructures should therefore be aware of the underlying relations of power and the wider structures within which they are embedded.

However, the spatially sensitive nature of Splintering Urbanism does provide some useful insights to the transitions approach as it uncovers much of the contemporary sources of variation and innovation in distribution network sectors which emanate from the uneven development of infrastructures, their changing relationship with territories, and the plurality of urban responses to the move towards a post-Fordist accumulation regime. This refers back to the earlier historical literature which highlighted the role of multiple scales of decision making (in cities, regions, nations) in the emergence of these large technical systems in the first instance[15] (Hughes, 1983, Tarr and Dupuy, 1988). An analysis of contemporary dynamics in the electricity and heat distribution sectors must consider how they are linked to changes in the broader societal governance regimes, and also take into account the spatial implications and the relationships between different scales and tiers of governing which might result.

2.3 Summary of the Literature on Infrastructure Networks

As mentioned in the introduction to this chapter, the purpose of the review was to explore the existing literatures which broadly address the research questions outlined in the introduction. This is with a view to developing an analytical framework which can be applied and tested across the two case studies and, if successful, can inform theoretical and policy debates surrounding the contemporary dynamics of energy distribution networks. It was argued that each of the literatures contribute to an understanding of the dynamics of infrastructures with economic and socio-technical approaches tending to place different degrees of emphasis on the

[15] For example, Thomas Hughes' concept of Technical Styles described above.

relative importance of institutions, technical change, and agency in processes of change. It is also noted that they have different ontological and epistemological assumptions underpinning them. For example, TCE proposes that actors can choose efficient governance arrangements so as to economize on transaction costs, while the evolutionary approach argues that capabilities differ between actors within a sector and as a consequence they will have different responses. The table below synthesises some of the main features of these literatures and the key causal mechanisms which are forwarded to explain structural changes in infrastructure networks – these will be drawn upon in chapter 7 as part of the cross-case analysis.

Table 2.2: Synthesis of Literature Review and Identification of Causal Mechanisms

Approach	Causal Mechanisms
New-Institutional Economics	*Vertical Dynamics*: The nature of transactions taking place determines the dynamic between integration (hierarchies) and de-integration (markets) in a network industry value chain
Evolutionary Economics	*Innovation*: The nature and pattern of technical change - whether this is incremental or disruptive - and the response of firms strongly influences sectoral dynamics
	Path dependency and Lock-in: Institutional change is not a process of optimisation at the margin but is influenced by the historical trajectory of change.
SCOT/ ANT	*Social Construction*: Technical change is a contested process which is characterised by the multiple framings and interpretations of different actors and groups of actors.
Large Technical Systems/ANT	*System Evolution*: Technical systems evolve with their environment initially being shaped by influential system builders but over time develop momentum and become prone to inertia. Different technical styles emerge as systems evolve.
Multi-Level Perspective	*Multi-level dynamics*: Interactions between niche, regime and landscape levels lead to different types of socio-technical patterns or pathways – reproduction, transformation or transition.
Splintering urbanism	*Scalar Dynamics*: In the context of liberalisation and globalisation the notion of nationally integrated infrastructures has been diminished and new spaces of agency are being opened up at different scales

2.3.1 Critique of the Literature

There are two specific critiques of the literature which this thesis seeks to explore in more detail. The first is on the nature of the relationship between infrastructures and institutions. Although institutions are discussed in the NIE and evolutionary literatures, it is argued that there are often inconsistencies in how institutions and institutional change are conceptualised in the literature. Because distribution networks and the services they provide cannot be categorised as conventional goods which are traded in a market, institutions are an important analytical tool as they can characterise the interdependencies involved in energy networks and provide a useful analytical tool to explore various aspects of how these sectors are structured and coordinated. It is argued that while the TCE and evolutionary approaches provide useful insights, their framing of institutions can be problematic at times. Firstly, TCE's functional account of institutional change - between markets and hierarchies - is unsuitable for the analysis of longer run dynamics in infrastructure sectors, and although there is a more dynamic view presented in evolutionary economics, institutions tend to be viewed in simplistic terms as either barriers or enablers to technical change. Contributions from the socio-technical literatures suggest that a) institutions should be seen as actively shaping and moulding technical change in these sectors, b) institutional change in infrastructure sectors occurs in the context of broader societal structures, and c) that the influence of a wide array of actors and groups of actors, both public and private, in this ongoing process needs to be recognised. This critique will be developed in the next chapter where it is proposed that institutions must be considered as embedded in every aspect of infrastructures, in their technical configuration and operation, in how actors interact and influence change, and in the broader structural patterns which influence sector level structures. Three analytical categories are elucidated which describe the physical, relational and structural dimensions of the relationship between infrastructure networks and institutions and provide a more systematic and ontologically coherent way of analysing the interplay between actors, institutions and technologies in these sectors.

The second critique focuses on the specific role of the state in the governance of infrastructure sectors. As has been outlined in the introductory chapter, due to the technical and institutional features of infrastructures, institutional change in these sectors will involve different types of interplay between both public and private actors. Although the Splintering Urbanism literature does discuss the changing role of the state in this regard, it is argued that this is from a structural perspective which does not capture the more subtle and strategic ways in which the involvement of the state in the governance of these sectors is changing. In the next section this argument is developed by incorporating insights from a broad range of governance literatures.

2.4 Revealing the role of the State in the Governance of Infrastructure Networks

In the introductory chapter it was argued that socio-technical transitions and the dynamics of energy distribution sectors must be considered in the context of a wider set of socio-political structures which are characterised by the changing nature and role of the state in economic governance. A small number of recent studies (Mitchell, 2008, Helm, 2004) have shown that energy policy in the UK cannot be decoupled from the state and its role in influencing the institutions of energy systems. For example, Catherine Mitchell (Mitchell, 2008) has argued that in recent years efforts to promote renewable energy have largely been shaped and defined by a Regulatory State Paradigm which tends to favour marginal rather than long term efficiencies and incumbent technologies and actors. This has led to a poor diffusion rate for low carbon technologies in the UK as the RSP promotes incremental rather than radical or architectural technical change and is largely incompatible with the need to fundamentally restructure energy systems for the transition to a low carbon economy. Despite these studies the changing influence of the state in energy governance is an underexplored area for studies of transitions and structural changes in energy systems and therefore has been a key motivation for the formulation of the research questions of this thesis; in particular questions 2 and 3.

Questioning the role of the state in this regard is particularly salient in the case of network industries such as distribution systems due to their technical and institutional characteristics which mean that they are not traded in markets in a conventional sense but are characterised by some form of non-market governance (Groenewegen and Künneke, 2005). It must be the case that observable technical dynamics in infrastructures sectors, such as interconnection across national boundaries, decentralisation, and the development of localised infrastructures, are bound up with the dynamics of nation-states through processes of privatization, the articulation of national energy policy priorities, and the changing relationships between different tiers of government at the local, regional, national and international levels. Following a discussion of the ways in which states have been represented in the literatures that were reviewed in the sections above, debates surrounding the changing role of the state in economic governance will be engaged with.

2.4.1 Representations of the State in the Literature

Within the different strands of the literature introduced in the sections above, the state and its role with regard to infrastructures and socio-technical systems is conceptualised in a number of ways. Within the institutional and economics literatures, debates surrounding the ongoing liberalisation and privatisation of network industries have often framed governance in terms of a binary distinction between the 'market'/'hierarchy' or 'public/private'. For example, the role of the state in the governance of electricity distribution networks tends to be relegated to a passive one where 'independent' sector regulators and private network operators are the key actors, removed from political influence. The role of government is often viewed in binary terms as changing from being 'interventionist' prior to privatisation to being 'non-interventionist', and not an active participant in the everyday reproduction and transformation of these sectors. This binary perspective is illustrated in the following quote from Karen Bakker in the context of the water sector:

> *"Policy debates tend to rely on the assumptions of utilitarian liberalism, in which the distinction between public and private equates with that between governmental and nongovernmental…From this perspective, the distinction between "public" or state authority and "private" individual activity is assumed to be clear. Debate over the scope of state and market activity is thus essentially a debate over jurisdiction, adjudicated via utilitarian standards of performance" (Bakker, 2010: p.29/30)*

Typically, this view is forwarded in arguments surrounding the privatization and liberalization of network industries where the state's role is framed in terms of ownership of assets e.g. nationalisation or privatisation. This is particularly prevalent in NIE based studies which present an unrealistically clear distinction between governance transformations between markets and hierarchies which, as Campbell and Lingberg (1991b) note, 'relegates the state and state actors to a subordinate position, relative to economic and technological factors, as causes of governance transformations' (*ibid*: p.364). Although the role of the state in defining property rights regimes and facilitating the establishment of monopolies in network industries is widely recognised (Campbell and Lingberg, 1991b, Fox-Penner, 2010, Hughes, 1983); following the wide scale privatization and liberalization of network industries, governments are often viewed as passive actors whose functions have been outsourced to an independent sector regulator where the state is 'standing outside and above society' (Jessop, 2007a). It is proposed that this framing of the state's role solely in terms of ownership relies on a narrow view of the state and neglects the more subtle ways in which states exert their influence in the ongoing reproduction and transformation of network industries.

From a reading of the literatures presented in the previous sections, a similar representation of the state is presented in the Splintering Urbanism literature where the state is becoming less relevant as a result of wider shifts in society, often framed in terms of post-Fordism and the crisis of Keynesianism. Here, as a result of these societal dynamics, the nation-state has been bypassed and a neo-liberal governance regime based on an emerging relationship between global flows of capital and urban entrepreneurialism (termed ‘glocalism’) has emerged (Guy et al., 1999). This has largely displaced integrated infrastructures and the pursuit of energy policy goals at the national level. It is undoubtedly the case that these macro level political and economic dynamics have seen the emergence of new forms and processes of governance where ‘infrastructure development increasingly centres on seamlessly interconnecting highly valued local spaces and global networks to support new vectors of flow’ (Graham and Marvin, 2001: p.100). The traditional role of the nation state, ‘to support the shift to regulated, near universal access to infrastructure networks’ (*ibid*: p.73), has become less relevant as a new network logic based on liberalisation and the profit motive has emerged. However, this presents a view of state involvement in these sectors as diminishing or failing to exerting influence which, as Offner (2000) argues, fails to take into account the more subtle ways in which public authorities exert their influence; of particular relevance is the growing importance of sector regulators (Moran, 2003, Majone, 1994, Hood et al., 2001, Scott, 2004, Levi-Faur and Sharon, 2004). Also, by focusing on the urban or city scale as a unit of analysis, this body of literature tends to downplay the importance of broader policy goals and regimes which, in the case of energy, are largely pursued at the nation-state level in the UK.

The socio-technical transitions literature has more recently sought to explore the potential roles that states can play in the governance of longer term transitions to sustainability (Rotmans and Loorbach, 2008). As Florian Kern outlines governments can stimulate ‘the development of shared visions of the future, the setting up of stakeholder transition arenas and conducting transition experiments to explore possible pathways towards more sustainable systems’ (Kern, 2009). However, proponents of this approach ‘have prescribed an important role for government in steering such transitions without explicitly recognising and conceptualising the politics of such processes’ (Kern, 2009). Although there have been some questions raised as to whether this perspective adequately takes into account the complexities of the policy making process (Kern and Smith, 2008), it does at least have some recognition of the important relationship between the state and socio-technical systems and to some extent recognises the interdependencies involved. This effort to ‘bring the state back in’ has been termed Transitions Management (TM) (Rotmans and Loorbach, 2008, Loorbach, 2007) and draws from the MLP and the innovation system literature which both advocate public intervention along the innovation chain (Foxon, 2006). A central feature of the TM approach is that states can play a key role in ascribing a normative directionality to technical and institutional innovation within sectors of the economy, particularly those which are locked-in to unsustainable trajectories e.g. high carbon energy systems. This is achieved by facilitating processes of variation (in protected spaces or niches) and altering structures at the regime level in order to de-institutionalise existing (unsustainable) modes of production and consumption. However, while the approach prescribes a more active role for the state in directing the long term future of systems, it does not provide a critical account of the ways in which states are deeply embedded in the day to day operation of socio-technical systems and infrastructure networks. For example, in her analysis of the emerging low-energy housing sector in the UK, Heather Lovell argues that because governments;

> *"…tend to be deeply embedded within socio-technical systems, they face difficulties in bringing about radical changes, and policies are therefore typically aimed towards encouraging incremental or conservative innovations. The findings from research into low-energy housing in the UK similarly highlight the ad hoc, unstrategic and political nature of socio-technical change in practice." (Lovell, 2007: p.37)*

This lack of recognition of the political interdependencies between governments and socio-technical systems, such as low-carbon housing, she argues, can result in programs such as TM becoming a useful policy tool for governments but which can become subsumed into the wider set of governance regimes:

> *"…the politics of sociotechnical system change need to be considered in more depth. There are reasons why policies to encourage niches might appeal to governments more than sector-wide regulatory changes, in particular because niches are less likely to threaten powerful interests embedded within the existing socio-technical system." (Lovell, 2007)*

TM therefore lacks an 'analysis of the variety of ways in which niches originate and are used by governments' (Lovell, 2007). This lack of subjectivity in the approach to analysing these socio-technical governance interventions is also observed by Smith and Stirling (2007):

> *"…the manner in which governance processes may realize sustainable socio-technical systems depends on the general way in which each is conceptualized in relation to the other. Too often in the socio-technical systems literature, these conceptualizations remain implicit and confused….there needs to be greater appreciation of the internal loci of governance processes within the socio-technical systems themselves"(Smith and Stirling, 2007: p.369)*

While it is recognised that TM has potential to offer a useful prescriptive framework for the relationship between the state and energy systems in transition, it is proposed that it does not recognise the ways in which a wide array of functions and strategies of nation states are closely intertwined with the day-to-day functioning of energy networks and socio-technical systems more generally – the central paradox which was referred to in the introductory chapter. The argument that 'government is not a unitary actor and is deeply embedded in existing structures of current socio-technical regimes' (Kern, 2009) is developed below for the case of infrastructure sectors.

2.4.2 Governance Perspectives

In order to explore in more depth the changing relationship between the state and distribution networks, the literature on governance offers a useful entry point into the discussion on the nature and role of the state in this regard and how it can be conceptualised. In the literature, an ongoing trend within society has been observed involving a shift from hierarchical 'government', based on the concentration of power at the level of nation-states and the exercise of coercion, towards flatter forms of 'governance' which are based on 'self-organizing, interorganizational networks' (Rhodes, 1996) and power inter-dependencies. Governance in this context refers to 'a change in the meaning of government, referring to a *new* process of governing; or a *changed* condition of ordered rule; or the *new* method by which society is governed' (Rhodes, 1996) [16]. Governance studies approach this trend from a number of different perspectives ranging from public administration, international relations and comparative politics (Davies, 2008). Broadly, these literatures have applied the governance concept in three different ways (Adger and Jordan, 2009); as an empirical phenomenon of changing state-society relations, as a theory or 'an explanatory framework' (Murphy and Yanacopulos, 2005) which explores how diverse inter-organisational networks achieve policy goals through mechanisms of self-steering (Marsh and Rhodes, 1992) and thirdly, as a prescriptive framework e.g. 'good governance' which prescribes 'openness, participation, accountability, effectiveness, and coherence' (CEC, 2001: Quoted from Davies (2008: p.27)). Also worthy of note are more critical perspectives on governance which propose that the underlying dynamic behind the shift from government to governance is to 'channel capitalism in novel directions' (Paterson, 2009) or as a response to a legitimacy deficit of the state (Murphy, 2006a) e.g. as 'the acceptable face of spending cuts' (Stoker, 1994: Referenced in Rhodes (1996: p.653)).

Regardless of the differing perspectives and views on governance, they share a basic premise regarding the changing relationship between the state and society, as outlined by Albert Weale:

> *"…the historic assumption was that concentrated patterns of authority produced adequate solutions to the policy problems that political systems faced. To say that there has been a transition from government to governance is a way of saying that this assumption can no longer be made" (Weale, 2009: p.59)*

In its treatment of the state, a governance perspective rejects 'ideas of the nation-state as a single site of political power, as a unified and discrete entity, and as territorially sovereign in the

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[16] This should be distinguished from the use of term in the NIE literature where governance tends to refer to achieving some form of coordination or collective action - an *outcome* rather than a *process* (Stoker 1998) – we are more interested in the process of governance.

traditional Westphalian sense' (Bulkeley et al., 2007: p.2734). In the context of the UK, debates surrounding governance emerged from a rejection of the 'Westminster model' which emphasised 'parliamentary sovereignty, strong cabinet government and accountability through elections' (Stoker, 1998: p.19), towards a perspective which focuses the analytical lens on '*new* processes of governing' described by Roderick Rhodes as '…*self-organising, interorganizational networks* characterised by interdependence, resource exchange, rules of the game and significant autonomy from the state' (Rhodes, 1997: p.15). This marks a shift from governments exerting power through coercion, moving towards inter-dependencies and partnerships thus 'blurring the boundaries' (Stoker, 1998) between the state, the market and civil society.

In the light of these debates over the shift from government to governance, it is generally acknowledged that the role of the state is changing and cannot be taken for granted. The question therefore arises; what is the role of the state in this context? Some argue that it has been diminished or hallowed out; for example, Martin Jänicke, in his book 'State Failure' (Jänicke, 1990), argues that states have become impotent and reactive in the face of increasing bureaucracy and industrialisation. Others see it as a result of a reduction in state sovereignty and power due to governments failing to exert their influence in an increasingly globalised context. On the other hand, this shift from government to governance can be seen as a strategic reorientation of the way states exercise their power and influence. As Bulkeley et al. (2007) summarise; 'for some, the state has been all but replaced in the shift from "government" to "governance"(…) while for others, governing continues to take place "in the shadow of hierarchy"(…)' (p.2734).

The latter explanation, that the state is exerting its influence in more subtle and efficient ways in response to an expanding and increasingly complex set of objectives (Hooghe and Marks, 2003)[17], is forwarded by Pierre and Peters (2000) who propose that 'it is erroneous to conflate state structures with state power' (Davies, 2008: p.24). Anna Davies points to the work of John Pierre (2000) to argue that 'current trends demonstrate a process of state transformation rather than a decline in state authority' and that rather than there being a 'smooth linear trajectory (…) government-governance practices can ebb and flow over time and across space' (Davies, 2008: p.24/5). This distinction between state form and state power is highlighted by Pierre and Peters (2000):

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[17] Hooghe and Marks only propose this as a potential explanation.

> *“The creation of a more participatory style of governing does not mean the government is in reality less powerful. It does mean that the state and society are bounded together in the process of creating government” (Pierre and Peters, 2000: p.49)*

Therefore, rather than the state being ‘hollowed-out’ or diminished, we are witnessing a change in ‘the selection of instruments and organizational arrangements through which the state imposes its will on society and also the nature of the points of contact between state and society’ (Pierre and Peters, 2000: p.93). The question is therefore not whether the state will exert its power but how it will do so and in what form.

It is proposed that the relationship between the state and energy systems has proceeded in this fashion, and as the process of liberalisation and privatisation have unfolded, the role of the state in the governance of energy distribution networks has become more subtle and strategic. In order to uncover these changing dynamics, two relevant areas of this literature are drawn upon; state transformation (drawing from the work of Bob Jessop) and governmentality (drawing from the work of Michael Foucault).

State Transformation

In analysing the nature of the state and its transformation, the work of Bob Jessop has been particularly influential. Drawing from neo-Gramscian and Marxist theories, Jessop defines the state in relational terms as; ‘a distinct ensemble of institutions and organisations whose socially accepted function is to define and enforce collectively binding decisions…’ (Jessop, 2007b). These concepts of ‘common interest’ and ‘the general will’ are ‘illusory’ and are strategically selected according to different values and opinions because ‘there is never a general interest that embraces all possible particular interests’ (*ibid*: 2007: p.11). Therefore, rather than existing as a unified entity in ‘majestic isolation’, the state is ‘embedded in a wider political system (or systems)’ (Jessop, 2007: p.6) and, as a social relation, is constantly being redefined as it interacts with its environment. It is ‘the site, the generator and the product of strategies’ (Jessop, 1990: p.260. Quoted from Macleod and Goodwin (1999)). As the state pursues its interests (core roles of the state include maintaining domestic order and civil legitimacy, developing international relations, promoting economic growth and raising revenues (Scrase and Ockwell, 2009)) it develops strategies and draws upon its resources, capacities to coerce, and the mutually interdependent networks of actors which ‘link the state to its broader social environment’ (Jessop, 2007: p.6). Jessop argues that it is difficult to define the state as it is an ever changing and fluid concept, its ‘lines of difference’ with its environment are constantly in flux and the state is therefore ‘a complex institutional system’ that changes form in a strategic manner.

Interestingly, Jessop characterises this dialectic between the state and its environment according to the Strategic-Relational Approach (SRA), where the state changes form through processes of strategic selection (processes of variation, selection and retention) which 'privilege some actors, some identities, some strategies, some spatial and temporal horizons, and some actions over others' (Jessop, 2009: p.378). Therefore, rather than governance being 'autonomous' and removed from influence of the state 'institutional arrangements and forms of interdependency which characterise governance are, in this account, created by the (central) state as a means of pursuing its own ends, and are only partially autonomous from the exercise of hierarchical power' (Bulkeley et al., 2007).

The metagovernance approach described above, where states are engaged in the 'governance of governance', proposes that it is not about the power which the state possesses as a unified all-encompassing entity in itself, rather its capacity to transform and achieve its objectives. States draw on 'resources produced elsewhere in its environment' (Jessop, 2007b) in a strategic manner in order to exert influence. This is characterised by the ability of states to exert control over the 'web of structural interdependencies and strategic networks' (Jessop, 2007: p.6); the capacities and liabilities of the state determine the nature of its interventions. Strategies include; redefining priorities, expanding or reducing activities and rescaling activities (Jessop, 2007b). Jessop (1997) identifies three broader trends which are shaping and being shaped by state strategies:

- De-nationalisation – involving a process of state transformation 'with old and new state capacities being reorganized territorially and functionally on sub-national, national, supranational and trans-local levels' (Jessop, 1997: p.575, 576). Such processes of 'multi-level governance', particularly regionalisation, have been observed in the UK energy industry (Winskel, 2006, Smith, 2007).
- De-statization – reflecting the shift from government to governance, states must engage in the 'complex art of steering multiple agencies in order to achieve their objectives' (Jessop, 1997: p.575). A relevant example of this process is the privatisation and de-regulation of network industries.
- Internationalisation - partially due to the crisis of the Keynesian welfare state and the rise of neo-liberalism, 'state action has extended to include a widening range of extra-territorial or transnational factors and processes' (ibid: 1997: p.575). In their analysis of emerging relationships between cities and climate change, Hodson and Marvin (2011) argue that this processes has prompted new forms of urban entrepreneurialism where

cities must innovate in order to remain competitive and attract international flows of financial capital for investment in infrastructure networks.

Within technological systems, particularly infrastructure sectors, these activities strategically select certain types of interactions, technologies, practices, organisational forms and sector structures. For example, due to concerns over the security of centralised energy systems, the state may pursue a polycentric approach to achieving its energy policy goals thus favouring more decentralised and fragmented responses e.g. local CHP-DH schemes. The following section explores in more detail the multiple ways in which the strategic selectivity of the state takes place.

The State and Power

Noting the dangers of conflating state structure with state powers (Davies, 2008), we turn to Michael Foucault's lectures and writings on governmentality to provide useful insights into the ways in which state power is diffused throughout society (Foucault, 1978) and how this in turn affects distribution networks. While the structurally orientated approach described above 'seeks to explain the *why* of capital accumulation and state power' the governmentality approach developed by Foucault tries to 'explain the *how* of economic exploitation and political domination' (Jessop, 2006: own emphasis). The neo-Foucauldian approach moves away from preconceived notions of institutional structures and material objects and places the attention on the multiple sites where governing takes place and the heterogeneous set of techniques and tactics of government, or 'arts of government'. Referring to the governmentality approach, Foucault notes the following:

> *"In short, the point of view adopted in all these studies involved the attempt to free relations of power from the institution, in order to analyze them from the point of view of technologies; to distinguish them also from the function, so as to take them up within a strategic analysis; and to detach them from the privilege of the object, so as to resituate them within the perspective of the constitution of fields, domains, and objects of knowledge" (Foucault, 2004: p.118)*

Rather than particular institutional arrangements or forms (Bulkeley et al., 2007) through which power is exercised, Foucault was concerned with the processes and practices of government[18]

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[18] This is not equated with the state in a conventional sense: '…Foucault's work on governmentality takes us beyond the State, by emphasising…the diversity of forces, as well as groups, whose aim is to regulate' (Ezzamel and Reed: p.608). However, a neo-Foucauldian conceptualisation of Government (or the 'conduct of conduct') is quite close to Jessop's relational definition of the state: "Government is the historically constituted matrix within which are articulated all these dreams, schemes, strategies and

which 'render populations of individuals amenable to intervention, calculation, classification, homogenization and ordering' (Ezzamel and Reed, 2008: p.608). He argued that 'power does not flow from centres to eventually impact on the minutiae of daily life but instead is produced through the play of forces in decidedly local settings' (Uitermark: p.145). In essence the approach analyses the micro-physics of power i.e. 'the local settings in which power actually makes itself visible and sensible' (Uitermark, 2005: p.145). This 'analytics of government' approach described by Foucault focuses on the everyday techniques, practices, rationalities, programmes and means of calculation which control populations. What Foucault proposes is 'a relational understanding of power. Power is therefore not conceived as a stable and fixed entity that could be 'stored' at particular institutional sites but signifies the result of a mobile and flexible interactional and associational network' (Lemke, 2007: p.13).

Foucault's previous analyses had displayed 'hostility to general theorizations about the state' and taking 'the existence of the state for granted' (Jessop, 2006), rather the focus was on how power relations emerged from 'dispersed local sites well away from the centres of state power'. However, his later work considered how these dispersed power relations became codified, institutionalised and consolidated (Jessop, 2006) in structures and institutions associated with the nation-state. Therefore the governmentality approach concerns itself with the recursive relationship between dispersed and fragmented practices of government, and changing state forms[19], while arguing that the pre-existence of the state cannot be taken for granted. Similar to the state transformation approach described above, the state is not understood in 'juridical categories' but 'within the logic of strategic relations that constitute a collective will', however there is less of an emphasis on the 'materiality' of the state (Lemke, 2007).

Rose and Miller summarise the governmentality perspective:

> *"…the state can be seen as a specific way in which the problem of government is discursively codified, a way of dividing a 'political sphere', with its particular characteristics of rule, from other 'non-political spheres' to which it must be related, and a way in which certain technologies of government are given a temporary institutional durability and brought into particular kinds of relations with one another" (Rose and Miller, 1992: p.176/177)*

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manoeuvres of authorities that seek to shape the beliefs and conduct of others in desired directions…" (Rose and Miller, 1992: p.175)

[19] Foucault distinguishes between sovereignty (medieval states, controlling territory), disciplinarity (administrative states in the 15th and 16th centuries) , and governmentality (controlling populations)

In an effort to understand the activities aimed at shaping, guiding and controlling the behaviour of actors and groups of actors, the approach analyses both the rationalities and technologies of government:

- Governmental rationalities: These are 'the changing discursive fields within which the exercise of power is conceptualised' (Rose and Miller, 1992: p.175). Such rationalities define the objects to be governed and the goals and means of government i.e. programs of government; where 'reality can be governed and managed, evaluated and programmed' (Rose and Miller, 1992: p.182). These act as the 'cognitive and normative maps' (Lemke, 2007) for state activities; knowledge and expertise have a key role to play in defining problematics of government and in shaping programmes. In energy infrastructure sectors these programmes - such as market liberalisation - reflect underlying governmental rationalities and a sense of a collective will.
- Technologies of government: These are 'the complex of mundane programmes, calculations, techniques, apparatuses, documents and procedures which authorities seek to employ and give effect to government ambitions' (Rose and Miller, 1992: p.175). These provide a means by which one can measure 'the real against the ideal'(Macleod and Goodwin, 1999: p.181). Broadly two types of governmental technology have been identified; those which focus on performance and those which seek to promote agency i.e. 'which seek to invoke particular subjects and their participation in processes of governing' (Bulkeley et al., 2007). Studying these micro-level techniques and instruments highlights that 'the difference between state and society, politics and the economy does not function as a foundation or a borderline, but as an element and effect of specific governmental technologies' (Lemke, 2007). In the case of distribution networks, technologies of government can refer to ways of calculating and controlling flows within a network e.g. network regulation and various licensing regimes, or more direct means such as ownership of a CHP-DH scheme by a local authority.

Recognising the utility of both governance (structural) and the neo-Foucauldian governmentality approach, a number of authors (Bulkeley et al., 2007, MacKinnon, 2000, Macleod and Goodwin, 1999, Uitermark, 2005) have argued that although they derive from distinct ontological underpinnings (particularly regarding the nature of the state) there is significant scope to combine the approaches in order to explore how everyday practices of control across different scales are emblematic of and reinforce broader state structures i.e. 'how the strategic selectivity of the state takes place' (Bulkeley et al., 2007: p.2738). The approach has been particularly useful in analysing the changing scales through which power is exercised;

this has been an increasingly prominent theme in the governance (Macleod and Goodwin, 1999) and environmental governance (Davies, 2008) literatures.

This discussion is relevant to the analysis of energy systems in a number of ways. For the case of incumbent and established networks such as electricity distribution systems, the involvement of the state should be considered in the context of what Jessop terms ‘de-statization’ i.e. the shift from government to governance and the associated efforts to engage with networks of actors and utilise less direct and more subtle techniques – such as economic regulation and licensing - in order to achieve objectives. Within these sectors, the privatization and liberalisation of energy systems and the associated problematization of natural monopoly can be viewed in the context of the move away from a Keynesian welfare state towards a more fragmented form based on the introduction of competition, unbundling and market liberalisation of network industries (Hodson and Marvin, 2011). Similarly, for the case of less established local infrastructures, such as CHP-DH in the UK, the traditional conceptualization of national integrated infrastructures and hierarchical institutions is being eroded by processes of ‘de-nationalisation’. At a sector level this is opening up new spaces for agency and transformation at different spatial scales which are creating new types of interdependencies and interactions between different tiers of government (Graham and Marvin, 2001). This is important because distribution networks in particular are spatially bound (typically at a local or regional level) and shaped in part by local contexts (for example the socio-political characteristics of cities or sites where renewable generators are most likely to connect). It is therefore crucial to consider their governance in a way which recognises these local contingencies and scalar dynamics.

The literature on governance and state theory therefore provide useful theoretical insights regarding the diversity of ways in which the relationship between the state and infrastructure sectors can proceed. The next section synthesises these insights within an analytical framework which can operationalise the hypotheses and propositions outlined in this chapter and to act as a framework to structure the empirical chapters. From a reading of the governance and governmentality literatures, a key task is to frame the interplay between actors, institutions and technologies as a complex governance process which can capture the relationships between changing state forms, different governmental rationalities and the instruments and technologies of government.

2.5 Chapter Summary

This chapter had two main purposes. The first was to review the existing literatures which address the overarching research question regarding the interplay between actors, institutions and technologies in distribution networks, and the second was to make a contribution to this body of literature by elucidating the role of the state in the governance of energy systems. The literature review discussed both economic/institutional and socio-technical approaches to the study of infrastructure networks. It was found that these literatures provide valuable insights into various aspects of the dynamics of energy distribution networks and a number of causal mechanisms were identified which will be used in chapter 7 to analyse the two case studies. However, it was recognised that they adopt different approaches to the analysis of institutions and institutional change in these sectors and place different degrees of emphasis on actors and structures in the process of change. The analytical framework which is developed in the next chapter will be cognisant of these differences and will propose a number of distinct analytical categories which will provide an ontologically coherent framework for the analysis of the interplay between actors, institutions and technologies in the two case studies.

The second part of the chapter concentrated on one particular actor in this interplay – the state. It was argued in the introductory chapter that despite a number of notable exceptions, studies of energy sector transformations in a liberalised context have either downplayed or undertheorized the state and its role in shaping the governance of infrastructure sectors such as energy distribution. Literatures on governance, state theory and governmentality were engaged with in order to elucidate the ways in which state transformations and the rationalities and technologies of government influence meso level sector transformations. These insights will inform the analytical framework which is outlined in the following chapter.

3 Analysing the interplay between actors, institutions and technologies in infrastructure sectors

3.1 Introduction

This chapter develops a novel analytical framework which is utilised in the empirical chapters to highlight specific aspects of the social and technical reproduction and transformation of distribution networks. The analytical approach is based on two critiques of the economic and socio-technical literatures which were discussed in the previous chapter:

1. That existing approaches offer an inconsistent and incomplete explanation of the role of institutions and the nature of institutional change in infrastructure sectors.
2. That the role of the state in influencing the governance patterns of socio-technical systems requires a more systematic treatment, particularly in the case of network industries.

The framework itself analyses the interplay between actors, institution and technologies in infrastructure sectors as a governance process exploring the outcomes of a series of interventions and interactions between a range of sector level stakeholders in the context of a wider governance regime. Following Davies (2008)[20] a tripartite approach is taken; the *governance regime* (Paavola et al., 2009) outlines the national level policy and regulatory framework which embodies various political rationalities, programmes which are undertaken by the state and policy instruments. This is the structural context within which socio-technical processes - described here as *interventions and interactions* - take place between a wide range of actors to shape infrastructure sectors at the meso and micro levels. The *outcomes* of these interventions and interactions are analysed according to three analytical dimensions which characterise the interplay between actors, institutions and technologies in infrastructures - the physical, the relational and the structural.

The chapter proceeds by discussing the analytical framework in more detail with the final section outlining the research design and methodology.

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[20] The framework draws from Davies' approach to the analysis of governance processes in the waste sector (Davies, 2009). In two national level case studies of the waste regimes in New-Zealand and Ireland she examines the relationships between policy *interventions*, *interactions* between actors across different scales and the associated *outcomes*.

3.2 Characterising the Governance Regime

In the previous chapter, various approaches which relate to governance and the nature of the state were introduced. It was argued that the interdependencies between states and socio-technical systems can be discussed in the context of changing state forms and strategies which are made visible though micro-level processes of calculation and control such as policy instruments, regulatory frameworks and licensing regimes; all of which have a key role in shaping interactions within infrastructure sectors. It is proposed that for the case of infrastructures such as distribution networks which have strong non-market characteristics, this wider governance regime constitutes the structural preconditions for agency and acts as the main selection environment for innovation in these sectors.

This framing of a wider governance regime is developed by Paavola et al (2009) in their analysis of the governance of biodiversity in Europe. They argue that while it is important to study specific interventions (which they term governance frameworks) in a particular context 'there is a danger that an analysis of specific governance frameworks over-states the influence of the institutions in question whilst overlooking or under-emphasizing the influence of other important factors that lie beyond the boundaries of the study' (*ibid*: p.151). They propose the concept of a governance regime, or a 'range of multi-level and multi-actor governance processes' which contextualises more specific and localised interventions and interactions.

In order to elucidate the governance regime in each of the cases, the study draws from Bulkeley et al's. (2007) concept of 'modes of governing'. Bulkeley et al. argue that a governance landscape or regime should not be defined solely by the institutions and objects of governance in a structural sense, but also by the processes and practices through which governance takes place and outcomes occur. As Davies notes; 'While it is important to establish the 'what' and 'how' of governing in particular places it is also necessary to consider the outcomes of those governing moments and how governing entities react or resist the modes of governing that are being implemented' (Davies, 2008: p.36). By incorporating insights from the governance and governmentality literatures, they propose a stratified model of a governance regime where a mode of governing is; 'a set of governmental technologies deployed through particular institutional relations through which agents seek to act on the world/other people in order to attain distinctive objectives in line with particular kinds of governmental rationality' (Bulkeley et al., 2007). Each mode of governing, they argue, is characterised by a specific governmental rationality, associated objectives and programmes/policies, sets of institutional relations between actors and agencies and technologies of governing e.g. regulatory frameworks and licensing regimes. This provides a framework by which state strategies and the structural preconditions for agency can be made more visible in each of the cases (Davies, 2008). It is proposed that multiple modes of governing co-exist to constitute a governance regime for a sector i.e. ‘different constellations of actors, rationalities, technologies, institutional relations, and entities are brought together as problems are defined and solutions sought’ (Bulkeley et al., 2007: p.2740).

There are a number of ways to define and characterise the governance regime for an infrastructure sector. For example, one may seek to do this by considering the broader institutional and regulatory apparatus in place to mitigate a range of environmental, health and security risks (Hood et al., 2001). However, in the interests of clarity it was decided to confine the analysis of governance regimes to the energy sphere. In this study a national level focus is taken in examining the governance regime for energy distribution sectors because in the UK this has been the tier or level of government at which the state has traditionally pursued its energy policies (Russell, 1993, Hannah, 1979, Hannah, 1982). This being said it is also important to be aware of the different scales (local, national and international) through which governance takes place. In the case of electricity distribution systems in the UK, the governance regime tends to be predominantly instituted at the national level and characterised by a strong regulatory framework. Here the objectives and institutional relations are quite well defined and centre on the relationship between the regulatory authority (Ofgem) and the seven private network operators. This is because the distribution (and transmission) networks have been unbundled from the other segments of the value chain; therefore the governance regime can be isolated in this respect. A number of objectives or modes of governing can be identified in network regulation such as allocating the economic rents of natural monopoly (as this is not a competitive activity), providing incentives to private operators to reducing the costs of operating the networks, and enabling competition in other segments of the value chain such as retail and generation.

In the case of heat distribution networks the governance regime is more dispersed and heterogeneous where modes of governing include efforts to promote energy efficiency in energy use and within the built environment, and more recently, the promotion of low carbon and renewable sources of heat generation. This is because the networks themselves operate within localised contexts and are more integrated with upstream and downstream value chain functions such as generation and retail. Also, they are not interconnected at the regional level and are more dispersed; they therefore tend not to be framed in terms of natural monopoly to the same extent as electricity distribution and are not as tightly regulated.

3.3 Interventions and Interactions

Whilst the governance regime provides the macro level structural context, it is important to analyse the diverse sets of interventions and interactions between actors occurring in different contexts and scales at the meso-micro levels. For distribution networks these interventions and interactions refer to a broad range of actor strategies, motivations and framings, and the articulation and implementation of different modes of governing. Due the fact that electricity and heat distribution networks operate across different spatial scales and have a diverse set of governance arrangements, the main aim of this section is to provide an open framing whereby the unfolding storylines emerging as a result of the interplay between technologies, actors and institutions can be uncovered. For the case of electricity distribution systems, this may refer to the application of regulatory instruments and the ways in which network operators interact with the regulator. It may also incorporate how network operators interact with equipment manufacturers and engineering consultants to introduce new technologies to their networks, or the changing relationships between the sector regulator and government departments in the formation and implementation of energy policy in this area. For the case of heat distribution networks, a key set of interventions and interactions occur in the changing relationships between different tiers of government (national and local) in the UK and how this creates space for new forms of agency in the area of the provision of energy services within localities.

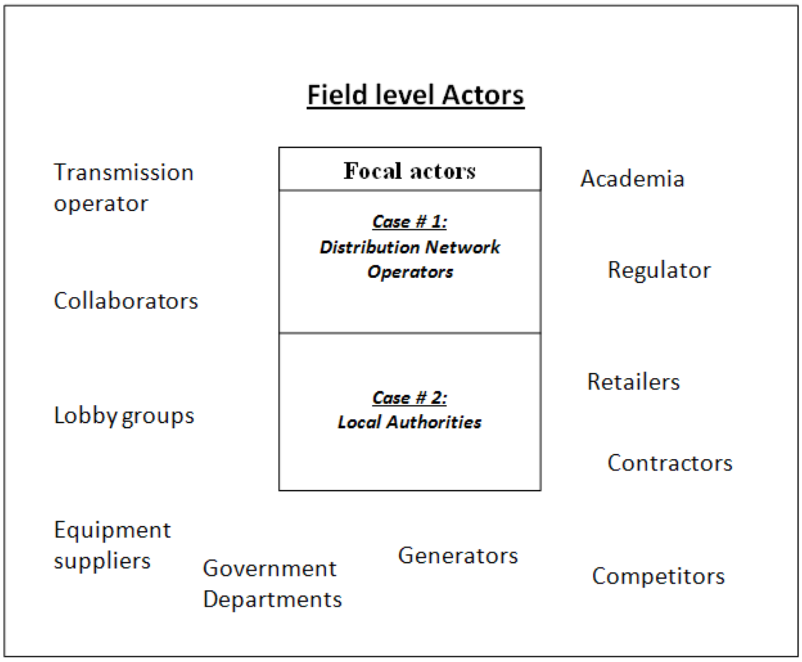
In order to frame these sector or meso level processes the concept of an organisational field, as proposed in the sociological branch of new institutionalism (DiMaggio and Powell, 1991, Scott and Meyer, 1991, Scott, 2001, DiMaggio and Powell, 1983)[21], provides a useful framing for the sets of formal and informal interactions taking place between a wide range of actors in an infrastructure sector. An organizational field is defined as ‘a community of organizations that partakes in a common meaning system and whose participants interact more frequently and fatefully with one another than with actors outside the field’ (Scott, 2001: p.84). The electricity

[21] The difference between economic and more constructivist/sociological approaches to institutions is summarised by Garud et al. as follows: “Among institutional economists, for instance, the appearance and maintenance of institutional arrangements are explained in terms of economizing on transaction costs (Coase, 1937; Williamson, 1985). According to this perspective, institutional arrangements function to reduce uncertainty and to mitigate opportunistic behavior such that transaction costs associated with negotiating, monitoring and enforcing contracts between boundedly rational actors are reduced. Institutional arrangements, in turn, tend to reproduce – rather than change – existing social arrangements. Sociological perspectives on institutional theory emphasize how institutional arrangements confer legitimacy, which is ‘a generalized perception or assumption that the actions of an entity are desirable, proper or appropriate within some socially constructed system of norms, values, beliefs, and definitions’ (Suchman, 1995: 574). As a result, some actions within a particular institutional field come to be seen as legitimate (Meyer and Rowan, 1977) and may even be ‘prescribed’, making it difficult for actors to deviate from them.” (Garud et al., 2007)

distribution sector in the UK can be defined along these lines with a number of private network operators operating under the terms of a licensing arrangement and regulated by a sector specific energy regulator. The heat distribution sector in the UK is more fragmented because the local systems are not integrated at a regional or national level and are operated by a more dispersed set of actors who are embedded at the local level. However, it is argued that in the context of the UK energy policy environment, they do ‘constitute a recognised area of institutional life’ incorporating ‘key suppliers, resource and product consumers, regulatory agencies, and other organizations that produce similar services or products’ (DiMaggio and Powell, 1983).

Although the composition of an organisational field is different in each case, the following diagram illustrates some examples of actors within an energy distribution network organisational field. The organisational field constitutes a sector with core or focal actors – electricity network operators and local authorities – who tend to own and/or operate distribution networks in each of the cases, along with more peripheral actors who do not directly interact with the networks themselves but whose actions influence and shape the organisational field.

Figure 3.1: Examples of actors within infrastructure sectors

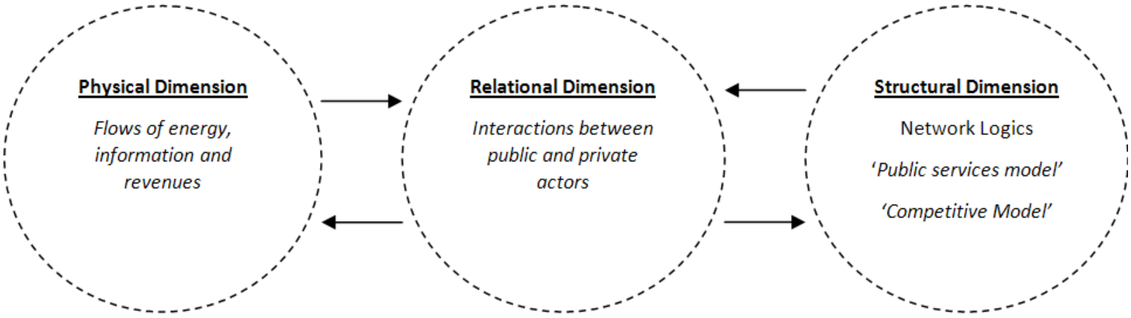


Of particular interest is how interventions associated with the dual agendas of liberalisation and the decarbonisation of energy systems are shaping field level interactions and the ways in which this process is shaped by the different modes of governing in the wider governance regime.

3.4 Outcomes

As the main aim of this thesis is to explore the nature of the interplay between actors, institutions and technologies in distribution networks, a key question is how to assess the outcomes of the field level interventions and interactions which take place. It has been argued in the literature review that existing approaches tend to be inconsistent on the relationship between institutions and infrastructures and that the role of agency in shaping institutional change needs to be better conceptualised. The figure below presents a novel way to conceptualise these relationships which can be used to assess the outcomes of governance processes in each of the cases.

Figure 3.2: Dimensions of Institutions and Infrastructure Networks



This draws from the MLP but is a novel framework which has been tailored to analyse the specific socio-technical dynamics of infrastructure networks whereby the institutional composition of sectors such as energy distribution and the role of actors in shaping change can be can be assessed in a systemic fashion. It distinguishes between three analytical categories or dimensions of institutions and infrastructure networks – the physical, the relational and the structural - and proposes that institutions are embedded in each of these three dimensions. This, it is argued, can provide a useful analytical tool whereby the outcomes of governance processes - particularly how institutional change happens - in different sectors and contexts can be analysed. This draws from a critical realist ontology[22] where a 'stratified model of reality' (Leca and Naccache, 2006) is presented (Sayer, 1999, Jessop, 2005, Clegg, 2010). Critical realism 'adopts an ontological realist position that distinguishes between the real, actual, and empirical'(Leca and Naccache, 2006) or 'structures, events, and experiences' (Clegg, 2010) respectively. In the domain of the *empirical* are experienced events, which are characterised as measurable physical flows within a network i.e. the material dynamics of the system – this is the

[22] A researcher's ontology 'conceptualises social reality in certain terms, thus identifying what there is to be explained' (Archer, 1995: p.17)

physical dimension. In the domain of the *actual* events also occur, however these can be experienced and perceived in different ways by different actors – this is the relational dimension. This is characterised as the ongoing sets of interactions between actors within a particular infrastructure sector and across different scales where actors and groups of actors have different motivations, interpretations and framings of reality. Finally, the domain of the *real* is where all three of structures, events and experiences exist and reflects deeper 'structures and causal powers that generate events' (Leca and Naccache, 2006) – this is the structural dimension. For the case of infrastructures this is defined in terms of different network logics (Graham and Marvin, 2001) which are drawn upon by actors to rationalise and legitimise certain types of activity within sectors. It is proposed that institutions act across these three interrelated dimensions and are embedded in the materials, practices and structures of the ongoing construction and reproduction of distribution networks.

These three analytical dimensions which will be used to assess the outcomes of governance processes in each of the cases are discussed in more detail below.

Physical Dimension

In the physical dimension *institutions coordinate physical flows within a network which can be measured, monitored and controlled*. Institutions in this respect operate at the micro level and are the transactions which mediate between and direct these flows in order to develop what Rip and Kemp term a 'configuration that works' i.e. 'materials and components, combined into devices and linkages that, in their turn, are combined into an overall working system'(Rip and Kemp, 1998). In the figure above these physical flows are characterised as flows of information, material (energy) and revenues which can be measured, monitored and controlled. By coordinating these flows, mainly formal institutional arrangements carry out two main functions:

Achieve System Economies

In large scale technical systems the management of networks has tended to be informed by a perception of the most economically rational way of controlling flows within a system (Hughes, 1987, Hughes, 1983, Nightingale et al., 2003, Davies, 1996). In small scale urban distribution systems e.g. D.C. electricity systems such as the ones which emerged in cities in the 19th century or modern CHP-DH schemes, system design and operation is informed by efforts to achieve *economies of scope* in service delivery. This entails sizing the system in order to provide a range of services to customers and therefore benefit from the associated economies 'which are obtained by using the same plant and equipment within a single operating unit to provide (…)

services at a lower cost than that of providing each service separately' (Davies, 1996: p.1159). In countries such as the Netherlands and Denmark many of the formal institutions which control flows in the energy networks, e.g. pricing regimes and access regulations, have been designed in order to favour the development of energy schemes at a local level which provide a range of energy services (Verbong and Geels, 2007, Raven and Verbong, 2007, Toke and Fragaki, 2008).

When energy infrastructures began to expand significantly in the mid twentieth century the conventional way of achieving system economies were through *economies of scale* where large capital investments in fixed cost components were spread over an increasing number of units in order to benefit from supply side efficiencies e.g. improving the load factor[23] of electricity generating plant. Energy networks began to expand over wider geographical areas in order to encompass a greater diversity of loads (demands) thus facilitating cost recovery for large sunk investments. The economic regulation of integrated natural monopoly systems facilitated this process by reducing investment risk and by allocating economic rents. Increasingly however, due to institutional changes associated with liberalisation and unbundling, the allocation of network capacity and the nature of flows within energy networks have been influenced by market allocation mechanisms. This has placed a greater emphasis on improving the information flows within systems and has resulted in a more complex set of revenue flows as private operators must facilitate connection by third parties to their networks. Achieving these *economies of system* (Davies, 1996) through the development of more sophisticated control components has seen the diffusion of ICT based control systems on many networks which improve capacity utilisation - the monitoring and measuring of flows and the allocation of network capacity.

Maintain the reliability and integrity of the system

As noted in the literature on TCE, depending on the nature of the network itself, whether it is an electricity, heating, or gas infrastructure, a degree of complementarity must be maintained between the components of the system in order to ensure system security and reliability i.e. maintain the critical transactions of the system. Kaijser (2004) characterises these components as the nodes (points where decisions regarding flows are made), and the links (pipes, wires etc.) which mediate the various flows in a particular network. These physical elements are arranged within a 'nested hierarchy' at the component (individual nodes and links), sub-systems (e.g. regional distribution networks) or system level (a nationally interconnected infrastructure). Therefore it is important not only to consider individual components but also the

[23] The ratio of average output to maximum potential output.

complementarities between these components within sub-systems and systems. Institutions which ensure this complementarity can include hierarchical centralised arrangements which control flows and access to nodes across an entire network or more decentralised arrangements where individual nodes are more independent. Institutions which control access to the components of networks (nodes and links) are also important in order to maintain system integrity and security (property rights) and in a liberalised context this function has become increasingly important for the revenue streams of private network operators.

In terms of accessing a network, a distinction can be made between point-shaped networks which are accessible to users at some of the nodes (e.g. airports and train stations), line-shaped networks which can be accessed along their links where it is easier to create new nodes (e.g. telephone systems, electricity wires and heating pipes), and surface-shaped networks which can be accessed at all points within a particular area (e.g. satellite communications, radio frequencies) (Kaijser 1994). The nature of the system in question is also important in terms of the types of flows of material (energy), information and revenues taking place. Kaijser (2004) distinguishes between three types of arrangements.

- *Distributive* – this includes energy and water systems where there is ‘a unidirectional flow from one or several central nodes to a large number of users’ (Kaijser, 2004) e.g. electricity and heat distribution networks.
- *Accumulative* – such as waste collection or sanitation where there is a ‘reverse unidirectional flow, from many users to one or several central nodes’ (Kaijser, 2004)
- *Communicative* – these are systems with a two-way flow e.g. telephones & transport.

Although these distinctions are useful, in reality many energy systems involve a combination of the above e.g. in most energy systems raw material is accumulated (waste, biomass, coal) prior to a conversion process e.g. at an electricity or heat generating station after which energy is converted and distributed to the point of consumption via an energy carrier e.g. electricity or hot water. Also, it has been noted that there are often different forms of interplay which create synergies between various networks (Konrad et al., 2008, Jonsson, 2000, Frantzeskaki and Loorbach, 2010); for example communications systems are increasingly being used across a number of distributive and accumulative systems in order to enable real-time capacity utilization; these synergies help to create new system economies e.g. reducing the need to build large amounts of redundancy into the system. However, it should be noted that these interactions between different systems can cross previously strong sector based institutional boundaries at the relational dimension.

Relational Dimension

Institutional change from the physical perspective may appear to occur in a functional or rational manner as flows within a network can be empirically measured and calculated. However, it is proposed that this cannot be considered in isolation and that it is heavily influenced by the structure of the sector, the types of interactions taking place, and the differing motivations, interpretations, strategies and capabilities of different actors and groups of actors within an organisational field. At this level, although interactions take place, these are less prone to measurement or verification as they can happen 'independently of the experience and perception that actors may have of them' (Leca and Naccache, 2006). In terms of infrastructures, this is what Jane Summerton refers to as the 'invisible grid' or 'the seamless web of interdependencies that enables and sustains the operation of these systems' (Summerton, 1992: p.81). Summerton proposes that this includes regulators, legislative and political bodies, public agencies, financial institutions, professional interest groups etc. Institutions in these terms address the issue of '…independent but autonomous organisations, each controlling important resources' and *the role of institutions is 'to coordinate their actions to produce a joint outcome which is deemed mutually beneficial*' (Jessop, 1995). This moves away from a rule based view of institutions towards an actor based one where 'institutional change involves not simply remaking the formal rules, but fundamentally it requires realignment of interests, norms and power' (Nee, 2003: p.24). Institutions therefore shouldn't be seen as a solution to an abstract notion of efficiency or promoting system economies, but as a mechanism of coordinating actors, aligning interests and which characterise the structure of a sector.

As discussed in the previous chapter, one way of thinking about infrastructure sectors is in terms of their value chain from production, distribution and through to consumption. This can be organised hierarchically i.e. vertically integrated or based on market transactions where coordination is achieved through the price mechanism. It is argued however that a reliance on these binary distinctions can often obscure many of the different types of collective action which take place in infrastructure sectors. For example, Campbell et al. (1991) point to numerous forms of governance within industry sectors with different forms interactions taking place such as obligational networks, joint ventures, R&D alliances, trade associations and producer cooperatives. This is based on the premise that each industry and sector 'is a matrix of interdependent social exchange relationships' (Campbell et al., 1991: p.5,6). Infrastructure networks are no different, consisting of a series of vertical and horizontal relationships in which actions are institutionally embedded (Granovetter and McGuire, 1998). There are therefore a multitude of types of interactions taking place within organisational fields which can be assessed with vertical interactions along a value chain and horizontal interactions between focal actors and the regulator, component manufacturers and consultants.

Over time, repetitive interactions with an organisational field can lead to the institutionalisation of certain types of behaviour often to the exclusion of others. This notion of a dialectic between structures and agents draws from the work of Anthony Giddens whose structuration theory (Giddens, 1984) has been adopted by transitions theorists in their framing of the socio-technical regime (Geels, 2004). The structuration of organizational fields leads to isomorphism or similarity between organisations within fields as actors seek to conform to their institutional environment (or selection environment). This leads to the creation of a sense of collectively defined rationality within sectors which can be characterised as '…widespread social understandings (rationalized myths) that define what it is to be rational' (Clegg, 2010). Therefore, it is possible that across different infrastructure sectors actors will pursue the 'efficient' operation of energy networks and define system economies in entirely different ways. This process of isomorphism occurs through coercive, normative, and mimetic processes[24]; thus 'institutionalized fields limit the direction and content of change, causing an inexorable push towards homogenization' (DiMaggio and Powell, 1983: p.148). As a result of these processes 'organizational success depends on factors other than efficient coordination and control of productive activities'; organizations which 'succeed in becoming isomorphic with these environments gain the legitimacy and resources needed to survive' (Meyer and Rowan, 1977: p.53).

However, this is not a recipe for terminal inertia or obduracy. Although actors, organisations and interactions can become highly structured over time, they 'are also capable of responding to these influence attempts creatively and strategically' (Scott, 2001: p.179) both in a collective and individual capacity. Also, from the literature on STS, organisational fields should be seen as 'contested terrains' which are 'contoured' by competing strategies, variations and struggles (Greenwood et al., 2008: p.20). In their study of the changing relationships between infrastructures and cities, Hodson and Marvin (2010) draw from the work of Pierre Bordieu (1993) to provide a more differentiated view of 'fields' which are characterised by closed spaces of reproduction or alternatively by open spaces of radical reconfiguration.

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[24] Clegg (2010) describes these: 'coercive (when external agencies impose changes on organizations—most obviously through practices of state regulation), normative (when professionalization projects shape entire occupational fields), and mimetic mechanisms (essentially the copying of what is constituted as culturally valuable ways of doing or arranging things—cultural capital).

Structural Dimension

The third analytical category in the analysis of governance outcomes in distribution sectors is the structural dimension. Here *institutions represent the underlying rationality behind the system which shape field level interactions and act as a source of legitimacy for action*. This is the structural element of infrastructures i.e. the 'generative structures or causal mechanisms' (Jessop, 2005) and is defined by institutional logics. Returning to the literature on sociological institutionalism, an institutional logic can be defined as 'a set of material practices and symbolic constructions - which constitutes its organizing principles and which is available to organizations and individuals to elaborate' (Friedland and Alford, 1991). Institutional logics constitute the 'content and meaning of institutions' and shape 'the interests, identities, values, and assumptions of individuals and organizations' which are embedded within them (Thornton and Ocasio, 2008). By following a 'logic of appropriateness' actors who are embedded within these broader contexts conform to norms and rules 'because they are seen as natural, rightful, expected, and legitimate' (March and Olsen, 2004). A sense of collective identity emerges when actors in organizational fields fulfil roles and obligations and draw legitimacy from institutional logics where 'what is legitimate changes depending on the context in which it is negotiated and evaluated' (Thornton and Ocasio, 2008). Within an organizational field therefore, institutional logics shape action, provide 'socially constructed systems of classifications that constitute categories of social actors' and they convey a set of rules and norms 'for deciding which problems get attended to, which solutions get considered, and which solutions get linked to which situations' (Thornton and Ocasio, 2008). However, it must also be noted that institutional logics can also motivate strategic behaviour which can act as a source of institutional change. The role of the institutional entrepreneur has been highlighted in this regard; they use causal powers of logics by exploiting differentiation and inconsistencies in their environments to bring about change (Tracey et al., 2011) i.e. 'organized actors who skilfully use institutional logics to create or change institutions, in order to realize an interest that they value highly'…'they must mobilize institutional logics that are likely to match potential allies' interests and/or values' (Leca and Naccache, 2006).

Drawing on the concept of institutional logics, a number of ideal type network logics (Graham and Marvin, 2001) can be identified in the case of energy distribution sectors which represent the different rationalities which characterise the nature of service provision and are underpinned by distinct political and economic rationalities (Offner, 2000). The first is termed the '*public services model*' which is rooted in the view that the services that infrastructures provide should be 'delivered by social institutions based on private or public monopoly control' (Graham and

Marvin, 2001 p.73). The political rationality behind this is that energy systems are public goods, therefore the costs of providing these services and the financial risks should essentially be socialised. This was influenced by notions of 'Keynesian models of state policy and demand management, to balance Fordist production and consumption practices' (Graham and Marvin, 2001). This logic prevailed during much of the 20th century when many of the large scale infrastructure systems such as electricity, telecommunications and sanitation were constructed in industrialized countries. The second ideal type network logic is termed the '*competitive model'*, where certain functions of infrastructure service provision are privatized and opened up to competition (liberalization) e.g. energy retail, electricity generation. Under this model the networks themselves, the pipes and wires, tend to be treated as natural monopolies which are privately operated under some form of regulatory supervision[25] in order to ensure third party access to the network. This network logic is based on the neo-liberal premise that regulation and/or public ownership is costly and that the price mechanism, as a mode of coordination in these sectors, promotes efficiency in investment decisions and system operation.

These network logics do not exist in isolation and are not temporally bound. Throughout the evolution of infrastructures actors have drawn from these ideal type logics in different ways to legitimise certain practices and influence interactions and perceptions of technical and economic rationality[26] e.g. the development of state owned public monopolies and their subsequent privatization have drawn in different ways from these logics (Graham and Marvin, 2001, Guy et al., 1999). A key question that this research seeks to address is how, in the contemporary context, actors draw upon these broader logics to shape organizational fields and influence technical change.

Summary of the Dimensions Approach

By presenting the relationships between infrastructures, institutions and actors in this multi-dimensional way it is hoped to move away from linear, cause-and-effect explanations for change in infrastructure sectors towards a more open framing whereby different contextual factors can be taken into account and the ontological depth of these large scale socio-technical

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[25] Although there have been cases where network operation has been opened up to competition in certain forms e.g. franchise bidding for natural monopoly (Williamson, 1976) or facilities based competition in the telecoms sector (Pollitt, 2010)

[26] Ezzamel and Reed (2008) characterise this as an ongoing tension between 'the simultaneous drive for technical efficiency and the need for symbolic legitimacy' i.e. 'the symbolic and cultural prerequisites for legitimacy and the material and technical prerequisites for survivability' (2008: p.609).

systems can be represented. For each of the analytical dimensions the following analytical variables apply across both of the case studies:

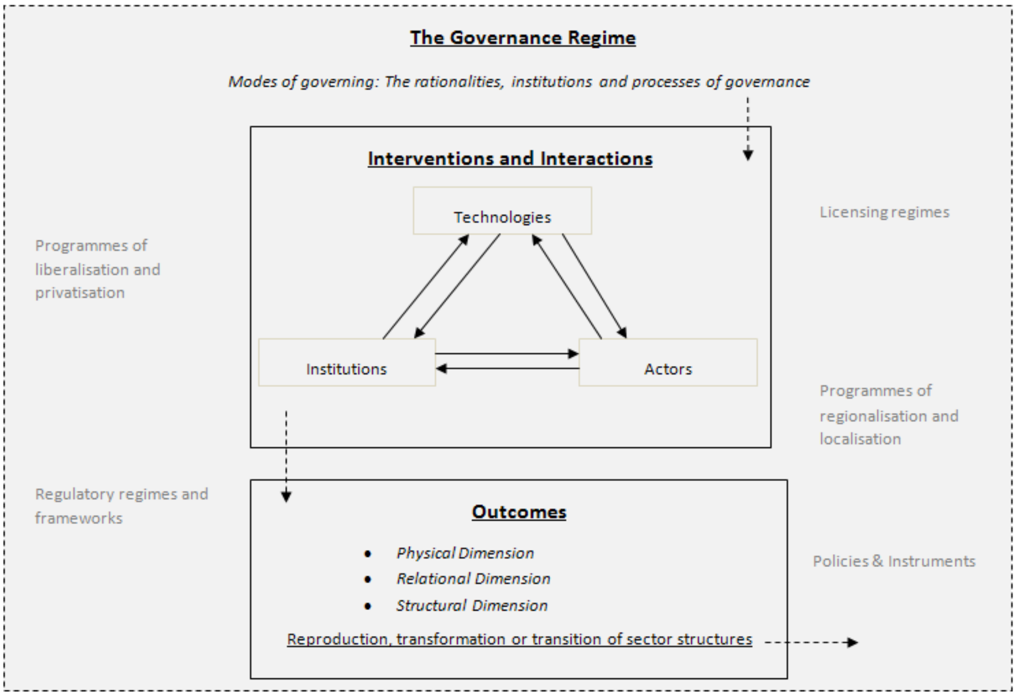
- *Physical Dimension*: How are the relationships between nodes, links and flows (of material (energy), information and revenues) being altered? How is capacity utilisation being achieved? What is the changing interplay between functions of a network (vertical) and across different networks (horizontal)?
- *Relational Dimension*: What is the changing structure of the organisational-field? What is the outcome of differential strategies, motivations and capacities amongst a diverse array of actors? How are actors forming new alliances and partnerships? What are the changing roles of incumbents and new entrants in the organisational-field? How are new spaces of interaction emerging across different scales of the system?
- *Structural Dimension*: In what ways do actors draw upon network logics in order to legitimise their actions? How are network logics being reproduced or transformed in different contexts?

A key concern is whether these outcomes represent a reproduction, transformation or more fundamental transition in sector structures for each of the cases.

3.5 Summary of the Analytical Framework

The purpose of the analytical framework described above is to provide a structure whereby two quite distinct sector level cases in the UK can be analysed in terms of the changing relationships between institutions, technologies, and actors. Central to the approach is the characterisation of the interplay between actors, institutions and technologies in distribution networks as the outcome of a series of interventions and interactions and contextualised by a broader governance regime; questioning whether this results in processes of transformation, reproduction or transition of sector structures. This is summarised in the following diagram:

Figure 3.3: Summary of analytical framework



It is proposed that by developing the framework described above, valuable insights from a range of relevant literatures can be incorporated whilst maintaining a sense of overall coherence. Of course, the outcomes that will be observed are context specific but it is hoped that by providing an overarching analytical framework, useful generalisations across the two case studies can be uncovered in chapter 7. Due to the fact the unit of analysis, distribution network sectors in the UK, is quite broad, chapter 4 will provide a contextual background to each of the two cases by introducing the energy policy context in the UK and the more specific technical and institutional characteristics of the electricity and heat networks. This chapter will outline how the analytical framework can be operationalised for each of the cases by identifying more detailed analytical variables for each of the energy distribution sectors.

3.6 Research Design

The first part of this chapter discussed the conceptual and theoretical issues relating to the study of distribution networks, focusing in particular the complex interplay between actors, institutions and technologies. A model was proposed which outlined the key analytical variables which will be considered when analysing the socio-technical dynamics of energy infrastructures in the case studies; this drew from a number of literatures ranging from new institutionalism to science and technology studies. This second part outlines some of the more practical issues involved in applying the analytical framework to a real world context and it serves to act as a bridge between the theoretical and empirical sections of the thesis as a whole. Firstly, the rationale for choosing a qualitative case study approach as a basic methodology is outlined, following this the justification for the case study choices is outlined along with the national/sector level unit of analysis, and finally the specific research methods which were used to gather information on the cases is laid out.

3.6.1 A Qualitative Case Study Approach

The purpose of the empirical part of this thesis is to refine and further develop the conceptual and theoretical understands of energy infrastructures and their socio-technical dynamics which have been developed earlier in this chapter. The overarching rationale behind this is to contribute to ongoing debates in a number of literatures which have been discussed in chapter two, and doing so with a view to developing policy orientated insights into the specific dynamics of infrastructure networks in socio-technical transition processes. Following much of the institutionalist and STS literatures which were discussed in the literature review, it is argued that the outcomes of the interplay between actors, institutions and technologies cannot be predicted ex-ante and should not be evaluated in terms of objective criteria such as efficiency or optimality. Rather, the purpose of developing an analytical framework and applying it in an empirical/real world context is to refine and further develop the conceptual and theoretical understands energy infrastructures and their socio-technical dynamics. This approach draws from a critical realist philosophy of science (Blaikie, 2007, Sayer, 1999, Bhaskar, 1978), where it is argued that knowledge is best advanced through ‘the historical interaction of theory and experience’ (Proctor, 1998: p.361) in an approach to social inquiry that has been termed retroduction. This is a middle-range perspective which rejects the extremes of both objectivism and subjectivism; rather proposing that ‘the truth- content of different ideas can be compared on a relative basis: some (social) explanations are more adequate representations of reality than others’ (Proctor, 1998: p.361).

With this in mind, it is argued that a comparative case study approach is the most appropriate research strategy for this particular study. A comparative case study approach is adopted for two main reasons; firstly it will allow the analytical framework to be applied in a number of different contexts and because this type of analysis is not confined to a small number of variables which are measured and analysed in a linear fashion, a broader and more holistic account of a complex social process (Yin, 1994) such as the interplay between actors, institutions and technologies in energy systems can be developed. This has been motivated in particular by the evolutionary/institutional and STS literatures discussed in chapter two which have highlighted the particular importance of context in shaping the process of technical change for example with concepts such as the 'selection environment' in evolutionary economies and the 'system and its environment' in Hughes' LTS approach. A second rationale for choosing this approach is that case studies tend to be deployed in order to analyse processes rather than expected or optimal/efficient outcomes. An analysis of processes has been identified as a suitable strategy to identify causal mechanisms in complex social processes because they allow the researcher to extensively explore historical background and context (George and Bennett, 2005). Causal mechanisms are 'recurrent processes generating a specific kind of outcome' (Mayntz, 2004: p.237) which identify 'frequently occurring and easily recognizable causal patterns' (Elster, 1998: p.45) and facilitate broader generalisation from a case or cases. Table 2.2 has identified a number of causal mechanisms from the literature which will be used to analyse the two case studies in chapter 7 in order to explore different aspects of the interplay between actors, institutions and technology in energy distribution sectors. This type of causal analysis attempts 'to explain a given social phenomenon - a given event, structure, or development - by identifying the processes through which it is generated' (Mayntz, 2004) and is in contrast to a multivariate approach which seeks to identify 'statistical relationships among variables' (Mayntz, 2004).

As case studies are useful for the analysis of 'a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and context are not clearly evident' (Yin 1994: 13); it is argued that this is particularly suitable for the study of large scale and complex socio-technical systems such as energy networks. However, the case study approach has been criticised on a number of grounds[27] (Flyvbjerg, 2006), e.g. that context-dependent knowledge holds little validity and that it is difficult to make generalisations from one or a small number of cases, In order to avoid these pitfalls which have been associated with case study research, a multiple case study design has been selected where the interplay between

[27] Flyvbjerg (2006) refutes five of the common misunderstandings regarding case studies: *Misunderstanding 1:* 'General, theoretical (context-independent) knowledge is more valuable than concrete, practical (context-dependent) knowledge', *Misunderstanding 2:* 'One cannot generalize on the basis of an individual case; therefore, the case study cannot contribute to scientific development', *Misunderstanding 3:* 'The case study is most useful for generating hypotheses; that is, in the first stage of a total research process, whereas other methods are more suitable for hypotheses testing and theory building': *Misunderstanding 4:* 'The case study contains a bias toward verification, that is, a tendency to confirm the researcher's preconceived notions', *Misunderstanding 5:* 'It is often difficult to summarize and develop general propositions and theories on the basis of specific case studies'. Also, George and Bennett (2005) argue that case studies can be used alongside and complement statistical and formal modelling methods.

actors, institutions and technologies will be analysed in two different cases, thus facilitating generalisability. This type of approach has been termed as instrumental case study research where a number of cases are developed with the purpose of analytical generalisation; this is contrasted with an intrinsic case where the purpose is to develop an in-depth knowledge of one particular case (Stake, 2005).

3.6.2 Case Study Selection and the Unit of Analysis

The cases which have been selected to form the basis of the study are the electricity and heat distribution networks in the UK. Electricity distribution networks are incumbent systems which have been in place in some form or another since the early/mid twentieth century in most industrialised countries. These are highly interconnected systems across both urban and regional areas and treated as natural monopolies which are organised in a regional basis in the UK. Electricity distribution networks transmit high voltage bulk power from the national transmission grid (the National Grid) and deliver it to the customer's meter. In doing so the network operator must comply with strict quality and safety codes and standards and periodically make investments to maintain the asset base. Traditionally this has been carried out in a relatively conservative manner whether by the state or a private company. However, in the context of the transition to low carbon energy systems, there is increasing focus on the role that electricity distribution networks can play in facilitating the deployment of renewable and low carbon generation (which is often connected to distribution networks whereas in traditional electricity systems generators are large scale and connected to the high voltage transmission network) and enabling more efficient and responsive demand side behaviours (as the electrical output from renewable generators tends to be less predictable than conventional generation). There is therefore an ongoing debate within the electricity industry as to how regional networks can be made more intelligent or smarter and the potential implications for the technical and organisational structure of distribution systems.

In contrast, heat distribution networks are non-incumbent networks which have never been part of the mainstream of energy provision in the UK. In conventional energy systems, heat provision is typically based on each customer having an individual boiler which is connected to the gas grid. The alternative approach is to distribute heat, rather than gas, using a network of pipes which run into businesses and dwellings – this is termed district heating (DH). Due to the heat losses which result from distributing hot water or steam over distance, heat networks are typically organised on a local basis for example within a city centre or a university campus, however in cities such as Malmö and Copenhagen these have expanded over larger areas. As chapter four will outline, in certain circumstances, depending on the density and mix of dwellings within an area, this can be a more energy efficient form of heat provision and generation because heat is typically generated using a gas-fired combined heat and power (CHP) plant which also generates electricity (CHP-DH). In UK cities, CHP-DH has traditionally not been a common technology for a variety of reasons; primarily the due to the national level structure of the electricity industry which has treated CHP-DH as a competitor and the lack of supporting sector level institutions for local energy systems (Russell, 1993). However, recently it has been proposed that CHP-DH should be encouraged as a low carbon alternative to centralised energy and can contribute to significant emissions reductions in certain circumstances, however a number of barriers exist to its deployment in the UK (DECC, 2009d, DECC and DCLG, 2010); this will be explored in more detail in the following chapters.

The purpose of choosing these contrasting case studies is twofold: Firstly, it is a well established practice when conducting case studies that extreme or polar cases be chosen in order to facilitate subsequent generalisation. Flyvbjerg notes: ‘This is because the typical or average case is often not the richest in information. Atypical or extreme cases often reveal more information because they activate more actors and more basic mechanisms in the situation studied’ (Flyvbjerg, 2006). Secondly, insights form transitions theory suggest that an understanding of the interplay between actors, institutions and technologies in both of these types of cases – structured (regime) and unstructured (niche) – is necessary to fully comprehend the governance challenges involved in the transition to a low carbon energy system. As one of the central aims of the study is to develop policy relevant insights regarding the longer term transition to a low carbon energy system in the UK, it is argued that selecting such extreme or polar cases can lead to more relevant insights for policy makers and regulators than would be the case if ‘a representative case or a random sample’ (Flyvbjerg, 2006) strategy was chosen.

There is however an issue as to the comparability of these two cases; Davies articulates this as establishing ‘functional equivalence between actors and agencies to capture the complexity of the cases’ (Davies, 2008: p.85) – the table below summarises some of the main institutional differences between the two cases.

Table 3.1: Differences in the institutional make-up of the two cases

	Electricity Case	Heat Case
Ownership	Private	Typically a local authority
Regulation	Regulated by Ofgem	Unregulated
Scale	Regional	Local
Level of interconnection	Part of a national electricity system	Small scale fragmented systems

In an effort to overcome these difficulties a particular focus on the UK context has been maintained which provides a consistent backdrop for each of the studies and facilitates both analytical generalisation and the extraction of relevant policy insights. Although comparison between networks in different countries was considered, it was felt that a study of incumbent and non-incumbent sectors in the UK would contribute to a broader understanding of infrastructure networks in the context of the long term transition to a low carbon energy system. Also, because the UK has been a first mover in terms of the privatisation and liberalisation of energy sectors it was felt that it could be an interesting case study of the changing nature of energy network governance in a liberalised environment; thus addressing research questions 2 & 3. Such a country specific analysis could then subsequently be used as a basis for comparisons with other countries.

As the central aim of the study is to explore various aspects of the interplay between actors, institutions and technologies in energy networks, the unit of analysis in each of the cases is the sector or meso level. Although project (e.g. a particular or part of a network where an innovative technology is being deployed) and firm level (a particular network operator or local authority) approaches were also considered as units of analysis, it was felt that such a micro-level approach would neglect some of the important structural and political aspects of energy network governance which in the case of the UK is best studied at the national level (Winskel, 1998, Russell, 1993, Russell, 1994). As a key aim of the research is to explore the changing role of the state in the governance of these sectors, these micro level firm and project level approaches were rejected in order to capture the influence of these structural dynamics. A similar argument regarding the appropriate level of analysis for studies of the relationship between technology and the environment was made by Arthur Mol in his study of Ecological Modernisation in the Dutch Chemicals Industry:

> *"A micro-level analysis may miss inter-firm changes and sectoral changes and may consider (collective) actors and factors which are in fact relevant to be independent variables of the social environment. A macro-level focus would abstract from relevant environment-induced inter-firm transformations by putting too much emphasis on the net national effect"* (Mol, 1995: p.62)

However, by deploying the analytical framework outlined earlier in the chapter, it is proposed to capture the key interactions taking place between the micro, meso and macro levels.

3.6.3 Data Collection and Analysis

Exploring the dynamics between actors, institutions and technologies in each of the cases necessitates that a number of practical issues had to be addressed, namely methods of data collection and analysis. In order to achieve some level of triangulation; i.e. 'using multiple perceptions to clarify meaning, verifying the repeatability of an observation or interpretation' (Stake, 2005: p.454) the empirical chapters draw from four sources:

- Established histories of energy systems in the UK covering the pre-nationalised, nationalised and early privatised periods
- Relevant literature covering various technical, economic and institutional issues within contemporary energy systems
- Policy documents including departmental consultations and white papers along with regulatory documents
- A series of semi-structured interviews with relevant stakeholders

Studies of UK energy policy typically delineate between three main periods; nationalisation (late 1940s – 1980s), privatisation (1980s-2000s) and the contemporary period since approximately 2000 when issues surrounding climate change and resource scarcity have begun to reshape the policy landscape. It is this contemporary period that is of primary concern in the two main empirical chapters, however the established histories proved to be a useful source in understanding the background and context to each of the cases (see chapter 4). In order to understand the contemporary issues facing energy systems and to develop an adequate understanding of the technical and institutional composition of these sectors, a range of literatures on these topics were consulted.

Selected policy documents were reviewed firstly to provide an overview of the governance regime in each of the cases and also to give an outline of the most significant developments which have taken place within the sectors in the past ten years or so. Government departments and the energy regulator, Ofgem, retain significant repositories of their documents including white papers, consultations and regulatory documents. Accessing these documents allowed me to map out the policy landscape for each of the cases and also to follow some of the key debates within each of the sectors; consultation documents and price control reviews for electricity distribution networks proved to be very useful in this regard. As it was not possible to review each and every policy document in this field, a selective approach was taken with documents relating to key moments and debates in the cases being prioritised; Appendix A contains a summary table of the key documents which were reviewed as part of the study.

These policy documents provided an overview of the key events and debates across the two cases and were used to gain initial insights and to structure early chapter drafts. However it was felt that they could only provide a stylised account of developments in each of the sectors which in reality are shaped by the different motivations and strategies of a range of actors. In order to explore this, over forty semi-structured interviews were conducted with key stakeholders throughout the study period. The purpose of conducting these interviews was to complement the documentary analysis by highlighting and elucidating the key areas of contestation and interpretive flexibility which are shaping change in the two cases.

In the early stages of the interview process potential interviewees were identified using a targeted approach. This started with existing contacts from the Transition Pathways to a Low Carbon Economy project and by identifying key individuals who were members of industry coordinating bodies such as the Electricity Networks Strategy Group. Following a number of initial contacts, a snowballing sampling method was also used where the interviewees would help in identifying relevant and influential actors. This process continued until data saturation was reached and the participants' suggestions for further interviewees began to be repeated. In total 41 interviews were conducted (Appendix B contains a list of all interviewees who participated in the study); 22 of these covered the electricity distribution case, 17 covered the CHP-DH case and the first two interviews covered both cases. In order to avoid any form of selection bias, for each of the cases every effort was made to speak to a wide range of stakeholders from focal organisations (DNOs and local authorities) but also actors who are less central such as consultants and equipment manufacturers. The table below illustrates the range of stakeholders interviewed as part of both cases and the number of interviews conducted in each category.

Table 3.2: Summary of Stakeholder Groups Interviewed

Stakeholder	Electricity Distribution Case	CHP-DH Case
Distribution Network Operator	7	-
Local Authority	-	10
Academia	3	2*
Big Six' Energy Supplier	3	-
Specialist DE company/division	-	2
Engineering Consultancy	6	1
Electrical Engineering Manufacturer	1	-
Energy Regulator	1	-
Government Department	1	1
Government Agency	-	1
Industry Body	-	2
Transmission Network Operator	2	-

**Interviews 1&2 covered both cases*

The interviews on average lasted for one hour and were recorded as the interviewees were assured anonymity. A guide was used as an outline structure during the interviews but they were conducted in such as way as to allow the interviewee as much scope as possible to express their opinions. Key issues discussed in the interviews included:

- The interviewees background and current role within the relevant sector
- Opinions on the most significant technical/institutional issues facing the relevant sector
- The interviewees personal involvement in developing technologies/projects/new organisations
- Their views on how policy/regulation is affecting change
- Opinions on how is the sector evolving and what will this mean for the types of interactions taking place between actors
- Their views on the medium/long term evolution of the sector and potential implications for their particular organisation

Subsequent to an interview the recording was transcribed and analysed. Analysis was a three step process, according to Strauss and Corbin (1998). Beginning with open coding the transcripts were analysed in order to extract a large number of themes and concepts which were broadly related to the research questions. This was done by highlighting relevant sentences/paragraphs in the transcripts and labelling them according to a particular theme or issue. Following a more theoretically informed analysis which was guided by the research questions, these ideas and codes were then aggregated into a smaller number of themes which emerged and were given separate headings. Appendix C contains an example of a coded extract from one of the interviews which illustrates this. Following a further process of refinement and analysis the most predominant and relevant themes or issues were then identified, these formed the main sub headings of the ‘interventions and interactions’ sections in the empirical chapters. These are seen as the key issues, debates, and areas of interpretive flexibility which have punctuated and shaped the process of change in each of the organisational fields. Upon completing the initial drafts of the empirical chapters the interview transcripts were once again reviewed in order to ensure that all relevant issues were accounted for and there were no inconsistencies between the chapter and the data.

When conducting research of this kind a number of confidentiality issues needed to be addressed. In order to reassure interviewees that data would be treated with sensitivity, I undertook to store any interview transcripts in a secure place, not distribute them to any other individuals, and to protect the anonymity of the research participants. This was in accordance with guidelines set out by the University of Leeds who oblige researchers to undertake an ethical review of their project[28].

The next chapter will lay out the contextual background to the two case studies and outline how the analytical framework has been operationalised.

[28] Ethical approval for this project was granted under Faculty Reference Number: AREA 09-018.

4 Overview of UK Energy Policy and Networks

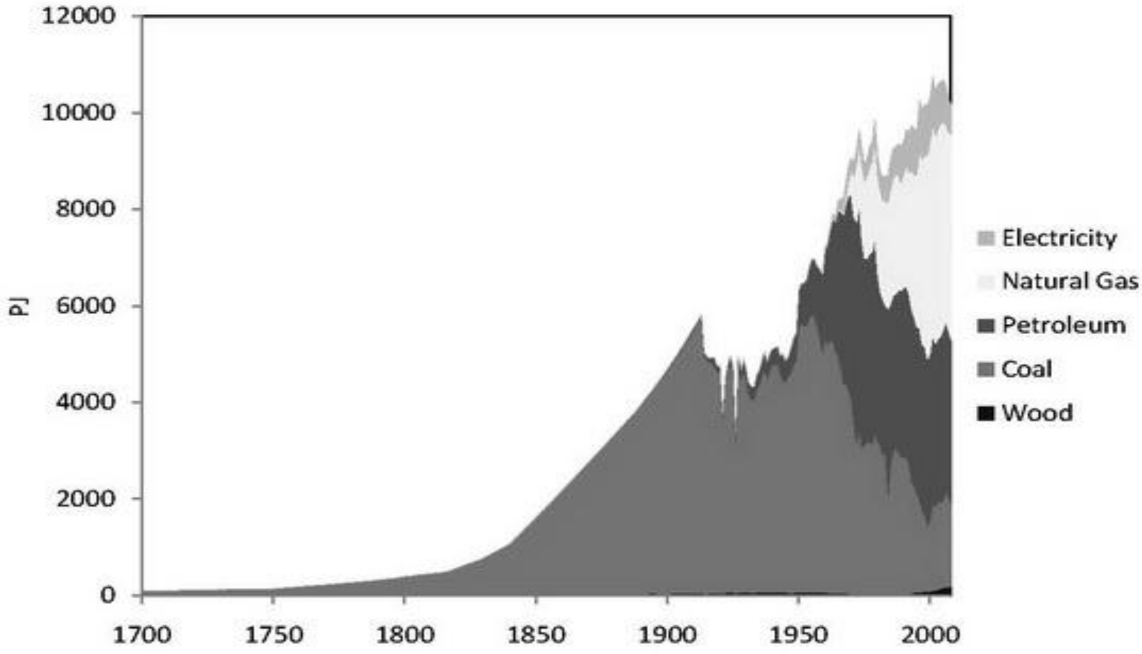
4.1 Introduction

The purpose of this chapter is to provide an overview of the technological and institutional context of the case studies and to outline on how the proposed analytical framework can be operationalised. This is necessary because the distribution pipes and wires which are the focus of this study are one part of a wider energy system which begins with the sourcing and extraction of raw energy (fossil fuels fuel or ambient energy e.g. wind and solar) and ends with the provision of an energy service such as heating, cooling or lighting to end customers. In the intermediary stages a number of processes take place which convert the raw material into various forms of energy carrier (e.g. electricity, hot water) and they are transported to sites of demand via infrastructure networks e.g. gas and electricity transmission, distribution networks etc. Of particular importance are the interactions which take place between different elements of energy systems e.g. the networks, generating plants and end use. The nature of these systemic relationships has changed quite dramatically throughout the history of modern energy systems and therefore it is important to situate the analysis of distribution networks in the context of the wider energy policy and technological environment.

4.2 Energy in the UK

The provision of energy in the UK has had a dramatic influence on the social and economic development of the country throughout the centuries from the steam powered industrial revolution in the 18th and 19th centuries to the electrification of the country during the 20th century. These long run changes in the nature of energy provision in the UK are reflected in the figure below where primary energy inputs are shown from 1700 to 2008. It can be observed that since the middle part of the 20th century the relative importance of natural gas and electricity have increased dramatically. The increasing prominence of electricity and natural gas in the overall energy mix has of course been enabled by the development of large scale infrastructures such as transmission and distribution networks during this period.

Figure 4.1: UK primary energy demand (1700-2008)



Source: (Skea et al., 2010)

The levels of demand for energy during this period have been affected in particular by the two world wars and the oil crises of the 1970s. Since the oil shocks, the nature of demand has changed in the UK; the figure below shows the sectoral breakdown for energy demand since the 1970s. It can be observed that there has been a decrease in demand from the industrial sector, which is as a result of a general trend towards a services based economy, but increases in the domestic and transport sectors. Currently in the UK, overall energy demand is 220.0 million tonnes of oil equivalent[29] (DECC, 2010g) of which approximately 37% is transport, 22% electricity and 41% is heat (DECC, 2009d).

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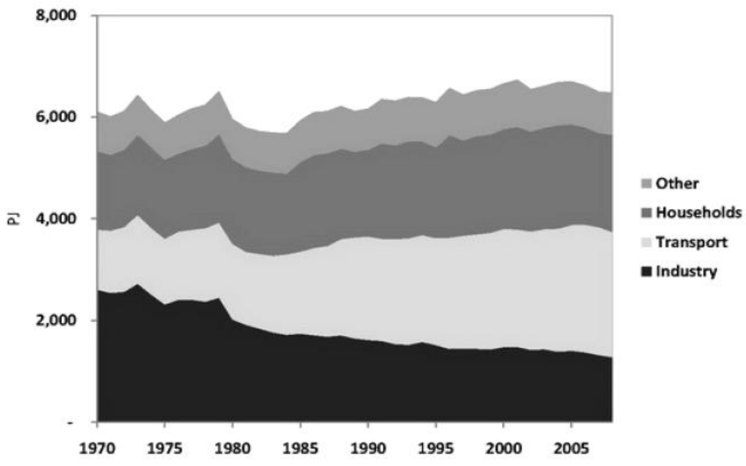
[29] This figure is for 2009 and is 6.3% lower than in 2008 – DUKES (DECC, 2010a)

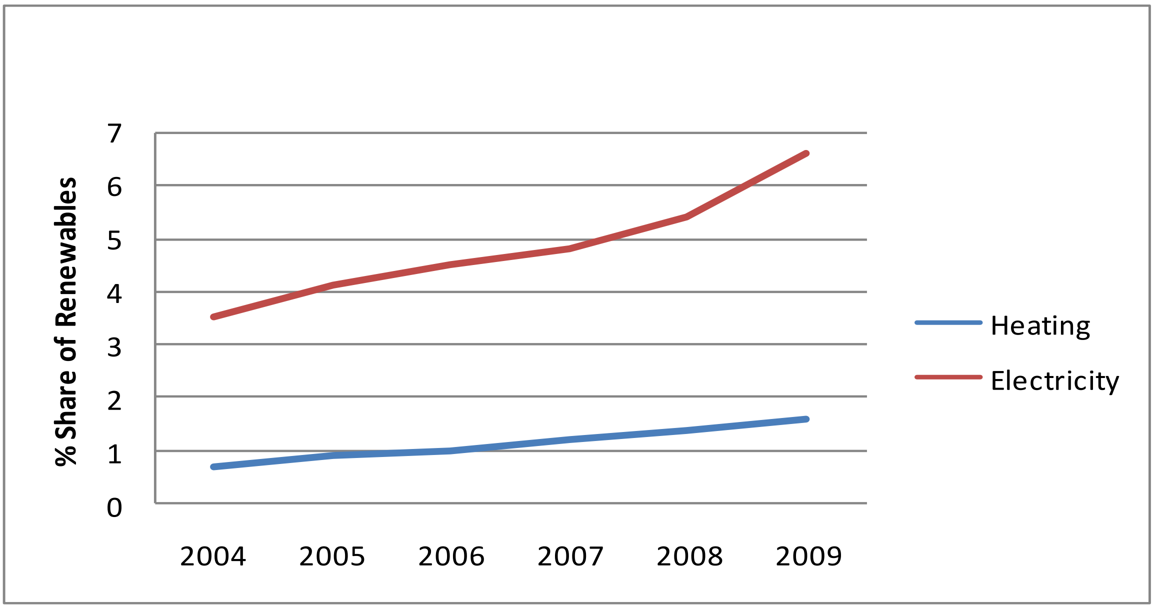
Figure 4.2: Final Demand by Sector 1970-2008



Source: (Skea et al., 2010)

Achieving the UK's greenhouse emissions reductions targets of 80% by 2050 from 1990 levels and a renewables target of 15 % of gross final energy consumption from renewables by 2020 presents a significant challenge. In the electricity and heating components, which this study is particularly interested in, although there has been a steady rise in the levels of renewables over the past number of years (see graph below), largely due to incentives such as the renewables obligation, even for the case of electricity this only comprises 6-7%.

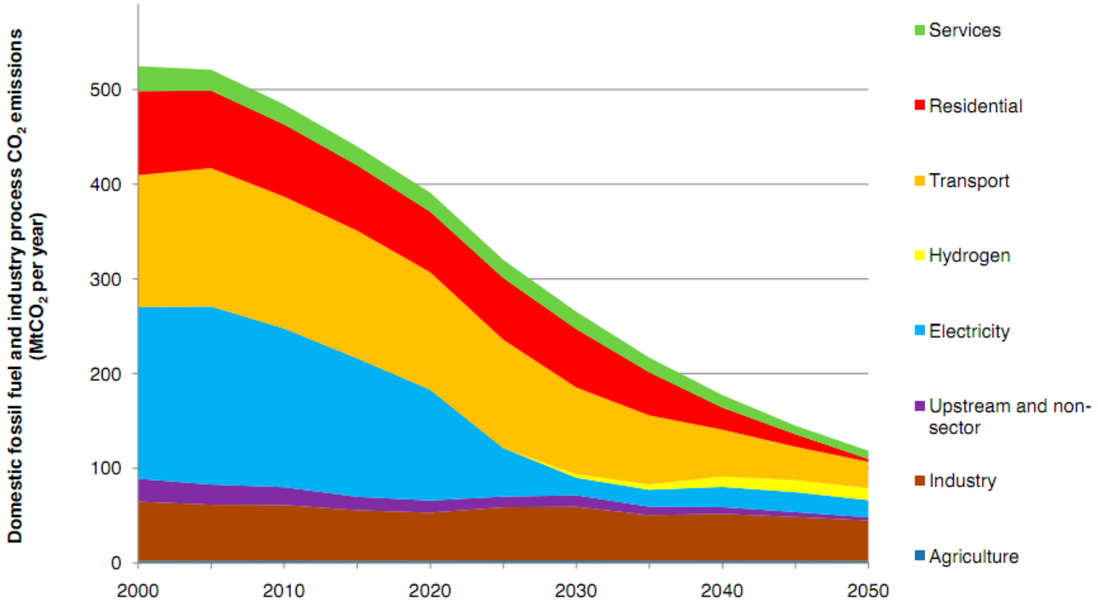
Figure 4.3: Growth Share of Renewables in Heating and Electricity 2004-2009



Source: (Figures for share of renewables are from DECC, 2010c)

The figure below from the Committee on Climate Change shows the scale of the challenge facing key sectors in the UK economy. As part of the UK's decarbonisation strategy it is expected that the electricity and residential sectors will radically decarbonise meaning that the diffusion of renewable and low carbon heating and electricity technologies will need to increase rapidly.

Figure 4.4: UK sectoral CO2 emissions to 2050 on an 80% emissions reduction path



ource: MARKAL modelling based on CCC assumptions (2008).

Source: (Climate Change Committee, 2008)

The next sections will explore in more detail each of these sectors and the potential implications for the distribution network component of each.

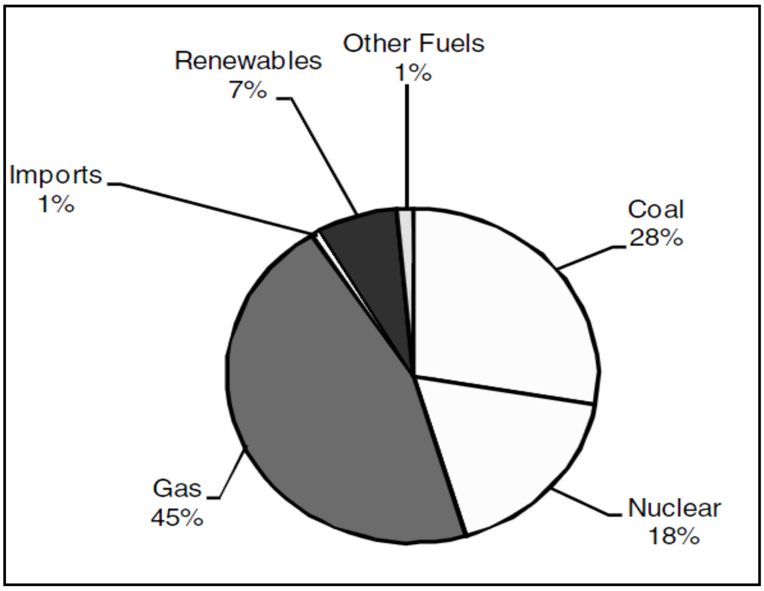
4.3 The Electricity Supply Industry (ESI)

This sub-section gives a general introduction to the electricity supply industry (ESI) outlining the basic structure of the industry, it historical evolution and the most significant contemporary challenges facing the ESI as a whole and distribution networks in particular. Electricity systems in industrialised countries typically have a similar structure with the majority of electricity being generated in large plants which are connected to a high voltage transmission network. Currently there are 32 'Major Power Producers'[30] who generate the majority of electricity in the UK. The

[30] Companies whose main function is to generate electricity, includes major wind farm companies: AES Electric Ltd., Baglan Generation Ltd., Barking Power Ltd., British Energy plc., Centrica Energy, Coolkeeragh ESB Ltd., Corby Power Ltd., Coryton Energy Company Ltd., Derwent Cogeneration Ltd., Drax Power Ltd., EDF Energy plc., E.On UK plc., Energy Power Resources, Gaz De France, GDP Suez

figure below shows figures for the generation mix as of 2009. The gas segment refers to either conventional gas turbines or combined cycle gas turbine (CCGT) plants which incorporate both gas and steam turbines. Coal and nuclear fission are used in conventional steam turbines. Of the renewables segment 35.7% is wind, 20.1% is hydro and 44.1% (DECC, 2010c)[31] is other renewables which includes solar PV, municipal solid waste (MSW) and sewage sludge, biomass, wave and tidal and landfill gas.

Figure 4.5: Share of net electricity supplied in 2009, by fuel input



Source: (DECC, 2010c)

Generation (if greater than approximately 50MW) is connected to the high voltage transmission network which is either 400KV or 275KV. The purpose of the transmission network is to transport power from generation to sub-stations which are closer to locations of demand; this typically results in an overall north-south flow in GB. The transmission network in England and Wales is owned by National Grid and the two transmission networks in Scotland are owned by Scottish and Southern, and Scottish Power. National Grid is the overall system operator (TSO) whose job it is to ensure that the demand for electricity can be met at all times. If this is not ensured the frequency of the system will become imbalanced and there is a possibility of

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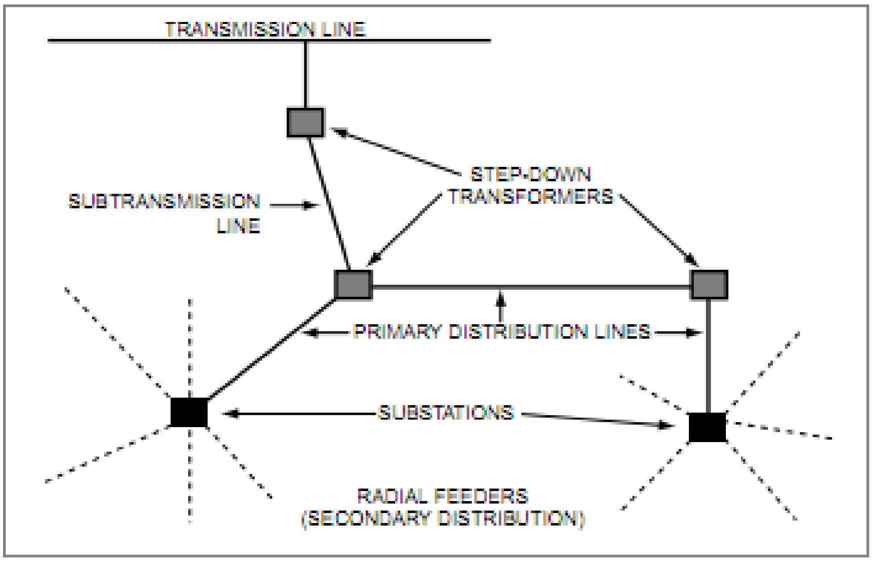
Teesside Power Ltd., Immingham CHP, International Power Mitsui, Magnox North Ltd., Premier Power Ltd., RGS Energy Ltd, Rocksavage Power Company Ltd., RWE Npower plc., Scottish Power plc., Scottish and Southern Energy plc., Seabank Power Ltd., SELCHP Ltd., Spalding Energy Company Ltd., Western Power Generation Ltd. (DECC, 2010a)

[31] Percentages for renewables were calculated from Table 5.1 on page 133 of DUKES 2010 (DECC, 2010a)

failures occurring on the system. Appendix D contains a map showing the layout of the GB electricity transmission network and the locations of major generating stations.

As the figure below shows, the next step in the electricity chain is to distribute power to the end customers.

Figure 4.6: A Generic Electricity Distribution System



Source: (Schienbein and Dagle, 2001)

Traditionally, the central role of a distribution network has been to reliably deliver power to the customer within a certain voltage limits for safety. Along distribution lines transformers are used to progressively reduce the voltage[32] closer to customers (or loads). There are also protection devices e.g. relays which ensure that voltage, current and frequency are kept within certain limits and if limits are exceeded these devices can isolate certain equipment if there is a fault somewhere on the system. The flow of electricity in a distribution system has typically been one way and unlike transmission networks they are passive systems as they were not designed to accommodate significant amounts of generation which would lead to dynamic two way flows; much of the case study chapter is concerned with how this is changing and distribution networks are needing to become more active.

[32] The power flowing through a line is a function of its current and voltage

4.3.1 The Evolution of Electricity Markets in the UK[33]

In 1948 the UK ESI was nationalised by the post-war Labour government. Prior to this the sector was dominated by approximately 600 small scale local electricity supply undertakings which were owned both by private actors and municipal authorities – municipal authorities were the dominant players in the industry (Hannah, 1979, Hughes, 1983). The first national transmission grid (the 'Gridiron') was constructed in the 1920s and 1930s and the Central Electricity Board (CEB) was created which sought to bring about standardization and interconnection of the many local electricity systems. There were efforts to rationalise the industry through voluntary coordination based on regional Joint Electricity Authorities (JEAs) (similar to the German model), but this failed and eventually the ESI was taken into public ownership by the Labour Government in 1947/48 following World war II. The nationalisation of the ESI also occurred alongside the taking into public ownership of the gas and coal industries, and it reflected a political rationality where 'the industry regarded electricity as a public service to be universally available, and the monopoly structure enabled full pass-through of costs' (Parker, 1996: p.295).

Following nationalisation, the British Electricity Authority (BEA)[34] was formed whose job it was to control the generation and transmission assets and 14 Area Boards[35] who received bulk power from the BEA and distributed it to customers. These were coordinated centrally by an Electricity Council who were also responsible for 'central management of finance, taxation, industrial relations, R&D, national advertising and marketing campaigns'(Chesshire, 1996: p.18). During the early years of nationalisation in the 1950s, the need to meet an ever growing demand[36] meant that the emphasis became focused on using central planning and top-down demand projections to coordinate network investments, thus securing a low cost of capital than would have been the case through market based financing. The system was operated in a non-market hierarchical fashion which meant that generators were dispatched according to a predefined code.

Following the economic recession of the 1970s, the rationality which underpinned the structure of the industry (expansion, growing demand) was undermined[37] and following the election to

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[33] This section is largely based on Hannah (1979, 1982) and Helm (2004)
[34] This later became the Central Electricity Generating Board (CEGB) in 1957
[35] These later became Regional Energy Companies (RECs)
[36] Demand for electricity in the UK grew by 7% per annum between 1955-1970 (Chesshire, 1996)
[37] Many of the predictions regarding demand growth proved to be overly optimistic as economic growth slowed during the 1970s resulting in 'substantial surplus capacity' where the plant margin or the excess of

power of Margaret Thatcher's conservative government, the Keynesian welfare state started to be dismantled. Throughout the 1980s and 1990s a series of privatisations occurred across the energy sectors[38] (see table below) and arrangements for the privatisation of the ESI were set out in the 1989 Electricity Act.

Table 4.1: Summary of ownership changes in UK energy industries

TABLE 2.1 Ownership changes

	Pre-war ownership	Nationalized	Privatized[a]
Coal	Private	National Coal Board (1947)	RJB Mining and others (1995)
Electricity	Central Electricity Board, municipalities, and private companies	Central Electricity Authority (1948) and then the Central Electricity Generating Board, Area Boards, and the Electricity Council (1957)	National Power, PowerGen (1990) National Grid Company (1990) Regional electricity companies (1990) Scottish Power and Scottish Hydro-Electric (1991)
Gas	Municipalities and private gas undertakings	Area Boards and the Gas Council (1948), and then British Gas Corporation (1972)	British Gas (Gas Act 1986)
Oil	Anglo-Iranian Oil Company	BP (partial), British National Oil Company (1977)	BP final sale (1987) Britoil (1982) Enterprise Oil (1984)
Nuclear	None	United Kingdom Atomic Energy Authority (1954), British Nuclear Fuels (1971), Nuclear Electric (1990), Scottish Nuclear (1990)	British Energy (1996)

[a] Dates refer to Vesting of assets, except BP.

Source: (Helm, 2004: p.18)

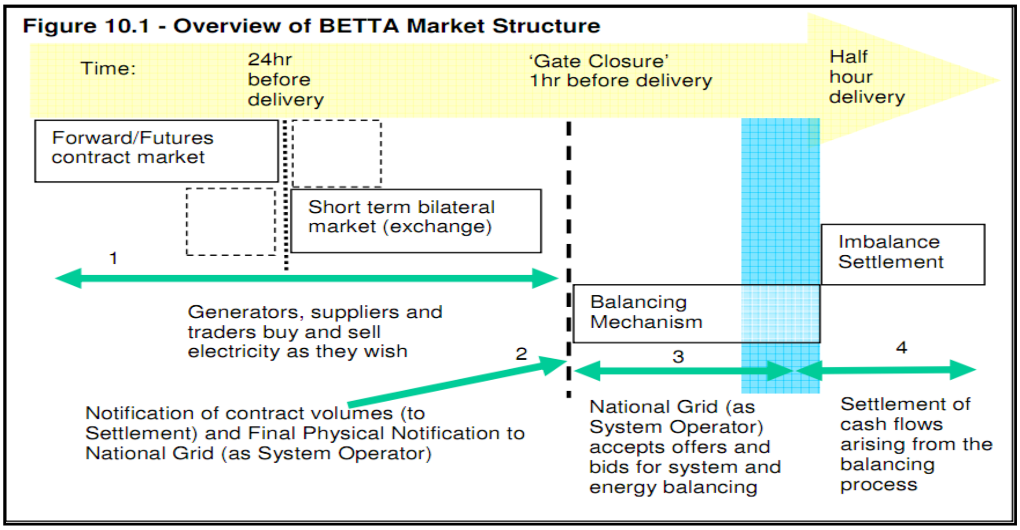
A program of rolling privatizations followed; in Nov 1990 the RECs were floated, in March 1991 two generating companies National Power and PowerGen were sold, and finally, in 1995 the transmission company, National Grid Company, was floated. The nuclear companies were partly privatized in 1996 with an umbrella organization, British Energy, being established.

generation capacity over demand 'rose from 21% in 1970-71 to 42 per cent in the period 1973-1976' (Chesshire, 1996: p.27)

[38] The 1980 competition act - the monopoly companies were opened up to scrutiny by the Monopoly and Mergers Commission (MMC) - the oil and gas enterprise act in 1982, the 1983 Energy Act- obliged the Regional Electricity Companies (RECs) to open up their networks to alternative sources e.g. CHP - the 1986 Gas Act, and the 1989 Electricity Act

In order to bring about competition in electricity generation a wholesale market called the Electricity Pool was established[39] and a licensing and regulatory regime for networks was established. Liberalisation of the retail markets took place towards the end of the 1990s[40] and in 2001 the electricity pool was replaced by NETA[41] in England and Wales, this was subsequently replaced by BETTA[42] in 2005, this covers Scotland, England and Wales. As the schematic below shows, unlike the Electricity Pool BETTA is a voluntary market which allows generators and suppliers to enter into a variety of contracts including bilateral arrangements and there is no central pool price. The TSO's role is to ensure that there is a balance between supply and demand and operate the balancing mechanism where after 'gate closure' they review contracts and then accept or rejects any further offers or bids from generators and suppliers.

Figure 4.7: Overview of BETTA Market Structure



Source: (National Grid, 2011)

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[39] This was a compulsory market where generators placed day-ahead bids to generate a certain amount of power. The pool price, or system marginal price (SMP), was set each half hour according to the 'computed unit cost of electricity from the most expensive unconstrained generation unit called on to operate' (Newbery, 1998). Unconstrained generators which were dispatched received the pool purchase price (PPP: a capacity constrained payment plus the SMP), unconstrained generators which were not dispatched received a capacity payment. RECs then supplied electricity to customers at a price based on the PPP plus network charges and ancillary services. The system was criticised as there was an effective duopoly at the time between National Power and PowerGen which led to concerns that the system could be gamed for example by generators being taken offline to raise the pool price (Toke and Fragaki, 2008).

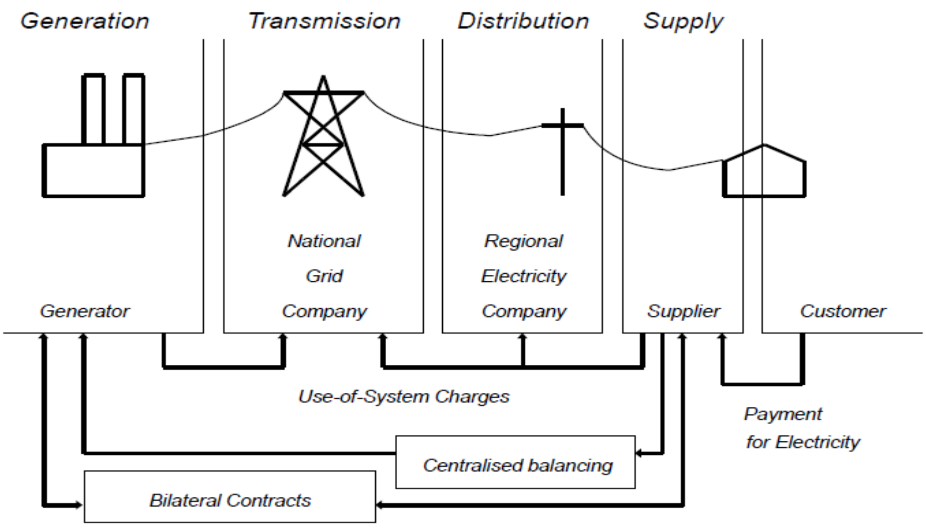
[40] Retail competition was introduced in a staged process as follows: 'From 1 April 1990, customers with peak loads of more than 1 MW (about 45 per cent of the nondomestic market) were able to choose their supplier…From 1 April 1994, customers with peak loads of more than 100 kW were able to choose their supplier…Between September 1998 and May 1999, the remaining part of the electricity market (i.e. below 100 kW peak load) was opened up to competition' (DECC 2010a)

[41] New Electricity Trading Arrangements

[42] The British Electricity Trading Arrangements

Following the introduction of BETTA the ESI has become dominated by six large vertically integrated companies (they own retail & generation licences, and sometimes distribution and transmission licences also) who use long term contracts and the bilateral trading facility to conduct internal deals within their companies in order to reduce the risks of imbalance. As a result less that 5% is traded through the balancing mechanism (Toke and Fragaki, 2008). The schematic below shows the overall market arrangements in the ESI today:

Figure 4.8: The Electricity Market in the UK



Source: (Green, 2011)

4.3.2 Challenges Facing the ESI and Distribution Networks

There are a number of significant challenges facing the ESI as a whole in the coming decades. In their fourth carbon budget, the UK's Committee on Climate Change used the following graph to summarise the scale of the challenge in decarbonising electricity supply in order to meet the greenhouse gas emissions reductions targets which were set out in the 2008 Climate Change Act[43]:

[43] A reduction in 'Kyoto greenhouse gas emissions by at least 80% below 1990 levels by 2050 (77% below 2005 levels)' (CCC, 2008). There is also a renewables target of 15% of all energy by 2020, which has been translated into 30% of all electricity from renewables by 2020

Figure 4.9: Trajectory for decarbonising the power sector (2010-2050)

Source: (Climate Change Committee, 2010: p.243)

The red line shows an increase in the overall demand for electricity because the 'costs of reducing carbon-intensity in the power sector are generally lower than doing so in other sectors' (Climate Change Committee, 2010: p.243) it is therefore likely that there will be a large scale electrification of much of the heating and transport sectors (through heat pumps and electric vehicles respectively). It is expected however that there will be some demand side efficiencies which will offset the need for greater levels of investment. This increase in demand combined with expected plant closures[44] will necessitate a cumulative new build of over 45GW by 2022 (Climate Change Committee, 2008) with approximately 30% of electricity being generated from renewable sources (DECC, 2009f). During the 2020s it is expected that 30-40GW worth of investments in low carbon generation will be required to meet the growing demand due to the increase in electrification of transport and heat (CCC, 2010).

This poses significant challenges to the electricity distribution sector in the UK. In conventional electricity system, as described above, large scale generators are typically connected to a

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[44] The EU's Large Combustion Plant Directive means that a number of coal generating stations will close. Also, a number of nuclear plants are nearing the end of their lives and will need to be decommissioned. "The introduction of the Large Combustion Plants Directive (LCPD) has required large electricity generators to meet more stringent air quality standards since 1 January 2008. Plant that has "opted out" of this obligation will have to close by the end of 2015 or after 20,000 hours of operation from 1 January 2008, whichever is the sooner. This affects some 12 GW of coal and oil-fired generating plant which will therefore now close by 1st January 2016. However, the exact timing of these closures is a commercial matter for plant owners, taking into account factors such as other environmental restrictions and the state of repair of the plants. Consequently, it is not possible to predict with certainty the precise timing of the impact of the LCPD on generation capacity, particularly if a replacement station is planned to be constructed on the same site." (National Grid, 2011)

transmission system. Because there needs to be a real-time balance between electricity supply and demand in order to ensure system security, the flexibility required to achieve this has been built into the transmission system which is actively managed and can respond to real time flows of energy and information. Distribution networks (and the demand side) have essentially been passive elements within the overall system with little in-built flexibility and real time management of the system (Strbac, 2008, McDonald, 2008, Farhangi, 2009). There are three main reasons why this is likely to change in the future:

1. It is likely that an increasing proportion of low carbon generation, particularly small scale renewables[45] and CHP, will be connected directly to the distribution networks or on the customer's side of the meter. If this connected generation exceeds local demand this will change the direction of flows on the networks. This will necessitate a more active approach to managing distribution networks[46], similar to transmission networks, in order to facilitate these connections whilst ensuring that the networks fulfil their basic functions.
2. As demand increases due to the electrification of heat and transport the flow of electricity through the distribution lines will increase, particularly on the low voltage 11KV lines in built up areas. Improving the capacity management through the utilisation of information processing technologies will help to off-set the expensive reinforcement of these lines (Strbac et al., 2010, Baker et al., 2010).
3. In the future the demand side will become a more active component in the electricity system. This is because as increasing levels of intermittent renewable generators are connected to the system balancing supply and demand will become increasingly complex and will benefit from a more flexible demand side. This will also reduce the need for large capacity margins and network reinforcements (Strbac et al., 2010) and help with efforts to reduce the per capita electricity demand and promote the more efficient use of electricity. Because customers are connected to the distribution networks, these systems will become an increasingly important part of developing a more interactive relationship between customers and the electricity system.

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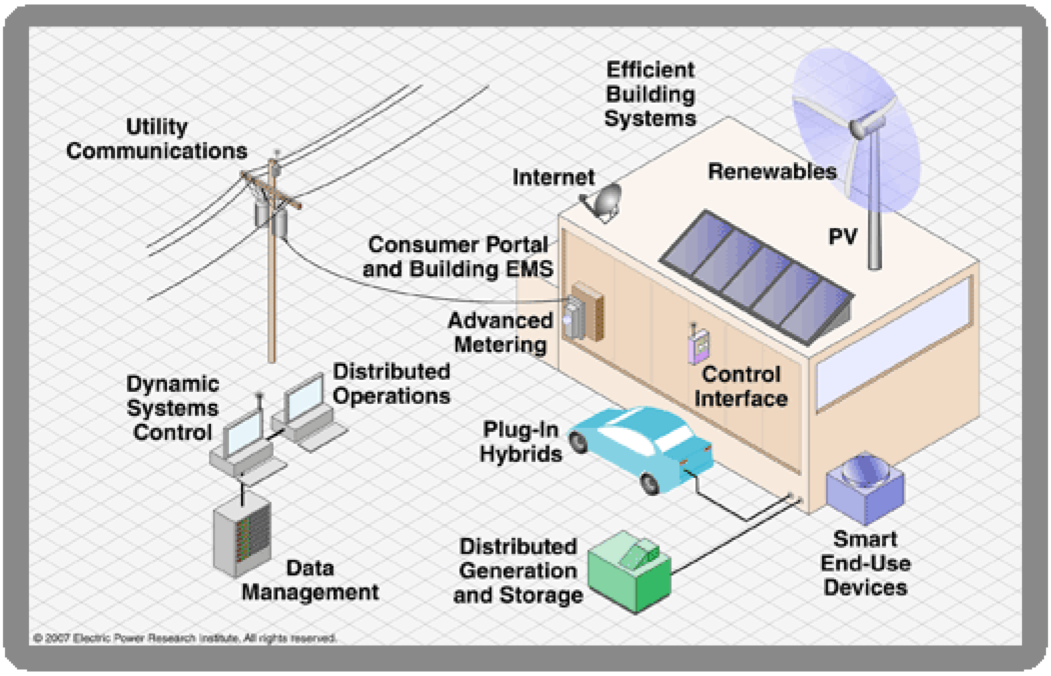
[45] For example, a feed-in tariff subsidy has been introduced for small scale renewable generators (under 5MW); this provides a fixed subsidy for every kilowatt hour of electricity produced.

[46] More generation connected to the grids will increase the fault current and runs the risk of increasing the fault levels. There are ways of overcoming through the use of power electronic interfaces (Green T.C. and Hernández Arámburo C.A., 2006). The second major issue is voltage control. Using more flexible transformers e.g. with on-load-tap changers can help to improve the voltage profile of distribution lines with more dynamic flows.

As a result of these issues facing distribution networks, concepts such as 'The Smart Grid'[47] and active and intelligent distribution systems have become increasingly prominent – the figure below illustrates how a more complex and dynamic relationship between energy and information flows are a key aspect of this:

Figure 4.10: Illustration of a smart grid concept

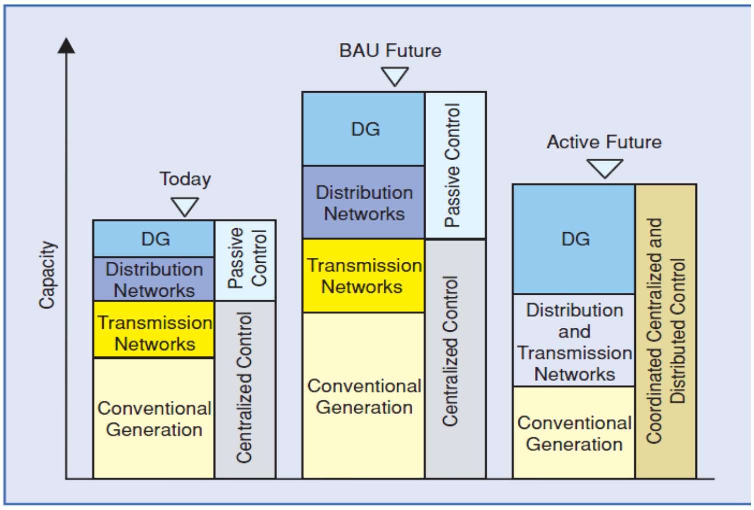


Source: (EPRI, 2011)

Essentially these concepts refer to ways in which distribution systems can facilitate a low carbon future by improving capacity management and becoming more similar to actively managed transmission systems; thus avoiding the need for conventional solutions i.e. expanding the networks – this is illustrated in the figure below:

[47] Defined as 'An electricity network which makes use of information and communications technologies, enabling more dynamics 'real-time' flows of information on the network and more interaction between suppliers and consumers' (CCC,2010: p.273)

Figure 4.11: Relative levels of system capacity under centralized and distributed control strategies



Source: (Djapic et al., 2007)

In the UK context, a recent scenarios report published by Ofgem (Ault et al., 2008) outlined five different potential futures for the transmission and distribution networks in 2050 (summarised in the table below). These scenarios show that there is a wide range of potential technical futures for the distribution networks ranging from a scenario which is characterised by dispersed micro-grids which are managed on a local basis, to one which sees an expansion of the current networks to meet a growing demand.

Table 4.2: Summary of the LENS Scenarios

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 characterised by diversity in network development and management approaches.

Source: (Ault et al., 2008): Table taken from Pollitt (2009)

With this uncertainty in mind regarding the range of potential transition pathways for electricity distribution networks in the future, the following table outlines how the analytical framework can be operationalised:

Table 4.3: Operationalising the Analytical Framework for the Electricity Distribution Case

The Governance Regime for Electricity Distribution
• How are distribution network regulated in the UK? • How does energy policy influence network regulation? What is the regulatory style in the UK? • What are the political rationalities, institutional relations and key instruments/tools which underpin the modes of governing distribution networks? • Who are the network operators and how are their businesses structured and operated?
Interventions and Interactions
• How have technical changes influenced the dynamics of the sector? • How have DNOs dealt with the issue of DGs connecting to their networks? • What is the changing role of the customer and what does this mean for DNOs? • How has the regulatory framework changed during the period of study? • How are DNOs deploying innovative technologies on their networks as a long term strategy for the transition to a low carbon energy system?
Outcomes
Physical Dimension
• How have flows of energy, information and revenues changed? • How is capacity management being achieved? Are system economies being achieved?
Relational Dimension
• How have DNOs interacted vertically with other actors in the value chain • How have DNOs interacted horizontally with actors such as equipment manufacturers

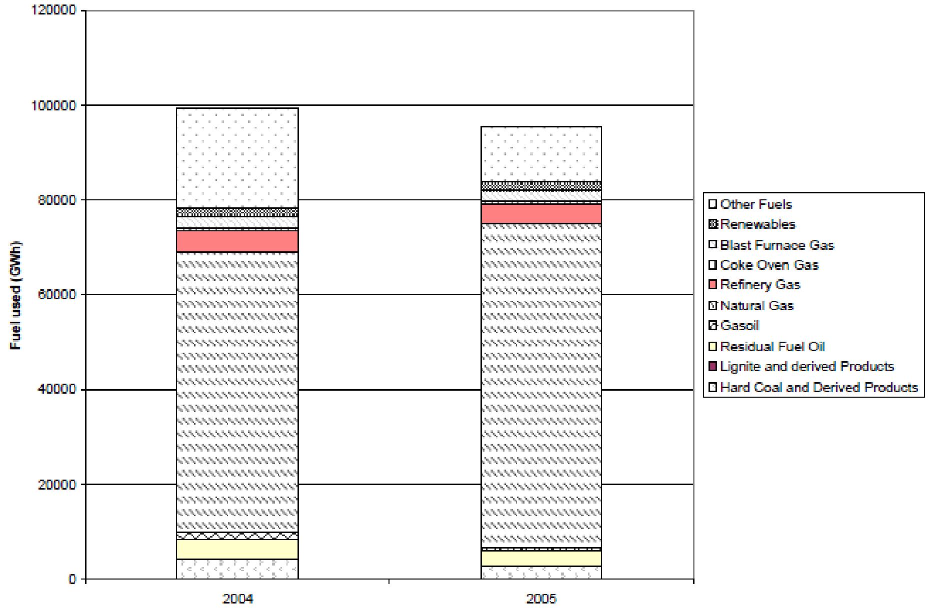
• How has the relationship between the regulator and the network companies changed? • How has the relationship between network regulation and energy policy changed?
Structural Dimension
• How do actors in the organisational field draw on different network logics to frame and legitimise their actions?

4.4 Combined Heat and Power with District Heating (CHP-DH)

The basic principle behind combined heat and power (CHP) technology is that heat (hot water or steam) and electrical power are produced simultaneously at the same site. Today in the UK, as in most other developed nations, the vast majority of electricity is generated at large centralised generating stations and transported long distances via a high voltage transmission grid and regional distribution systems – as described above. Heat, particularly at the domestic level, is predominantly supplied by natural gas with individual boilers in each dwelling. This emerged due to the UK's abundance of North Sea natural gas reserves and the legacy of town gas infrastructures in many of the major cities across the country. District heating (DH) on the other hand is organised on the basis of networking hot water or steam, rather than gas. This involves an energy centre, which is typically a gas-fired CHP plant connected to the regional distribution gas and electricity networks, supplying a locality with heat via a piped distribution network and the pipes and radiators within buildings (Roberts, 2008). The electricity is typically fed back into the public distribution grid but due to the proximity, the power will tend to be consumed by local loads.

A number of fuels can be used in the process such as natural gas, landfill and sewage gas, fuel and gas oils, coal, lignite and coke, biomass and biogas, solid waste (e.g. refuse, tyres), waste gases (e.g. refinery off gas) and waste process heat (IET, 2007). The figure below shows that in the UK the vast majority of fuel used in CHP plants is natural gas:

Figure 4.12: Types of Fuel used in CHP in 2004 & 2005



Source: (DEFRA, 2007)

CHP-DH schemes benefit from proximity economies as there are less electrical losses[48] and the heat produced can be distributed locally more efficiently. Also, economies of scope are achieved by supplying electricity and heat simultaneously (co-generation), thus increasing the efficiency of fuel utilisation. Currently the aggregate efficiency of such CHP plants in the UK is approaching 70%; as oppose to 40% for power generating plants (Pollitt and Kelly, 2010) where the waste heat is 'dumped'. In cases where the most modern gas turbines are utilised this can exceed 80% for CHP, also the economies of scope can be improved by deploying absorption chillers to provide chilled water as well as heat and power, a process known as 'tri-generation'. Economies of scale in the provision of heat are achieved by balancing and sequencing a diverse set of loads, therefore more efficient fuel utilisation can be brought about than with individual boilers which often operate at part load and the performance of the boiler is less efficient (Roberts, 2008). Also, schemes with a distribution network have the potential to connect to a range of heat sources aside from CHP plants such as distilleries and electrical transformer stations (Roberts, 2008) – these benefits vary from location to location where successful schemes tend to rely on a dense and diverse set of loads and often a large anchor load such as a public building (university, library etc.) which can act as a stable and long-term customer.

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[48] In centralised systems electricity distribution and transmission thermal losses account for 7-9% of power consumption. These benefits are poorly recognised in transmission and distribution charging regimes.

There is a large upfront capital cost involved with a heat distribution network; ‘the capital and installation costs of the energy-distribution network then tend to become the pre-dominant cost, i.e. exceeding the cost of the CHP plant, and the scheme is likely to become more of a public service than a private-sector profitable business’ (Babus'Haq and Probert, 1996). However, ‘if the differences between heat production cost and heat selling price is high enough the DHN capital cost can be recovered over time’(PÖYRY, 2009). Key variables include the cost of fuels supplied, the spark spread (‘the relationship between the cost of fuel inputs and the price for which electricity production can be sold’ (Toke and Fragaki, 2008)), and the nature of the loads (customers) within the reach of the network.

Despite the potential efficiency benefits, CHP-DH has not developed to the same scale as other European countries. In the UK, electrical power from CHP accounts for approximately 6% of total capacity, with 98% of this being stand-alone industrial plants[49] and only 2% district heating (Pollitt and Kelly, 2010); accounting for only 2% of overall heat demand (PÖYRY, 2009) and 1% of households (Roberts, 2008). This is in contrast to Scandinavian countries; for example in Finland and Denmark district heating accounts for 49% and 60% of total supply respectively, and in Vienna 36% is supplied via heat pipes (PÖYRY, 2009). There are a number of reasons for this; for example in a country such as Denmark, due to the colder climate there is a greater demand for heat - in Copenhagen there are 2,900 ‘heat degree days’[50] per year while the figure in London is 1,700 - therefore the economic viability of CHP-DH is greater. This was helped by the fact that many of the Scandinavian countries have set electricity tariffs at beneficial rates for CHP generation (Toke and Fragaki, 2008).

A unique feature of CHP-DH is its reliance on strong local energy institutions to successfully develop schemes. Due to the public good characteristics, high upfront capital cost, the need for large anchor loads and the planning and legal complexities involved, in most cases local authorities tend to be at the centre of schemes, or the focal actor. Strong local government involvement in coordinating a range of actors has been a significant feature of the diffusion of district heating in Scandinavian countries (Summerton, 1992). In these countries municipal authorities tend to have had a much greater role than in the UK in the provision of energy services and shaping energy institutions (Lehtonen and Nye, 2009).

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[49] ‘Much industrial CHP is concentrated in a few industries which have both a high overall energy usage and a ratio of heat to power needs which suits CHP well: chemicals, refineries, paper and board, food and drink, iron and steel’ (Brown, 1994)

[50] “…the difference between 15.5^{o} C (60^{o} F) and the daily mean (average) temperature when the latter is less than 15.5^{o} C.” (Roberts, 2008)

4.4.1 Historical Overview of CHP-DH in the UK

When the electricity sector was nationalised in 1947/1948 there was already underway a strong technological trajectory towards the interconnection of the fragmented municipal electricity systems and the aggregation of loads in order to achieve economies of scale in electricity generation. Although there were a number of significant CHP-DH schemes operating in the pre-war period, such as the Bloom Street power station in central Manchester and Battersea power station in London, many of the smaller municipal undertakings (private and local authority owned) which had dominated the ESI were essentially bypassed by the construction of the 'Gridiron' – a high voltage transmission system which connected the largest power stations – throughout the 1920s and1930s. Throughout the nationalised period from 1948 until the 1980s there were short periods when interest in CHP-DH was heightened, but this tended to result in the formulation of grand plans and strategies which resulted in little material outcome (Russell, 1986). One such 'hype-cycle' (Verbong et al., 2008) was during the reconstruction period immediately following World War II where a number of local authorities received funding to develop schemes e.g. Birmingham, Manchester, Coventry, Pimlico and a number of the new towns (Russell, 1993: p.35). Russell notes that thirty five schemes 'reached the stage of preliminary plans and costings' but eventually most were scaled back for a number of reasons e.g. cost and inability to secure a heat source from the ESI. Also, because the role of local authorities in the energy industry had been diminished following nationalisation, and central government's attitude to CHP-DH 'was characterised by ambivalence' reflecting 'conflicting interests and opinions within government and among advisers' (Russell, 1993: p. 38), district heating lacked both the national/sector level supporting institutions and local level leadership and coordination.

The public electricity companies tended to have free reign over technology related decisions often with little political interference and, due to coal supply shortages and blackouts in the 1940s, attention was focused on increasing centralised electricity generating capacity rather than local CHP-DH schemes. Overall therefore 'CHP was seen as marginal to the main thrust of growth and operation of the supply industry in large centralised condensing stations, increasingly remote from major heat loads' (Russell, 1993: p.40). Although a number of strategy documents and visions were produced during this periods; 'the eventual outcomes of visionary plans for heat networks in major cities and the many smaller projects around the country was a pathetic handful of DH schemes, many were much reduced from their planned size' (Russell, 1993: p.40).

The oil shocks of the 1970s led to a renewed interest in the potential of CHP to deliver greater levels of fuel efficiency than centralised generating plant; most notably in Nordic countries and the Netherlands who were heavily dependent on imported fuels. Due to the discovery of North Sea oil and gas reserves this was less the case in the UK; however there were a number of reports commissioned to assess the potential for CHP-DH in major UK cities. The 1979 Marshall Group report recommended a greater degree of national coordination in the form of a national heat board and the 'resulting Combined Heat-and-Power Group of the government concluded that CHP-DH would be important for the UK when oil and natural gas became scarce fuels (…) it recommended setting up of CHP-DH demonstration schemes and a national Heat Board. However, these two recommendations were subsequently rejected by the now defunct Department of Energy (DoE)' (Babus'Haq and Probert, 1996).

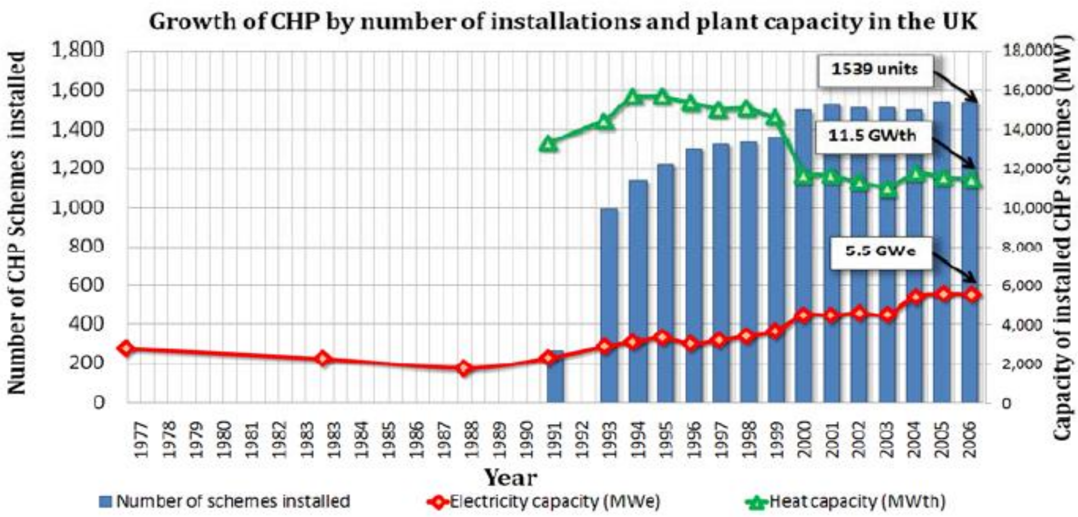
The subsequent Atkins report of 1982 was commissioned in order to identify suitable locations for CHP-DH in UK cities. Recommended were Belfast, Glasgow, Liverpool, London, Sheffield and Tyneside. Eventually Belfast, Edinburgh and Leicester were granted funding (£750,000 in 1985) under the 'lead city scheme' (Babus'Haq and Probert, 1996) and later on Sheffield, London and Newcastle were selected. Writing in 1996, Babus'Haq and Probert (1996) argue that 'To date, the progress in the implementation of CHP-DH in the three lead cities, as well as the other three privately supported cities has been disappointing' (Babus'Haq and Probert, 1996). The scheme in Belfast did not go ahead due to a lack of local government involvement and in Edinburgh and Newcastle 'the predicted rates of return on the proposed investments for the Belfast and Edinburgh schemes were too low to attract finance solely from the private sector' (Babus'Haq and Probert, 1996). Successful schemes were however developed in Sheffield and Leicester. In the case of Leicester 'development started in 1987 with a planned DH network across large parts of the city and a combined-cycle cogeneration system' (Babus'Haq and Probert, 1996), currently the scheme is one of the largest in the UK. In Sheffield a large scheme based around a waste incinerator was initiated in 1988.

In his history of district heating in the UK Russell (1993) points to a number of factors that account for the lack of development of CHP-DH during the nationalised period: the lack of an institutional framework to support 'the distribution of two products', CHP's 'possible value for energy saving', this was not in line with the expansionary model of the ESI which relied on demand growth, and the fact that energy policy at the national level tended to prioritise the interests of the publically owned electricity companies thus negating the benefits of local energy provision.

Since the 1980s the overarching institutional dynamic within the energy sector as a whole has been the progressive introduction of market liberalisation and the eventual privatisation of state owned assets in 1990. The 1983 Energy Act provided ‘the first legislative support for CHP’, as it allowed a generator to ‘buy electricity from Local Electricity Boards (LEBs) for its own use or the use of its customers’, to ‘sell its privately generated electricity to the LEBs’, and to ‘use the national transmission and distribution network for its own use or the use of its customers’ (Babus'Haq and Probert, 1996). There was ‘a duty on the regional distribution boards to “adopt and support” combined heat and power’ (Brown, 1994) under the 1983 Act as they had to guarantee that ‘any company with power to export had a market for that power’. However ‘the price varied from year to year and was subject to the changes that the Central Electricity Generating Board (CEGB) made in its bulk supply tariff’ (Brown, 1994 p.174). Babus'Haq and Probert (1996) note that, although the intention was to get the CEGB to ‘promote the sale of heat in the same way that they had developed the nationwide electricity grids’, in its implementation ‘the Act mainly helped those investors in industrial and small scale CHP applications’ rather than investment in local infrastructure (Babus'Haq and Probert, 1996 p.51).

Although the tentative steps towards the opening up of the electricity market in the 1983 Act had little material effect on CHP diffusion (see graph below), the eventual de-regulation of the electricity trading market following the 1989 Electricity Act saw a more rapid increase in the diffusion rate of CHP:

Figure 4.13: Growth of CHP in the UK (1977-2006)



Source: (Kelly and Pollitt, 2010)

Following liberalisation of the wholesale electricity generating market the newly privatised companies National Power and PowerGen began to take an interest in CHP. They setup specialist co-generation companies (National Power Cogen and PowerGen CHP respectively) which were particularly focused on marketing CHP to industrial customers and along with this a number of the RECs began to sell small scale CHP systems to commercial customers[51] (Brown, 1994). Also, the Combined Heat and Power Association (CHPA) was set-up in this period in order to represent the interests of the emerging sector. Incentives for CHP were put in place during this period such as a Climate Change Levy (CCL) exemption for units which meet environmental standards under 'CHP Quality Assurance (CHPQA) programme' and an 'enhanced capital allowance' which allowed 'companies installing CHP [to] write off their taxes on profits against the value of the CHP capital investment in the year in which the investment was made' (Toke and Fragaki, 2008).

The growth in CHP was part of a overarching trend towards investment in more efficient and flexible gas turbines which became economically viable following liberalisation (Winskel, 2002, Watson, 2004). However, although there was a significant increase in CHP, the majority of new investments which were made in medium sized CCGT electricity plants did not capture the heat. The demand in a competitive environment for plants to be built cheaply with short construction periods meant that new gas plants tended to be located far away from built up areas closer to main gas lines as land was cheaper and there were less planning delays (Kelly and Pollitt, 2010). The lack of a regulated tariff for the output from CHP, the time and upfront capital cost associated with laying distribution pipes and the time and difficulty involved in developing a market for the heat meant that there was no significant uptake of CHP-DH during this period unlike Nordic countries.

4.4.2 Challenges facing the Heat Sector and Networks

Heat demand constitutes approximately 41% of final energy consumption in the UK (Speirs et al., 2010) and in households the vast majority of heat is provided through gas[52] with 18-20 million gas boilers installed in dwellings (DECC, 2011b). As of the mid-2000s, the UK has become a net importer of gas (POSTNOTE, 2004, Watson, 2010) and this has become problematic as it supplies approximately 40% of total UK energy, and because the gas and oil

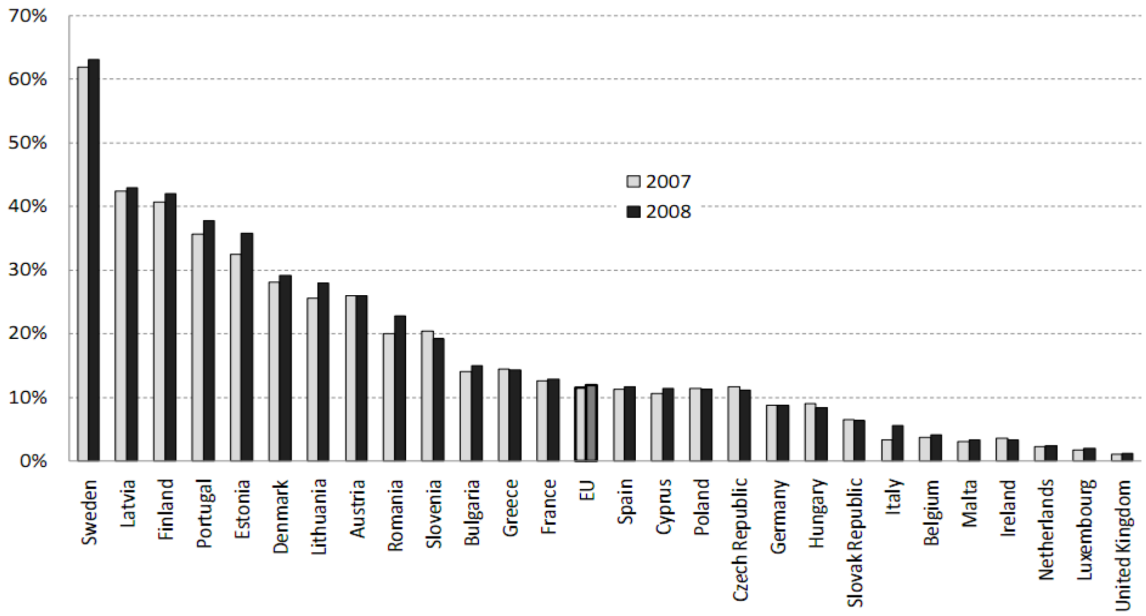
[51] 'Midlands Electricity established Cogen systems in 1991 to market packaged systems. Also in 1992, three RECs – London, Northern and NORWEB – each formed a joint venture company with the established manufacturer and installer, Combined Power Systems, to market units across the country' (Brown, 1996: p.175)

[52] Approximately 81% gas, and around 8% electricity and oil (BERR, 2008)

price remain to be completely decoupled (Stevens, 2010), the recent rise in oil prices have raised concerns over the long term energy security implications of this heavy reliance on gas.

In order to reduce carbon emissions and reduce the reliance on imported gas, the government has put in place a target of 12% of heat to be supplied from renewable sources by 2020. As the graph below shows, the UK is starting from a low base with only 1% approx of final heat consumption from renewables (Friends of the Earth, 2010).

Figure 4.14: Percentage of total final consumption of heat from renewable sources, 2007 and 2008



Source: (DECC, 2010e: p.82)

As the figure shows, counteries with a high penetration of CHP and district heating such as Denmark and Finland, tend to have a greater percentage of their heat supplied from renewable sources, particularly biomass. Although the government has set targets for CHP in the past, these have not been met[53]; however, a number of recent government white papers have cited district heating networks as an important enabler for the more efficient utilisation of gas and the diffusion of renewable heating technologies (DECC, 2009d, DECC and DCLG, 2010).

It has been well documented that heat networks in particular have faced a number of barriers to their development in the UK. Stewart Russell, in his history of CHP-DH during the nationalised

[53] A target was set in 1993 as part of the climate change programme to reach 5 GW CHP capacity by 2000 which was not achieved and in 2000 a 10 GW of good quality CHP capacity target was set by 2010 which again was not met (Pollitt and Kelly, 2010)

period, noted that district heating did not take off in the UK due to a lack of local level leadership and an absence of a national level framework to support the development of decentralised energy (Russell, 1986). A recent report by the PÖYRY engineering consultancy for DECC largely reiterated this and pointed to a range of economic and financial barriers to CHP-DH (PÖYRY, 2009).

Recognising CHP-DH therefore as a niche technology which has not been part of the mainstream energy regime in the UK, the following table outlines how the analytical framework can be operationalised for the case study:

Table 4.4: Operationalising the Analytical Framework for the CHP-DH Case

The Governance Regime for CHP-DH
• Which local authorities are involved in CHP-DH and to what extent? • What policy areas and government departments influence the CHP-DH sector? • What are the political rationalities, institutional relations and key instruments/tools which constitute the modes of governing CHP-DH?
Interventions and Interactions
• How do local authorities engage in energy issues and how has this been evolving? • What is motivating a small number of local authorities to develop CHP-DH schemes? • What are the different approaches being taken to CHP-DH and how are the different schemes structured and organised? • What are the financial arrangements surrounding CHP-DH? • How does CHP-DH interact with the incumbent energy regime?
Outcomes
Physical Dimension
• How have flows of energy, information and revenues influenced change? • How are system economies being achieved?
Relational Dimension
• How have local authorities engaged with public and private sector actors to develop schemes? • Is there a CHP-DH sector in the UK? How is this being coordinated? • What is the nature of the national and local level interacts?
Structural Dimension
• How do actors in the organisational field draw on different network logics to frame and legitimise their actions?

4.5 Chapter Conclusions

This chapter provided a brief overview of energy policy in the UK which described the broader context within which energy distribution sectors operate. It was outlined that the transition to a low carbon economy in the UK is placing a significant emphasis on achieving emissions reductions via the decarbonisation of energy supply along with demand reductions and energy efficiency measures. The chapter outlined the challenges that this poses for electricity and heat distribution networks which, for different reasons, traditionally have not been an active or prominent part of the energy system as a whole. By referring to the analytical framework which was developed in the previous chapter, each of the case studies were considered in more detail by outlining key analytical variables which relate to the governance and socio-technical characteristics of the sectors; this will guide the discussion in the following two chapters.

5 The Electricity Distribution Sector in the UK

This chapter charts the interplay between actors, institutions and technologies in the electricity distribution sector. The chapter begins by focusing on two particular issues - the connection of distributed generation and promoting flexible demand side behaviour - and their effect on the governance regime for electricity distribution. These issues have both been shaped in recent years by the liberalisation agenda and concerns over climate change and in a number of ways have begun to challenge existing institutions and modes of governing the sector. The interventions and interactions section charts the emergence of these issues and how the governance regime is changing and adapting. Following this, the outcomes section summarises how these co-evolutionary processes are influencing the physical, relational and structural dynamics of electricity distribution in the UK. The chapter begins by introducing the governance regime and the key actors within the sector.

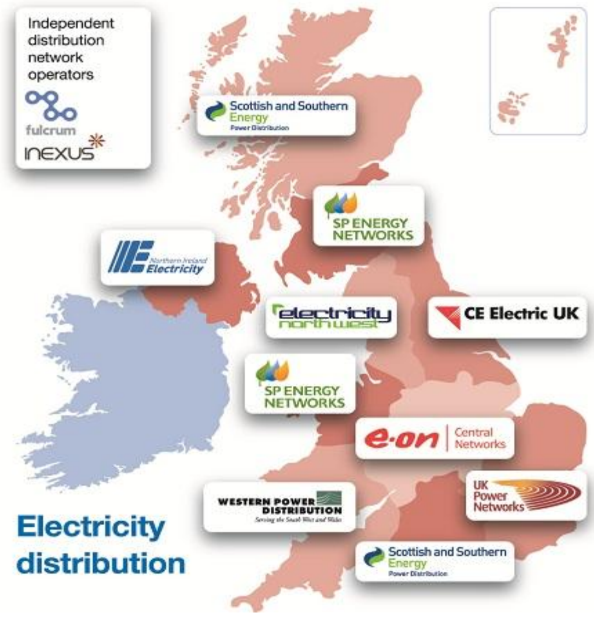
5.1 Electricity Distribution in the UK

The current structure of the electricity distribution sector emerged following the 1989 Electricity act which established licences for 14 private regional electricity companies (RECs). RECs carried out a similar function to the nationalized Area Boards; however, rather than accepting bulk power from a monopoly generator (the CEGB), they received power from the electricity pool, and along with owning proportionate shares in the transmission network, their role was to distribute and supply electricity in their respective areas. Following the Utilities Act in 2000 and the introduction of retail competition, a specialised distribution licence was created for the 14 areas. Over the years there have been a number of mergers and acquisitions, and today there are seven companies who operate the 14 distribution licences - these are termed Distribution Network Operators (DNOs). There are also a small number of independent DNOs (IDNOs) who do not operate in a specific area but compete with incumbent DNOs for new connections[54]. The map of the UK below shows the companies and their respective areas[55]

[54] For example EDF Energy (IDNO) Ltd, a subsidiary of EDF energy, is developing the electricity distribution system for the 2012 Olympic Games

[55] This study focuses on England, Wales and Scotland. Northern Ireland Electricity is a transmission and distribution company which is regulated separately by the Northern Ireland Authority for Utility Regulation (NIAUR). There is a high level of cooperation and interconnection between NI and the Republic of Ireland this makes the institutional context more unique and outside the bounds of this study (see http://www.allislandproject.org/en/homepage.aspx)

Figure 5.1: Map of DNOs in the UK



Source: (Nationwide Utilities, 2011)[56]

A number of the DNOs are separate business units of larger energy companies (the 'big six') who also operate in the electricity and gas retail markets and the wholesale generation market, whilst others are specialised asset management companies e.g. CE Electric.

Under the 1989 and 2000 Acts, the main duties of DNOs are as follows (ILEX, 2002):

- To 'develop and maintain an efficient, co-ordinated and economical system of electricity supply' (Section 50)
- To 'facilitate competition in the supply and generation of electricity' (Section 50)
- To make a connection on request (Sections 16) and to recover expenditure for 'any expenses reasonably incurred' (Section 46)
- To 'secure all monies owed for both delivery of energy (distribution use of system charges) and for connection' (ILEX, 2002)

Due to the fact that distribution networks are organised as regional monopolies, the distribution of electricity is treated largely as a non-competitive activity which is governed by a sector

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[56] This is as of 2010. In 2011 Central Networks was purchased by the PPL Corporation who also own Western Power Distribution.

specific regulator - Ofgem[57]. Ofgem is non-departmental agency but it shares with the Secretary of State the responsibilities of regulating the gas and electricity networks and overseeing the operation of the wholesale and retail markets for energy (MacKerron and Boira-Segarra, 1996). Ofgem's main duty with regards to electricity distribution is to ensure that the DNOs fulfil their licence obligations whilst remaining financially viable. In order to do this, the regulator must strike a balance between the interests of present and future customers (e.g. the levels of investment that should be made and whether they should be funded through price increases today or through future borrowing) and divide economic rents between the shareholders of private companies and customers (the levels of profit of the DNOs) in an equitable manner (Surrey, 1996). Any changes made to the terms of the distribution licence must be jointly agreed by Ofgem and the companies prior to parliamentary approval. If agreement cannot be found, a case can be referred to the Competition Commission for adjudication.

5.2 Characterising the governance regime

Broadly there are two approaches to the governance of natural monopoly networks which have been employed by regulators. The first is where the regulator focuses on the input costs or the revenue requirements of operating the networks and the company is compensated for the costs that it incurs by charging prices based on an agreed rate-of-return on investment. This 'cost of service' approach means that there is no risk for the company, as their costs are covered, or for the regulator as there are no excess profits left to the company (Joskow, 2008). However, it has been argued that this is an inappropriate mechanism as linking company profits to the size of their asset base increases the likelihood that companies may over-invest in order to expand their capital base (Averch and Leland, 1962). At the opposite end of the spectrum is a form of regulation where constraints are placed on the prices that companies can charge ex-ante. Here the regulator specifies how much tariffs can increase plus or minus a specified amount; in theory this places an incentive on companies to run their businesses in a more efficient manner as they benefit from any savings they achieve i.e. 'networks are set targets upfront and are encouraged to outperform these' (Utilityweek, 2009). However placing the obligation on private companies runs the risk of under-investment and poor service quality. Also, companies may game the system by providing inadequate information to the regulator regarding their underlying costs, thus making excess profits.

[57] Following the 1989 Act, the RECs were regulated by the Office of Electricity Regulation (OFFER). Following the 2000 Utilities Act, OFFER was merged with the gas regulator to form the Office of Gas and Electricity Markets (Ofgem)

This latter approach has been favoured in many countries, including the UK which since the 1980s has been at the forefront of the liberalisation and privatisation of network industries, along with Chile and New Zealand (Voß, 2007). The particular form of price regulation which has been applied to the UK was designed by the academic economist Stephen Littlechild (Littlechild, 1983) and is based on setting price-caps for groups of customers which are linked to the rate of inflation over a specified period of time (5 years[58]); in theory giving autonomy to the companies in reducing costs and finding efficiencies. Beesley and Littlechild (1989) summarise this approach which has been termed RPI-x in the UK:

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

This mechanism was designed to 'mimic the market' and was indicative of boarder trends in society such as the move away from a Keynesian interventionist state and a reorientation of energy policies towards the use of prices to allocate resources 'efficiently' (Mitchell, 2008). Over time, the RPI-x model has become more complex with separate incentive schemes for operating expenditures (OPEX)[59], capital expenditures (CAPEX)[60], the quality of service, and network losses (Jamasb and Marantes, 2011).

As part of what has been a five-yearly price control review process[61], Ofgem set an initial price (Po) and which is then linked to the RPI which sets a basis for how prices will change from year to year. Then, through a process which is described below, they determine an x factor which is a target productivity change factor for the companies to achieve (Joskow, 2008) and hence the price for the price control period (P_1) . Joskow (2008) summarises this in the following equation:

The aim of the process is to estimate the likely OPEX for an efficient DNO and to set Po i.e. a return on the regulated asset base[62] which is adjusted for investment requirements and

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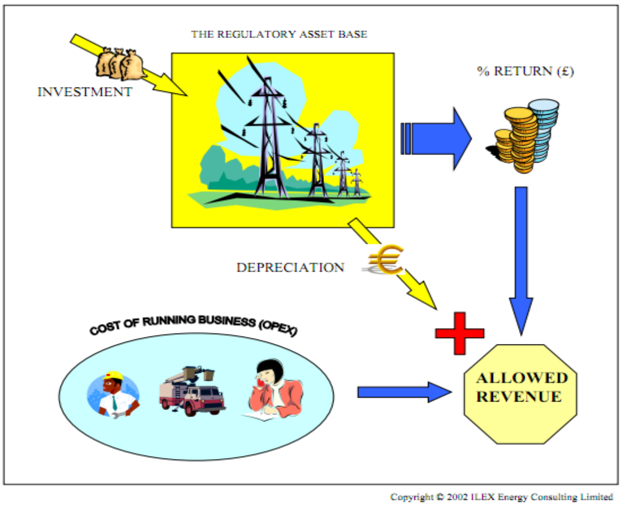
[58] The risks to the regulated company are reduced the longer the period between price controls
[59] The amount of money needed to run the network operator business
[60] 'The amount of money needed to invest in the distribution network in order to maintain required service levels' (ILEX, 2002)
[61] The first distribution price control review was in 1990 (DCPR1) and the most recent was DCPR5 in 2010
[62] The worth of existing network assets

depreciation[63] (ILEX, 2002) - this has been set each five year period. This is termed the allowed revenue of the DNO, as summarised in the schematic below:

Figure 5.2: DNOs' allowed revenues



Source: (ILEX, 2002)

The price control review process begins with the publication of a consultation document 18 months prior to the commencement of the price control period; this generally centres on topics such as the timetable for the price control process and particular issues that need to be dealt with during the process. Six months prior to the deadline, a 'Final Proposals' document is published which includes the first estimates for the calculation of the x factor. Companies then submit business plans 'for operating and capital expenditure requirements' and the x-factors for each DNO are determined in a two step process: Initially an efficiency analysis which focuses on CAPEX requirements is carried out by management consultants, and a subsequent benchmarking exercise using a regression analysis is conducted to determine the efficient level of controllable OPEX for each DNO (Giannakis et al., 2005). The companies are compared using an efficiency frontier of the 'best practice DNOs in the sector' (Jamasb and Pollitt, 2007) and a target is set for the allowed OPEX 'such that it requires them to close a specific proportion of their performance gap relative to the frontier during the price control period. In addition, the DNOs are given a general technical efficiency improvement target that is common to all DNOs' (Jamasb and Marantes, 2011). The total allowed revenues of the DNO is therefore

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[63] The regulator decides on a specific rate of return for existing and new investments and this reflects the cost of capital for DNOs to either fund their activities either through equity or borrowing based on a weighted average cost of capital (WACC) (ILEX, 2002). Theoretically DNOs should be allowed to recover their costs i.e. capital costs (WACC x RAB), operating costs, and depreciation costs.

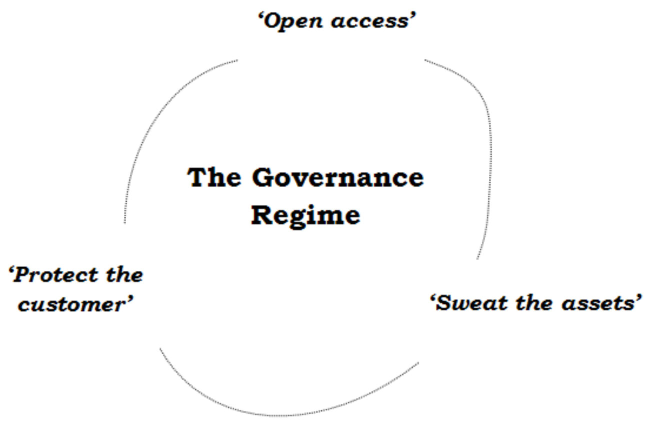
a combination of its OPEX and CAPEX, and is used as a basis to calculate the x factors for each DNO along with the maximum charges which can be charged to customers in the different 'tariff baskets'.

Although the RPI-x approach was intentioned to be an apolitical and mathematical method of adjusting prices (Moran, 2003), in practice the periodic price control review process means that the regulator does have to make some decisions regarding the cost base of the companies. In order to set Po, Ofgem needs to make decisions regarding the costs of operating the networks and therefore setting appropriate rates of return for the existing asset base, which in turn influence prices (Alexander and Irwin, 1996). As a result there is a risk that an operator will front load its cost saving measures early in a price control period and 'towards the end, when resetting is being considered, companies may have an incentive to conceal or postpone price cutting initiatives so as to encourage the regulator to impose an lenient x term in the next round'(MacKerron and Boira-Segarra, 1996: p.101). The regulator must make decisions and judge the relative risks of over or under-investment in a situation where they know less about the underlying cost structure of the companies than the companies themselves (Joskow, 2008), thus creating information asymmetries which increase the transaction costs of the regulatory review process. The system of regulating distribution (and transmission) networks is therefore closer to a hybrid of rate-of-return and price regulation (Surrey, 1996). The regulator must pursue economic objectives (which are largely achieved through setting pricing regimes) whilst gaining legitimacy for its actions by 'distributing the economic rent in a way which retains the broad acceptability of the various stakeholders, especially consumers and shareholders' (Surrey, 1996: p.254).

Modes of Governing Electricity Distribution Networks

Having outlined that RPI-x regulation is more complex and multi-faceted that simply setting prices in order to achieve predefined and efficient outcomes, the various modes of governing (Bulkeley et al., 2007) distribution networks are explored in more detail i.e. the rationalities, programmes and instruments which are developed and implemented in order to pursue state strategies with regards to the distribution networks. These rationalities, programs and instruments which constitute the governance regime, have largely evolved from the underlying market based logic of the competitive model with privatisation, liberalisation and unbundling of the ESI. As can be seen in the figure below, these are characterised by three modes of governing which are described in more detail below:

Figure 5.3: Modes of governing the electricity distribution sector



'Sweat the assets'

A key rationality and outcome of the RPI-x governance regime has been to shift the emphasis of regulation away from capital investments towards achieving short-run operational efficiencies (interviews – 1, 3, 6, 10, 16, 17, 18, 20). This was largely due to the fact that under nationalisation the expansionary model which relied upon an ever increasing demand[64] and utilised top-down and long term demand forecasting models in order to plan and coordinate investments (Chesshire, 1996), became largely obsolete following the economic slowdown of the 1970s which meant that many of these long term predictions proved to be inaccurate, leading to significant over-investment[65]. One of the central aims therefore of RPI-x was to adjust to a new environment where demand growth was no longer the driver behind the momentum of the system. The new system goal was to exploit the existing asset base which had been developed during nationalisation (interview – 10) – this has been termed 'sweating the assets' (Helm, 2004). Shifting the emphasis away from asset investments towards exploiting the installed asset base has meant that the regulation of OPEX has received more attention from the regulator involving a more thorough process during price controls with techniques such as ex-ante incentives to reduce costs and benchmarking of company performance. However, as the next section will outline, the natural asset replacement cycle and the need for investment in order to facilitate low carbon technologies, means that the focus of the regulator is beginning to shift towards CAPEX regulation.

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[64] 2.7 million new houses were built in the first 10 years of nationalization and the number of domestic customers rose from 9.7 million to 14.3 million (Hannah, 1982). Demand for electricity in the UK grew by an average of 7% per annum between 1955-1970 (Chesshire 1996)
[65] For example the plant margin, or the excess of generation capacity over demand, 'rose from 21% in 1970-71 to 42 per cent in the period 1973-1976' (Chesshire, 1996)

'Open Access'

A second mode of governing electricity distribution networks in the UK is based on the competitive network logic where the networks are governed in order to facilitate competition in the retail and generation markets. The rationality behind 'open access' is that 'with respective regulation for network services in place, competition can unfold in other market segments (such as supply, trading, and retail provision)' (Voß, 2007); it therefore forms a key pillar of the governance regime of infrastructure networks in a liberalised and privatised context[66]. The function of maintaining access to the networks for third-parties has a significant influence in determining the structure of pricing regimes for operators because 'the introduction of competition in electricity and gas necessitated non-discriminatory charging schemes to allow competitors access to the transmission and distribution systems. This involved estimating the value of the relevant capital assets and deciding appropriate rates of return for existing assets and for new investment' (Surrey, 1996: p.245). Under the 1989 and the 2000 Acts, 'DNOs have a statutory duty[67] to make a connection when requested to do so by the owner or occupier or premises (or by an authorised supplier acting on behalf of the owner or occupier) for the purposes of enabling electricity to be conveyed to or from the premises. There is a complementary statutory right[68] to recover the expenditure reasonably incurred in making a connection' (Ofgem, 2001a). Regulating connection is important because 'those seeking demand and generation connections do not have the advantages of information and knowledge of network conditions enjoyed by DNOs: they cannot deal with them on an equal footing' (Ofgem, 2001a). Ensuring third party access became particularly important after the separation of distribution and retail to ensure the connection of new customers and generators to the networks and to allow customers to switch supplier in a de-regulated environment whilst

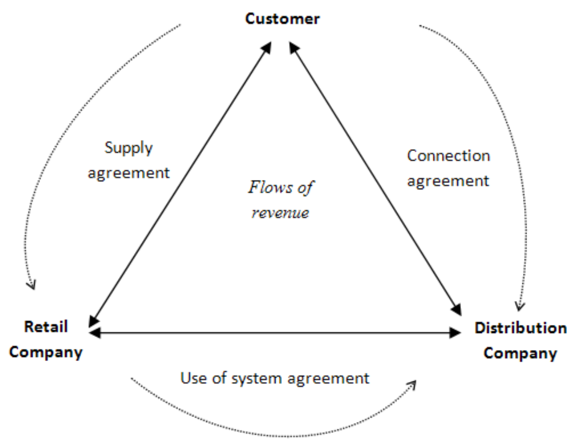
[66] Prior to privatisation third party access to the networks tended not to be a major issue as Area Boards were monopolies in the distribution of electrical power all the way to the end customer. The 1989 Electricity Act amended this situation by outlining a number of specific duties that privatised RECs would have in relation to allowing parties to access network services: (a) 'To make a connection between a distribution system of his and any premises, when required to do so by – (i) the owner or occupier of the premises; or (ii) an authorised supplier acting with the consent of the owner or occupier of the premises, for the purpose of enabling electricity to be conveyed to or from the premises'; (b) 'to make a connection between a distribution system of his and any distribution system of another authorised distributor, when required to do so by that authorised distributor for the purpose of enabling electricity to be conveyed to or from that other system' (1989 electricity Act). Following the 2000 utilities act these obligations were extended to accommodate the de-regulation of retail whilst ensuring a sustainable revenue stream for the newly constituted DNOs where 'statutory duties will be placed on DNOs similar to those placed on the holder of a transmission licence requiring them to facilitate competition in generation and supply, not to discriminate between classes of persons when setting connection charges, and to develop and maintain an efficient, co-ordinated and economical system of distribution' (EGWG 2001: p. 9).

[67] Electricity Act 1989, section 16, as substituted by section 44 of the Utilities Act 2000

[68] Electricity Act 1989, section 19, as amended by section 46 of the Utilities Act 2000

developing revenue streams from those connections and the use of the system. The figure below outlines how non-discriminatory, open access forms the basis of how DNOs collect their allowed revenues:

Figure 5.4: Flows of revenue and contractual relationships in the distribution sector



Source: (Adapted from ILEX (2002))

The following contractual arrangements are directly relevant to DNOs:

Use of system agreement: This is a contract between licensed retailers and network operators; 'it sets out the conditions of, and provision for, use of the distribution system by licensed suppliers. End customers are not party to the use of system agreement – although the commercial terms under which a customer's energy supplier has access to the local distribution network' (ILEX, 2002: p.7)

Connection agreement: The purpose of this contract is to 'formalise the terms and conditions of connection' to the network. The agreement contains details of metering equipment, financial liability, maximum capacity (KVa/MVa) and other technical issues' (ILEX, 2002).

DNO revenues are collected through: (a) 'charges for *use* of the distribution system' (DUoS) where DUoS are levied on the suppliers according to their use of system agreement, and (b) charges for *connection* to the distribution system' (ILEX, 2002). There is a competitive environment for new connections where a number of licensed independent DNOs (IDNOs) compete with incumbent operators in this market. Until recently 'the DNOs have been reasonably free to determine how charges are levied for use of system and connection' (ILEX, 2002), however, we will see later how this situation has been made more complex by increasing levels of generation being connected to the distribution networks.

'Protect the Customer'

A key underlying rationale behind unbundling and price regulation has been the problematization of natural monopoly in network industries (Voß, 2007). The logic behind this is that although competition is possible in certain areas of the value chain - retail and generation - the networks (pipes and wires) are natural monopolies. A network industry such as the ESI is seen as 'a chain of vertically related stages of production of which transmission/transport via networks is one stage that can be isolated from the others and be treated as a self-contained activity' (Voß, 2007: p.121). Customers therefore need to be protected from monopoly pricing and poor quality of service. In the UK electricity context, this notion of protecting the customer has been interpreted in a very specific way; to promote competition and enabling customers to switch between suppliers i.e. through prices (Mitchell, 2008, SDC, 2007). This is illustrated in the following extract from an Ofgem document:

> *"Ofgem's principal statutory objective is to protect the interests of consumers, wherever appropriate by promoting effective competition. Where there is scope to do so, it has been Ofgem's policy to seek appropriate market-based solutions, ensuring equitable treatment of parties, and cost-reflective pricing. In other circumstances the appropriate regulatory policy is one of controlling the exercise of monopoly power" (Ofgem, 2001a)*

Again, this mode of governing is closely linked to the other two modes of governing; 'sweat the assets', and 'open access'. For example, the relationship between the supplier and the DNO described in the 'open access' section is based on the premise that customers can switch between suppliers thus necessitating a fluid contractual relationship between parties which reduces asset specificity[69]. Pure price regulation which promotes the optimal operation of a network only exists in theory however and throughout the period of privatisation a number of specific measures have been in place to ensure safety standards[70] and quality of service standards (QOS)[71] . Prior to 2000, QOS was regulated through 'guaranteed standards of

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[69] Under Standard License Condition 46 suppliers must allow customers to switch between companies without being unduly penalized. Before 2007 this had to be done within 28 days; however, following modification of the license conditions, suppliers can offer contracts to customers with longer notice periods.

[70] 'The UK Electricity Safety, Quality and Continuity Regulations specify steady-state voltages within ±6% of nominal for systems up to 132 kV and within +10/-6% at 400 V' (Harrison and Wallace)

[71] 'Revenues [which are] are linked directly to what customers actually value (e.g. few interruptions, stable voltages, speedy response to queries or requests for work or connection, low accident rates etc) rather than the size of a DNOs asset base' (EGWG, 2001), have become an increasingly important aspect of the regulatory landscape, particularly since 2000. Rather than receiving return on a regulatory asset base; 'the DNOs [would] have an incentive to score well on the performance measures…to spend as little money in doing so. In essence, they would seek to deliver the system at lowest possible cost by whatever means possible' (EGWG, 2001). A move towards an incentive based model was introduced for 2000-2005 where 'the third price control review set company-specific quality standards for 2004/2005 on the

performance, which entitle consumers to compensation if the firms breach them' (Giannakis et al., 2005) but in the subsequent PCRs these aggregate standards were replaced by a company specific incentive regime – the growing prominence of QOS regulation is discussed in a later section.

Summary

The section above outlined the prevailing governance regime which has emerged from privatisation and market liberalisation, largely as a response to the perceived inefficiencies of state run companies. Using the modes of governing framework (Bulkeley et al., 2005), the underlying rationalities, programs, institutional relations, and regulatory instruments were outlined. These represent the changing nature of state strategies with regards to the ESI which can be summarised as a move away from an investment led/expansionary strategy towards efforts to utilise an existing asset base more efficiently, using pricing strategies as a key tool to achieve this. The table below summarises the governance regime for electricity distribution in the UK:

Table 5.1: Summary of the electricity distribution governance regime

Mode of governing	**Rationality**	**Institutional Relations**	**Policy/Regulatory Instruments**
'Sweat the assets'	Public ownership is inefficient due to over-investment and a lack of incentive for efficiency	Periodic price control reviews (5 years) with interdependencies between the regulator and private companies	RPI-x incentive regulation, benchmarking of company performance
'Open access'	Promote competition in generation and retail.	Contractual relationships between DNO, retailer and customer.	Access regulation: Licence obligations, network access codes and standards.

basis of their standards of performance (OFGEM, 1999a)'. Following the 2000 price control review, Ofgem began to link some revenues to performance measures; this was initially at 2% but has increased. The main reason that these outputs based incentives were introduced was concerns that with strong incentives for cost reduction, a trade-off would result between OPEX and QOS which would not be of benefit to customers

'Protect the customer'	Natural monopoly is an economic externality which can be priced and regulated	Price control reviews carried out by the regulator on behalf of the customer	Prices designed to 'mimic the market', efforts to promote customer switching. The introduction of QOS incentives

The next section outlines how various interventions and interactions, broadly associated with the transition to a low carbon electricity system, are shaping and being shaped by the governance regime described above. Following this, the outcomes section will discuss the emerging interplay between actors, institutions and technologies and the implication for the evolution of the sector.

5.3 Interventions and Interactions

The previous section outlined the structures and modes of governing which are associated with the structural legacy of privatisation and market liberalisation. In order to explore how these structures are affecting the uptake of different technologies and practices, this section describes the various interventions and interactions that have taken place in the electricity distribution sector which are characterising the emerging smart grid concept in the UK context. This section provides a process orientated analysis of the ongoing sets of interventions and interactions which are shaping the organisational field. Explored are the 'mechanisms of governance', and the 'practice and processes (or rationalities and technologies) of governing' that give a 'comprehension of how the identified institutions, structures and agencies of governance become articulated and interact' (Davies, 2005 p.36). The analysis is divided into four parts and where possible follows a chronological order.

5.3.1 Distributed Generation

This section explores how the issue of distributed generation (DG) - which is connected to the distribution networks - has begun to challenge aspects of the governance regime described above. As discussed in the previous section, prior to the introduction of retail competition in the late 1990s and the creation of the DNO licence following the Utilities Act in 2000, the RECs carried out the functions of both distribution and retail of electricity to end customers under a Public Electricity Supply (PES) licence. Under this regime the REC could recover the costs of new connections and in the relatively rare cases where a medium/small scale[72] generator would

[72] Typically under 50MW

request a connection to the distribution networks, these costs could be recovered through 'deep' connection charges[73] where the upfront costs of any reinforcement needs would have to be borne by the DG developer (Harrison et al., 2007, Cossent et al., 2009). This typically acted as a disincentive to DG development (Interview - 10), however it was not a major issue within the sector at the time because of the overarching emphasis was on the restructuring of the industry and the introduction of competitive markets (interview – 4). Although 'It was recognised, at the time that the Utilities Act 2000 received Royal Assent, that distributed generation would necessitate modification of the Electricity (Connection Charges) Regulations 1990. At that time, however, the priority was to ensure that the 1990 Regulations were amended to accord with the provisions of the new primary legislation – particularly in respect of the separation of electricity supply and distribution and the abolition of Public Electricity Suppliers (PESs)' (Ofgem, 2002). Also, because RECs had been incentivised to follow a relatively conservative business strategy with regards to the operation of the networks, their attention was focused on 'sweating the assets' (interview – 11). One interviewee from a distribution company who worked within the sector at the time describes how this affected their approach to dealing with DG connections during this early period of privatisation:

> *"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" (Interview - 20)*

However, following the 2000 act and the new 'statutory duty on DNOs to facilitate competition' (Ofgem, 2002), the connection of DG became a more substantial issue within the sector and led to calls for the sector to change what had been piecemeal approach to the connection of DG.

Although small and medium scale generation has been part of energy systems for many years (accounting for approximately 10% of new capacity amongst countries associated with the International Energy Agency countries in 2000 (IEA, 2002)), these have mainly been mature technologies typically used for industrial applications e.g. 'diesel and gas reciprocating engines and gas turbines' along with 'Industrial-sized engines and turbines' (IEA, 2002). In a small

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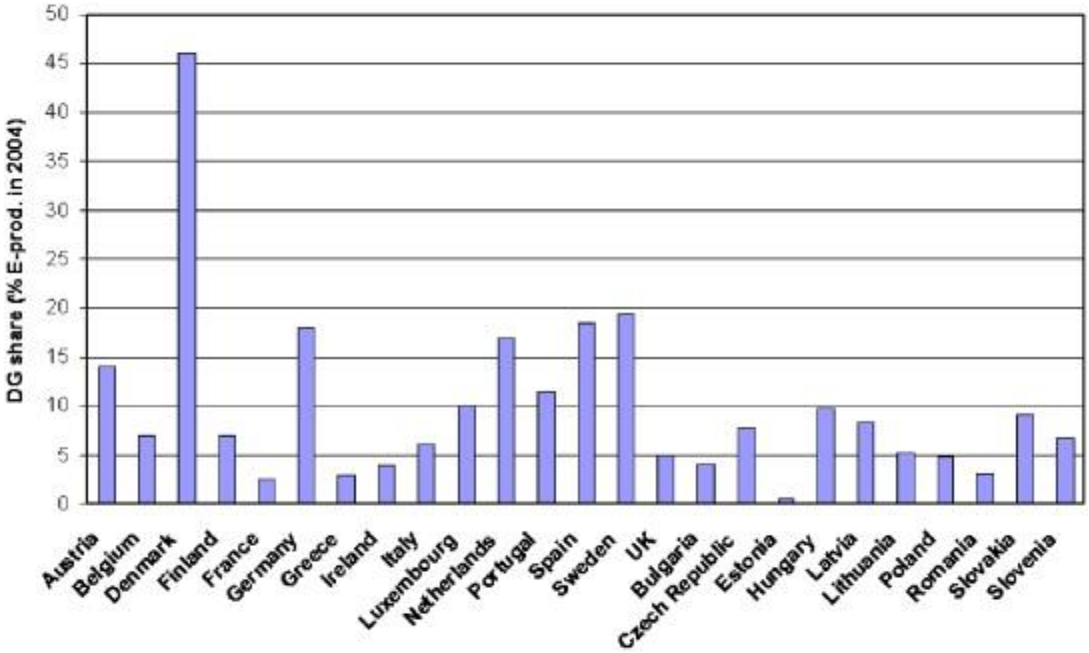
[73] The difference between deep and shallow connection charges are summarised as follows: 'Deep connection charges involve a one off, upfront payment. The charges include the costs of replacing equipment associated with protecting the network or with voltage control, up to the boundary of the distribution network. Where fault levels are increased above the rating of installed equipment, the cost of replacing that equipment would be included in the charge. By contrast, shallow connection charges involve paying for the assets specifically required for the connection, usually up to the first transforming point. The remaining re-inforcement costs, if any, are regarded as general load growth. They are recovered through use of system charges' (Ofgem, 2001)

number of EU countries DG has become a central plank of their energy policies as it is seen as a way of promoting energy efficiency, particularly in Nordic countries where CHP is common. However, as the figure below shows, this has not traditionally been a feature of the UK system where DG penetration has been relatively low:

Figure 5.5: DG across the EU



Source: (Cossent et al., 2009)

During the early part of the last decade there has been an increased focus on DG as a significant source of low carbon energy because renewable technologies can operate at all scales of the network and in some cases are optimally deployed closer to loads (or demands). This has called into question the traditional role of distribution networks (Strbac et al., 2006, Strbac et al., 2002, Djapic et al., 2007, Strbac et al., 2009, McDonald, 2008, Bayod-Rújula, 2009) which were designed in the context of large scale centralised plants with a predictable output. The momentum behind DG as a potential low carbon technology was reinforced by a number of influential reports during the 2000s, for example the Royal Commission on Environmental Pollution (RCEP) stated in an influential report on climate change that ‘generating electricity at or near the point of use reduces energy losses within the network; electricity is transmitted over shorter distances and undergoes fewer changes in voltage’(RCEP, 2000). During this period, DG also became part of a wider public discourse where it was seen as a more cost effective solution which could achieve social as well as environmental benefits. The following quote from the then major of London, Ken Livingstone, illustrates the growing political support behind unconventional energy solutions such as DG:

> *"Decentralised energy allows the financial costs and energy losses associated with the long-distance national transmission system to be reduced and savings passed on to consumers. Bringing energy production closer to people's lives helps in our efforts to promote energy efficiency. Security of supply can be improved, with power blackouts reduced. The UK could take the opportunity to develop expertise and technologies, leading the developed world, and facilitating the developing world's path to a sustainable energy future." (Greenpeace, 2005)*

Reflecting this growing momentum behind DG, in a 2001 speech Prime Minister Tony Blair optimistically announced that 'Electricity suppliers will be obliged to generate 10% of their energy from renewable sources by 2010. And we have set a target of at least doubling combined heat and power, also by 2010' (Blair, 2001).

For the distribution sector, this of course posed a number of difficulties because the underlying asset base was 'designed and really optimised over the last 50-60 years for one way flow of power and are not really designed to have significant generation input to them' (Interview - 19). The RCEP report highlighted a number of technical issues associated with integrating DG into the system effectively in order to capitalise on the potential system benefits:

> *"…embedded generation adds to the technical difficulties of ensuring security of supply and maintaining the stability of the network, including maintaining an appropriate element of reactive power among end users… The relatively small size of renewable energy plants generating electricity and local CHP plants does not fit easily with an electricity distribution and transmission network based on massive generators and highly centralised control. The national grid and the regional distribution systems need to become more favourable to small and very small environmentally friendly generators which sometimes need to import electricity" (RCEP, 2000)*

A number of non-technical barriers relating to commercial and regulatory issues were also highlighted in the report:

> *Regulatory policies will need to promote, and must not inhibit, this development (…) [Where] (…) Transmission and distribution companies remain as monopolies and have their prices controlled by the regulator. In the absence of any special provision by the regulator to cover the additional costs of such activity, they have no incentive to operate in a way that would be beneficial or encouraging to small embedded and/or intermittent generating plants nor to decentralise the control of their networks (RCEP, 2000)*

Within the context of a liberalised regime however, the DNOs were obliged to maintain '*open access*' to their networks following the deregulation of electricity generation and retail. In particular the charging regime for DG, where developers pay upfront the costs of reinforcement, became problematized as there was a perception that it acted as a barrier to DG investment by placing an undue burden on DG developers (Harrison et al., 2007). There was also a concern that 'subsequent generation connection might 'free-ride' in the use of expensive network assets paid for by an earlier generation connection (the 'initial contributor') to the same part of the network' (Ofgem, 2002).

Issues also arose due to the short time horizons engendered by the five year price control period (Interview – 14, 17, 19, 22) meaning that if capital investments had to be made in order to accommodate DG the companies would tend to invest in short term conventional solutions such as investing in new lines or 'invest in more copper' (Interview - 20). This piecemeal approach would allow a company to quickly expand its asset base and costs in advance of the following price control period, rather than improving the capacity management of the existing asset base by managing more complex flows in an innovative way. This became problematic because a fundamental motivation behind the design of the RPI-x regulatory regime was to act as a disincentive for companies to expand their asset base ('sweat the assets'); but if companies were forced to reinforce large parts of their networks to connect large numbers of DG this would undermine this (interview - 3).

In response to these developments, the Department for Trade and Industry (DTI)[74] set up the Embedded Generation Working Group (EGWG[75]) which in 2001 produced a report exploring the barriers to the efficient integration of DG into UK distribution systems (EGWG, 2001). The report argued that in the context of government targets for CHP and renewables and the licensing terms of the Utilities Act, 2000, there is an obligation on DNOs to better facilitate the connection of DG to their networks, however '...current arrangements are not conducive to the development of embedded generation' (EGWG, 2001: p.1). The report outlined three 'technical and practical limitations to expanding levels of embedded generation'; 1) capacity constraints in rural areas, 2) 'fault restrictions in urban areas', and 3) 'Design standards which prevent the variable nature of loads, generation and network capability being fully recognised'. It also highlighted issues relating to charging and transparency, i.e. that embedded generators were charged the 'full reinforcement costs which result from their connection', and that DNOs have weak incentives to connect DG as they have no clear revenue stream from it. Also pointed out

[74] In the absence of a dedicated dept. for energy, the DTI were in charge of energy production and the Department for Food and Rural Affairs (DEFRA) controlled demand side policies until the formation of the Department for Energy and Climate Change (DECC) in 2008

[75] Which subsequently became part of the Energy Networks strategy Group - ENSG

was a lack of transparency and information on locations i.e. ‘potential generators have difficulty in determining charges and the best (or worst) places to connect…’ (ibid: p.5).

The report issued a number of recommendations, key amongst these being a review of regulatory incentives where ‘Ofgem should review the structure of the regulatory incentives on DNOs in the light of the new statutory duty on DNOs to facilitate competition’ (*ibid*: p.6). A number of specific proposals for regulatory reform were made; to ‘allow the contribution of embedded generation to network performance to be fully taken into account’[76] (*ibid*: p.45) and to ‘establish more transparent and consistent arrangements for the provision of information by DNOs to developers’ (*ibid*: p.45) e.g. in which parts of the networks is it most economic to develop new connection nodes. In terms of creating a sustainable revenue stream, the report argued that the ‘deep’ connection charges imposed on DG developers was a barrier, particularly to early investors because ‘there is no mechanism for sharing the costs of the reinforcement with subsequent connecters’ (*ibid*: p.5).

Therefore, DG became a problem as it did not fit or align readily with the prevailing modes of governing – this is summarised in the table below:

Table 5.2: DG connection and modes of governing

Mode of Governing	**Impact of DG**
‘Sweat the assets’	Conventional approaches to DG connection increases reinforcement costs thus adding to the capital expenditure of companies and their RAB
‘Open access’	There is a lack of information regarding the best connection nodes and no revenue generating model. A free rider problem where the first DG developer pays costs of reinforcement
‘Protect the customer’	DG potentially reduces quality of service standards and clashes with existing codes e.g. UK Electricity Safety, Quality and Continuity Regulations specifications on voltage levels. There is no way of valuing the potential input DG can provide a flexible way of managing the networks[77].

[76] The potential flexibility of DG can be used by network operators to manage voltage and fault levels on their networks.
[77] As part of their requirements to reliably deliver power to customers, the DNOs are obliged to ‘to design networks in accordance with Engineering Recommendation P2/5. Reliance on embedded generation rather than on network reinforcement could breach P2/5. The possible value of embedded generation (e.g. in terms of reduced losses) is not reflected’ (Ofgem, 2001).

A number of the interviews pointed to a second dimension of the DG issue; the organisational routines of the network companies themselves (Interview – 1, 3, 4, 6, 9, 10, 17, 18, 24). Conventional network solutions such as investing in copper not only came about due to prevailing incentive structures, but also because of the cognitive behavioural routines within network companies. One interviewee who started his career during the nationalised period argues that this can be traced back to the days of the CEGB:

> *" ….the systems and people are still in place, not a lot of the people to be fair now but I used to work for a company that was part of CEGB (…) so I understand what was going on in there, I spent a lot of years in that kind of environment. 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 and it was all about mak[ing] sure suppliers weren't lost, price was (…) not really a priority (…) Thatcher really went for the CEGB to break it up, it was just costing too much, it was a huge massive civil service basically (…) It has a lot of really good things about it, 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 (…) it's like chewing through different bits of insulation in a wire and we're gradually getting through to the core, we can't go any further, it needs investment now. All of that good investment was built up over 40 years is being eroded now (…) There's a lot of corporate memory there about conservatism, a lot of that is still there so things are very conservative in how it [is] approached especially around the regulatory side" (Interview - 10)*

This conservative approach to planning and operating the networks has been reinforced by RPI-x regulation where the companies operating the networks had been incentivised to develop a low risk approach in the area of CAPEX efficiency (Interview - 13).

The Regulatory response: 4th Distribution Price Control Review

As the EGWG report suggested, this 'passive role for distribution networks has been formalised in design codes, charging structures, price controls and other regulatory incentives' (EGWG, 2001). DUoS became a particular focus; although these were already capped under the RPI-x price controls as part of the companies' 'allowed revenue' under the terms of the licence, this applied only to demand customers and not DG. Although it is possible for Ofgem to propose licence modifications, this cannot however be imposed as it is subject to agreement by the companies and can be referred to the Competition Commissioner if necessary (Ofgem, 2001a). As a response to the various issues raised, the regulator initiated a consultation document (Ofgem, 2001a) in advance of the 2005 price control review. In the consultation it was recommended that 'DNOs should be encouraged to move to a shallower basis of connection charges for embedded generators, recovering costs up-front only in relation to dedicated connection assets'; and where a conflict arises, a right of appeal to Ofgem for DG developers would be put in place. DNOs would be required to publish their connection and use of system charges which would eventually evolve into a simplified and standardised connection regime, thus reducing transaction costs. Following an industry-wide consultation process, the final proposals in price control review itself (DPCR 4) contained a number of relevant changes to the regulatory regime:

DG Incentive

As discussed above, 'there have been concerns that deep-connection charging models which oblige developers to fund, upfront, the full capital costs of connection, [were] acting as a disincentive to DG' (Harrison et al., 2007). In response to government targets for CHP and renewables (Ofgem, 2004), the 2005 price control review proposed shallower charges which sought to 'reflect the costs and benefits associated with DG' (Harrison et al., 2007). Following this, a DG developer 'had to pay a much smaller [amount] for the same investment upfront cost related to a well defined smaller bit of any reinforcement (…) But then they had to pay a use of system charge which is an ongoing thing, you pay every year, which is meant to cover some of the costs of reinforcement' (Interviewee - 19). This reduced the upfront capital costs, spreading it out over a number of years through use of system charges. The costs to the DNO of connection are 'are given a partial pass-through treatment' and 'the DNOs are given a further supplementary £/kW revenue driver (or incentive rate) to incentivise the connection of distributed generation to the network' (Ofgem, 2004). The details of the proposals were as follows (Harrison et al., 2007):

- 80% pass through rate - 'A 15-year annuity charge based on 80% of the cost of reinforcement works required to connect the DG, if any.'
- 'An annual capacity charge of £1.50/kW of DG capacity installed in lieu of remaining reinforcement cost.'
- 'An annual operations and maintenance (O&M) charge of £1/kW of DG capacity to recover appropriate costs.'

Thus, the DG Incentive (DGI) was designed to alter the flows of revenue within the sector and remove barriers to the connection of small scale generators to the distribution networks. One interviewee from a DNO notes that the rationale behind the scheme was '…to try and get the DNOs themselves play in that game. It gives them an opportunity to gain additional revenues…That's what the incentive is trying to do, and to a certain extent, reasonably risk free' (Interview - 13). This was to be achieved whilst also seeking to align developments within the sector with broader energy policy goals; the interviewee suggests that 'it's being driven by the government agenda to try and make sure there is (…) more generation dispersed across our networks' (Interview - 13).

Innovation Incentives

As was discussed the previous section, the success of the RPI-x regulatory regime was based on achieving efficiencies through OPEX savings and disincentivising capital investments. However, as part of DPCR4, Ofgem allowed the companies to on average increase their CAPEX by 48% on the previous price control period (Ofgem, 2004), this reflected both a general trend in the asset replacement cycle i.e. the ageing asset base, and an expectation that DG penetration levels would increase (Interview – 9). The EGWG noted that 'If extended from its initial very low level, a change to performance-based regulation could increase the extent to which DNOs use embedded generation as a means of catering for increased demand as an alternative to the replacement of time expired assets or network reinforcement…' (EGWG, 2001). The inherent 'bias toward achieving OPEX over CAPEX efficiencies' (EGWG, 2001) within the RPI-x regime and the 'ad-hoc' approach to DG that this engendered therefore provided a rationale to explicitly incentivise R&D and innovation – CAPEX efficiency - for the first time. The EGWG report argued; 'once it has been established that reinforcement of supplies is needed, investments in network assets have been favoured by DNOs since they are rewarded by an increased revenue through the price control mechanism...' (EGWG, 2001).

The innovation incentives that Ofgem introduced in 2005 was 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. The following points summarize the main rationale behind the scheme (Ofgem, 2003a):

- 'To encourage DNOs to integrate appropriate technical development plans as part of their wider business innovation'.
- 'To deploy new technologies, and encourage their wider application, where this enables distributed generation to be integrated more effectively and efficiently, to help meet the government's targets for renewables and CHP'.
- 'To signal to potential generators and other interested parties a DNO's development intentions or network capabilities at a particular location'

So, innovation became a strategy to deal with increasing levels of DG connection for the regulator, however, this was not achieved without some degree of contestation. Within the industry it was generally accepted that innovation levels in liberalised energy systems had dropped since nationalisation (Jamasb and Pollitt, 2008, Jamasb and Pollitt, 2011). The distribution sector was no exception; as one interviewee who has been working in a DNO throughout these periods notes; ‘Ofgem provided no incentive for R&D and in fact any money you spent on R&D was just a cost you were carrying that you weren’t being rewarded for’ (Interview – 20).

The introduction of the scheme came in the wake of the 2004 Energy Act which gave Ofgem a secondary duty to consider sustainable development in its decision making (Owen, 2006). However, moving away from the application of pure RPI-x and introducing specific incentives for low carbon innovation was not uncontested within Ofgem. Referring to a leading proponent of the innovation incentives within Ofgem itself, one interviewee describes the difficulties involved in changing the culture within the organisation:

> *“(…) he had a real battle trying to get Ofgem to agree to that because they thought it was fundamentally wrong that you give DNOs an artificial incentive like that.” (Interview – 20)*

A later section will explore in more detail the outcomes of this regulatory initiative and how the issue of innovation in distribution networks has become an increasingly important part of the regulatory agenda in the UK.

Summary

This sub-section has shown how during the early part of the last decade changes in the energy policy landscape and associated politically driven efforts to promote the diffusion of DG has resulted in changing energy flows within the networks which have necessitated changes to the revenue flows within the electricity distribution sector. As a result, a process of regime adaptation (Smith et al., 2005) followed where efforts were made to integrate DG both technically and institutionally, and to break the lock-in to the passive operation of networks and piecemeal approaches to generator connections. A number of barriers were encountered such as incentive structures in the regulatory regime and firm level organisational routines. In 2005, DPCR4 sought to address these by incorporating DG into the revenue flows within the sector and to incentivise network operators to innovate and reorientate their organisational routines and approaches to CAPEX efficiency.

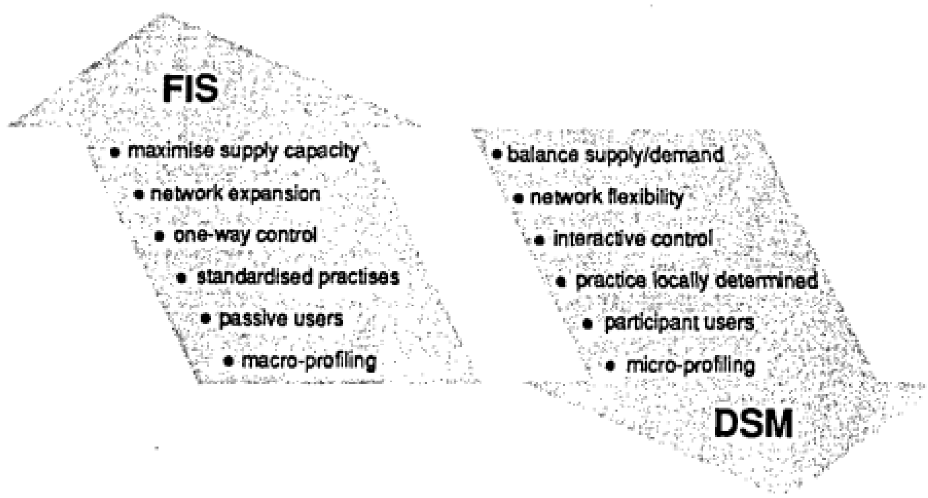
5.3.2 The Demand side

Since the introduction of retail competition following the Electricity Act in 1989 and the Utilities Act in 2000, a greater emphasis has been placed on understanding energy use patterns (Guy and Marvin, 1996b, Guy et al., 1999, Guy and Marvin, 1996c). Under public ownership electricity systems were based on a 'predict and provide' paradigm (Guy and Marvin, 1996b) which 'doesn't really recognise customers as anything other really than demand takers and taking [whatever] they want whenever they [want it]' (Interview – 6). This supply side dominated approach was supported by a sector structure which was configured in order to achieve economies of scale (high load factors) and eventually led to the interconnection of dispersed local systems in order to aggregate consumption (Fox-Penner, 2010). This led to 'a near-total disconnect between the industry's instantaneous balancing function and the utility's pricing and billing activities' (Fox-Penner, 2010: p.30). This frame within which 'customer' and particularly domestic customers have been viewed has been a cornerstone of the growth of electricity systems and their governance structures throughout the 20th century. Network planning and operation has proceeded on this basis resulting in little real time management of distribution systems (particularly at the low voltage level), and large margins being built in at the network planning stage (Interview - 10). However, since market liberalisation, this framing of the customer as passive has changed and there have been efforts to engage with customers, understand their practices, and segment and understand the retail market in new ways with the role of the regulator under the Utilities Act, 2000; to '…protect the interests of consumers… wherever appropriate by promoting effective competition'.

Opening up the black-box of the demand side

Since the introduction of privatization in the 1989 Electricity Act and the eventual introduction of retail competition in the UK domestic market following the 2000 Utilities act, efforts have been made to engage with customers and understand how they use electricity at different times (interviewee – 4). This alternative to the 'predict and provide' paradigm has been termed 'demand-side management' which moves away from the supply side/economies of scale approach towards a more differentiated treatment of different types of customers using techniques such as market segmentation and micro-profiling. The difference between these paradigms of managing an electricity system is illustrated in the following diagram:

Figure 5.6: Approaches to Infrastructure Management



Source: (Guy and Marvin, 1996c)[78]

A report by the consultants Earnst and Young outlines that; 'segmentation draws on leading practice in consumer management, where we would expect the UK energy consumers to fall into segments with different energy services needs. These segments can then be targeted with specific education and propositions' (E&Y, 2009). They outline four 'types' of energy customer:

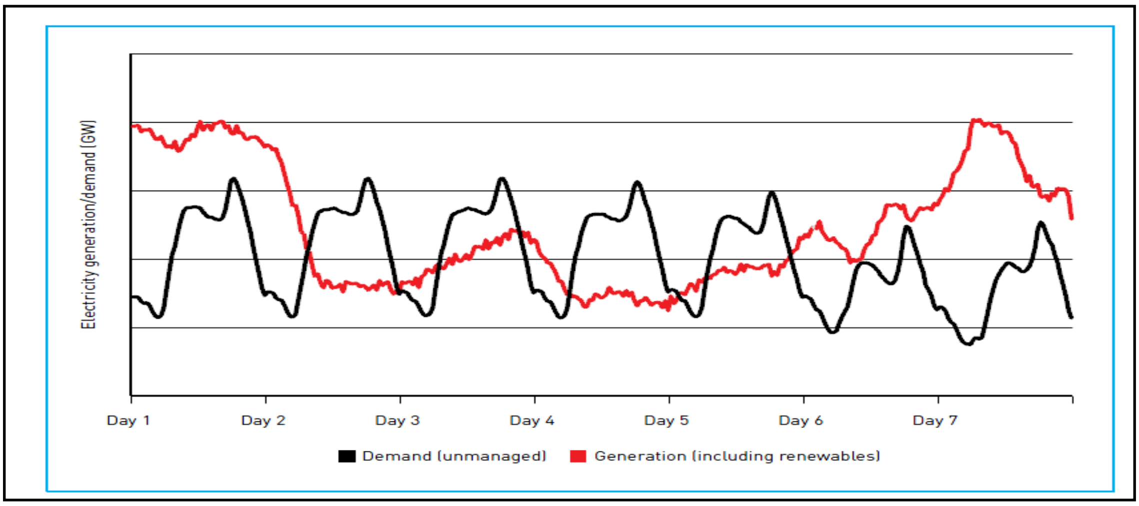
- Passive: Customers who are 'happy with their energy consumption, cost and service' and have 'no explicit need for reduced energy consumption, cost or better service'.
- Price conscious: These customers make decisions on the basis of price rather than any environmental concerns i.e. they are 'unhappy with the price they pay'.
- Consumption conscious: A particular segment which 'has started to take ownership of their own consumption as a factor in their energy bill, either on cost or environmental grounds'.
- Energy aware: Customers who are 'prepared to invest time and energy in energy services and related products such as automated analysis of consumption'.

In recent years this trend towards a more synergistic relationship between end-use patterns and system planning and operation has been reinforced due to the expectation that intermittent renewables such as wind power will become much more prominent in the system. Using the potential flexibility of the demand side is increasingly being seen as a way of promoting the

[78] FIS refers to 'Facilitating Infrastructure Supply' i.e. 'Predict and Provide'

transition to a low carbon electricity system with much greater levels of DG and renewables e.g. demand side management and load shifting to balance supply and demand (Interview – 10, 12, 11, 16, 21). To illustrate this, the figure below shows a scenario where changes in demand patterns become out of synch with generation, thus posing a risk to system security.

Figure 5.7: An illustrative scenario where there is a mismatch between generation and demand

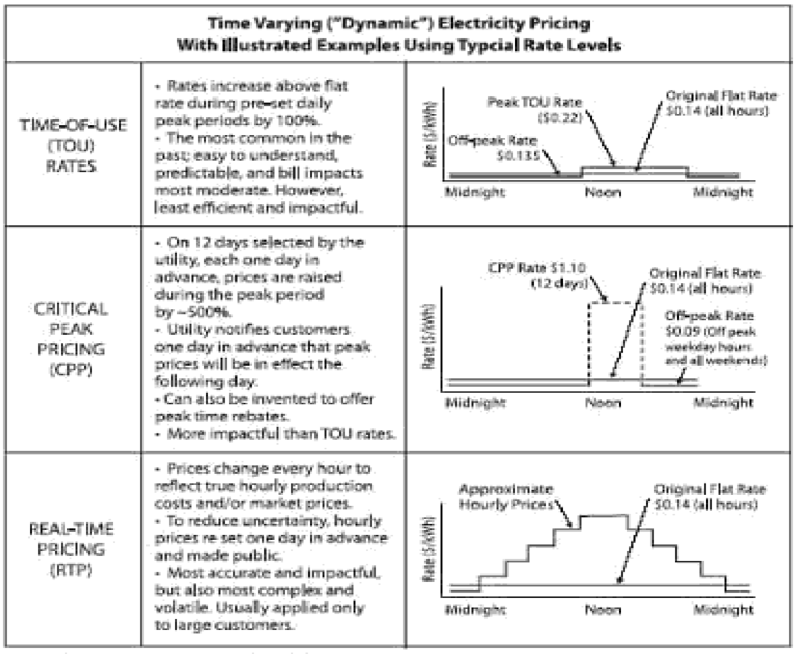


Source: (DECC, 2009e)

Concerns over the operation of a system with a high penetration of intermittent generation have led to calls for customer activity to become part of the day-to-day operation of the system by utilising information regarding customer behaviour, price elasticities and incentivising customers to change their demand, particularly at peak periods. There is an expectation within the sector that this will 'create a system that works efficiently' (Interview – 22) with large amounts of intermittent generation connected to the system. A number of studies have argued that by incentivising customers to become more flexible in their usage patterns through more dynamic pricing there can be a reduction in the overall network reinforcement costs (Strbac et al., 2010) and peaking plant requirements (Faruqui et al., 2009). Demand response (DR), which is a broad concept 'that refers to all policies and programs that get customers to shift their use around' (Fox-Penner, 2010: p.40), as a technique to achieve system economies, has had limited application in the UK, typically being confined to large industrial users. One of the reasons for this has been a lack of metering technology which can facilitate two-way communication between the customer and their supplier – commonly referred to as smart meters[79].

As expectations surrounding the large scale diffusion of renewables grow, smart metering is being seen as a way of utilising the potential flexibility of the increasingly price conscious and energy aware customers in order to achieve system economies (interviews – 2, 4). The figure below shows the different methods of achieving DR through dynamic pricing which have been utilised. These techniques range from short term real-time pricing i.e 'setting the prices that retail customers pay equal to these hourly wholesale process…' (Fox-Penner, 2010: p.40), to longer term contractual arrangements such as time of use rates where average prices are taken over a longer period.

Figure 5.8: Dynamic pricing techniques



Source: (Fox-Penner, 2010)

These changing conceptualisations of the customer and the perception that system economies can be achieved through DR measures have influenced ongoing debates in the UK ESI surrounding the implementation of smart metering and the respective roles of DNOs, retail companies and customers.

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[79] A smart meter is defined as electricity and gas meters that 'collect meter values on a half hourly basis and transmit the data without the need for the customer to read the meter manually' (Ofgem, 2010a)

Smart Meters and Distribution Networks

In the light of debates surrounding the transition to a low carbon electricity system, the issue of smart metering has taken on added significance. The move towards an all-electric future, which involves the electrification of heat and transport (described in the previous chapter), has also added weight to the momentum behind smart metering and a UK roll out strategy. Plug-in hybrid electric vehicles (PHEVs) in particular are seen as a potential source of energy storage allowing customers to become more flexible and responsive to more dynamic pricing tariffs (Interviews – 2, 6, 20). However, as one interviewee describes, there are concerns that this could lead to constraints by increasing the demand for capacity on low voltage (LV) distribution cables:

> *"…if you look at the cable that runs down your street and that supplies your house or whatever, then you'll find no measurement and no control (…) the DNO that owns it doesn't know how much current is passing through it at any one time and doesn't know what voltage is on it" (Interview - 14)*

Similarly, renewable subsidies such as the feed-in tariff provide incentives for investment in small scale low carbon generation technologies. However this may have significant implications for distribution networks as these inputs to the grid could create two-way power flows and potentially create 'bottlenecks' within the networks; particularly due to the fact that control systems on low voltage distribution networks remain basic (Interview - 14). As another interviewee from a DNO notes:

> *"Deployment of generation at domestic level we can cope with, [but] suddenly if everybody starts to do it, it gives you problems. Having more real time information of what is happening on our system in terms of power flows [and] in terms of voltages (…) Tak[ing] action rather than guessing what the impact might be" (Interview - 15)*

As a result of these issues, advanced metering technology is increasingly being viewed as a way of achieving DR and economies of system; thus reducing the need for expensive reinforcement of LV cables and reducing the need for expensive peaking plant (Strbac, 2008, Strbac et al., 2010).

Ofgem's approach to the issue of smart metering has been that it could fulfil a dual role of facilitating pro-environmental behaviours such as micro-generation and reducing consumption, whilst also furthering competition in the retail market by facilitating customer switching (Ofgem, 2003b). Prior to the unbundling of distribution and retail, the RECs held a monopoly on metering services within their respective areas however, following unbundling of retail and distribution, the metering function began to be opened up to competition where Ofgem sought to ‘separate metering from monopoly transportation and distribution businesses’ and discontinue metering as ‘a regulated activity’ (Ofgem, 2001b). In its 2001 metering strategy, Ofgem sought to promote competition in the delivery of metering technology, arguing that ‘the current degree of competition is limited. Energy consumers would be better served by more effective competition, which would reduce costs and promote innovation’ (Ofgem, 2001b) and ‘protect and advance the interests of customers’ (Ofgem, 2003b) by promoting competition and facilitating switching between suppliers. However, following the announcement of a national roll out to be coordinated by DECC, there has been a move away from the competitive de-regulated approach that Ofgem had originally envisaged.

The Smart Metering Roll Out

In 2008 the UK government announced a roll-out of domestic smart meters across UK domestic households to be carried out before 2020. The announcement to roll out smart meters came after it was added as an amendment to the 2008 Energy Act in the house of Lords (by Lord Hunt). During the debate (Hansard, 2008) Lord Hunt argued that; ‘Consumers would be given better information on how to manage their energy use, they would be provided with accurate bills and gain potentially easier access to a wider range of tariffs. It is a bit of a no-brainer when one thinks about it. For suppliers, too, the benefits include reduced costs through remote meter reading, better customer service through more accurate billing, and the potential to switch consumers between tariffs’. This was given a two year period for consideration of roll out strategies and given a ten year implementation program which was subsequently shortened. A 2009 consultation on the implementation strategy for the roll out (DECC, 2009b) by DECC made proposals regarding electricity and gas meters ‘in domestic households’ and ‘at small and medium non-domestic (business and public sector) sites’. In this context the role of smart meters is to ‘provide accurate real time information on energy consumption’ but also to ‘both change our energy habits and provide an essential stepping stone to smart grids in the future’.

A follow-up document outlined a wide range of objectives and motivations for the roll out; proposing that ‘the new consumption data smart meters will make available will help network operators to make better informed investment decisions’ … ‘help the system deal with the intermittent character of significant new renewable energy generation’ … ‘Smart meters , will allow exported energy to be measured, and therefore support the development of microgeneration in the home’, and ‘Smart meters combined with time of use tariffs will also enable the grid to support increasing numbers of electric and plug-in hybrid vehicles’ (DECC, 2009a: p.13/14). The added significance that has been attributed to smart meters – that they will enable smart grids – and the DECC led approach signalled a change in approach from the market-led, competitive model which Ofgem had been advocating since the early 2000s. This has led to some uncertainty and interpretive flexibility surrounding the issue. Since the announcement of a national roll-out, there has been considerable debate within the industry as to the manner in which it should be coordinated and how the demand side information flows can be utilised in order to improve system economies (interview – 4, 15, 23). This is largely due to the unbundled structure of the UK ESI which means that the retail and distribution functions are carried out in separate business units, therefore creating uncertainty as to how the new flows of information can be utilised and optimised by different parties along the value chain.

In their subsequent 2009 consultation (DECC, 2009b), DECC made proposals regarding the delivery model for the national roll out for electricity and gas smart metering and the degree of meter functionality which would be required. The consultation favoured a central communications delivery model where ‘gas and electricity supply companies will have responsibility for the provision of smart meters’ but ‘a single provider will be appointed centrally to provide communications services to and from meters’. This was favoured ahead of the competitive model previously proposed by Ofgem; where ‘suppliers are free to determine their own deployment strategy, choose the metering services they require, and have the ability to contract the management of such services’ (DECC, 2009a). However, the proposals did not go so far as to favour a fully regulated roll-out with ‘regional franchises to manage meter asset selection, ownership, deployment and maintenance, via a time-based competitive franchise or licence awarded under competition’. It was argued that a centralised communications strategy ‘should provide a platform to support innovation and competition between the supply companies, leading to more choice for customers in metering and other products and services’ and ‘It also retains many of the advantages of the Competitive model such as supplier flexibility over the customer proposition, deployment strategy and differentiated service offerings. Competitive pressures for metering services are retained in this model’.

Amongst distribution companies however there was some concern regarding the non-regulated supplier led model, with one interviewee noting:

> *“Nobody else has even thought about suppliers doing it (…) in other countries it’s the network operator. In most cases they are not really that separated anyway at the residential level, so there’s no real issue which is why it has been a bit of an uphill battle for us as DNOs to get what we want from the smart meter because the supplier had their views on what they wanted from a smart meter. As I say I think it’s beginning to dawn on them that they need the same things that we are pressing for aswell. (…) There will be still some people out there who still want an automatic meter reading function and really aren’t thinking about anything cleverer than that, whereas*

> *we are. But that's absolutely why it is so difficult in this country"* (Interview - 20)

This raised issues regarding how smart meters could enable smart distribution networks i.e. how information flows could be coordinated and optimised across the value chain. This is because 'there is a regulatory boundary at the metering point and there are business separation issues (...) [distribution operators] are forbidden through (…) statutory business separation to talk to suppliers or generators' (interview - 16). Therefore, due to the legal unbundling of distribution, retail and generation businesses; 'there is no opportunity for the networks business to favour the affiliate generator or the affiliate supplier' (interview - 16) thus increasing transaction costs and creating a barrier to the coordination of information flows in order to achieve system economies. In an article for an industry magazine, the managing director of Central Networks, Bob Crackett, stated the following:

> *"It means the communications and data will be engineered to suit the supplier's requirement (...) Engineering communications to deliver automated meter readings is not sufficient to run a smart grid. If you need to monitor loads in a particular street, you need all the data from the meters in that street immediately. I worry that we may end up with something that is not integrated with smart grids (...) There are 32 suppliers in the Central Networks area, so 32 firms might pull up in any one street over the next ten years to fit a smart meter" (Utilityweek, 2010)*

Carckett argued for a regulated DNO led roll out with a set rate-of-return; however in their proposals DECC argued that 're-regulation of metering would be particularly disruptive of the existing market resulting in delay to initial deployment' (DECC, 2009a)

A second area of contestation and interpretive flexibility surrounding the proposals centred on the degree of functionality of the smart meters i.e. 'common minimum technical specifications' and how they would interact with the upstream asset base. The consultation document (DECC, 2009a) made the following proposals:

- That 'smart meters must be sufficiently standardised to be interoperable, so that any energy supply company can work with any smart meter'
- That there would be capability to carry out remote reading and provision of information to customers
- The meters would 'support for a range of time of use tariffs' and measure electricity exports from microgeneration

Once again, although the proposals noted that interoperability and standardisation must ensure that 'the requirements of the network operators are efficiently met' and that functionality would enable 'Load management capability to deliver demand side management'; there was a considerable degree of uncertainty as to how this might work in practice. As one interviewee noted, there is uncertainty whether the functionality of the meter would be used to improve the capacity management of the local distribution networks or as a measure to ensure the stability of the overall system at a national level.

> *"What do we change the demand for? Is it for the national power balance which affects the grid frequency, or is it because of an undesirable local imbalance between power generated and consumed which affects the local power flow and the local voltage profile in an adverse manner" (interview - 11)*

As an illustrative example, the following scenario laid out by an interviewee from an energy company illustrates potential inconsistencies and conflicts between the retailer and the DNO in this respect:

> *"... [a] retail company perhaps wants to avoid people using power between 7pm and 9pm because it's expensive for when they buy it, but from a grid point of view it might be six am [that's] a real problem because that's when generators start up (...) and it might want to pull back loads. So their idea of controlling your loads might be very different from the retail company who's the one who's talking to the end customer "(interview - 4)*

The interviewee went on to note that because DNOs currently have no direct interaction with customers, there is little clarity as to how price signals and DR could improve capacity management on distribution networks;

> *"As an end consumer I really only talk to my suppliers, bills come and that's all I really need to know about electricity is my supply company. Whereas what we're talking about now is that the local distribution company will be needing to control loads in my house perhaps; whether I can switch my car on to recharge. So I don't know how that relationship will work whether it'll be via the supply company or whether [you've] got another relationship with a distribution company aswell" (interview – 4).*

Following DECCs December 2009 response to its initial consultation, a subsequent consultation outlined further details of the implementation program (DECC, 2010f) and issues surrounding meter functionality are under consideration of a government 'Smart Meter Design Group'[80] involving technical experts and industry stakeholders. These ongoing debates within the industry illustrate how processes of contestation and interpretive flexibility are part of the innovation process and highlight the difficulty of coordination within an unbundled context.

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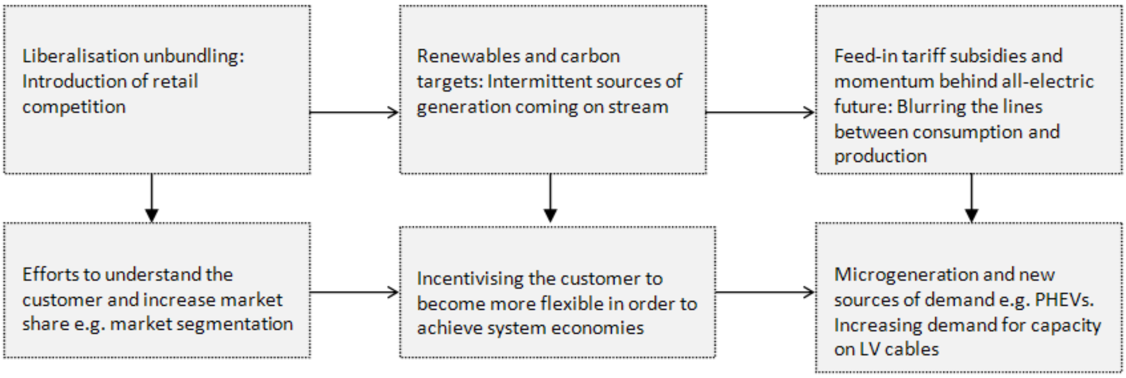
[80] http://www.ofgem.gov.uk/e-serve/sm/Stakeholder/SMDG/Pages/SMDG.aspx

Summary

Emerging from the liberalisation agenda, a more nuanced and complex view of the customer has emerged and following low carbon and sustainability debates, a reframing of the customer has taken place where they are seen as a more active component of the system and a resource which can be utilised in order to achieve system economies - the table below summarises this. This evolving role and conceptualisation of the demand side has however begun to challenge previously well defined sector boundaries and interactions within the organisational field as there is uncertainty regarding how resultant flows of information (data), revenues (tariff structures), and energy (PHEVs, microgeneration) can be optimised.

Figure 5.9: Different framings of the customer



It is clear that by intervening in order to coordinate the smart meter roll-out, DECC are seeking to use smart metering as a strategy to achieve longer-term sustainability and low carbon goals within the overall context of a liberalised/unbundled energy policy paradigm. Within the distribution sector this has however resulted in a degree of uncertainty regarding the coherence between the liberalisation and the smart grid agenda.

5.3.3 Changing the Regulatory Regime

The previous sections described how two issues which have been shaped by liberalisation and climate change agendas - DG and demand side developments - in different ways have challenged the governance regime. As a result, since the fourth price control review in 2005, a number of changes have been made to the regulatory framework for electricity distribution networks.

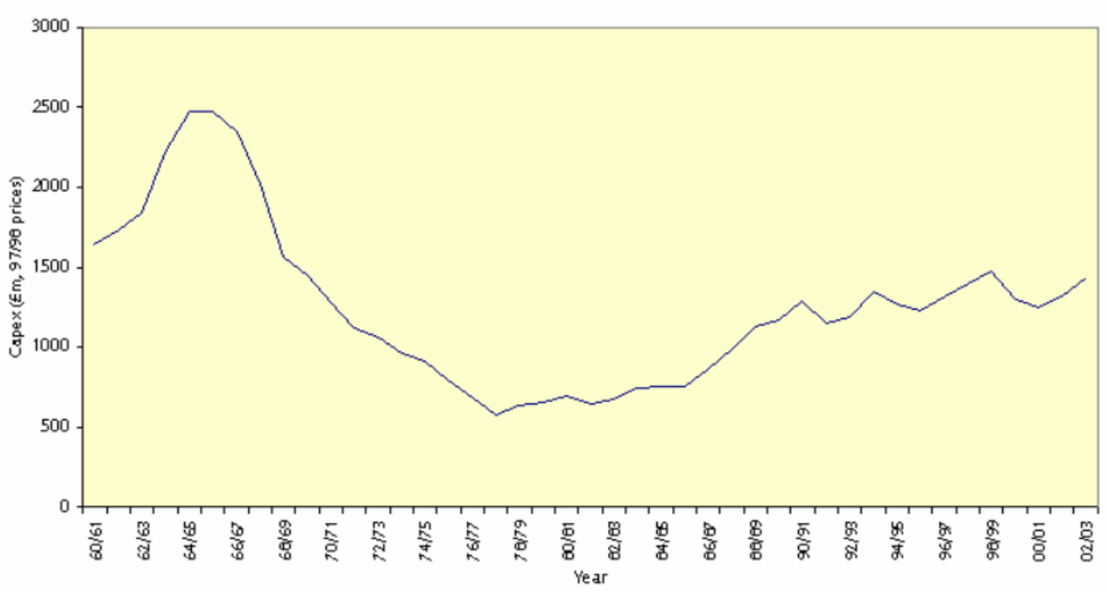
4th Distribution Price control Review

Following the 2003 Sustainable Energy Act and the Energy Bill in 2004, the role of the regulator has been amended to incorporate a sustainable development duty. The primary role of Ofgem was set out in the Utilities Act, 2000; 'to protect the interests of consumers… wherever appropriate by promoting effective competition' (Owen, 2006). This was amended such that Ofgem was obliged to 'contribute to the achievement of sustainable development' (Owen, 2006). In this context and the DG issues discussed above, DPCR4 (Ofgem, 2004) signalled a number of changes to the traditional RPI-x regulatory regime.

Regulating Investments

As discussed, RPI-x had been designed to place the emphasis of efficiency savings on OPEX rather than CAPEX i.e. to 'sweat the assets' and squeeze the margins which were built in during nationalisation. However, as the figure below shows, much of this asset base was installed during the 1960s and is thus approaching the end of its life; necessitating higher levels of allowed CAPEX each price control review:

Figure 5.10: Capital investment in the UK electricity distribution network



Source: (Ofgem, 2006)

As a result of this, and expectations surrounding the likely costs of DG connections (Shaw et al., 2010), DCPR4 began to consider how to regulate CAPEX to a degree that previous price control reviews had not. As part of DCPR4, Ofgem allowed for an average 48% increase in investment over the previous five years, totalling 5.7 billion (Ofgem, 2004), and for the first time since DPCR1, there was not a real price decrease[81] i.e. 'OPEX cuts were now outweighed by increasing CAPEX programmes' (Littlechild, 2009). The following quote illustrates the regulatory dilemma facing Ofgem:

> *"Current regulatory arrangements may provide DNOs with a skewed incentive to solve network performance or constraint problems through further investment in transformers and cables, rather than maintaining existing assets to prolong their life or seeking to reduce or manage load, even when the latter solution is cheaper. This is because, relative to the arrangements for network investment, the DNO can currently keep a much higher proportion of underspend against the regulatory operating cost allowance, and is not able to pass onto customers any of the overspend" (Ofgem, 2009b)*

Ofgem introduced a new incentive scheme where 'DNOs are rewarded by higher rate of returns if their actual investments are lower than the predicted levels' (Jamasb and Marantes, 2011) in their business plan submissions. This was achieved via a 'sliding scale mechanism' (Ofgem, 2004) where 'the higher the ratio selected by the company to PB power's [consultant] assessment, the weaker the incentive if the company actually delivered its investment below budget' (Jamasb and Pollitt, 2007). The rationale behind this was to incentivise companies to reveal accurate information regarding their costs and avoid gaming (Crouch, 2006). Although this provides an efficient way of regulating large scale investments and improving the rate of return, such piecemeal or modular approaches to network investment do not benefit from the of economies of scale that can be achieved through an integrated and systemic approach to investment programmes in the networks (Helm, 2004).

Quality of Service (QOS) Incentives

As a result of the strong drive for efficiency savings for DNOs under RPI-x, there have been concerns that this could result in a trade-off against the quality of service provision to customers[82] e.g. the number of interruptions[83], quality of communication with customers, storm

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[81] In DCPR4 the annual price change was set according to the RPI (x=0), whereas in the previous two it was RPI minus 3% (x=3) (Littlechild, 2009)

[82] "In an idealised competitive electricity market, customers could choose a network provider offering a level of service quality that reflected their willingness to pay for it. Assuming that the maximum amount that consumers would pay for quality equals the total quality-induced costs they incur, the socio-economic optimum occurs at a quality level where the sum of the total cost of quality provision by network operators and the total quality induced costs faced by consumers is minimised. However, in the absence of (incentive) regulation, natural monopolies may operate at sub-optimal quality and social cost levels. In order to prevent inefficient resource allocation, service quality standards and incentives need to be incorporated in the regulation of the utilities" (Giannakis et al., 2005)

compensation arrangements and other the standards of performance i.e. the network services which customers value. It is generally recognised that because CAPEX, OPEX and quality outputs are treated separately, this 'may provide firms with distorted incentives that lead them to adopt an inefficient output mix. Under the current regulatory regime, a firm receives greater benefits from saving OPEX than by an equal amount of CAPEX reduction… firms may seek to capitalise OPEX to obtain higher efficiency score and allowed revenue' (Giannakis et al., 2005).

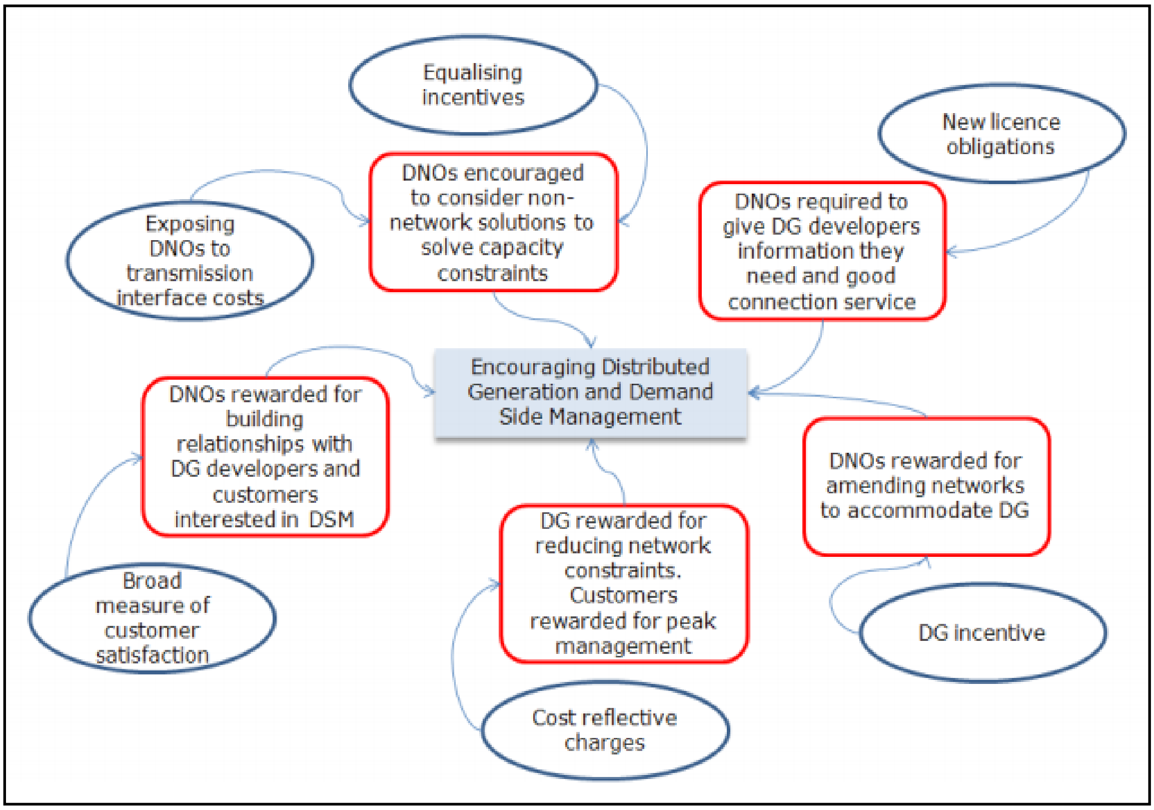
Until 2000, QOS was achieved through guaranteed standards of performance where customers received compensation if the standards were not met (Giannakis et al., 2005). DCPR4 explicitly included 'targets for significant improvements in performance' and 'stronger incentives to exceed those targets' e.g. 'incentives for DNOs to restore customers promptly and efficiently following severe weather events and streamline the arrangements for compensation for prolonged outages' (Ofgem, 2004). Following a customer survey which sought to uncover the willingness to pay for different network services, a proportion of DNO revenue (2%) was 'exposed' to QOS incentives. This could penalise DNOs for not meeting targets, reward those who do and 'reward frontier performance by guaranteeing less strict standards for the next control period' (Giannakis et al., 2005).

5th Distribution Price control Review

The key changes in DCPR5 related to the manner in which DNOs collect revenues and how these changes have been linked to efforts to promote DG and DSM. The following diagram illustrates some of the measures introduced and their impact on DG and demand side issues. Broadly, these measures relate to how DNOs can be incentivised to avoid conventional reinforcements:

[83] This consists of 'the number of customers interrupted per 100 customers (CI)' and 'number of customer minutes lost per customer (CML)' (OFGEM, 2004)

Figure 5.11: Measures in DCPR5 to encourage DG and DSM



Source: (Ofgem, 2009b)

Key measures within this diagram include obligations to remove the information asymmetries between DG developers and DNOs and equalising incentives for OPEX and CAPEX. Equalising incentives means ‘a common incentive rate for all network costs’ (Ofgem, 2010c); ‘This means that a fixed proportion of costs across all these activities will be funded through a return on the company's Regulatory Asset Value (RAV) and depreciation, and the same sharing factor will apply between customers and the DNO for any over or underspend against allowances’ (Ofgem, 2009b) i.e. the regulator will allocate rents associated with network operating costs and investments in the same way in an effort to take a more holistic approach to the costs of OPEX and CAPEX.

Additional to these measures, DCPR5 continued the broader trends in the regulatory regime described above - the regulation of CAPEX[84] and outputs incentives - but also signalled further changes to the ways in which DNOs revenue is regulated. Traditionally there had been a direct correlation between the revenues of distribution companies and the volume of electricity

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[84] For example there was a 32% increase on allowed revenue for reinforcements across the networks compared to DCPR4 levels (OFGEM, 2009)

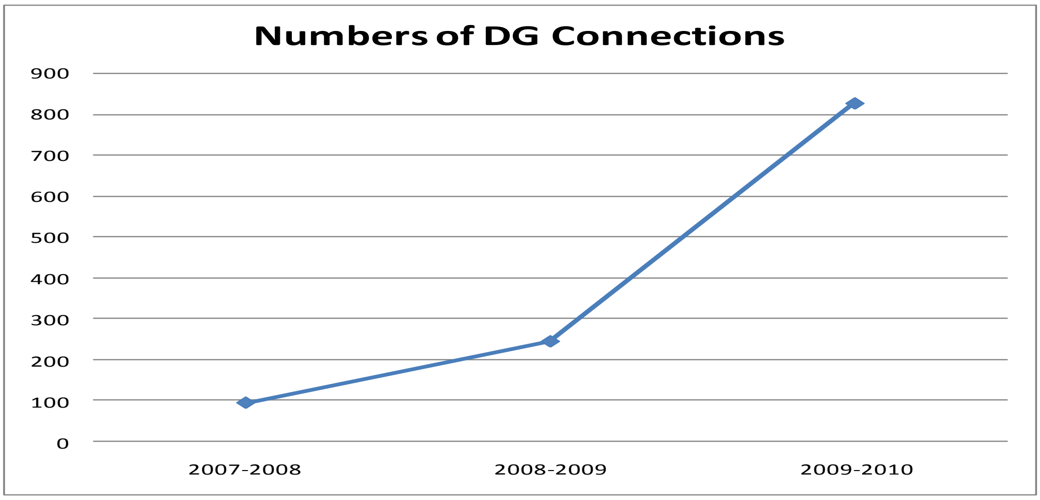
flowing through their networks where ‘the overall income of the DNO scales with the amount of energy distributed from the network’(Shaw et al., 2010) . However, due to expectations that developments such as DG and DR would reduce the average flows of energy through the networks, this income driver has started to be removed because the companies costs are based on peak flows rather than average volume, thus creating a potential mismatch between the capital cost requirements to run the networks and revenues (Shaw et al., 2010). As Shaw et al. note (2010); ‘DNOs would lose income because of efficient electricity use by their customers. DNOs’ costs would not reduce in the same way, because peak power flows are the main driver of their costs, rather than energy distributed’ therefore ‘DNOs would be financially penalised for reductions in net demand for energy from their networks, such as when on-site generation offsets gross energy demand’.

During this period Ofgem (Ofgem, 2009b) announced a move towards cost reflexive charging for new connections. This replaces the ‘Distribution Reinforcement model’ which had been the industry standard from the days of the Electricity Council when in 1984 the Electricity Board originally established charges for ‘use of the distribution system’ (ILEX, 2002). This calculated the long run marginal costs of connection (inputs including design, transportation, equipment), and allocated ‘costs between customer groups on a fair, equitable and transparent basis in accordance with well established, and proven, long run marginal cost principles’ (ILEX, 2002). However, a 2002 study found that the ‘underlying assumptions, design philosophy and asset types’ were not questioned and it ‘...does not consider embedded generation’ (ILEX, 2002); i.e. ‘it does nothing to encourage people to go to locations where the costs they impose on the network are less’ (interview – 19). Under new arrangements DNOs set charges for connections based on the actual costs of connection; for example, a generator which is located close to an area of high demand will be less costly and this will be reflected in the charging regime. As of 2010, this will include a common set of charges at the low voltage level across all DNOs (a Common Distribution Charging Methodology (CDCM)) and company specific charges which will be published. This is designed to promote ‘consistency and transparency in connection charging, caused largely by variations in the interpretation of connection charging methodologies across DNOs’ (Ofgem, 2009d: p.8/9): Ofgem note:

> *“In our view cost reflective charging arrangements are necessary to encourage efficient siting and use of network decisions, particularly for larger users, and for rewarding users who provide a benefit to the distribution network, for example distributed generation (DG) located close to load or for customers implementing demand side management” (Ofgem, 2009d)*

This is significant due to the increasing numbers of DGs seeking connection (see graph below) and the introduction of feed-in tariff subsidies for small scale renewable technologies connected at the customer side of the meter:

Figure 5.12: Numbers of DG Connections 2007-2010



Source: (Ofgem, 2009d)[85]

Future Price Controls: RIIO

In 2010, an Ofgem document noted the following:

> *"The existing 'RPI-X' regulatory framework has served consumers well, delivering lower prices, better quality of service and more than £35bn in network investment since privatisation twenty years ago. But RPI-X was designed for a very different environment to the one we will face in the future. The regulatory framework needs to change to encourage network companies to deliver a sustainable energy sector and provide value for money" (Ofgem, 2010e)*

This statement was contained in a report which introduced changes to the regulatory framework which will be implemented following DCPR6 in 2015 for the electricity networks. The publication of the document ('RIIO: A new way to regulate energy networks, final decision') followed a period of consultation and engagement with a range of stakeholders, including academics. The following excerpts from an article in the Utilityweek magazine by the director of the regulatory review, Hannah Nixon, gives an insight into the rationale for undertaking the review and points to the reasons behind the cautious nature of the final proposals where, from

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[85] Data was taken from table 2.2 on page 14

the outset, a 'full review of the structure of the gas and electricity industries [was] beyond the scope of RPI-X@20' (Ofgem, 2010c):

> *"The decision to undertake RPI-X@20 did not arise because there were signs of cracking in the regime that has, since privatisation, driven efficiency in the energy network businesses. There are no such signs. Indeed, our current approach has served, and continues to serve, customers well. The review was born out of awareness that it is better not to wait until it comes to the crunch, before testing the vehicle – especially before a journey across new terrain" (Utilityweek, 2009)*

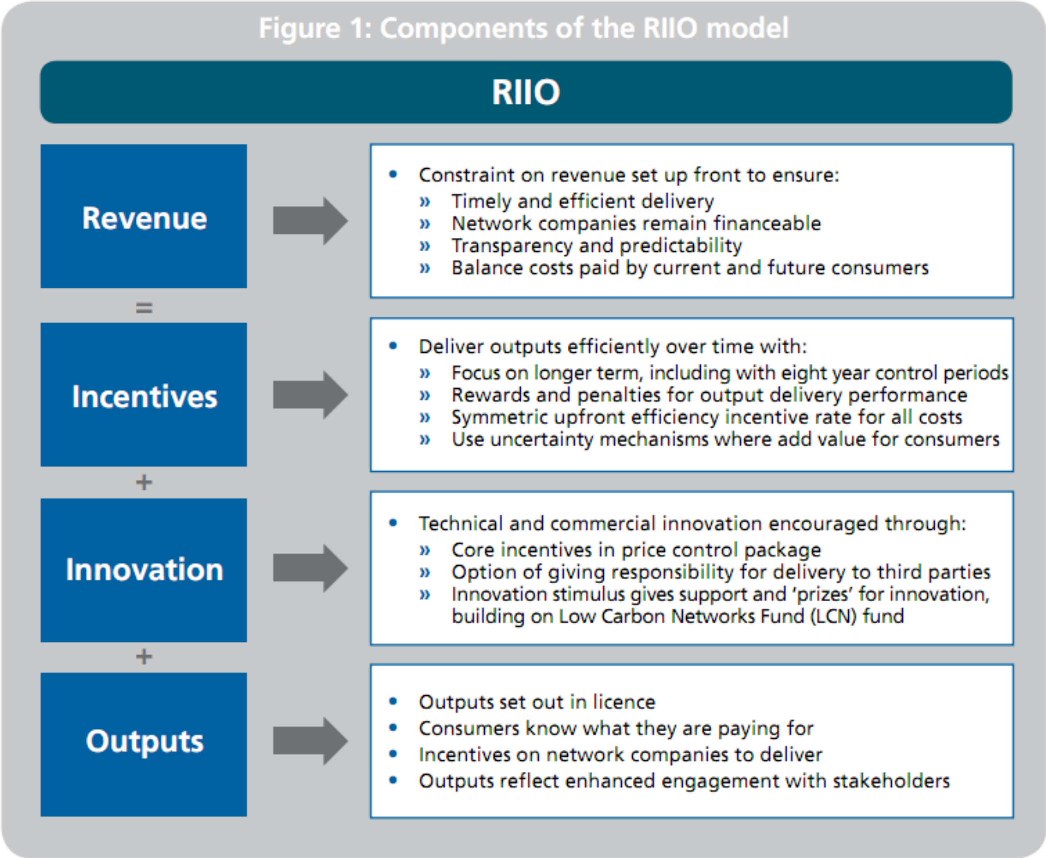
As part of the RPI-x@20 review[86] Ofgem commissioned a number of reports and studies; for example, investigating the role of benchmarking in price controls (Frontier, 2010c), the regulation of outputs (Frontier, 2010b), and on the extension of the regulatory period (which is currently five years) (Reckon, 2009). Contributions by a number of prominent academics in the field were also made (Helm, 2009, Littlechild, 2009, Pollitt, 2010). During the process Ofgem produced a set of interim proposals titled 'Emerging Thinking' (Ofgem, 2010c) in which the following proposals were made:

- An outputs led approach: The ex-ante approach is to be retained however there will be an even greater focus on an outputs led approach, therefore less discretion for the companies on how they achieve their efficiencies i.e. 'focusing on what is delivered rather than how it is delivered' with network companies retaining 'a fixed proportion of the benefit of any saving made' (Ofgem, 2010c).
- Measures to promote more effective 'engagement and accountability': Including rights for third parties, e.g. customers, generators, environmental groups etc, to challenge decisions, 'encouraging network companies to engage with consumers on an ongoing basis' and to 'encourage network companies to focus on the needs of their consumers rather than on the regulator' (Ofgem, 2010c).
- Promoting long term efficiency: Extending the regulatory period in order to incentivise longer term decision horizons (the final proposals have changed this from 5 to 8 years), requiring companies to submit longer term business plan proposals and more differential treatment for network companies e.g. some 'Network companies could earn a below average return if they fail to deliver outputs or if they deliver them inefficiently' (Ofgem, 2010c)
- Promoting Innovation: The proposals regarding incentives for innovation will be discussed in more detail in the next section

[86] http://www.ofgem.gov.uk/Networks/RPIx20/Pages/RPIX20.aspx

Following these proposals, Ofgem published its decision document later in 2010 in which it outlined its future approach to price controls; Revenue = Incentives + Innovation + Outputs (RIIO) – the figure below summarises the main components of the framework:

Figure 5.13: Key components of RIIO



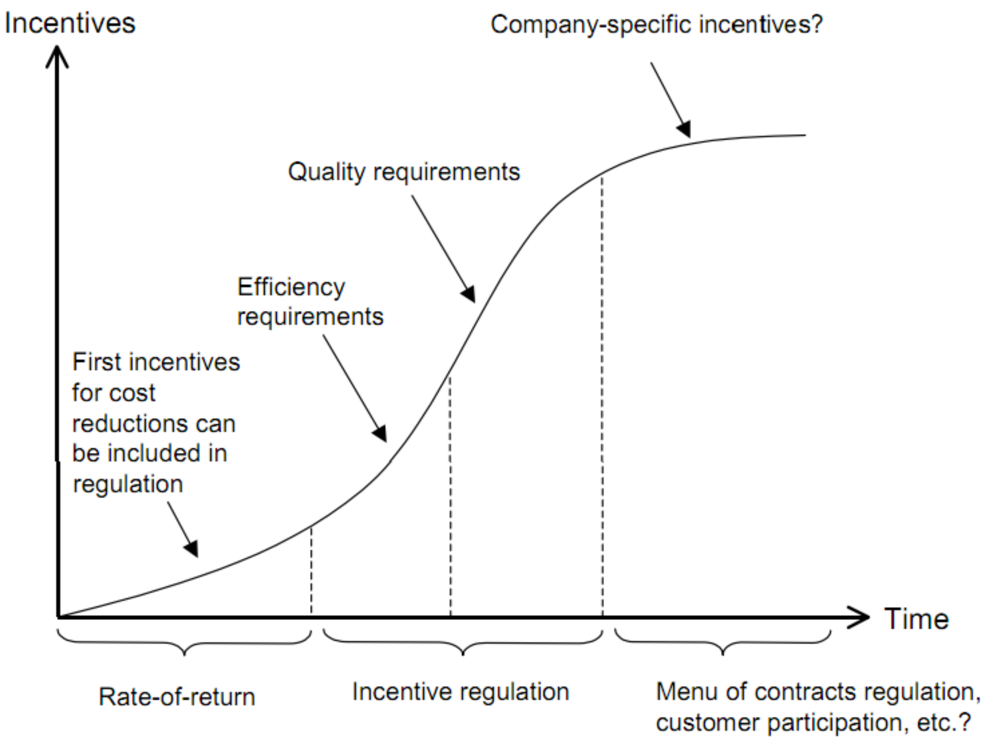
Source: (Ofgem, 2010e)

Although concerns have been expressed over the financeability of investments (interview – 20) and the regulatory risks of proportionate assessment (Utilityweek, 2010), many of the measures have been welcomed, in particular a continuing commitment to offering incentives for innovation (Interviews – 18, 23). However, the proposals are very much aligned with the broader regulatory trends towards regulating CAPEX and focusing on outputs, thus building on measures which had already been incorporated into DCPR5 (Utilityweek, 2010). In this sense RIIO does not signal a major paradigmatic shift in the regulatory regime; Ofgem 'are building on the principles and practices of the RPI-X framework' and have 'taken the elements that deliver benefits effectively, adapted and developed other elements, and added new elements to enhance the framework' (Ofgem, 2010e).

Summary

This sub section has shown how the regulatory regime has evolved, mainly since 2005 when issues relating to DG and engaging with the demand side began to be addressed. Measures such as innovation incentives (which will be discussed in more detail below), cost reflexive pricing and incentives to promote more transparency and the disclosure of information have been introduced during the period. These developments have taken place in the context of two overarching trends in regulation; efforts to promote more efficient CAPEX with an ageing asset base and a trend towards outputs based form of regulation which offers less autonomy to the private operators in how they achieve their efficiencies and begins to judge the performance of the individual companies rather than the aggregate performance of the sector – this general trend is illustrated in the figure below:

Figure 5.14: The evolution of network regulation



Source: (Viljainen, 2005)

RIIO is broadly in line with these regulatory trends and has ‘tweaked’ the existing modes of governing associated with RPI-x in the following ways:

Table 5.3: Changes to the regulatory governance regime

Mode of governing	Adapting the UK regulatory regime
'Sweat the assets'	Regulation of CAPEX through closer scrutiny of business plans, extending the regulatory period, incentives for innovation, differential treatment of companies
'Open Access'	New charging methodologies, incentives to connect DG, move towards cost reflexive charging regime
'Protect the customer'	Increasing emphasis on outputs, maintain industry structure to enable customer switching, measures to promote 'engagement and accountability'

5.3.4 Promoting Innovation

One aspect of the regulatory change process which is worthy of particular note has been efforts to incentivise and promote innovation within the electricity distribution sector. The RPI-x regulatory approach had initially been designed to be a technology blind tool which, in terms of promoting innovation, was underpinned by the neo-liberal rationale that market forces would place a competitive discipline on firms thus promoting innovation (Kern, 2009, Mitchell, 2008, Watson, 2008). For the case of regulated monopoly sectors such as electricity distribution this 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 entry to the market, and through periodic interventions and price controls, the regulator could simulate a competitive market, thus placing downward pressure on prices and a quasi-competitive disciplining the companies (Helm, 2004). Littlechild's view was that over time the need for sector specific regulation would diminish as competitive forces would lead to the self-regulation of the networks with competition and contract law providing an appropriate institutional framework. Innovation would therefore 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).

This view, that innovation was a natural consequence of pure market competition, illustrated a poor understanding of the innovation processes set out in chapter 2. What transpired was that RPI-x created a selection environment which favoured non-infrastructure solutions, i.e. cutting the costs of organising network companies, and short-term/piecemeal approaches to network planning which were often inefficient from a system perspective (Helm, 2004, Helm, 2009). This was illustrated in the case of DG where, due to a lack of progress, the network operator was eventually forced to create an artificial incentive for innovation through the IFI and RPZ schemes. The problematization of demand side issues has added another dimension to the innovation debate and the view that pure ex-ante price regulation cannot deliver innovation is now well recognised (interview – 1, 3, 13, 17). For example, Tooraj Jamasb and Michael Pollitt, academic economists who have argued that RPI-x has been a successful regulatory instrument, have stated the following:

> *"...we note the impact of future innovation on network regulation. Technological progress has in the past and will continue in the future to transform the nature and economics of networks. It is therefore very important that any regulatory framework will provide the right incentives for innovation and adoption of new technologies in the networks. It is also important that the regulatory system is flexible. The UK system of regulation has performed well from 1990 to 2006. However, it will need to evolve in the face of new technology and the challenge of demands from electricity consumers and producers for cleaner and more decentralised production(...) Thus, an important question is whether the UK regulation model provides the necessary incentives for innovation and accommodates the "active networks" of the future with renewables, distributed generation, micro-generation, and active demand. Micro-generation units installed by households, industrial CHP, and decentralised renewable generation sources will impose new challenges for network regulation. This implies that European electricity regulators should take into account the power and long-term effects of incentive schemes in influencing the features and behaviour of regulated firms. In responding to the choice of benchmarking, models and target variables firms are led to follow a certain path. This can mean a narrow focus on a limited number of strategic variables. Regulatory models will therefore need to be reviewed and evolve constantly to meet the needs of future networks" (Jamasb and Pollitt, 2007).*

This section discusses how the regulator has attempted to incorporate innovation incentives into the regulatory framework and the success to date.

RPZ and IFI: Promoting Active Network Management

The application of ICT technologies to the operation of distribution systems is not a wholly new development; distribution automation technologies have been deployed within the industry for over 20 years in order to promote operational efficiencies e.g. in improving response times to fault events (Northcote-Green and Wilson, 2006, Kendrew and Marks, 1989) but have typically only been deployed at the higher voltage levels (interview - 9). These technologies can include; inline voltage regulators, SVCs and STATCOMs, active voltage controllers and dynamic line rating systems (BERR, 2008a). In recent years however, due to DG connection and projections of future demand growth, concerns have been raised that increased fault levels along with increased and more complex power flows could result in distribution lines exceeding their thermal ratings or voltage fluctuations which may exceed safety requirements (interview - 7).

Active Network Management (ANM) can be seen as an evolution of distribution automation which involves both generation and the demand side i.e. 'controlling the inputs onto the network from generators or storage owners (supply-side options) or the offtakes from the network by customers (demand-side options)' (Frontier, 2010a). BERR (BERR, 2008a) outline the basics of ANM:

> *"ANM means devices, systems and practices that operate pre-emptively to maintain networks within accepted operating parameters. ANM may be compatible with automation of the network to speed supply restoration following an abnormal event, and increased visibility and control of the network to facilitate management practices" (BERR, 2008a: p.1)*

As has been discussed previously, the conventional response of the DNOs operating under the RPI-x incentive regime to these issues has been to expand the capacity of the network by investing in reinforcements, thus expanding their asset base. However, the increasing emphasis being placed on CAPEX regulation means that the regulator is looking towards less capital intensive solutions. The IFI and RPZ schemes were designed to assist ANM based technologies along the innovation chain, this is because;

> *"Distribution Network Operators (DNOs) typically operate passive networks today, with relatively straightforward flows of electricity. They do not have a history of making trade-offs between network investment and active management options"(Frontier, 2010a)*

The innovation incentives that Ofgem introduced in 2005[87] was an R&D funding mechanism: the Innovation Funding Incentive (IFI) where DNOs were permitted to spend up to 0.5% of its regulated revenue on R&D which 'allows a DNO to pass through to customers 80% (tapered from 90% to 70% from 2005 to 2010) of the cost of eligible IFI projects' (Ofgem, 2010d). Along with the IFI, a measure to promote trials of network innovations was also introduced; Registered Power Zones (RPZ), where a DNO could spend up to £500,000/year and earn enhanced revenues for the connection of DGs. RPZ offered 'an additional incentive of an extra £3/kW/year (over and above the main DG incentive) for a five year period commencing on the date of commissioning of the project' (Ofgem, 2004), this was 'capped at £0.5 million per DNO per year' (Ofgem, 2005).

The RPZ scheme was introduced as part of DCPR4 where 'DNOs will be allowed to seek registration for up to two RPZs per year for the first two years of the scheme' (Ofgem, 2005) and 'Ofgem will register, though not approve, RPZ projects and, where appropriate, will seek

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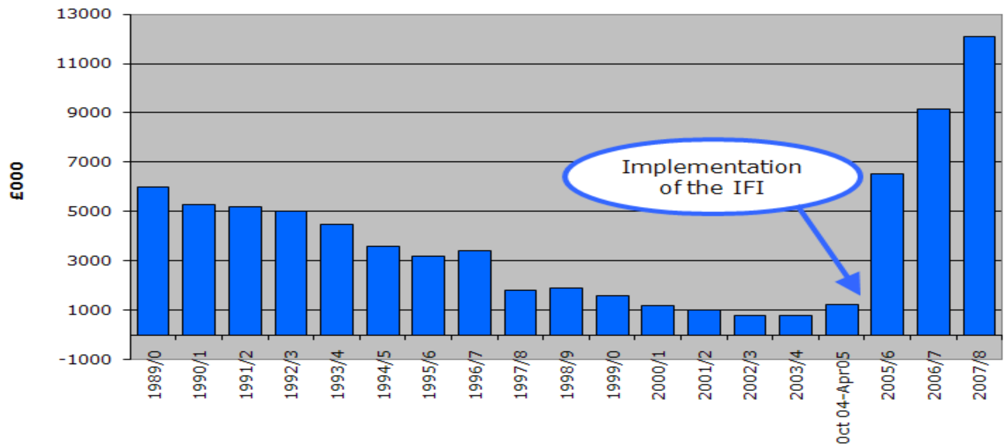
[87] The following paragraphs draw from Bolton and Foxon (2011)

advice from an independent panel, established by Ofgem, in relation to the innovation content and potential benefits of an RPZ Proposal' (Ofgem, 2005). As part of an RPZ, a DNO had to 'demonstrate that an innovative solution could offer material advantages to DG customers compared to a conventional solution' (ENA, 2007). An RPZ was loosely defined as; 'a collection of contiguously connected distribution system assets (i.e. which provide an electrical path for the distribution of electrical energy) having one or more terminal points which together describe in full the RPZ's boundary with the total system. These terminal points will be selected such that any system components or connected customers (existing demand and generation) that may be affected by the RPZ project are included within them' (ENA, 2007).

As Figure 4 below shows, the IFI did have a significant positive impact on R&D spending in the sector as R&D had declined significantly since liberalization (Jamasb and Pollitt, 2008, Jamasb and Pollitt, 2011). It was a clear incentive where the risks to the DNOs were low and companies did not have to rely on Ofgem for approval. They therefore had a degree of autonomy in how they spent the money as the scope of the IFI covered 'all aspects of distribution system asset management from design through to construction, commissioning, operation, maintenance and decommissioning' (Ofgem, 2004).

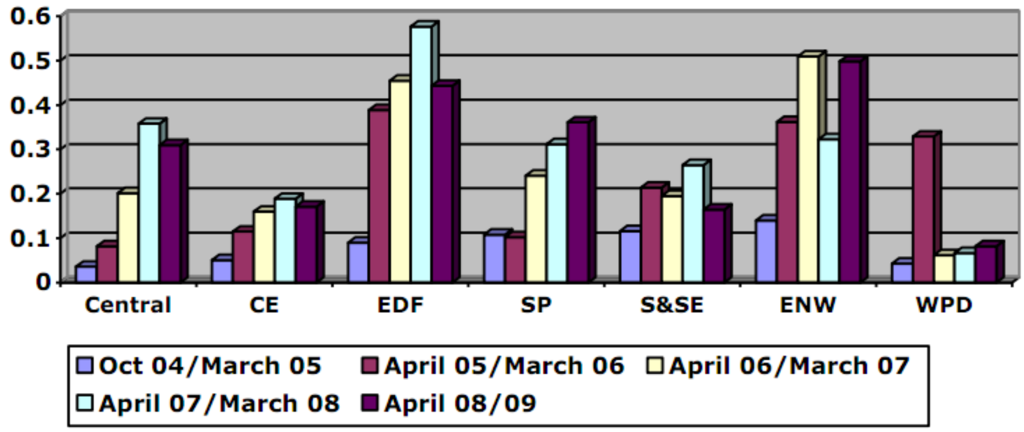
Figure 5.15: UK electricity distribution R&D spending



Source: (Ofgem, 2009c: p.5)

The figure below shows that EDF and ENW were particularly active in the uptake of the IFI:

Figure 5.16: R&D Intensity (%)



Source: (Ofgem, 2010d)

In a review of the scheme Ofgem noted that ‘In total some £10.9 million has been invested by the Distribution Network Operators (DNO) in IFI projects in 2008/9. This represents an overall research and development (R&D) intensity (spend as a proportion of allowed revenue) of 0.30%. This is 60% of the maximum allowed under the scheme. It is less than the outturn for 2007/8 when total spend was £12.1m, an R&D intensity of 0.33%’ (Ofgem, 2010d). This essentially was a task of fixing a market failure of a lack of R&D spending since privatization; a number of interviews have noted that this was waiting to happen (Interview – 6, 7) and the scheme has been continued into DPCR5.

The RPZ scheme on the other hand was not so successful; only four projects were undertaken by the companies throughout the five years of the price control period:

1. The Orkney Island RPZ involves a collaboration between the University of Strathclyde, SSE and Smarter Grid Solutions (start-up company) deploying active network management technologies. Problems were encountered in connecting DG to the island network due to capacity constraints and limited connectivity to the mainland networks via sub-sea cables (Interviews – 3, 18). This caused voltage rise and thermal limit issues on the network. The ‘voltage problems were resolved by installing a dynamic VAr compensator (DVAr)’ and thermal issues were addressed by sequencing generator input into the network based on theoretical scenarios and ‘on the basis of last on, first off to keep the system within the theoretical limits determined by the studies’ (BERR, 2008a). A key factor in the economic success of the scheme was the avoided cost of investing in additional sub-sea cable capacity.

2. Central Networks' Boston/Skegness project uses dynamic line rating techniques in order to accommodate a greater number of DG connections on a particular section of their network. Transmission power through a line increases its temperature. In order to deal with this the typical approach has been to use conservative ambient air predictions, based on the summer months, according to Engineering Recommendation P17 (BERR, 2008a). In response to this Central Network utilised an ENMAC™ SCADA system to measure real-time weather data and increase the capacity of the line for DG.
3. At the Martham primary substation EDF Networks used Econnect's (a specialist power engineering firm) GenAVC™ to actively control voltage levels such that when DG is connected the statutory voltage limits are not breached.
4. A similar project was undertaken on the EDF network at Steyning primary in order to accommodate a landfill gas generator. This avoided the installation of 4.5km of underground cable (EDF, 2008)

Although these individual schemes are innovative in their own right, there was a poor uptake of the RPZ incentive. 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:

> *"…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" (interview – 20)*

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 [which] may undermine its business model" (interview – 2)*

This relative failure can largely be explained using the systems failure arguments in the IS literature. The RPZ scheme treated a lack of innovation as a market externality which can be priced, rather than recognizing the systemic barriers produced by multiple externalities. For example, the following table which draws from Meeus et al. (2010) illustrates some of these systemic barriers to the development of an innovation system in the electricity distribution sector:

Table 5.4: Systemic barriers to innovation

Cost increase	Connecting DG, integrating demand and storage all increase the cost of operating the grids (OPEX) and the cost of maintaining quality – this goes against the prevailing incentives to reduce OPEX and improve QOS.
Short term costs for long term benefits	Also with more DG and demand, companies should substitute CAPEX for OPEX, but they are incentivised to do the opposite due to the short regulatory period i.e. cut OPEX, particularly due to the length of the regulatory periods which skews the regulatory trade-off towards cutting OPEX
Distributed benefits	For the case of many smart technologies 'system wide costs and benefits do not always coincide' i.e. a smart grid investment e.g. ANM may benefit many parties along the value chain whilst the investment risk is confined to one party.
Systemic vs. company specific	According to the IS literature Innovation requires systemic interventions and the development of a sector innovation system. However, the RPZ innovation incentive was aimed at individual companies and did little to promote collaboration across the value chain.

Source: Table draws from (Meeus et al., 2010)

The Low Carbon Networks Fund

Whilst continuing the IFI in DCPR5, the regulator has replaced the RPZ scheme with the Low Carbon Networks Fund (LCNF). Following the relative failure of the RPZ scheme, in DCPR5 Ofgem announced the LCNF to promote the deployment of innovative technologies. Similar to the RPZ scheme, there is an almost total partial pass-through (90%) of costs to customers and the aim of the LCNF is to 'try to replicate the incentives on unregulated companies to innovate' (Ofgem, 2010a). A significant difference is that the LNCF is not confined to the connection of DG alone because 'DNOs may need to radically change the way they charge for access to their networks if customers (including domestic customers) change their patterns of use in response to smart metering and become customers and producers of electricity at different times of the day. DNOs' charges will need to reflect the costs (or cost savings) associated with very different patterns of use and encourage customers who have control over their demand to use more at times of the day when there is spare network capacity to avoid the need for expensive network investment in new capacity' (Ofgem, 2010e).

There are two tiers to the LCNF. The first tier of funding is £80million and is for smaller projects with funding per DNO being limited annually, these projects are registered with Ofgem and in 2010 nine projects have been registered as tier one projects[88]. The second tier provides £320million for 'flagship projects'; 'Ofgem will hold an annual competition for project funding and the DNOs will compete against each other for an allocation of the funds' (Ofgem, 2010e). Submissions are assessed by a panel of experts and each year a number of projects are awarded funding. There is also an ex-post 'discretionary funding mechanism' of £100million which 'enables Ofgem to reward successful delivery and projects that bring particular value in helping the DNOs understand what investment, commercial arrangements and operating strategies they should be putting in place to provide security of supply at value for money for future network users, while doing all they can to tackle climate change' (Ofgem, 2010e).

In 2010 four projects were selected on a competitive basis:

- Customer-led Network Revolution: This was submitted by CE Electric UK and is a partnership with British Gas' smart metering program, the Durham Energy Institute, Sustainability First, National Energy Action and EA Technology. The aim of the project is to align demand response with ANM techniques (voltage control, real time thermal rating and storage) to learn about customer load characteristics, the potential for more flexible customer behaviour, to manage network constraint issues and the 'most effective means to deliver optimal solutions between customer, supplier and distributor' (CE Electric UK, 2010). £26.8million was awarded (Ofgem, 2010b) .
- Low Carbon London was submitted by EDF Energy Networks for the London area (now UK Power Networks) and was awarded £24.3 million. The project utilises data from 5,000 smart meters to allow the DNO to connect microgenerators and improve the capacity utilisation of the urban network. They also seek to develop novel contractual arrangements involving customers, companies who aggregate a number of microgenerators and the DNO. Project partners include Siemens, Imperial College, Smarter Grid Solutions, the GLA, National Grid amongst others (EDF, 2010).
- Central Networks' Low Carbon Hub involves the utilisation of ANM techniques to connect DG to a 33KV segment of their network. This applies dynamic line rating, flexible AC transmission system devices which are typically deployed on transmission networks, dynamic voltage control and new commercial arrangements between the DG and DNO (Central Networks, 2010). This received £2.8million from the LCNF

[88] A further 9 have been registered in 2011: http://www.ofgem.gov.uk/Networks/ElecDist/lcnf/ftp/Documents1/First%20Tier%20registration%20log%2010062011.pdf

- LV Network Templates for a low carbon future was submitted by Western Power Distribution (WPD) and awarded £7.8million. Along with the University of Bath WPD will monitors LV feeder lines in South Wales with the expectation that the data will help National Grid to manage the grid with greater levels of microgeneration. This uses information from the Welsh Assembly's low carbon initiative which involves over 1,000 PV installations (Western Power Distribution, 2010).

It is clear that Ofgem have learned some of the lessons of the failure to incentivise deployment of innovative technologies and practices under the RPZ scheme (interview – 14). By awarding the companies the vast majority of their upfront costs and giving them more autonomy to design projects according to the particular needs of their networks, the LNCF is an improvement on the RPZ demand pull model. Although it is early to assess whether the scheme is a success, it has largely been welcomed (interviews – 7, 8, 9, 12, 13, 17, 18, 20, 23, 24) and in the RIIO proposals a similar program is planned for DPCR6 which is called the 'Innovation Stimulus' (Ofgem, 2010e).

These inventive schemes are important not only in trialling new technologies and developing innovative responses to network related issues, but also in developing the capabilities and organisational routines necessary to promote innovation as a strategy within the network companies (interviews – 3, 6, 18, 20). Emerging from the period of nationalisation when network investments were made on the basis of demand growth and network expansion (Surrey, 1996), under the RPI-x incentive scheme disincentives were put in place for long term thinking about the networks (Scott and Evans, 2007). As a result, the organisational routines of the network companies have not developed in ways that promote innovation - the following quote from an interviewee from a big six company illustrates this:

> *"I'm not sure and speaking honestly that we're that big on innovation ourselves (…) we're a utility that runs a business and a set of assets and those assets we buy from manufacturers, equipment manufacturers of one description or another. So a lot of the innovation will be done there and we're buying it in and putting it together" (interview - 4)*

Programs such as the LNCF can begin to change this culture within the sector (interview – 6); however, it is envisioned that over time specific innovation incentive schemes will be 'wound down' and innovation will need to become part of the day to day planning and operation of the networks (Ofgem, 2010e). The following quote from an innovation manager within one of the DNOs illustrates that ultimately, separate innovation programs such as the LCNF will be sideline issues to the main business of operating the networks under the price based incentive regime.

> *"Say we have some load growth on part of the network, the conventional way is to say we will buy a transformer (...) that is going to cost say a million to accommodate for load growth. If you use technology, say the LCNF, [and] we utilise storage to manage the load growth, whatever we spend we are going to get 90% back (...) So there is a conflict there straight away, so I can use the conventional route to manage that load growth and I'll get 100% return because I'll go to Ofgem and say 'well I need a transformer' (...) Or I can go the technological route and it's going to cost me 10% of my investment. There's a conflict there straight away" (interview – 17)*

If the costs associated with innovation are continually passed through to the customers through innovation incentives the shareholders of these companies bear little risk and it is unlikely that innovation can become embedded within the companies' organisational routines. 'Flagship projects' run the risk of becoming gold-plated, stand alone initiatives and thus not affecting the 'day-to-day' investment decisions and operation of the companies. It is as yet unclear as to how innovation can be institutionally embedded within the mainstream regulatory process as the RIIO proposals do not illustrate how the risks and benefits of innovation can be equitably shared between customers and shareholders and between different actors across the value chain (interviews – 18, 20, 23, 18). Also, the outputs led approach which RIIO seeks to reinforce runs the risk of reverting to a demand pull approach. The reasons why RPZ didn't work was because they were outputs based, or demand pull exclusively. IS theory suggests that the whole innovation chain needs to be considered and this is why the LCNF needed to be developed. However, it is uncertain how this will be incorporated into the mainstream regulatory regime which, as the following quote from the Ofgem illustrates, is evolving towards the regulation of outputs:

> *"In time we expect that an outcomes-led framework, with appropriately designed longer-term incentives and a greater role for competition in delivery, would encourage network companies to seek out innovative delivery solutions… The stimulus could be removed if, for example, it became clear the regulatory framework was itself encouraging sufficient innovation or there was evidence that the scale and nature of innovation required was reducing" (Ofgem, 2010c)*

With early stage technologies in particular outputs are inherently uncertain and difficult to measure; an over reliance on an outputs based approach to promote innovation will favour near commercial technologies and incremental changes which reduce the investment risks for companies (Meeus et al., 2010).

5.3.5 Conclusion to Interventions and Interactions Section

This section outlined some of the key regulatory and policy interventions that are taking place as a result of efforts to promote the transition to a low carbon economy. These interventions are resulting in new forms of interaction at the sector or organisational field level e.g. between the customer, retailer, and DNO, between the network operator and the regulator and across the sector as a whole as it attempts to govern in an increasingly complex and uncertain environment. The next section of the chapter will discuss the outcomes of these interventions and interactions in terms of the physical, relational and structural institutional dimensions.

5.4 Outcomes

This section utilises the dimensions of infrastructures approach which was introduced in chapter 3 where the physical, relational and structural analytical categories characterise the interplay between actors, institutions and technologies in energy distribution sectors as a the outcome of a governance process. It was argued that institutions can be considered as embedded in each of the infrastructure dimensions and analysed in a systematic fashion where actors within the organisational field simultaneously seek to strive for notions of technical efficiency and legitimacy for their actions.

5.4.1 Physical Dimension

In the physical dimension institutions *coordinate physical flows within a network which can be measured, monitored and controlled*. Key analytical variables which were outlined in chapter 3 include the changing relationships between nodes, links and flows, how system economies are being achieved, and how system reliability and integrity is maintained. In the electricity distribution case the focus was on the manner in which DG and demand side issues are affecting physical flows within the networks - the following table summarises the main outcomes.

Table 5.5: Characterising the changing flows within electricity distribution systems

Flows	Electricity Distribution
Energy	• DG connecting to the distribution networks and the potential for two-way flows • Increasing demand for electricity due to electrification of heat and transport • Increasing volume of flow on the low voltage feeder lines
Information	• Increasing amounts of information available due to liberalisation of the retail market • Smart metering to make customer data more available • Incentive schemes designed to reduce information asymmetries between companies and regulator • Efforts to deploy ICT to manage more complex flows of energy and revenues
Revenues	• New charging regime for DGs • Revenues of network companies to be increasingly determined through specified outputs • New measures to regulate CAPEX • Incentives for real-time transacting and active management of networks through innovation funding

One key outcome has been increasing efforts to use new flows of information to achieve system economies rather than expand the network in order to accommodate an increasingly complex and diverse set of energy flows (interview – 2, 23). The traditional approach of expanding the network using conventional technologies and practices is seen as a costly solution, therefore new measures to regulate CAPEX and early attempts to incentivise innovation are seeking to act as a disincentive to this. As one interviewee noted it is;

> *'about understanding the capacity of our networks, because particularly at the low voltage levels we don't have the ability to monitor the capacity of those networks, the only way we know is when the customer complains about the quality of their supply, so that will allow us to fill that capacity up' (interview - 23).*

However, efforts to improve capacity management and achieve economies of system through the utilisation of new information flows are encountering barriers as a result of the organisation of the ESI which artificially separates key components of the system, thus increasing transaction costs and making it difficult to bring about system complementarities. The example of the smart metering roll out, which is designed to make available information regarding demand side energy use patterns, highlights an ongoing tension between the use of prices to reduce the asset specificity of transactions taking place within the industry, and the technical requirements of the system which demands a real-time balance between supply and demand. It is questionable whether the latter can be achieved through prices and incentives alone as the physical flows within the system become more complex.

The example of distributed generation illustrates how increasingly complex flows have undermined the traditional revenue streams of DNOs. Distribution networks, which had traditionally been passive systems with one-way flows of power, are increasingly being seen as more dynamic systems which can accommodate and manage a diverse set of inputs and loads. This increased demand for third party access to nodes of the network has prompted changes to the revenue model of DNOs in order to maintain the integrity of the system; for example in how they collect charges from DG operators. Also, the localisation of flows which is resulting from increased DG connection is making the regional networks less uniform entities with more differentiated approaches emerging to how rural and urban systems are planned and operated[89]. This is resulting in a trend towards cost reflexive charging regimes which can reflect these geographical differences. As a result, the concept of a Distribution System Operator (DSO), where DNOs manage their systems in a real-time dynamic way using ANM techniques – similar to a Transmission System Operator (TSO) – is seen as a potential evolution of the DNO business model in the future (interview – 13, 15, 17, 18, 20).

5.4.2 Relational Dimension

The relational dimension address the issue of ‘independent but autonomous organisations, each controlling important resources’ and the role of institutions is ‘to *coordinate their actions to produce a joint outcome which is deemed mutually beneficial*’ (Jessop, 1995). The problematization of passive distribution networks due to issues relating to DG connection and the uncertainty surrounding the integration with retail and the end customer has begun to change the relational dynamics within the organisational field in a number of ways.

Changing Vertical Dynamics

The structure of the ESI in the UK has been based on a set of vertical relationships between electricity generators, the transmission operator (who is responsible for ensuring that the system is balanced at a national level) and regional distribution network companies (who deliver power to end customers according to the Safety, Quality and Continuity standards) and retailers. Although market based mechanisms (the development of retail and wholesale markets for electricity) have been increasingly introduced with the aim of promoting the efficient dispatch

[89] In rural areas the main issue is voltage rise and in urban areas it is increasing fault levels (Strbac et al., 2006)

of generation and the reduction of capacity margins, the system relies on a set of hierarchical institutions in order to achieve the necessary system balance and coordination. The TSO has ultimate responsibility to maintain system security and the distribution networks as a result have had a passive role i.e. manage one-way flows of power to the end customer. However, increasing levels of DG and the ongoing trend towards integration with the demand side are creating expectations and visions surrounding more active distribution systems and smart grids. This is creating uncertainty surrounding how these relationships might be configured in the future e.g. between the TSO, DNO, retailers and DG operators (interview – 4, 22, 23).

In order to illustrate, one interviewee from a DNO which is owned by one of the 'big six' energy companies outlines potential conflicts which may arise due to increased DG diffusion:

> *"…if NGC[90] want to re-secure the network by changing generation patterns they can dispatch-off generation or they can dispatch generation on to secure the network (...) [however] (...) the distribution network [generators] don't have access rights and they can be turned off for system control purposes. If you've got multiple embedded generators how do you decide who goes off first because there's no formal connection arrangements; is it last on first off? Is it a pro rata reduction? There's no regulatory framework for managing that" (interview - 16).*

Similar conflicts of interests emerge in customer interactions where 'you've got all these different bodies (…); national grid at a national level, the network operator at a local level and the supply company perhaps wanting to do different things with your devices at home and actually want to send/use different control mechanisms or price signals' (interview - 4).

This may potentially necessitate new formal institutions to coordinate activity within the sector (interview – 23) in a different way as; 'there is no question that the current structure of the market here in the UK, in a deregulated environment where you've got the TSOs, DNOs, and electricity suppliers, does not lend itself to a very effective integration (…) because you've got conflicting interests obviously among the different players in that market' (Interview - 12). As has been noted, this uncertainty regarding vertical relationships within the sector have most recently been played out in disputes over the smart meter roll out where the transmission operator may be concerned with the national level power balance and grid frequency while the DNO would be concerned with local power imbalances and voltage profiles (interview – 11).

Whether this institutional coordination is achieved through market based approaches e.g. 'real time' pricing, or a return of more conventional forms of hierarchical strategic planning, is as yet

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[90] National Grid – the transmission operator

uncertain (Foxon et al., 2010). However, this interpretive flexibility surrounding how the set of vertical relationships in organisational field might develop in the future is resulting in stakeholders beginning to question the current unbundled structure of the sector; i.e. 'the boundaries between suppliers, network operators, and virtual power plant operators will become very very blurred and you could even argue that it becomes so blurred that it becomes more of an entity' and '... it starts to challenge the highly unbundled organisation we have in this country; we have separate suppliers, DNOs, new players coming in…aggregators, VPP[91] operators and so on' (interview - 20). Thus questions over prevailing institutional arrangements have arisen as there is a great degree of uncertainty regarding 'the nuts and bolts: who's controlling the smart grid or how much is it controlling itself? How smart is it? And what does it mean?' (interview – 4) - the same interviewee from one of the 'big six' energy companies notes;

> *'One of the things that's exercising us is if you put in a smart grid in a local distribution network then that's got to be controlled from somewhere; it makes sense for the distribution companies (DNO) to control that, not NG. So the DNO probably needs a much better control infrastructure than there is at the moment (...) and there are a number of solutions proposed like somehow a distribution network operator will take control of the time you charge your car up so you make sure it charges overnight' (interview - 4).*

A related issue is how the traditional model for revenue generation in distribution networks is changing. In the past, revenue was secured through vertical relationships via connection and use of system charges imposed on retailers; however, the development of more complex flows within distribution systems is beginning to challenge this linear model of revenue generation. For example, DG connection until recently has been relatively rare and traditional forms of reinforcement were used to accommodate it (the 'fit and forget' approach). This prevailed because it benefited the DNO as it increased the overall regulatory asset base and because CAPEX efficiency was a secondary consideration for the regulator. However, developments such as new DG connections, the need for new investments due to the natural asset replacement cycle, and the increased emphasis on CAPEX efficiency are beginning to undermine these traditional revenue streams. Under the existing institutional framework it is increasingly difficult to account for the risks and benefits of investments and to achieve system economies with more complex physical flows of energy and information – as one interviewee notes, this is beginning to call into question the traditional 'value chain' model:

[91] Virtual Power Plant operators who aggregate multiple dispersed generators and loads

> *"[In a] market structure like today where there are conflicting interests and the interests are not aligned then obviously the ones that are closer to the customer might get the most value potentially (...) but when you take a look at the whole system you may not get the most value (...) because you would still have that value really focused more towards the customer end versus all the way upstream (...) The market is in a state of flux right now, certainly not optimised in order to have a smart grid infrastructure ... [if] everybody says ok fine, I'm going to plug a meter which is going to cost me x, what's really the benefit? But the benefit is not only to the consumer; it's to the consumer, it's to the operator, it's the distribution network operator, it's the national grid potentially, and back to whoever is going to be generating that power as well" (interview - 12)*

An example of these emerging conflicts is how many technologies that have been associated with the smart grid tend to be of benefit to the system as a whole, and not just the party who invests and takes on the risk. A number of examples are highlighted by interviewees:

Battery storage:

> *"If you take battery storage for example; if we had a big battery that we could plug into the system it might remove the need for asset investment, but the fact is the cost of a battery with significant power capability is absolutely astronomical, you're talking about (...) a 2mw battery for 4million pounds. If you really did want to put in a battery, the business case for its installation would have to take into account the energy trading revenue from that facility to make it worthwhile. So the business case has got to accommodate network benefit and the ability for a supplier to trade that energy and never the twain shall meet in terms of regulatory Chinese walls" (interview - 16)*

Active management of distribution networks – the interviewee is responding to a question on the commercial incentives required for smart grid investments:

> *"I think clarity on what are the most valuable smart grid functions as I said earlier and gave some examples of different things a smart grid could do which have a real value; enhancing customer security or increasing efficiency or connecting more renewables (...) there's not yet good clarity on what's the most valuable things to do and certainly no priority on which to do first" (interview - 3)*

Demand side management:

> *"Demand Side Management, as well as Energy Storage are two smart concepts where it remains to be seen which of the sectors in the electricity industry in the UK could benefit, and for what reason. These technologies are able to provide ancillary services, but what organisation will pay them and who administers this?" (interview - 11)*

And overall:

> *"I think there's some value there but I'm worried just how much change there needs to be to extract that value in terms of all these control systems that need to be put in place" (interview - 4)*

These issues are as yet unresolved but are creating uncertainty and interpretive flexibility regarding the future function of distribution networks and the nature of interactions between the TSO, DNOs, retailers and DG operators etc.

Changing Horizontal Dynamics: DNO Procurement Practices

Along with vertical dynamics within the organisational field there are new forms of horizontal dynamics emerging, particularly in how DNOs interact with equipment manufacturers and procure network components. The innovation chain for distribution networks has traditionally begun at the R&D stage in large multi-national engineering companies such as General Electric and ABB, with DNOs deploying their components on the networks (interview - 1). The RPI-x incentive structure, where the emphasis has been on achieving short term operational efficiencies, has shaped the nature of this relationship:

> *"Network companies have this strong incentive to push down capital costs so they have put a lot of emphasis on negotiating at the procurement stage which basically means they just keep pushing down prices for buying basic standardised, well specified pieces of equipment whereas [the] ABBs [and] General Electric's probably wanted to do a bit more than that and sell assets with lots of extra services added on (...) I'm not sure if the network companies have gone for that" (interview - 3)*

DNOs were incentivised to operate at the margin and to deploy standard off the shelf components rather than specialised pieces of control technology designed to deal with a particular issue on their network and as a result the large engineering companies themselves have tended to operate a low risk business model (interview – 3, 6, 18).

However, following the RPZ and IFI programs there are some signs that this is beginning to change within the sector. In an effort to develop a business case for RPZ projects and trials which were often location specific, relationships outside of the standard DNO-manufacturer have begun to develop (interview – 3, 18). A number of smaller engineering companies who develop specialised/site specific components and solutions have emerged and formed collaborations with DNOs: Their expertise tends to be in the areas of addressing constraint issues such as voltage control when integrating DG – see table below:

Table 5.6: Specialist R&D companies in the UK

Company	Product/expertise	Projects
Smarter-grid Solutions[92]	ANM constraint management solutions	Orkney Is. RPZ with SSE
Synergy Econnect[93]	GenAvc voltage control device	Martham primary RPZ with EDF
EA Technology[94]	A range of asset management solutions	IFI funded study with SSE on the Ashton Hayes Microgrid pilot

During interviews, employees of one of these companies (interviews – 9, 10, 18) argue that their competitive advantage lies in finding the value for DNOs i.e. developing revenue streams, particularly in relation to DG connection.

> *"What we're doing is coming at it from a sort of functional perspective; what are the problems? What kind of control systems do you need to solve those problems? What are the commercial arrangements that will sit around them to enable that to happen? (...) These problems are emerging as you said on a localised basis so that's small fry for someone like GE, as much as some of the people in the company would want to go and solve that problem they're probably not, there's no scale in that for them, they're not sure about how the market is going to go, so they're probably happy that a company like us would go and do that" (interview - 18)*

> *"We are giving them some benefit in that it works with their existing requirements, it [will] act automatically so they don't have to think about getting involved with it, so it allows them to connect more generation to the networks, they normally wouldn't be able to connect it because there isn't another option other than building more lines" (interview – 18)*

Also in creating a business case for the deployment of innovative technologies on the networks:

> *"We know where the value is, we can show them and give them (...) what that value means in terms of pounds and pence, in terms of megawatts" (interview - 10)*

> *"I think the key thing of any sort of development like that is in messaging and in getting the message across to the big dominant players in the right way so*

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[92] http://www.smartergridsolutions.com/
[93] http://www.senergyworld.com/alternative-energy
[94] http://www.eatechnology.com/

> *that they can understand where the business case fits, where the real benefits for them comes" (interview - 9)*

In contrast, an interviewee from one of the larger multi-national manufacturers described their role as thinking about the whole value chain rather than addressing specific network issues that may arise in the UK context:

> *"the point is that we are driving innovation (...) Innovation is not only linking up all of the different features of the T&D network but we are also showcasing how that can be linked to appliances in the home for example. [We are] a big appliance manufacturer, [we are] looking and showcasing at how we can link that infrastructure to the smart fringe at home or the smart stove or the smart whatever at home" (interview - 12)*

These small niche/specialist companies could potentially form an important part of the emerging smart grid innovation system in the UK, this is discussed further in the analysis chapter.

Changing Regulator-Government Interactions

In chapter three of this thesis it was proposed that approaches to infrastructure governance tend to view the state as a passive actor with little influence over an all powerful ‘independent’ regulator. The case of electricity distribution networks in the UK has shown that state strategies, broadly relating to the transition to a low carbon electricity system, have been key in shaping the nature of sector regulation and how it has changed over the period. Beginning with the political momentum behind DG in the early 2000s, the institutionalisation of carbon targets in 2008 and the national roll out of smart meters to be controlled by DECC, energy policy has become an increasingly prominent part of the political landscape during this period. As a result, the governance model of the electricity networks has become more politicised and role of the regulator is becoming more complex as it seeks to balance the interests of the different stakeholders in a time of increasing investment in the networks. This blurring of the boundaries between the regulator and government departments is reflected in the evolution of regulatory instruments over the period where the initial concept of an apolitical/mathematical formula for achieving cost reductions has been made more complex as various social and environmental goals have come under the remit of the regulator. The RIIO proposals signal a more ‘hands-on’ regulatory style where companies are increasingly judged on the basis of their actual performance against defined targets, rather than given autonomy to reduce costs on the basis of ex-ante incentives.

Within this context one should view Ofgem as a quasi-independent implementation body which is part of an increasingly politicised national energy policy environment. Broadly three scenarios for how this role might evolve in the future can be identified – elements of all three are contained in the RIIO proposals:

- Continue on a liberalised path with a strengthening of innovation incentives; 'where you make sure the incentives for low carbon generation are correct and you remove as many barriers to entry as possible. You rely on innovation to come along and you concentrate subsidy on achieving learning benefits and removing barriers' (interview - 2).
- A more top-down hierarchical approach involving 'strategic investment that is centrally coordinated' with 'some kind of transition plan, maybe networks produce transition plans of how they are going to do this and that is a requirement' (interview – 22). This might involve a move away from periodic price controls with a greater degree of emphasis being placed on long term business plans submitted by DNOs.
- A further strengthening of the target or performance based approach 'where you say this is what we think is going to happen, this is what we expect to happen or for [the DNOs] to do' (interview - 22).

The nature of state involvement in the future of the sector and whether DECC begins to exert its influence over Ofgem is largely an open question as in the wake of the Climate Change Act in 2008, the institutional boundaries between state bodies is still in flux – as one interviewee notes:

> *"[Ofgem] do have disagreements with their sponsoring department DECC (…) Sometimes I suspect quite strongly that Ofgem has a lot more resources than DECC does in those debates. So I think even if you had a secretary of state who came in [and said] we must sort Ofgem out (…) I think for DECC, it may be quite difficult to do that. But also I think there are people within DECC, the civil service, who also have been around since the 90s and so also take this market based view and are (…) very cautious about leaving behind the way things have been done. So I'm sure there's a lot of debate" (interview - 1)*

This is also dependent on where state capacities (knowledge and resources) lie in these matters, currently this continues to reside in Ofgem with one interviewee noting that 'the specialist knowledge in government you're probably aware is incredibly depleted these days, close to nil', and therefore 'it would be very hard to recreate a new central planning organisation. Who would populate a new department of energy that will centrally plan these smart grids?' (interview - 6). The interviewee also recognises the political risks of doing so; 'how can you expect someone in Whitehall to really have a view and confidently recommend to their minister that this is something worth spending money on, and you're not going to get shot down in public for that' (interview - 6). Overall, as the following quote from a civil servant working the in the energy policy area suggests, a move towards a top-down hierarchical model is seen as a last resort:

> *"There are some calls for governments to take action and to show leadership, but they're quite vague calls in that when they are dug into a bit what does that mean for government to take leadership? (...) but that is not to say it is not something that might happen in the future, the door is open on that one and it is something that we are open to the idea of but I think we need to be very sure of what we are asking people to do" (interview - 22)*

Within this uncertain environment, industry platforms such as the Electricity Networks Strategy Group (ENSG[95]) and the Smart Grids Forum[96] are important bodies in bringing parties together to develop shared visions and creating a dialogue between industry stakeholders (interview – 1).

5.4.3 Structural Dimension

Network logics represent the underlying rationality behind the system which shape field level interactions and act as a source of legitimacy for action. Two 'ideal type' network logics were identified; the competitive model – where competition and prices promote efficient system planning and operation and the regulator's primary goal is to deal with the market externalities - and the public services model - where utility services are seen as a social good and risks are socialised. In important ways the evolution of the electricity distribution sector during this period draws from each of these two overarching logics. For example, emerging concepts such as the smart grid which emphasises flexibility, real-time transactions, demand-side management and customer choice, reside comfortably within the selection environment and technological trajectory which has been brought about by privatisation and liberalisation. However, in many ways making distribution networks a more active part of the system as a whole threatens to undermine the set of vertical relationships within the sector upon which the current competitive arrangements rely. These tensions are part of the ongoing discourse within the sector and form the basis for the multitude of smart grid visions which have emerged which seek to reconcile these inconstancies into a coherent whole.

From charting the various interventions and interactions in the sector it can be observed that efforts to adapt the governance regime to the challenges posed by DG connection etc. tend to draw their legitimacy from a market based logic where decisions are justified on the basis of how they reduce the costs of operating the networks or improve competition in other segments of the value chain e.g. the ability of customers to switch between suppliers. Issues such as DG

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[95] http://webarchive.nationalarchives.gov.uk/20100919181607/http:/www.ensg.gov.uk/
[96] http://www.ofgem.gov.uk/Networks/SGF/Pages/SGF.aspx

connection tend to be problematized in terms of how they affect market arrangements, as a consequence the solutions tend to be market and price based (e.g. locational pricing, smart metering and DR, new charging regimes etc) rather than formed on the basis of whether they address the underlying environmental or social concerns (Mitchell, 2008, SDC, 2007). Similarly incentives to promote innovation within the sector tend to be justified on the basis of whether they promote CAPEX efficiency i.e. innovation is about 'sweating the assets more' (interview – 11). This reinforces Mitchell's arguments surrounding the nature of energy policy and regulation in the UK which were introduced in the introductory chapter: Energy Governance in the UK tends to be structured according to a Regulatory State Paradigm (RSP) (Moran, 2003) which defines the principles and processes of regulation; this is based around market solutions and short term incentives where 'actions are designed to fit with these principles' (Mitchell, 2008: p.6).

5.5 Chapter Conclusions

This case study discussed the interplay between actors, institutions and technologies in the recent evolution of the electricity distribution sector in the UK. It was observed that in the early part of the 2000s, efforts to promote the connection of distributed generation which were often politically motivated encountered numerous barriers within the sector. This was because the governance regime which emerged from liberalisation was largely based on the rationale that natural monopoly is an economic externality which can be dealt with using a mathematical and apolitical approach to regulation. This did not favour particular technologies but sought to give autonomy to private network operators to run their businesses in an efficient manner. The RPI-x approach which regulated the prices companies could charge for network services on an ex-ante basis, incentivised short term time horizons and a focus on achieving OPEX rather than CAPEX efficiencies. This has become problematic because there has been little incentive for DNOs to approach the connection of DG in an integrated or innovative way, rather a piecemeal approach has been taken using conventional technologies, thus increasing the transaction costs for DG developers. Similar issues regarding the inflexibility of the current governance structures have emerged regarding DSM and the roll out of smart meters, in particular following the 2008 Energy Act. There has been considerable uncertainty as to how energy use information can be utilised to achieve system economies and how DSM can be achieved due to the fragmented and unbundled structure of the industry which separates the competitive from the non-competitive segments of the value chain.

The regulatory response to these issues has been to adapt the existing governance regime rather than fundamentally reconsider the current structure of the industry and the rationality behind network regulation. This evolutionary approach has seen the introduction of more cost reflexive charging regime for new connections, incentives to reduce losses and a gradual trend towards the regulation of outputs which are specified by the regulator. The issue of how to promote more innovative approach to DG connection and integration with the demand side has been problematic for the regulator. Although a number of incentives for innovation have been introduced there is as yet little indication as to how a more innovative approach to operating the networks can be embedded within the mainstream regulatory regime. However, it is likely that the provision of an innovation fund which reduces risk by covering upfront capital costs and which promotes collaboration between DNOs, third parties and other actors from across the value chain will likely increase the capacity for innovation across the sector which has been lacking to date. However, throughout the period changes to the governance regime have been extremely slow and not commensurate with the urgency required to enable a low carbon energy system. This is due to the embedded organisational routines of the regulator and the companies which have been slow to change and nature of the price control review and the licence modification processes which require consensus.

These issues point to an ongoing tension or misalignment (Künneke, 2008) between the governance regime which emerged following liberalisation and the demands that are being placed on the sector, particularly in the context of the long term transition to a low carbon electricity system. Following privatisation, and in order to facilitate liberalisation, the networks were siloed from the more competitive parts of the value chain and the primary focus of regulation has been to deal with the economic externality of natural monopoly through price regulation and the provision of incentives to reduce costs. Although this has lead to an overall reduction in the marginal costs of operating the networks (Jamasb and Pollitt, 2007), a techno-institutional mismatch is being exacerbated as the need for capital investment increases and the requirement to deliver a more synergistic relationship between different segments of the value chain in order to satisfy long term energy policy goals becomes more apparent.

6 The CHP-DH Sector in the UK

This chapter charts the interplay between actors, institutions and technologies in the CHP-DH sector in the UK. This sector is more fragmented than that of electricity distribution because CHP-DH schemes are not interconnected at a regional or national level and there has not been a history of district heating in the UK as compared to Scandinavian countries for example. The interventions and interactions section charts recent developments in CHP-DH in the UK; particular attention is paid to the relationships between national policy structures and initiatives in the areas of energy policy and local governance, along with the responses of different local authorities in terms what technologies they deploy and how they organise and structure their local energy schemes. The outcomes section summarises how these socio-technical interactions are changing both the physical and relational dynamics of the sector and how these responses draw from different network logics. The chapter begins by introducing the governance regime and the key actors within the sector.

6.1 Local Authorities and CHP-DH

As has been discussed in chapter 4, due to the local nature of CHP-DH, local authorities (LAs) generally tend to be the focal actors in the development of schemes. Broadly there have been two types of scheme which have been developed by local authorities. The first type of scheme are those which have been developed on large council housing estates, over the years these have developed a poor reputation as they have often fallen into disrepair due to poor maintenance (UKGBC, 2010, interview - 32, 36). The second type of scheme are those which have been developed as part of a city-wide energy strategy which involves a mix of both public and private buildings and are typically located in or close to city centres. It is this second type of scheme that this chapter pays particular attention to; the map of the UK below shows the significant city-wide schemes which formed the basis for this study[97].

[97] These were chosen as they are the largest mixed use and highly interconnected schemes which are currently operating and based in and around city centres which serve both commercial and residential loads (demand). There are a number of other schemes in UK cities which although they are expanding or there are plans to do so (e.g. Glasgow, London Development Agency), do not yet constitute city-wide CHP-DH schemes, rather community schemes which typically are smaller and heat only. Examples include the Byker scheme in Newcastle which services a large number of council housing units, the Manchester Alexandra Park and Longsight Estates Heating Schemes, and Barnsley and Bristol where a number of council tower blocks are served by communal heating. A number of CHP-DH schemes were also looked at but did not form part of the basis of the chapter: developments such the MediaCityUK scheme near Manchester – a new development which does not serve the city centre - and a district heating scheme in Lerwick on the remote Shetland Islands.

Figure 6.1: Significant City-Wide District Heating Schemes in the UK

Southampton: Initially developed in 1986 following a Council, EU and government funded project to investigate a geothermal heat source. The scheme supplies heating and cooling to a range of city centre commercial properties e.g. ASDA and BBC. Over the years it has expanded to the quays area of the city and has 14km of pipe work. It uses gas CHP (5.7MWe and 1.0MWe CHP engines) and a geothermal heat source (8MW CHP) (IEA); supplies 40,000 MWh of heat, 7,000 MWh of chilled water and 26,000 MWh of electricity per annum.

Woking: Electricity, heating and cooling scheme (1.3 MW electrical, 1.6 MW heating; 1.2 MW absorption cooling) which services civic and private buildings since 2001. The scheme within the town centre links the civic offices and car park, the Holiday Inn, a niteclub and events centre, and has been expanded to service 240 dwellings (Thorp and Curran, 2009, Woking Borough Council, 2001)

- London: There are a number of schemes across London. The Pimlico DH system (three 8MWe boilers and two 2MWe CHP units) which services 3016 residential, 46 commercial properties; the Whitehall scheme (4x6MW boilers and a 4.9MWe CHP) which services 23 Government offices – the LGA plans in place to link the Pimlico and Whitehall systems (interview – 40) - The Citigen scheme located around the Smithfield Markets which mainly serves commercial customers, the Barkentine scheme in Tower Hamlets which supplies 8,000MWh of heat and exports 5,500MWh of power per year and services over 700 residential units on an East London estate, a nearby leisure centre and a local primary school (URS, 2010).

- Milton Keynes: A scheme developed by Thamesway Energy (a company owned by Woking council) in 2007 which supplies electricity and heat to some 800 residential and 30 commercial units from a 3.2MWe CHP plant utilising a 12.6MWh thermal store. It supplies heat and power to a new commercial and residential area in the west end of the city along with a number of buildings in the CBD.

- Birmingham: The system began operating in 2007 and supplies heating, power and cooling to commercial customers and civic offices in central Birmingham. The Broad Street leg of the scheme has a 1.6 MWe CHP unit which services a number of large city centre civic and commercial premises, the Eastside leg services a regeneration area along with Aston University, the children's hospital and council buildings (BDE, 2007). It has an additional 1.6MWe CHP. Overall the scheme delivers 6,700MWh and 41,000MWh of electricity and heat output annually.

- Leicester: An initial investment was made as part of the Lead Cities scheme in 1987 to service 4 large social housing developments with 2142 housing units and 13 public buildings (Taki et al., 1993). The scheme is in four parts with council buildings and a number of schools connected with approx 20km of networks. It is currently undergoing an expansion to the university and the prison with 15 civic buildings through 7km of insulated pipe work which is partly funded by the Community Energy Saving Programme (CESP)[98]. The scheme has 5MW of CHP.

- Nottingham: The Nottingham scheme is one of the largest in the UK and has been running since 1973 with significant refurbishments made in the mid 1990s. It services approximately

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[98] CESP is discussed in more detail in table 6.1

5,000 homes and 100 businesses using 65km of pipes. Energy input is from the 15 MW CHP Eastcroft Energy from Waste (EfW) plant (LG Improvement and Development, 2011).

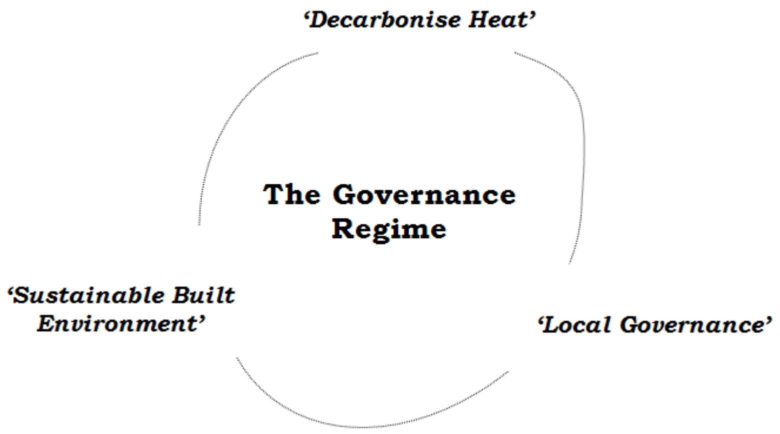
- Sheffield: The Sheffield scheme is also one of the largest in the UK with 44 km networks. The scheme was initiated in 1988 with the construction of a waste to energy plant for the city. The 19MWe CHP plant supplies many of the city's large civic and public buildings such as the Winter Gardens and the Victorian Theatre along with a number of council housing tower blocks (Veolia, 2009, Vital Energi, 2011)

- Aberdeen: The scheme began in 2001 and consists of three CHP plants (1 MWe each approx) covering 14 multi storey blocks and 8 public buildings including a sports facility and leisure complex. The scheme has recently been awarded a £1million grant to expand further.

6.2 Characterising the governance regime

This section describes the wider governance regime (Paavola et al., 2009) within which CH-DH is embedded, focusing in particular on the national level policy frameworks. Unlike incumbent networks such as gas and electricity, heat networks are not regulated by Ofgem as natural monopolies as there is currently little or no market for heating services in the UK. As a result heat distribution and local energy schemes operate within a wider national policy regime involving a number of government bodies in the energy and local government areas. In the figure below this governance regime is characterised according to three modes of governing; the sections below elucidate the rationalities, programs and instruments which are associated with these.

Figure 6.2: Modes of governing the heat distribution sector



'Local Governance'

Because local authorities tend to be the focal actors in CHP-DH schemes, a key aspect of the governance regime for decentralised energy scheme development is the changing relationship between national and local government in the UK. Traditionally, local government was structured according to a tiered system which emerged from the Victorian era; this included 'county, district/borough and parish councils' in London and rural areas along with a smaller number of single local authorities in the larger towns (Bulkeley and Betsill, 2003: p.60). The 1970s saw the amalgamation and rationalisation of a number of the smaller boroughs and following the 1982 Local Government Act, a number of unitary authorities which are responsible for all services were instituted in the larger urban centres (Bulkeley and Betsill, 2003: p.60) with the two tier system remaining in smaller towns, typically involving a borough/district council and a larger county council.

The core functions of local government cover areas such as education, health and well-being, environment and planning, transport, community safety, employment and skills, and housing and regeneration (Stoker, 2004 p.16). Until the 1970s, there was a greater degree of autonomy for LAs in the delivery of these services where 'it was possible to describe local authorities as the primary agents of local governance, as direct providers of services' (Bulkeley and Betsill, 2003: p.61). However, following the reforms of the Thatcher and Major governments, processes of deregulation and a rebalancing of power between the national and local levels have eroded this direct service provision role. Wilson and Game (1998) characterise the altered status of local government as having 'partial autonomy'- 'National governments can, through parliamentary legislation, create, abolish, restructure and amend the powers of local authorities as and when they determine'. They argue that the relationship has evolved from one of 'consultation, through corporatism, to confrontation and finally control'. Stoker (2004) proposes that following the election of New Labour in 1997, the nature of this relationship has changed once again where 'the debate about public service reform at least at the local level has moved beyond the concerns of new public management to an emerging concept of networked community governance' (p.10). Therefore, rather than a hierarchical relationship between the centre and localities; 'local governance has become more complex, with a wider range of public, private and voluntary organizations involved' (*ibid*: p.63).

One particular area relevant to CHP-DH where LAs have been granted a degree of autonomy is that of sustainability. Following the introduction of the Local Government Act and the Sustainable Communities Act in 2000 and 2007 respectively, local authorities have gained new forms of functional and financial autonomy in this area – in particular the 'power to do anything which they consider is likely to achieve' economic, social and environmental well-being in their area including incurring expenditure (DCLG, 2000). The Department for Communities and Local Government have stated that the Sustainable Communities Act 'begins from the principle that local people know best what needs to be done to promote the sustainability of their area, but that sometimes they need central government to act to enable them to do so (…) It is also a new way for local authorities to ask central government to take action which they believe would better enable them to improve the economic, social or environmental well-being of their area' (DCLG, 2008c).

Along with governance dynamics within the UK, the international climate change agenda is also delivering a more substantial role for local authorities in promoting sustainability (Bulkeley and Kern, 2006, Collier and Löfstedt, 1997). Local Agenda 21 (LA21), which was an outcome of the Rio Earth Summit in 1992, invites local authorities 'to draw up their own Local Agenda 21 in consultation with citizens, local organizations and private enterprises' (Collier and Löfstedt, 1997) to promote sustainability. The quote below from chapter 28 of LA21(UN, 1992) highlights this emerging local dimension to environmental issues:

> *"Because so many of the problems and solutions being addressed by Agenda 21 have their roots in local activities, the participation and cooperation of local authorities will be a determining factor in fulfilling its objectives. Local authorities construct, operate and maintain economic, social and environmental infrastructure, oversee planning processes, establish local environmental policies and regulations, and assist in implementing national and subnational environmental policies. As the level of governance closest to the people, they play a vital role in educating, mobilizing and responding to the public to promote sustainable development" (Quote is taken from Tuxworth (1996))*

Tuxworth (1996) notes that there has been strong response to LA21 amongst local councils in the UK and argues that 'the stripping away of powers from UK local authorities by national government, has perhaps made Local Agenda 21 (which Agenda 21 makes explicit only local authorities can deliver) an attractive area of activity for local authorities'. Similarly Collier and Löfstedt (1997) argue that '…local authorities consider the involvement in Local Agenda 21 and climate change policies as a means to regain some of the powers that have been taken away by central government (…) Local environmental policies can thus be viewed as self-defence and counter-attack mechanism, providing a new political space for local authorities'. An example of such a response is the 'Nottingham Declaration', launched in 2000 and signed by some 3000 LAs which commits signatories to; 'Work with central government to contribute, at a local level, to the delivery of the UK Climate Change Program' (Nottingham Declaration, 2000).

These trends have continued following the 2010 general election with emerging discourses surrounding ‘the big society’ and the appointment of a minister for decentralisation. The May 2010 coalition agreement stated that; ‘We will promote the radical devolution of power and greater financial autonomy to local government and community groups’ (HM Government, 2010a). The 2010/2011 Localism Bill, which is at the committee stage at the time of writing, proposes to grant a ‘general power of competence’ similar to that of the Fire and Rescue Authorities which gives local authorities ‘the legal capacity to do anything that an individual can do that is not specifically prohibited’ as well as new rights to community groups to take ‘over the running of a local authority service’ (DCLG, 2011a). However, in the light of public service expenditure cuts and limits on the borrowing capabilities of LAs there is uncertainty as to how effective these new powers will be (interview – 32).

‘Decarbonise Heat’

The uptake of CHP-DH is also contextualised by efforts to promote the decarbonisation of heating supply and promote demand side energy efficiency. As has been outlined in chapter 4, heat supply in the UK currently tends to be organised on an individual basis with domestic gas boilers which are connected to regulated distribution networks. Arising from concerns over the increasing reliance on imported gas and the need to meet climate change targets (heat accounts for over 41 percent of total energy consumption in 2006, 47% of total CO2 emissions and 60% of average domestic energy bills (DECC, 2009d)) the governance regime for heat is increasingly becoming part of the energy policy landscape and is affecting both the supply and demand side - these are discussed in turn.

As part of the overall efforts to deliver a low carbon energy supply in the UK, the electrification of heating (and transport) is being proposed as the most efficient long term trajectory – ‘the all-electric future’[99]. The work of the Committee on Climate Change (CCC), who provide independent advice to the government in relation to achieving the emissions reductions targets, has been particularly influential in this regard. Using the MARKAL macro-economic model, the CCC has been instrumental in proposing the electrification of heating using technologies

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[99] Speirs et al. (2010) critically review the ‘all-electric future’ as it relies heavily on ‘electricity-only thermal power stations, particularly fossil fired generation with Carbon Capture and Storage (CCS), with large amounts of primary energy lost as ‘waste’ heat’. They argue that ‘major system changes, may be under-represented in existing scenario analyses’ (p.15) and propose that a wider range of options, including a greater emphasis on CHP-DH, in order to benefit from generating electricity and heat close to demand and the potential benefits to the network associated with this e.g. reducing reinforcement costs. They also express concerns over the efficiency of heat pumps.

such as air and ground source heat pumps as a longer term strategy to meet targets[100]: The following quotation from their 2008 report highlights the rationale behind this:

> *"As electricity is decarbonised, it is likely that low-carbon electricity can be used to replace fossil fuels in space and water heating. Once the carbon intensity of electricity falls below about 200g/kWh it will be more carbon efficient to provide hot water and space heating with electricity than with gas burned in a condensing boiler, even using established technology such as electric bar or storage heaters (Figure 2.21). But far greater efficiency is possible with the use of heat pump technology. Ground-source heat pumps can deliver three to four times as much usable heat energy as they require in electricity input. The potential efficiency of air-source heat pumps is slightly lower (two to three times) but they can be deployed in many buildings (e.g. in dense urban areas) where ground source heat pumps are impractical. Either variant of heat pump can therefore already, even at the existing average UK carbon-intensity of electricity, deliver heat energy more carbon efficiently than gas." (Climate Change Committee, 2008: p.66)*

As a result, within the CCC analyses: 'There is a limited assumed role for district heating, reflecting uncertainties around technical and economic aspects of this option, with the possibility of deeper penetration as uncertainties are resolved' (Climate Change Committee, 2010: p.24). Along with overarching strategies for the decarbonisation of the energy system as a whole, specific policy instruments are being designed and implemented in order to promote the wider diffusion of different renewable fuels and heat generating technologies. Until recently UK renewable heat policies were based around the provision of capital grants, predominantly for biomass or small scale solar projects[101] (Connor and Xie, 2009). However, following the Renewable Energy Strategy consultation (BERR, 2008b) the case was forwarded for a financial incentive mechanism specifically for renewable heat generation.

A Renewable Heat Incentive (RHI) mechanism was proposed in the 2008 Energy Act which subsidises certain technologies 'on the basis of the quantity of heat generated – and so is similar in nature to the use of feed-in tariffs' (BERR, 2008b). As of 2011, the RHI is to be introduced on a phased basis beginning with the non-domestic sector and near commercial technologies and in 2012 phase II will support domestic technologies (DECC, 2011b) where the Treasury

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[100] 'Scenarios run by DECC suggest that around 30% of electricity, 12% of heat and 10% of transport demand will need to come from renewable sources if this target is to be met' (Spiers et. al, 2010)

[101] 'Community Energy Programme (grant, biomass, 2001-2007), Bio-energy Capital Grants Scheme (grants, biomass, 2002-), Community Renewables Initiative (small-scale, limited funds, 2002-2007), Clear Skies Initiative (grants, biomass & solar, 2003-2006) , Biomass Heat Acceleration Project (biomass heat, 2005-), Bioenergy Infrastructure Scheme (wood and straw supply chain, 2005-8), Low Carbon Buildings Programme (replaced Clear Skies), (grants, small scale RE inc. RES-H., oversubscribed, 2006-), Climate Change Programme Review (biomass, grants)' (Connor and Xie, 2009)

will subsidise a number of heating and cooling technologies[102]. The measures also include ‘premium payments’ to cover the upfront capital cost of installing equipment which qualifies, however this does not explicitly include DH as ‘there will be no specific ‘uplift’ for district heating installations’ (DECC, 2011b).

Efforts to reduce the carbon intensity of heating also include demand side measures, in particular efforts to promote energy efficiency. The issue of energy efficiency came to the fore following the oil crises of the 1970s and the subsequent liberalisation of energy markets throughout the 80s and 90s (Eyre and Staniaszek, 2005) and has since fed into the pursuit of ‘environmental policy objectives, both directly, through the reductions in energy consumption that might follow an increase in energy efficiency, and indirectly, by reducing the cost of adjustments to higher energy prices’ (Brechling and Smith, 1994). Traditionally energy efficiency has been framed as a market failure therefore ‘justifying government intervention in the market for domestic energy efficiency’ (Brechling and Smith, 1994). Brechling and Smith (1994) outline a number of such market failures associated with efficiency investments and a failure to adjust ‘efficiently to higher energy prices’:

- *Information*: Customers are poorly informed about different technologies and opportunities.
- *Benefits cannot be appropriated*: For example in rental properties where the owner may not be able to recoup the full benefits of an investment in energy efficiency.
- *Credit Market Failure*: There are issues relating to securing finance in order to make efficiency investments e.g. lack of collateral, poorer households with limited access to credit.
- *Uncertainty*: Uncertainty about how effective an efficiency measure will be because of future energy price fluctuations and changes in income.

In order to address these issues a number of policies relating to energy efficiency have been formulated in order to incentivise more efficient space and water heating in domestic premises and larger public and private sector buildings.

[102] Tier 1 technologies that are to receive support include biomass boilers, solar thermal, energy from waste combustion (biomass portion of waste), heating from biogas combustion – gas from waste, ground and water source heat pumps, biomethane injection into the gas grid, deep geothermal, renewable district or community heating (biomass), renewable combined heat and power (CHP), for biomass, biogas and geothermal. Different levels of support are to be given based on the technology type and size.

In the UK the predominant approach taken to address the above ‘market failures’ in the domestic sector have been regulated programs where obligations are placed on licensed energy suppliers to improve the efficient use of energy amongst their customers. The table below charts the evolution of these obligations which have been funded though a customer levy (Eyre, 2010):

Table 6.1: Energy Company Efficiency Obligations

Obligation	Year
Energy Efficiency Standards of Performance	Began in 1994 this placed an obligation on each energy supplier to achieve certain efficiency performance standards. Suppliers had scope to choose the best way of achieving this through insulation, lighting, appliance or heating measures.
Energy Efficiency Commitment	This was introduced following the utilities act in 2000 and saw a more direct role for government in setting the targets (Eyre and Staniaszek, 2005). The first phase began in 2002 and second in 2005. Addresses information and appropriateness problems. This saw a large increase in the level of expenditure with £400m collected in 2005 (Eyre and Staniaszek, 2005)
Carbon Emissions Reduction Target	CERT began in 2008 and is more directly related to carbon savings rather than an energy saving target. This has been extended until Dec 2012 (DECC, 2009c). Running parallel with CERT is the Community Energy Savings Program (CESP) which specifically targets funding for 4,500 low income areas[103] to address fuel poverty and delivered through community based partnerships between LAs, community groups and energy companies.
The Green Deal	After 2012 ‘The green Deal’ will be introduced. This signals a move away from the company obligation/regulated model where a levy is placed on customers, towards an incentive scheme for individuals to invest in energy efficiency. Households which do not qualify for the Green Deal scheme will fall under the Energy Company Obligation which will amalgamate CERT and CESP but focus on low income and ‘hard to treat’ households

[103] Areas within the ‘lowest 10% income decile in England and the 15% most income deprived areas within Scotland & Wales’ (Npower, 2011)

Eyre (2010) argues that these regulated programs have been successful ‘in helping to transform product markets (insulation, heating, lights and appliances), but less successful in engaging and restructuring the work of the key trades in the energy efficiency business, in particular those involved in day-today building maintenance and improvement’. Following CERT the proposed ‘Green Deal’ will de-regulate the energy efficiency market by shifting the emphasis from obligations on licensed suppliers to incentives for individuals and opening the market up to new operators. A key feature of the proposal is to deal with the credit market failure issue by introducing a ‘pay as you save’ model. This broadly continues the ‘market failure’ approach to addressing energy efficiency issues in the domestic sector.

For non-domestic customers, along with the EU Emissions Trading Scheme (EUETS), a Climate Change Levy (CCL) is chargeable ‘on the industrial and commercial supply of taxable commodities for lighting, heating and power’ (HM Revenue and Customs, 2011) e.g. electricity and gas; this applies to the industrial, commercial and public administrations sectors - local authorities are included in this. In large commercial and public sector buildings, along with non-energy intensive industries, the Carbon Reduction Commitment (CRC) has been introduced in 2010. This is a mandatory carbon trading scheme designed to promote energy efficiency. Under the scheme qualifying participants (those who consumed over 6000MWh of electricity in 2008) must report on their annual carbon emissions, and in 2012 will need to buy allowances to cover their emissions. It was originally designed so that savings would be recycled to the most efficient participants however as of budget 2010 this will be retained by the treasury.

‘The Built Environment’

A third area of national level policy making that is particularly relevant to CHP-DH are policies relating to building codes and standards. This is closely related to the energy efficiency policies described above but specifically focuses on the built environment and the energy performance of buildings, both commercial and residential, and are outlined in a number of building and planning regulations. Building regulations in the UK cover a number of issues, they ‘set baseline mandatory national standards for the health, welfare, safety and convenience of people in and around buildings, for the accessibility of those buildings, and for the reasonable conservation of fuel and power used by those buildings’ (DCLG, 2006) and have been put in place by the Department for Communities and Local Government (DCLG). Standards relating to the energy performance of buildings have been in place since the 1960s and increasingly these standards are affecting the carbon performance of buildings[104] where they outline minimum specifications in a number of areas such as 'improving the fabric of the building, e.g. through better insulation and sealing of the fabric, draught-proofing of windows and doors; improving the efficiency of heating and lighting; and through the use of lower carbon fuels and heating appliances' (DCLG, 2006).

In order to improve the efficiency of a range of building types and reduce the carbon intensity of the buildings, the government has introduced a number of standards and codes for existing residential and public buildings – they include the following (DCLG, 2008b):

- Energy Performance Certificates (EPCs) for homes and buildings. These became mandatory for private dwellings in 2008 when they are constructed or sold
- Display Certificates for public buildings
- Inspections for air conditioning systems
- Advice and guidance for boiler users

Aside from the mandatory standards for new homes which specify the 'conservation of fuel and power, health and safety, accessibility in buildings', the Code for Sustainable Homes (CSH) covers more generally 'sustainability in homes' (DCLG, 2006), covering a wider range of issues in the areas of energy/CO2, water, materials, waste, pollution, health and well-being, and ecology. This emerged following a consultation by the DCLG in 2006 (DCLG, 2006) which set out a target for achieving 'zero-carbon' development by 2016:

> *"New homes make up less than 1% of the stock every year. But, in 2050, around a third of the housing stock will have been built between now and then (...) That is why the Government has set out the ambition that we move towards zero carbon development over time. This means a transition first to low carbon development, through measures that drive down carbon dioxide emissions from homes, buildings and other infrastructure; and ultimately to zero carbon, i.e. zero net carbon emissions from new developments." (DCLG, 2006)*

The consultation document pays specific attention to three areas; the planning system, the building regulations, and the new code for sustainable homes; where 'the aim of the code is to increase environmental sustainability of homes and give homeowners better information about the running costs of their homes' (*ibid*: p.12). There are six levels to the code and it covers a

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[104] Part L of the Building Regulations introduced in 2002 deals with the conservation of fuel and power. Part L specifies 'minimum energy efficiency standards for the building fabric (such as walls, floors, ceilings and windows), as well as for space heating, hot water and lighting systems. Revisions to Part L came into force in 2006 following the introduction of the 2002 E.U. Performance Buildings Directive' (Greenwood, 2010)

range of areas such as waste, energy and building materials. The code is voluntary but the government has set out a number of targets for implementation:

Table 6.2: Targets for the CSH

Date	2010	2013	2016
Energy/carbon improvement as compared to Part L (Building Regulations 2006)	25%	44%	zero carbon
Equivalent energy/carbon standard in the Code	**Code level 3**	**Code level 4**	**Code level 6**

Source: (DCLG, 2006)

The definition of a 'Zero Carbon Home' has caused some confusion and uncertainty within the building industry (Greenwood, 2010) as it was 'requiring all CO_2 emissions to be mitigated on-site' (Zero Carbon Hub, 2009). In a subsequent study by the UK Green Building Council it was argued that '10% to 80% of new homes may not be able to meet the current definition of 'zero carbon' (UKGBC, 2008) and following this a new definition has been forwarded which includes a number of off-site 'allowable solutions' – which is likely to include CHP-DH - if the standard cannot be attained through built in efficiencies in the fabric and design of the dwelling and on-site, directly connected technologies such as microgeneration and renewable heating.

These measures have direct relevance for LAs as they have a key role in implementing national level policy guidelines and regulations. In the past LAs have played a leading role in the development of planning policy in relation to the sustainable built environment e.g. the 'Merton rule' which 'requires any new residential development of more than 10 units or any commercial building over 1000 square meters to reduce its carbon emissions by a certain percentage through the use of on-site renewables' (Solar Century, 2011). Also, Planning Policy Statements (PPS) which 'explain statutory provisions and provide guidance to local authorities and others on planning policy and the operation of the planning system' (DCLG, 2011b) can be used by LAs to tailor solutions suitable to a particular context in line with national regulations. In particular PPS1 for sustainable development and PPS22 for renewable energy outline a framework whereby individual local authorities can develop planning guidance within their areas (Local Development Frameworks) in line with national level priorities and local circumstances. PPS1 'mandates an evidence-based understanding of the local feasibility and potential for renewable and low and zero carbon technologies, including microgeneration, to supply new developments in their area' (UKGBC, 2010: p.16). This has been cited as an important mechanism to advance CHP-DH schemes in a number of examples (interview - 31).

Summary

The section above outlined the governance regime for CHP-DH in the UK. It is proposed that because CHP-DH is not regulated in a similar manner as other energy networks it is situated within a broader national level governance regime which is shaped by a diverse range of policy priorities and government bodies (UKGBC, 2010). This includes areas such as local governance and decentralisation, national energy policy priorities and regulations and planning codes relating to the built environment. Using the modes of governing framework (Bulkeley et al., 2005), the underlying rationalities, programs, institutional relations, and regulatory instruments were outlined. The table below summarises the governance regime for CHP-DH in the UK:

Table 6.3: Summary of the electricity distribution governance regime

Mode of governing	Rationality	Institutional Relations	Policy/Regulatory Instruments
'Local Governance'	Local authorities will become central actors in dealing with climate change and sustainability issues	Changing relationship between the national and local tiers of government	More autonomy being given to LAs and communities to deliver sustainability goals but with a reduction in central government expenditure
'Decarbonise heat'	Achieve national level carbon targets using supply and demand side measures	Much of policy is designed and implemented through DECC, CCC, Ofgem and the 'big six' energy companies	High level macro-economic modelling techniques and scenario analysis. A move towards incentives for individuals and companies to invest in efficiency and renewable heating technologies

'Sustainable Built Environment'	Reduce the carbon footprint of existing buildings and new developments	National level standards and regulations drawn up by the DCLG and implemented by LAs	Change building codes and standards to mandate carbon reductions, LAs have some autonomy in implementation

The next section outlines how various interventions and interactions involving LA involvement in CHP-DH schemes are shaping and being shaped by the governance regime described above. Following this, the outcomes section will discuss the emerging interplay between actors, institutions and technologies and the implications for the evolution of the sector

6.3 Interventions and Interactions

The previous section outlined the structures and modes of governing within which the CHP-DH schemes described above have been developing. Drawing from a series of semi-structured interviews with key stakeholders within the CHP-DH sector, this section explores in more detail how these schemes have been shaped though various interventions and interactions within the organisational field. This begins with a discussion of the different motivations behind local authority involvement in energy service provision such as dealing with fuel poverty issues within their own localities. Also, the different organisational models and financing arrangements that the schemes have adopted are discussed. It is found that local authorities structure their schemes according to their resources and level of risk they are willing to take on. The final sub-section explores how CHP-DH at the local level interacts in different ways with national energy regime structures such as electricity markets and regulatory licensing regimes. In line with transitions theory it is found that local energy niches face significant barriers as they interact with regime structures which tend to be institutionalised at the national level. The outcomes section explores the implications and the nature of the relationship between institutions, actors and technologies in this particular case.

6.3.1 The Evolving Role of Local Authorities in the Energy Sector

Chapter 4 outlined how prior to WWII local authorities were the dominant actors in the direct provision of energy in the UK. However, nationalisation and a technological trend towards interconnection and scale saw the amalgamation of many of these municipal schemes into regional monopolies and eventually led to national level coordination of a centralised electricity system (Hannah, 1979). The years of municipal dominance of the energy industry was seen as out of step with the techno-economic paradigm (Freeman and Perez, 1988, Perez, 2002) of centralised generation and the aggregation of loads to achieve economies of scale. This situation pervaded throughout the period of state ownership and, leading up the privatisation of the energy industries, the 1973 Local Government Act precluded LAs from selling electricity to the grid unless it was part of a CHP installation (DECC, 2010a) [105]. As a result local authority involvement in direct energy provision has diminished greatly from its pre-nationalisation status, and aside from a small number of CHP-DH schemes (Russell, 1993), their role with respect to energy had largely been relegated to the energy management of their own estates; energy supply became the preserve of the national energy bodies.

However, the liberalisation of the energy sectors throughout the 1980s prompted efforts by local authorities re-engage with the energy sector and to align themselves with the emerging logic of a market-led energy system. In approaching energy management they began to regard themselves as commercial entities and 'strive for efficiency' (interview - 25). Rather than investing in significant capital assets, efforts concentrated on saving money by promoting the use of energy more efficiently within their own estates. One interviewee who was in charge of a council building services unit in the 1980s notes that this prompted LAs to develop more comprehensive energy strategies:

> *"Back in the early to mid 80s the only thing that people really thought about was saving energy for saving money. Energy prices were beginning to go and so anything that you could save immediately got you to the bottom line, it was a net saving in revenue and that had appeal. Not only did it have appeal but was being encouraged anyway (...) So an energy policy was introduced in 1986" (interview – 32)*

However, Guy and Marvin (1996a) note that this trend towards 'local energy management' which emerged following liberalisation became 'disconnected from the commercial and regulatory forces shaping local energy economies' (p.145) and therefore tended to take place on an ad-hoc basis as there was 'no statutory basis for any form of subnational energy-related planning' (p.146).

Although ad-hoc and uncoordinated, a number of interviewees noted that these energy management programs laid the foundation for more sophisticated carbon management plans which have emerged in more recent years (interview – 26, 31, 32). In some of the schemes surveyed, an early focus on reducing energy related costs following liberalisation have evolved

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[105] This has been changed recently to allow councils avail of the feed-in tariff subsidy: "These Regulations provide that local authorities can also sell electricity which is produced from the following renewable sources: wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogases." (HM Government, 2010b)

into more sophisticated carbon management plans and a longer-term strategic perspective (interview - 26, 31, 30, 32, 34). Along with the CCL which was introduced in 2001, this has been supported by voluntary schemes such as the Carbon Trust's 'Carbon Management Plan' and 'The Local Authority Carbon Management Programme'. As a result 'many local authorities have built upon their role as major energy users to develop programmes of energy-efficiency and conversion measures, with innovative local authorities developing sophisticated energy-management strategies for their building stock' (Guy and Marvin, 1996a). Following from this there has been a growing sense that LAs need to 'drive action for the sake of their population in their district rather than just their organization' (interview - 28). Reflecting this evolution the same interviewee who had been involved in building services management since the 1980s reflects on how carbon management plans have evolved from earlier concerns over energy costs and efficiency:

> *"Yes there is a carbon management plan, it was adopted in March of 2008 and it replaced what was the energy efficiency policy that had been in place since 1986. So one replaced the other and not surprisingly you can see how the two are very very closely linked (...) the two are intrinsically linked anyway because energy is tied to carbon" (interview - 32)*

Another interviewee who has been involved in developing a large CHP-DH scheme describes how this evolution has resulted in the adoption of carbon reduction targets at the local level:

> *"Part of that was reducing carbon emissions by [a] carbon management program where we set ourselves targets for reducing carbon across a whole range of different facilities. Back in 2002 (...) we met and had a conference and as a result of that we developed an action plan for tackling climate change and mitigation. It just followed on from that really, looking at a whole range of different things to see how we can deal with carbon emissions and greenhouse gas emissions." (interview - 34)*

In many of the cases this re-engagement is being manifest in the development of detailed city/local level energy strategies which identify local opportunities and begin to engage with wider governance regimes at the national level (interview – 28). A number of these initiatives such as the Mayor of London's energy strategy have received a great deal of attention and have grown in prominence, in particular the Mayor of London's energy strategy which states that:

> *"How we use energy is fundamental to long-term sustainability. If London is to make a significant contribution to the reduction of greenhouse gas emissions we need to restrain our use of fossil fuels, encourage greater energy efficiency, and promote renewable energy. Implementation of the Mayor's Energy Strategy will help to mitigate climate change by reducing carbon dioxide emissions. This Strategy has wide implications, promoting new kinds of fuel for transport and encouraging high performance buildings with less demand for energy" (GLA, 2004: p.iv)*

And

> *"London should maximise its contribution to meeting the national target for combined heat and power by at least doubling its 2000 combined heat and power capacity by 2010 (...) The expansion of heat distribution networks will be critical to the success of CHP in London, which in turn will have a huge influence on London's ability to achieve its CO_2 emissions reduction targets" (ibid: p.76 & 80)*

In the CHP-DH cases, councils are drawing legitimacy from their historical role as energy suppliers before nationalisation (interview – 30) when 'local authorities in the UK would have been running gas and electric companies' (interview - 38) and are leveraging their role as significant energy users to expand their influence and begin to consider energy provision within their wider localities (interview – 27, 36, 37). Also, due to the fact that the distribution of heat tends to favour local actors who have better knowledge of the nature of loads in a particular area and the potential to develop a local market, CHP-DH has emerged as a key link in the emerging relationship between local authority energy strategies and the wider governance regime at the national level. There are a number of motivating factors which are shaping these local responses:

Reducing Fuel Bills

A key rationale behind LA involvement in CHP-DH is efforts to reduce the fuel bill of both the council itself and tenants in social housing. As has been noted in the previous section, since the liberalization of the energy sectors in the UK, councils have increasingly sought to promote energy efficiency on their own estates and more recently this has evolved into sustainable energy and carbon action plans. Increasingly efforts to address fuel poverty have become part of this agenda: The table below shows the increase in the levels of fuel poverty[106] that has occurred in the UK since 2003-2004:

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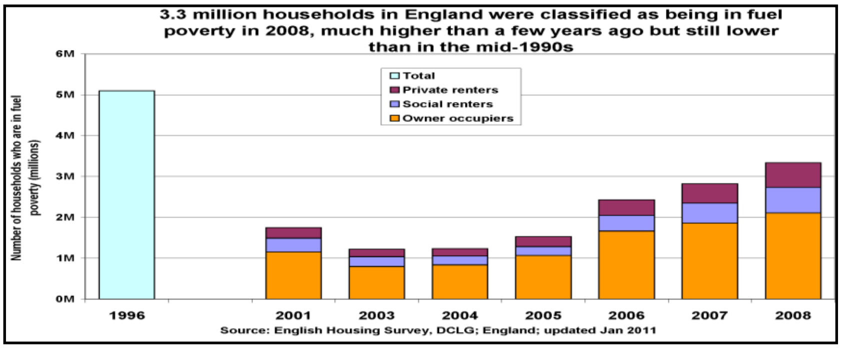
[106] 'Households are considered by the Government to be in 'fuel poverty' if they would have to spend more than 10% of their household income on fuel to keep their home in a 'satisfactory' condition' (The Poverty Site, 2011)

Figure 6.3: Fuel Poverty Statistics for UK



Source: (The Poverty Site, 2011)

As has been noted above, the role of local authorities is to deliver public services within their localities, and arising from the Local Government Act and the Sustainable Communities Acts (2000 and 2007), they have been granted increasing autonomy 'to do anything which they consider is likely' (DCLG, 2000) to improve well-being. In the light of increasing levels of fuel poverty this has prompted local authorities to address the issue in a more direct fashion. This is particularly the case within large city councils, often in former industrialized cities in the north of England e.g. Sheffield and Nottingham and in inner city areas with a large social housing stock in densely populated inner cities e.g. London, Aberdeen. An interviewee from one of these cities describes this as a key motivation for developing CHP-DH infrastructure:

> *"For us fuel poverty. We recognize that we have got many deprived communities; it is a good old socialist intent in many respects. The majority of people will be in fuel poverty if we don't do something to try and alleviate that, so I think that is a political driver, it's fuel poverty, deprivation and the rising cost of energy" (interview - 33)*

Although there has been a longer term trend towards a decrease in fuel poverty since the liberalization of the electricity sector in the UK in 1989/1990 (Pollitt, 2008), there are concerns that liberalised energy markets are having a detrimental effect on fuel poverty rates by making customers more venerable to volatile fossil fuel markets and prices (interview – 33, 37). The following quote from an official in a large council in the north of England illustrates how the council is using this to legitimize more direct involvement in energy provision:

> *"It is worrying because liberalising the market has not achieved a reduction of fuel poverty (...) we know that in terms of energy consumption, the wealthier areas consumed significantly more energy than the poorer areas even though they have all the opportunities to invest and reduce their energy consumption but they choose not to, so that is one of the big challenges" (interview - 37)*

A notable illustration of this is Aberdeen City Council which developed an Affordable Warmth Scheme in 1999 and following a study into the energy efficiency of the council owned multi-storey blocks, they began to invest in CHP-DH. This has since expanded to service other civic buildings within the city (EST, 2003).

Promoting Low carbon Development

A second significant motivating factor behind local authority involvement in the development CHP-DH has been to promote low carbon development within their localities. A similar theme has been explored in Hodson and Marvin's study of climate change strategies in large 'World Cities'; they argue that energy strategies are in part driven by efforts to improve the economic competitiveness of a city in a low carbon context (Hodson and Marvin, 2011). They note that '…territorial priorities at the scale of the city – economic growth targets, carbon emissions reductions aspirations and so on – are becoming strategically intertwined with the reconfiguration of socio-technical infrastructure systems…' (p.138). Similar processes are at play in developing CHP-DH schemes in large, medium and small sized cities in the UK. Interviewees saw low carbon infrastructure as a key strategy in attracting developers to an area (interview – 31), promoting local job growth (interview – 33), regeneration (interview – 27) and competing with other cities for investments (interview – 38).

This response is closely aligned with the ongoing institutionalization of sustainability and low carbon energy in planning guidance. As one interviewee notes; 'all local authorities need what is called a local [development] framework in order to guide planning, and we had our local development framework well underway for development until the government about two years ago came up with PPS1, planning policy statement one supplement, which then changed the basis on which you would write to your LDF[107]' (interview - 31). Some of the councils are keen to use CHP-DH to attract new developments; for example, within Woking Borough areas of the town have been zoned 'and depending on which zone you are developing in, you might be expected [to] either connect your development to an existing network (…) or provide a financial contribution towards a network' (interview - 38).

As the following quote suggests, some of the more proactive councils have begun to institutionalize sustainable energy within their planning strategies and guidance with CHP-DH being a key part of this:

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[107] Local Development Framework

> *"So you have got certain statutory solutions like the Merton 10% rule (...) If we ask for 40% we have got to be able to prove that that 30% is feasible and possible (...) An allowable solution would be (...) when a developer says that I can't do it on the building, do you have a low CO_2 option that I can connect into? And that is where our sustainable energy (...) system comes in. We say yes, if you pay to connect to us we can provide you with the low CO_2 energy" (interview - 31)*

Ensuring Energy security and long term resilience

A third motivation for local authorities to develop carbon management and energy strategies and invest in low carbon infrastructure has been issues of energy security and long term resilience. This is prompted by a view that the incumbent energy companies and the regime of energy provision in the UK will be unable to achieve national targets and reinvest in the energy system, thus leaving cities vulnerable to severe price rises or supply shortages. These concerns are highlighted in the following quotes from local authority officers:

> *"The more fundamental issue for the government will be overall energy supply, because I think the UK hasn't come to terms with the fact that it has failed to address its ageing energy infrastructure both in generation and distribution" (interview - 26)*

> *"I think we can see the vulnerabilities of the UK energy system, and we have not had a really honest and coherent energy strategy for far too long. I think we see that there is increasingly a requirement and a responsibility for local government to get a grip on some of these things that national government perhaps is not doing. I think we realized that the challenges are big, we are big-city with a half 1 million people, 200,000 homes, and yet we are entirely reliant on deals that are struck for the supply of gas and coal and oil at a national level, and yet we also recognize that we have got significant natural resources in the city, and man-made resources that we can exploit far more effectively. So we want to insure that the city is sustainable in the long term and we do not have the confidence that they are is a clear plan at the moment. Essentially what we are saying is that local authorities need to take a stronger role in local energy generation" (interview – 37)*

These perceived inconsistencies at the energy regime and landscape levels are prompting some LAs to 'take a much more prominent role in developing it because the utility companies are not coming forward' (interview - 37). Arising from these concerns, a number of interviewees expressed a view that through the development of local infrastructures cities can 'build long-term resilience' and 'develop some sense of self-sufficiency around energy' (interview – 37).

Summary

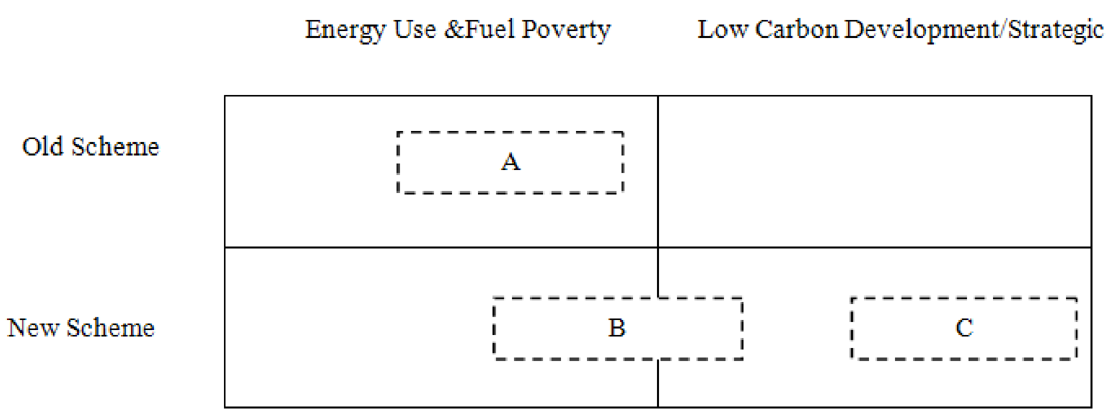
Throughout the period of liberalisation the relationship between LAs and the energy sector has evolved from a passive customer-producer relationship to one where a small number of leading

LAs are beginning to actively shape energy institutions within their own localities and make large scale infrastructure investments. This has been occurring in the context of national level policy drivers such as more autonomy for LAs in the delivery of certain services and more comprehensive building efficiency standards. In the cases surveyed CHP-DH has emerged as a key strategy to negotiate between these drivers in a strategic manner and deliver a sense of long term energy security and resilience.

6.3.2 Types of Local CHP-DH Schemes

Each of the CHP-DH schemes surveyed is organised and structured according to the particular context within a locality and the resources and motivations of the relevant LA. In order to synthesise this, the 2x2 matrix below identifies three types of CHP-DH scheme according to the main motivation behind the scheme – whether this is based on efforts to address rising energy prices and fuel poverty or it is part of a city-wide strategic development initiative - and whether the scheme has been initiated in the past 10-15 years when climate change has become part of the energy policy landscape or whether the scheme had been in place previous to this.

Figure 6.4: Types of CHP-DH scheme



Type A schemes tend to be within unitary authority cities where CHP-DH investments had occurred in the past often as part of the Marshall and Atkins Reports e.g. the lead cities program and subsequent publically funded investments which took place in the 70s and 80s (see chapter 4). Examples include Nottingham, Leicester, and Sheffield - these are amongst the largest city-wide schemes in the UK. LAs in these cities tend to have as their primary motivation the provision of local services and improving the well-being of residents; in particular addressing the issues of fuel poverty as these cities have large social housing tenants (interview – 33, 37). The schemes were initially built by council owned and operated bodies, such as Sheffield Heat and Power, but in the case of Sheffield the contract for waste collection and energy services have been tendered to private operators (Veolia Environmental Services), while in the case of Nottingham these functions have remained in-house within a council owned body (Enviroenergy). In these cases, after the networks were constructed in the 70s and 80s they sometimes fell into disrepair due to poor maintenance and reputational issues (they were associated with dirty fuels and inefficiency) (interviewees – 33, 37, 38). However, in more recent years due concerns over rising energy prices and climate change, LAs are beginning to view these schemes as a valuable resource and are expressing a desire to redevelop and expand the schemes which had tended to be run in an arm's length fashion and removed from the councils' core agenda (interview – 33, 37).

An interviewee from one of these cities describes how the CHP-DH scheme which is fueled from waste collected within the city has only recently become economical in part due to the Renewable Obligation Certificate (ROCs) scheme. This shift in perception can be viewed in terms of the 'opening up of closure' as described in the SCOT literature (Murphy, 2006b, Pinch and Bijker, 1987):

> *"I think we have had the incinerator from the 1970s (…) we are quite lucky in many respects, so a lot of our current renewable energy is delivered by and large by the district heating scheme. And we have gone through phases really with that; now we recognize it as an asset but for years it has been a liability, the council has had to prop it up by several million pounds each year until this year (…) Bear in mind that this has [been a] cost up until this year so, why would we wish to increase our level of subsidy. We were thinking about reducing cost, paring back the management structure, making sure that we are a lean mean organization that minimizes the liability. Our thinking has fundamentally shifted in the last year; we now recognize that as a fantastic asset that is key to our energy aspirations, we need to have a plan for expansion and growth of that scheme which is why we are expanding the infrastructure at the moment" (interview - 33)*

Type a schemes have taken a slightly ad-hoc approach where many of the earlier schemes, which were initially focused on energy management in the council buildings, expanded in an uncoordinated and piecemeal fashion, tending to take advantage of opportunities such as grant schemes as they arose.

Type B schemes such as those in Birmingham and Aberdeen are newer systems which have a mixture of motivations; both seeking to address fuel poverty issues but also to use CHP-DH to enhance the economic development of the city (interview – 30, 34). Unlike type 'A' schemes, these cases did not have significant upfront capital investment; therefore they are evolving from smaller projects which over the years have started to become amalgamated. This is a polycentric approach where a city picks off the low hanging fruit in terms of the large loads in city centres and over time seeks to join these up to create a city-wide scheme (Interview – 30, 34), this is a more pragmatic approach. In this case the developer of the scheme identifies the low risk anchor loads first, usually large public buildings, and then moves down the hierarchy in terms of loads. For example, in the Aberdeen case they ‘started off with islands’ and began ‘linking them all together over a period of time’ (interview – 34). This began with identifying the areas of high heating demand, which were within the high density multi-storey blocks, and have since begun to expand into the city centre areas. In the Birmingham case, the scheme began with the Broad Street scheme which services a number of the large commercial and civic units in the city centre, and a newer set of pipes which services the Eastside area of the city including Aston University and the Children’s hospital. Over time there is an intention to link these and also to expand the LAs low carbon heating strategy to the suburban areas of the city (interview – 30). In these cases the local authority has been instrumental in seeking out new markets and customers for an expanding DH scheme and there tends to be a mix of goals associated with this including energy efficiency, attracting new developments and fuel poverty (interview – 30, 34, 38). The role that the council takes on in these cases is predominantly as a long term anchor customer who coordinates the activities of a range of stakeholders across a city and provides a strategic backbone to a scheme.

Type C schemes are also recent developments but which have more of a strategic element to them and the CHP-DH scheme is closely aligned with the city’s long term strategic aims and with the overarching governance regime of heat and energy;

- by using a scheme to attract new developments and engage with planners (interview – 31) i.e. using CHP-DH as a catalyst (interview – 30)
- by engaging directly with customers and helping them to be more efficient
- by integrating across different infrastructures to diversify across fuel sources and to take advantages of economies of scope at a local level e.g. waste, cooling, electricity and heat, gas/biomethane

These schemes such as Southampton and Woking tend to be the frontrunners and risk takers and they have been involved in trialing new technologies whilst importing best practice techniques from European countries. For example, the Southampton scheme emerged from an experimental trial of using geothermal energy as a heat resource; the system has since expanded to become one of the largest commercial schemes in the UK. The Woking case is often cited within the emerging sector as a frontrunner within the UK (interview – 26, 27, 31, 36, 38) as it has been successful in developing an organizational model around the scheme which integrates CHP-DH with the planning section of the council and uses its infrastructure to leverage in new developments and make the area more attractive for commuters to London (interview – 31). The CHP-DH scheme acts as a key strategic tool in the long term future of the city and has raised the profile of the council e.g. Woking council has recently been awarded Beacon council status for supporting sustainable communities. Often these types of schemes are more sophisticated and there is a desire amongst A and B type councils to move towards this more integrated and strategic approach (interview – 30, 33, 34, 37, 38) - as one interviewee from a type B council outlines:

> *"Our planning system isn't as robust as it needs to be in prescribing district heating. So we have a planning policy that is very similar to most other planning authorities (…) It's doesn't recognize the unique opportunity that [we have] with the district heating scheme, and it needs to. So as part of the local development framework review process, that has been fed into our planning colleagues and will strengthen planning policy to make that a little bit more of a prescribed process in favor of district heating" (interview - 33)*

Woking Borough Council in particular stands out as having a longer term strategic perspective and a number of authorities are seeking to move in this direction e.g. the London Development Agency (LDA) have proposed the Thames Gateway Heat Network[108] which is planned will link the existing fragmented schemes together across London.

The table below summarizes the three main types of CHP-DH schemes in the UK:

Table 6.4: Summary of types of CHP-DH scheme in the UK

Type	Characteristics	Examples	Rationale
A	Existing infrastructures which had a poor reputation are being redeveloped	Sheffield, Nottingham, Leicester	Main rationale is to promote the well-being of residents and address fuel poverty
B	Recently developed fragmented infrastructure which is being linked and expanding across the city	Birmingham, Aberdeen	Mixture of fuel poverty and low carbon development drivers
C	Risk takers who are more strategic and integrated, are	Woking, Southampton	Uses CHP-DH to Integrate planning and

[108] http://www.ltgheat.net/heat-network/

	frontrunners in terms of technologies deployed		energy policies to promote the long term development of the locality

Amongst the types of schemes described above councils can often play a number of roles:

An Enabler:

As an enabler the council actively generates a market for heat and funds the expansion of a particular scheme; this is typically the case with type c schemes such as Woking. 'Local authorities have relevant planning powers and the ability to coordinate between developers and potential customers given their network of relationships with controllers of large heat loads (e.g. social housing groups, NHS trusts and public buildings)' (PÖYRY, 2009). One interviewee who has been involved in coordinating a government funding program for district heating notes that

> *'There are various roles, in some cases they will commission and contract with those providing or delivering the networks so they are procuring aswell. The fact that they have got all of those things in one place gives it a catalytic role to sort of do this thing, particularly in the digging up of the streets which is a bit of an issue for some of these networks alongside other statutory undertakings" (interview – 27).*

A Promoter:

In some cases councils also promote the schemes by using their reputation and trustworthiness to attract customers (Interview – 25, 29, 30, 37). One council official outlines this approach;

> *'We also have a strategic role in trying to encourage other people in trying to connect to the scheme, we champion it and you will have picked up that we sort of promote it. We promote it as a single issue (…) scheme and we promote connection to it as well to develop the new schemes and new developments' (interview – 25).*

A Customer:

In order to make schemes more viable, councils often act as an 'anchor tenant', typically in a dense built up area e.g. a city centre, in order to provide long term stability and reduce risks for the investment required to lay pipes. For example, as one interviewee notes, they are often the first customer to connect to a scheme because 'you really need that local authority leadership and perspective and one of the ways they are looking at rolling this out is by having the public buildings, the kind of first physical infrastructure willing to take on the heat' (interview – 36).

This first mover role often acts as the ‘bedrock contract and that then gives other customers the confidence to join’ (interview – 39).

An Investor:

In the absence of private sector funding, Local Authorities have the ability to access cheap finance by borrowing against their own assets, using the UK government’s prudential borrowing facility or accessing a range of UK and EU grants for investment in local level infrastructure (interview – 27). They can also use their status attract various sources of public funding for the expansion of a scheme (the sub section 6.3.4 will explore the financing of CHP-DH in more detail).

Although local authorities tend to be the focal actors in local energy systems as schemes tend to be either under their control or based around their energy demands, they are not always involved in the day-to-day operation of a CHP-DH system.The role(s) that a local authority takes up is largely dependent on the organizational model they chose to adopt which is a function of their resources, capabilities and willingness to take on operational and investment risk.

6.3.3 The Organisation of CHP-DH Schemes

This sub-section explores in more detail the various ways in which CHP-DH schemes are being organised and in particular how this shapes local authority involvement. As is noted in much of the evolutionary based innovation literature, technological change cannot be considered in isolation from organisational change (Stenzel and Frenzel, 2008, Chandler, 1990, Schumpeter, 1939). For example, in the case of large scale energy infrastructures, the development of centralised electricity grids in the mid twentieth century relied upon an industry structure which allowed investors to get a regulated return on large scale investments and enabled the massing of consumption, thus achieving the system goal of economies of scale and to ‘sell as much power as possible as cheaply as possible’ (Fox-Penner, 2010: p.6). Studies of CHP-DH schemes also emphasise the importance of developing an appropriate organisational model within the focal organisation themselves (in this case the local authority) and also how a wider network of actors are coordinated with the purpose of reshaping local energy technologies and institutions. In her study of CHP-DH in a Swedish town Summerton (1992) noted that ‘shaping a district heating system places considerable demands on organisational capacity’ (*ibid*: p.13). Here two dimensions of this organisational capacity are explored in detail; the first is how local authorities, as focal actors, have brought about change within their own organisations and secondly how they interact with a range of stakeholders to develop local energy infrastructures.

Shaping Organisational Change within Local Authorities

Thomas Hughes' insights regarding the role of individuals in shaping early stage energy infrastructures (Hughes, 1983) are relevant to the case of city-wide district heating schemes in the UK. Hughes stressed the importance of motivated and entrepreneurial system builders in overcoming both the technical and non-technical barriers to system building. Similarly, in her analysis of low energy housing in the UK, Lovell (2009) explores the role of entrepreneurs who have been instrumental in developing sustainable housing experiments and influencing the wider policy environment. Following interviews with a number of local authority officers who had been involved in CHP-DH, it emerged that the role of such entrepreneurial individuals within councils has been a key element in shaping the both the material and organisational approach to low carbon infrastructure – a number of the interviewees referred to these as 'champions' (interview – 39, 30, 36).

As the following quote from a policy officer who has been involved in advocacy on behalf of a number of LAs suggests, this reliance on individuals is largely due to the lack of an overarching regulatory and policy framework for non-incumbent energy infrastructure in the UK:

> *"...to get a champion or having the expert does make a big difference, and having that skill set does make a difference about whether you were able to get that project off the ground, it is really really important (...) You either have this very central government 'you will do this you will do that'; then you have no autonomy for the local circumstances, or you to rely on these gifted people" (interview - 36)*

Within this vacuum there tends therefore to be a reliance on individuals within the councils to drive the technological and political agenda and in a number of cases these individuals have gained a high profile. One prominent example is Allan Jones, originally the building services manager with Woking Borough Council, who has since moved on to head up climate change strategies at the London Climate Change agency and the City of Sydney. These individuals are important because organisations such as local authorities are known for their reluctance to take risks. For example one interviewee who has been involved in working with local government on energy projects argues that 'local authorities are basically set up not to make decisions because decisions cost money' and that the bureaucratic nature of the organizations themselves make change of any type difficult because 'there is a whole serious of checks and balances within the local authority that means that (…) decisions go through a sorting process and they can be stopped at any level. So even a decision that has gone through all of the minor levels is stopped higher up' (interview – 39).

The political nature of councils means that there are a number of tiers of decision making within a centralized and hierarchical structure which makes individuals or technical and political champions particularly important agents of change within this highly structured environment. An energy consultant who had previously worked in a council engaged in developing energy schemes notes that:

> *"…if you don't have the people with the desire and the drive or the knowledge to solve it then it just goes nowhere and it just fizzles out. There are lots of examples of people in local authorities going 'yeah why don't we do this' (…) But they will inevitably come up with their own problems and constraints that stop [you from] doing it, and if they don't have the resources to get over them it fizzles out. It is even worse because when it fizzles out people say that we tried that last year so we're not doing it next year" (interview - 28)*

In order to bring about the organizational changes necessary to develop long term infrastructure projects, policies and strategies across a number of departments need to be aligned e.g. planning, building services, finance, legal, procurement etc. This requires the co-coordination of a diverse set of actors across the organization 'so that you can bring in your procurement teams and your legal teams and you bring in anyone else across the council', a CHP-DH champion within a council is 'someone who's going to project manage the whole thing, and who is able to get partners in and is able to work with the private sector, because you need to be able to get at that funding' (interview – 36).

The roles of a champion in this sense are to possess and harness the knowledge necessary to develop a scheme (interview – 26, 36), to coordinate actors within and outside the council, to engage with politicians on the council in order to convince them of the long term benefits of CHP-DH investment, and to de-risk the long term investment. A champion is required to get the infrastructure issue 'elevated up through the organization and get it right at the top, that high level buy-in' (interview - 30). The central role of a political champion, often a prominent councilor, is outlined by the following interviewee who works on the technical side of a city-wide CHP-DH scheme. The quote emphasizes the importance of creating long term stability in an environment where the make-up of the council can change due to the political cycle:

> *"He bought in to the scheme very early on, he came on the visits with us [and] we went to look at other local authorities (…) and he bought in, so we have (…) buy in at that high level. One of the things that helps drive that through was when, and you do get barriers to certain things like this, people say; 'is it right having 25 year contracts'. You will always get the skeptics" (interview - 30)*

Another interviewee from a company who works with a number of councils in developing schemes argues that both a technical and a political champion are necessary to drive a scheme through the layers of decision making within a council and achieve the necessary coordination between different departments:

> *"We believe that every successful scheme is spawned from a public sector champion on the grassroots level and also a public sector champion on a senior-level within any Council. All of our schemes share that and it is essential that all parties buy into the scheme and its benefits, and again that political will is, if you like, for driving through the scheme"* (interview - 29)

The following table outlines the roles that both technical and political champions have played in bringing about the organizational environment necessary for the development of CHP-DH:

Table 6.5: The role of technical and political champions

Technical Champion	Political Champion
• Develop knowledge and capabilities of the building services/energy management department • Learn from other successful schemes both nationally and internationally • Coordinate actors from a number of council departments • Scope out the potential demand for heating within the locality and develop an overall strategic vision for the expansion of the scheme • Manage the contractual arrangements for the building and operation of the scheme	• Place CHP-DH on the political agenda • Enroll other councilors from across the political spectrum and create an advocacy coalition • Help to de-risk large scale investments by displaying a commitment to long term infrastructure development regardless of the political cycle • Use CHP-DH to advance the sustainability/low carbon agenda and raise the profile of the council

In the case of Woking Council, a leader in this area, the council Chief Executive[109] who was involved in developing the energy strategy of the council since its inception, argues that 'it's a combination of political and technical, managerial' requiring 'strong political leadership and direction, managerial support and technical support. And if you can't get those three aligned it doesn't work' (interview – 26). An illustrative example of the importance of this interdependency between the technical and the political came when the council owned energy company, Thamesway Energy, made a large investment in a CHP-DH scheme in central Milton Keynes. Due to the economic slowdown in 2008 a number of the buildings that the scheme was due to service had not been built resulting in stranded assets. The CEO noted; 'it brought criticism that we were undertaking this work outside of our borough' and as a result the ambitious program of expanding to other areas outside the borough has been stalled due to a lack of political support. The CEO notes that the 'set back we've had means there's a less ambition to go and set it up outside the Borough, so members don't want us to take that business

[109] This interviewee agreed to be directly quoted

line and do any more' (interview – 26). This example highlights the political nature of making large scale infrastructure investments and the need for a virtuous circle between both the technical and political elements of a CHP-DH scheme.

Creating Multi-Organisations

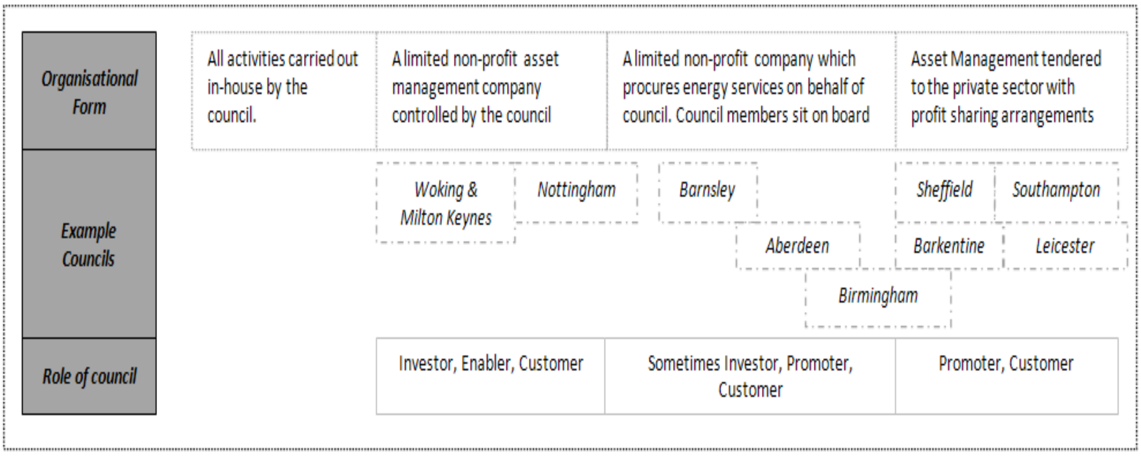
In order to develop successful CHP-DH schemes, local authorities must also interact with a range of stakeholders such as customers, consultants, contractors, regulators, financial institutions and so on. In her study of the development of a district heating scheme in Sweden, Jane Summerton highlights the importance of what she terms a 'multi-organisation' or an 'invisible –grid' where actors 'functionally interact to achieve a shared purpose, performing different roles in support of the system (…) this may be centered around a central body or "focal organisation" that has specific planning, coordinative and decision-making functions' (Summerton, 1992: p.79). As described above, LAs are the focal actors within CHP-DH schemes and can play a number of roles from being an anchor tenant who improves the financeability of local infrastructure, to being an investor. These 'multi-organisations', which bring coherence to a sometimes fragmented set of energy institutions and technologies at the local level, are unique to each of the schemes involving different relationships between public and private actors and different approaches to the planning and operation of the energy systems themselves.

Key variables in the organisational structure of CHP-DH schemes include the willingness of the council to take on investment risk, the council's priorities and the resources available to LAs and their organisational and technical capabilities (interview - 36). It has already been pointed out that in the past some of the schemes (such as the lead cities) would have been owned and operated by the council themselves, but in modern schemes councils can take up a multitude of roles and in some cases are not directly involved in the day-to-day running of the system. In each of the cases surveyed, councils have either set-up arms length organisations –termed Energy Services Companies (ESCOs[110]) – or have entered into contracts with private sector

[110] Following the 2003 Local Government Act, councils have been given scope to trade services in order to fulfil their well-being function. Prior to this, local authorities were prohibited from owning more that 20% of a company and had capital controls imposed on their activities: 'The position on trading and charging under the Local Government Act 2003 has a wide application and the power to trade is particularly useful in terms of energy services. Under the Act, a local authority can trade on a commercial basis in relation to any of its ordinary functions (section 95). This is in addition to the power to trade with other public bodies under the Local Government (Goods and Services) Act 1970. Only those authorities with a Comprehensive Performance Assessment rating of fair or above, or with a star rating can use the power to trade. The trading power, used with the Well Being Power, does enable these authorities to enter into trading agreements or arrangements for the provision of goods, materials, staff, accommodation and

specialist asset management companies to run the scheme, such as Cofely District Energy (Southampton, Leicester, Birmingham) or Veolia Environmental Services (Sheffield), with long term contracts being tendered to the market (typically in the region of 25 years). The figure below shows a range of these types of relationships and the role that a council tends to play in each[111]:

Figure 6.5: Organisational form of a selection of schemes



Given the complexity of these multi-organisational structures, there are a number of dimensions behind the design of ESCOs. The model which is closest to full council ownership is the asset management ESCO which is controlled by the council, e.g. Woking. In this case the council forms an organisation which is answerable directly to the councillors and the local authority themselves often finance the schemes and take on the associated risk. One key advantage of this model is that it is possible to secure cheaper sources of finance through council loans (see next section), however councils are often reluctant to take on investment and fuel price risk directly (interview – 30, 39, 40). It also enables the council to use CHP-DH to advance the strategic aims of the council, particularly in relation to planning (interview – 31, 36).

In the case of Woking, Thamesway Energy Ltd. is a subsidiary of a group holding company called Thamesway Ltd. which was set up in 1999 in order to advance the general climate change and sustainability agenda within the borough (interview – 31). Rather than being profit driven, the overarching aim of Thamesway Ltd is to advance the council's priorities in the areas of decent and affordable housing, the environment, health and well-being and economic development (Thamesway, 2011). As the schematic below shows, Thamesway Energy, a

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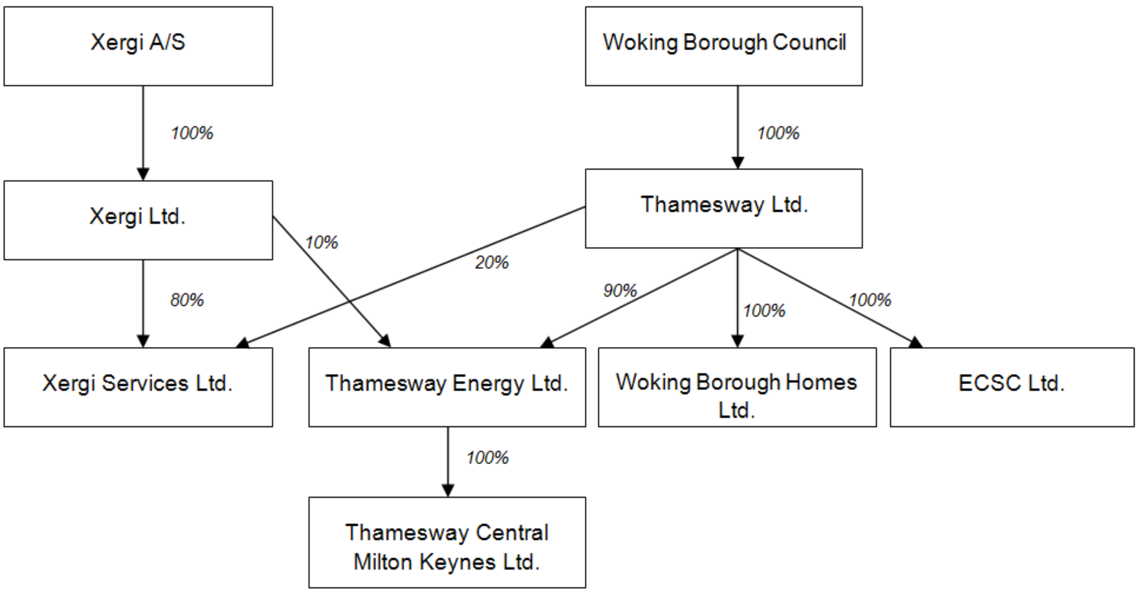
services for the purpose of promoting well-being. Local authorities also have the power to charge for discretionary services on a cost recovery basis' (Braybrook, 2008)

[111] Based on interviews and own observations

subsidiary of Thamesway Ltd, is part owned by the council and a Danish company called Xergi Ltd., whose expertise in the areas of decentralised energy and district heating have been drawn upon by the council; they are part owners (interview – 26). Also, as the investments were taking place prior to the introduction of the ‘well-being’ function which was introduced in 2003, the council could not be the sole owner of a company which traded services and would have been subject to capital controls (Braybrook, 2008).

Thamesway Energy also owns and operates the CHP-DH scheme in Milton Keynes. Thamesway Ltd. is also involved in housing development through Woking Borough Homes Ltd. and the provision of consultancy and project management services through Energy Centre for Sustainable Communities Ltd – the figure below outlines the complex organisational structure involved:

Figure 6.6: Thamesway Corporate Structure



Source: (interview – 26)

All profits from the company are re-invested into environmental sustainability projects within Woking, as one of the directors points out; ‘Thamesway is a CO2 reduction entity’ and ‘not a profit-making entity for the purpose of council tax reduction’ (interview – 31). Any profits from Thamesway Ltd. are not retained by the council but are re-invested in sustainability/energy saving measures within the Borough. The council is the sole shareholder in Thamesway Ltd and each of the subsidiaries are setup as a ‘special purpose vehicle company which encapsulates the business risk within this pyramid and keeps all of the business risk away from Woking’ (…)

‘Thamesway Limited is a holding company and all of the others are joint ventures or special purpose vehicles’ (interview – 31). This is a flexible and adaptive organisational structure which allows the council to pursue a number of strategies, CHP-DH being amongst them, in order to advance the overall aim of the council in the areas of climate change mitigation, sustainability and well-being.

In the case of a non-profit limited company, the council is a part owner of the ESCO and the council procures energy services from an arm’s length body which is only part-owned by the council. This is similar to the Woking arrangement where the ESCO operates on a non-for-profit basis as profits are reinvested; however, it acts independently of the council chamber, although some councillors may sit on its board (interview – 36). A key rationale behind adopting this organisational framework is that there is less risk for the council, particularly in relation to rises in the wholesale price of gas and investments made. However, as the ESCO has greater autonomy it is less integrated with other strategic aims of the council (interview – 31). These schemes tend to be less commercially orientated, with the LA acting as the main, if not sole, customer for the scheme.

An interviewee from a council where this arrangement is in place describes the main points of the council’s ESCO agreement:

> *"It is a separate entity, it is an independent not for profit company which is limited by guarantee. Essentially the council is [its main] customer, the council has board members, but it is set up as a separate organization. That does mean that its accounts have to be audited independently and all of those things, it is registered for VAT independently. It is a separate organization. The main framework agreement between the council and [the ESCO] sets out things like that the surplus generated, (...) the next capital cost, that the ownership of the assets will revert to council, (...) that the buildings will go on to council land; and the council give them a license to operate using that land. So all of those things come into the main framework agreement, then for each scheme that is developed there is an installation agreement which covers the capital cost" (interview – 34)*

The respondent goes on to describe the arrangement regarding funding:

> *"For each scheme that is developed there is an installation agreement which covers the capital cost; [The ESCO] provide XY and Z in return for the council providing this set amount of funding" (interview – 34)*

Also, with regard to fuel risk:

> *There is also a supply agreement that says [the ESCO] will provide heat to these properties at such and such a rate and that rates can be changed in future (...) It is directly linked to the cost to [the ESCO] of the gas that they*

> *buy to run the CHP system. So [the ESCO's] gas cost goes up, then the heat charge goes up proportionately" (interview – 34)*

In the case of Aberdeen there was an additional rationale for setting up an arm's length company due to the 1976 Local Government Act which precluded Scottish councils from selling electricity in any circumstances – in England and Wales an exception was made when 'produced in association with heat' (DECC, 2010a).

The third model is where the council offers a tender to the market for the operation of a CHP-DH scheme for a set period of time, typically up to 25 years. This is the risk averse approach in terms of financing the scheme and exposure fuel price fluctuations. In this case, a council enterers into a contract with a private company 'which says you will supply energy at this, electricity at that, heat at this rate over 25 years through low carbon technologies' (interview - 30). The council plays a more hands off role and the private operator has autonomy over the day-to-day operation and expansion of the scheme to commercial customers. In exchange for the operator taking a greater share of the risk, the council signs a long term energy supply contract and acts to promote the scheme to other potential customers. In some cases, because of public sector procurement rules, other public bodies that wish connect to the scheme do so through the local authority rather than the private operator, this is because of public sector procurement policies. These 'back-to-back' arrangements, where public sector customers procure energy from the council indirectly through the operator, allow the customer to purchase energy from a third party whilst avoiding strict procurement rules. In such instances there is a profit sharing arrangement between the council and the operator to incentivise the local authority to promote the scheme (interview - 30).

In other cases the relationship is more hands-off; the ESCO sells an energy service to the council, a defined amount of energy for a set period, and takes on all of the risks of price rises and asset management (investment and maintenance – depending on the contract). An interview from a prominent decentralised energy company who bids for these contracts outlines their role in such arrangements:

> *"(...) we also then agree to finance the plant (...) So we agree to the capital of the scheme and then we sell the energy to our clients, similar to a tracker mortgage (…) We will identify savings and regardless of fluctuations in the gas market we will always deliver that saving throughout the terms of the agreement, so it has maintained savings throughout the agreement (…) while the risk is borne to the private sector (…) Essentially we are a lean organization which has expertise and experience (…). Typically councils are asset rich - so they have got plenty of buildings and heat loads - but they are*

cash poor - they do not have the finance to bring the schemes on board themselves" (interview - 29)

In these arrangements the role of the council is act as a sustainable, long term customer base by connecting their large buildings which act as an anchor load around which the scheme can be built and potentially expand (interview - 29). These local authorities also promote the scheme within the city thus reducing the transaction costs for the private operator; they are treated as a 'statutory utility within the boundaries of the city so it can lay its mains without the need for a-way needs and planning' (interview - 29). Although this activity has tended to be carried out by smaller specialised decentralised energy companies such as Vital Energy, Cofely DE (formally Utilicom), and Veolia Environmental Services, there are also niche businesses within the major energy companies such as E-On[112] and EdF[113]. There are concerns however that a private sector led model could lead to cherry picking of the most profitable investments rather than 'a coherent city-wide approach' (interview - 33)

6.3.4 Obtaining Finance for CHP-DH Schemes

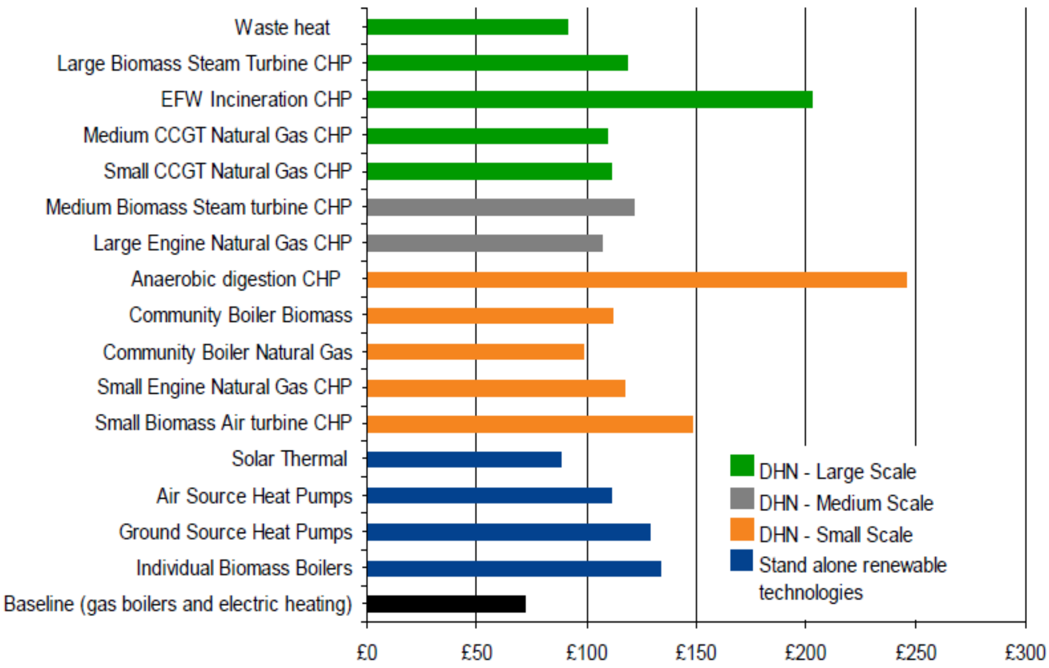
The characteristics of CHP-DH are such that contracts are 'generally 15-20 years because the infrastructure costs are so high' (interview - 25). A key variable in the organization and nature of a particular scheme is the attitude and approach taken to issues of financing and risk taking. The figure below shows the cost per technology of heating technologies which shows that district heating (DHN) and renewables are more costly compared to the baseline i.e. individual gas or electric heating[114]. The main component of the costs of district heating is the upfront cost of laying distribution pipes and procurement of components (there is currently no supplier in the UK (PÖYRY, 2009) and therefore little benefit from economies of scale in manufacturing components for CHP-DH systems (interview – 39))

[112] EON Community Energy operate the Citigen scheme in London: http://www.eonenergy.com/In-Business/Sustainable-Energy/Community+Energy/?WT.svl=4

[113] As part of London ESCO, EDF have been a partner in the Barkentine scheme: http://www.edfenergy.com/sustainability/our-sustainability-challenge/climate-change/london-ESCO.shtml

[114] These calculations do not include the RHI

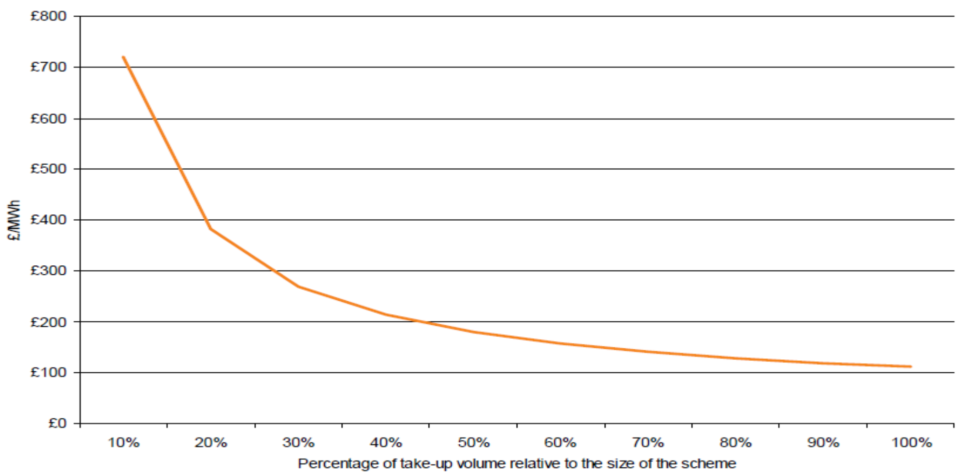
Figure 6.7: Cost of Heat Provision by technology in current market conditions (£/MWH)



Source: (PÖYRY, 2009)

However, as has been discussed previously, networks tend to benefit from strong increasing returns; therefore as more customers connect to the scheme, overall costs will reduce and as a consequence the heat tariff for customers should decline. The following graph from the PÖYRY study models this for an average sized CHP-DH scheme; it shows that as the connection rate increases the heat tariff for customers also decreases.

Figure 6.8: Quantifying the take-up risk. Heat tariff in £/MWh



Source: (PÖYRY, 2009)

However, because 'the required tariff to recover the initial outlay must be relatively high' (PÖYRY, 2009) the upfront capital costs are substantial for CHP-DH[115]. This, combined with the long payback period on investment, the lack of expertise in CHP-DH in the UK (PÖYRY, 2009), the long lead times involved in planning and delivering major infrastructure projects, and the fact that lending institutions in the UK tend to take a short-term approach and be conservative in their attitudes to risk (Mitchell, 1994), means that securing project financing at a reasonable cost-of-capital can be difficult for low carbon infrastructure projects (interview – 27, 31, 36). In supplementary evidence given to a Scottish Parliament hearing, Aberdeen City Council noted that 'CHP district heating schemes have high capital costs, but significantly lower running cost and carbon emissions. We need CAPEX grants. OPEX incentives (such as exemption from CCL, ROCS, feed-in tariffs or Heat Incentives) alone won't kick-start replication in other areas, or allow us to grow the heat network in Aberdeen' (Aberdeen City Council, 2009).

As a result, CHP-DH schemes rely on upfront capital funding. Broadly there are three sources of funding for low carbon infrastructure schemes at the local level; they are publicly funded grant schemes, council borrowing (against their own assets) and private finance – these are discussed in more detail below:

Capital Grants

This source of funding comes from a number of capital grant schemes, in particular from national government, but also from the EU level. These various sources of funding are outlined in the table below:

Table 6.6: Sources of public funding for CHP-DH

Sources of funding	Description
Community Energy Fund (CEF)	A program of £50mil for updating/installing community heating schemes from 2002 to 2005 managed by the Carbon Trust (CT) and Energy Savings Trust (EST), but has been discontinued. Schemes in Aberdeen and Birmingham benefited from this.
Low Carbon Infrastructure Fund	Introduced in 2009 and administered by the Homes and Communities Agency (HCA) on behalf of DECC and DCLG. This included £21million for community heating schemes. 13 projects were funded with 3 in the pipeline

115 Laying pipes costs in the region of £1,000/metre

(LCIF)	(interview - 27) which were typically extensions to existing networks. This ran until 2010.
European Funding	The European Regional Development Fund and the European Investment Bank who fund infrastructure projects.
Biomass Capital grants	UK Government/DEFRA funded schemes for up to £500,000 per installation.
Community Infrastructure Levy	This is a charge which LAs are enabled to impose on new developments. The charges are based on the size of the development (DCLG, 2008a). Similarly a proposed CHP-DH scheme in a new development can benefit from developer contributions as part of 'allowable solutions'.
CESP	As part of CESP, licensed energy suppliers can part fund DH projects with LAs in a number of low income zones e.g. Leicester.
District Heating Loan Fund (Scotland)	In 2011 the Scottish Government announced a £2.5million loan fund for DH

These grant programmes, in particular the CEF and the LCIF, have played a significant role in developing CHP-DH schemes; the majority of interviewees involved in schemes cited their importance in providing an initial capital injection to lay the piping (interview – 25, 30, 34, 33). As noted previously, local authorities are well placed to attract such funding and the ability to do so successfully has become a core competency in CHP-DH development (interview – 36). An interviewee who had been involved in administering one particular funding scheme pointed out that local authorities in particular were favoured for such funding as oppose to private sector bodies as it was felt that it was more likely that LAs would contribute to a wider range of policy goals and more effectively coordinate actors at the local level (interview – 27).

However, the rapidly evolving energy policy environment in recent years has meant that these funding schemes are temporary, thus undermining the requirements for long term certainty in infrastructure investments (interview – 29, 36). A number of interviewees from local authorities expressed frustration at the temporary nature of the schemes (Interviewee – 25, 31, 34). Referring to government support for CHP over the years, the following interviewee from a private CHP-DH operator argues that this has undermined confidence in the long term viability of local infrastructure investments; they argue that:

> *"…it has typically been over the last 20 odd years that CHP is very important and that has been one of our primary technologies and it has received various levels of support. What we have seen is that support mechanisms often disappear without a trace very quickly and with little warning and that has led to schemes being pulled at the last minute where funding disappears and can be quite an unsustainable practice" (interview - 29)*

Similarly, a local authority officer who was involved with a project which received a number of capital grants from the CEF argues that the reasons for closing the scheme were vague and unjustified:

> *"It closed because it did not appear to meet the objective. We more than met the objective - three projects within time, on budget and achieving carbon savings. I would say that the reason that it didn't achieve its objective was because of the way that the money was allocated, so huge schemes that were never going to, within the timescales, be deliverable' (interview - 34).*

The interviewee argues that the CEF had allocated funding to a small set of large schemes rather than a greater number of smaller initiatives where the viability and potential for carbon savings were greater.

Council Funding

In a number of the cases these capital grants were used alongside own council funding to initiate projects. For example, for one of the schemes in Aberdeen the split was council funding - 60% and a CEF grant - 40% (interview - 34). Council funding can come either from council borrowing or through a self-funded revolving investment fund – these are discussed in turn:

Under the 2003 Local Government Act new forms of autonomy were introduced to grant greater autonomy to LAs to go into debt to fund activities (LGA, 2005b). The Prudential Capital System introduced following the 2003 Act allows councils 'to borrow to invest in capital works and assets so long as the cost of that borrowing was affordable and in line with principles set out in a professional Prudential Code, endorsed by the Chartered Institute of Public Finance and Accountancy' (LGA, 2005a). In place of the borrowing cap which was set by central government the 'prudential code' assesses the ability of the council to service the debt, where 'projects identified by local authorities are self financing, in that the cost of borrowing and repayment can then be met by revenues gained through the investment' (LGA, 2005b) – investment in local energy infrastructures fits into this category. The rate is set by central government and this allows councils to borrow at a low cost of capital, thus making investment in such things as low carbon infrastructure networks more feasible. As a result 'local authorities are able to borrow at lower rates than pretty much any other organization' (interview - 36) and 'their interest rates are approaching zero' (interview - 39). This facility is typically availed of in conjunction with a capital grant e.g. this has been used in Nottingham along with a capital grant to fund a recent expansion of its scheme. In general councils do not tend to invest using cash reserves (interview - 39) as councils tend to be asset rich rather than cash rich (interview – 29), therefore prudential borrowing has emerged as an important facility for infrastructure investments. However, in the light of significant cuts to LA funding from central government, debt funding of capital investments is becoming less likely (interview – 32, 33, 38).

The second self-financing approach is a revolving investment fund or mechanism where over a number of years, a council reinvests the savings it makes from energy efficiency to create a capital fund which can be used to invest in capital assets such as DH pipes. Examples of councils using this approach include Aberdeen and Woking. In the Woking case, the council began monitoring its energy efficiency in 1992 and after a number of years of savings a capital fund was available for investment in the CHP-DH scheme in 2001 (interview – 26). In Aberdeen, the council invested the money set aside for the replacement of old and inefficient heating systems in its social housing stock and invested it in its ESCO, Aberdeen Heat and Power co. As investments take place in more efficient heating systems to service the buildings the savings that accrue are reinvested by the ESCO, thus allowing the scheme to expand to other areas of the city (interview – 34). This model is most common where the council has a greater stake in the ESCO, i.e. the non-profit/ council ownership model. The expectation with this approach is that it will become 'more and more self funding with the council just putting it what [they] would put in to replace the heating systems' (interview - 34) as is the case in Aberdeen. As the following quote suggests, this approach can allow a scheme to benefit from increasing returns:

> *"[The ESCO] was set up so that it can profit its surplus, it can be ploughed back into the next development. For the first scheme to make it stack up we needed a 40% grant, we are now onto fourth scheme and we need a 25% grant, which is what we have got" (interview - 34)*

As the quote suggests, this approach can allow a scheme to benefit from increasing returns as the system expands, thus reducing the reliance on public grant funding which decreases over time.

Private Financing

Due to ongoing cuts to budgets across the public sector there is an expectation that upfront capital funding and the ability of councils to fund infrastructure investment by going into debt will be severely curtailed (interview – 25, 27, 32, 33). As a result, it is likely that private sector financing will increasingly by relied upon. It is rarely the case that large lending institutions will fund local infrastructure projects because due to their short time horizons, which are typically 5-7 years, they will be reluctant to provide ‘long-term low interest rate’ loans (interview – 31). There are however a number of examples of private sector involvement in larger CH-DH schemes, this is secured through the public sector procurement processes where a local authority places a tender on the market for the provision of energy services to the council and operation of a scheme for a defined period of time, typically for 15-25 years (Carbon Trust, 2004). In this way a number of schemes have been contracted out to specialist district energy companies or ESCOs such as Cofely DE (formally Utilicom) who operate the Southampton, Leicester and Birmingham schemes, and Veolia Environmental Services who operate the Sheffield scheme. These companies have autonomy to achieve OPEX efficiencies and choose the most suitable generating solutions whilst allowing them to enter into separate third party heat supply agreements with commercial customers.

This private sector model is attractive because it transfers a great deal of the investment and operational risk to the private sector as the prices paid for energy services by the council will be indexed linked over the period. However, the required rate of return on new investment will likely be higher than would be the case under a council funded project (interview – 31, 39). One interviewee from a council which uses own funding stated that due to the lower cost-of-capital available to councils, their internal rate-of-return is 8% while a private sector operator may demand 15-25% return on shareholder investment (interview – 31). Also, because the private operator will have control over the operation and future evolution of the system, there will be less scope for the local authority to integrate a CHP-DH scheme into their wider energy and climate change strategies (interview – 31, 36, 39).

These tensions between risk and the cost of financing schemes are closely related to the individual council’s perspective on risk taking which in turn is influenced by the political make-up of a council. In a number of the councils surveyed, the balance of power within the council chamber was cited as a key factor in providing both a political framework to make strategic and long terms decisions regarding infrastructure investments, and also in terms of allowing the council to raise finance and take risks. One interviewee indentifies this relationship between politics and risk as crucial to whether the schemes go ahead and the form they take:

> *“Within the political bubble debt is bad! So councils need to go into debt to be entrepreneurial and they can do [so] at low interest rates for 50 years fixed; but electorally debt is bad. So they are between a rock and a hard place, they know that they have got to spend money, they have access to cheap*

> *funds, but electorally it is dangerous to borrow money and go into debt" (interview - 31)*

It is often the case that councils which have had long term coalition arrangements can be more amenable to large scale infrastructure investments such as CHP-DH (interview – 26, 36). For example, in the case of Woking, one of the interviewees describes the crucial role that a supporting political environment played in allowing an ambitious infrastructure project to go ahead:

> *"At least two thirds of the council has stayed on this agenda all of that time. And I think if you've got a political environment that says we want something done, we accept that not everything would work, but we are willing to try them and accept that sometimes it doesn't work and we'd learn from that and add to what we do next time. That's created a positive environment for the managerial and technical side to work within, and we still have a cross party climate change working group that steers the work that we do. I think the right political cross party framework is critical to success and when it's a party political issue of one wanting it and the other not or sniping, it won't work (...) Where there has been an alignment of will of the parties it tends to happen or when they're not aggressively party political it tends to happen" (interview - 26)*

As has been discussed, the role of a political champion is crucial in advocating a project at the political level because 'if you have got a Councilor who is particularly understanding of these issues and particularly motivating, they will push the Council to overcome certain risks' (interview - 36). At the national level, the issue of long term certainty is also an important factor in the relationship between politics, risk and investment. As one interviewee from a decentralized energy company notes; 'until there is that surety in place no one is going to invest, no one is going to put money up when they are not sure what the return is going to be. So without that surety, money does not get invested' (interview - 29).

6.3.5 Interacting with the energy regime

Unlike national energy infrastructures such as electricity or gas, heat networks operate in a largely unregulated environment as they are generally not regarded as natural monopolies (SDC, 2007). As a result, throughout the history of CHP-DH in the UK, 'electricity and heat production are almost entirely separate activities, physically and institutionally' (Russell, 1993: p.32). Also, as the institutions and technologies of energy provision have become increasingly embedded at the national level, CHP-DH has 'found only a limited role' and 'fallen in between the gaps separating the existing institutions' (Russell, 1993: p.34). However, as the CHP-DH systems reviewed as part of this study develop, they are beginning to encounter and engage with national level energy institutions which in many cases can act as a barrier to their expansion.

The following sub-section explores aspects of this interaction with the incumbent energy regime in more detail. Two issues are explored, the first is how CHP-DH schemes transact in the wholesale and retail electricity markets and the second is how small scale, local energy schemes are treated within the current licensing and regulatory regime.

Electricity Markets

The structure of the electricity supply industry has been introduced in chapter 4. BETTA, the current electricity trading arrangement, allows generators and suppliers to enter into a variety of contractual arrangement and prior to ‘gate closure’ any further activity following this in advance of generation dispatch is mediated by the TSO, National Grid. Following the Balancing Mechanism period, up to half an hour before generators are dispatched during the imbalance settlement, generators face significant penalties if they fail to generate the same amount of power they had agreed to before this period - they must pay either the system buy price or the system sell price on the amount of power the fail to generate. There has been much comment on the fact that these risks of transacting in the national electricity markets will tend to be greater for small scale generators because they face higher transaction costs relative to large scale generators (Mitchell, 2008, Toke and Fragaki, 2008). This is because it is more costly to deal with the administrative and credit conditions involved in registering with the Balance and Settlement Code (BSC), and secondly they run the risk of being penalised under the BSC because the output of small scale generators is less predictable (due to intermittency e.g. wind generators, and the fact that output is also subject to on-site electricity demand and potential mismatches between electricity and local heat demand[116]). As a result, following the introduction of NETA, a review indicated that there was a 44% overall drop in the output of small scale generators and for the specific case of CHP, the review indicated a there was a 61% drop (Mitchell, 2008).

This was particularly detrimental to district heating schemes as revenues from electrical output forms a key component of the economic rationale for CHP-DH because ‘the electricity output from CHP is more valuable than the heat output’ (IET, 2007). As a result of NETA and BETTA, ‘exported electricity from a CHP plant has a lower value than the electricity generated and used on site’ and this is ‘due to a number of factors including the buy/sell spread, the network costs to deliver the electricity to a customer, and market participation costs’ (IET, 2007) . Toke and Fragaki (2008) have noted that ‘a major factor in inhibiting the development

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[116] This problem has been largely overcome in Denmark through the use of thermal stores (Toke and Fragaki, 2008)

of a Danish style CHP-DH system is the poor rates of electricity that CHP-DH schemes can earn for selling power to the grid'. The IET report quoted above also argues that CHP suffers under these arrangements because its environmental benefits are not taken into account; there is a 'mismatch between economic and environmental efficiency flows from a number of energy pricing issues' such as the fact that 'the environmental costs of electricity and heat production - known as the cost externalities - are not yet fully incorporated in electricity prices' and 'the added value of electricity generation close to consumers - known as embedded generation benefits - may only be partly recoverable by the CHP owner' (IET, 2007). Unlike approaches which have been taken in countries such as the Netherlands (Raven and Verbong, 2007) and Denmark (Toke and Fragaki, 2008), the market arrangements in the UK do not explicitly reward CHP for its environmental and system benefits[117] as there has been a technology and fuel blind approach to energy policy in the UK which tends to favour incumbent technologies and actors (Mitchell, 2008).

Due to the difficulties that CHP-DH schemes face in transacting in the conventional national electricity markets, there are currently a number of approaches being taken by the schemes surveyed:

1. Sell the power locally to designated customers using the public distribution wires e.g. Leicester. Under this approach the operator bears the costs of using the distribution system (DUoS) and must engage with a licensed supplier who deals directly with the customers. In the case of Leicester: 'The district heating mains take up all the available heat from the CHP units whilst the excess electricity is transmitted through the local distribution network to 17 nominated sites owned by the Council' (Ofgem, 2007). The council tenders to the market for supplier services called 'netting-off' which means that all excess electricity from the CHP units is taken and this is then credited back to the council minus the DUoS charges. In the event that there is not enough electrical output to service the customers the supplier will top this up (Ofgem, 2007).

[117] In Denmark for example, the flexibility of CHP and its proximity to loads is seen as a benefit to the system as it can displace less environmentally efficient forms of generation and help the system operator to balance the grid due to the high penetration of wind, which is a variable output. CHP receives preferential prices, called a 'triple tariff' where CHP operators receive higher prices during peak periods, this can amount to three times the off-peak prices. These market arrangements, the fact that many of the CHP operators utilise thermal stores which allows them to generate extra electricity during peak periods, and the presence of effective aggregators operating in the market have meant that CHP can compete with conventional generators and has contributed to the fact that up to half of all the electricity in Denmark is produced from CHP, much of which is connected to district heating schemes (Toke and Fragaki, 2008)

2. Employing a consolidator to act on behalf of the ESCO. For example Aberdeen. Aberdeen Heat and Power Co. do not directly supply their customer base with electricity but employ a consolidating service to carry out the administrative duties (Ofgem, 2007). This company will pool the output of a number of such generators which are treated as a negative demand and can be traded as an ancillary service, thus reducing the risks of transacting in the BSC (Toke and Fragaki, 2008). The ECSO receives a discounted price for its electrical output and is supplied electricity by the consolidator.
3. Selling surplus electricity directly to an energy company who transact in BETTA e.g. Pimlico. In this case licensed suppliers bid for the exported electricity each year. Due to the costs of transacting in BETTA it is typically sold to one of the large energy companies. Because the electrical output is not used on-site the scheme must be synchronised with the grid and the operator of the scheme therefore needs permission from the DNO to switch on the units each morning (Ofgem, 2007). This is a disadvantageous arrangement for the scheme operator as they will pay a lot more for electricity at the retail price than what it is sold for.
4. Sell the electricity directly to onsite customers using private wires which are owned by the scheme operator e.g. Woking. This is currently the only way that schemes can benefit fully from the retail price of their electricity whilst avoiding DUoS. In the case of Woking the ESCO utilises both its own private wires and the public distribution system to sell electricity to a number of its customers and to supply its own buildings. Each of the private wires has its own connection to the grid if back-up supply is required. However, investing in private wire imposes a significant additional upfront capital cost and there are also a number of legal issues surrounding private networks (these are discussed in more detail in the section below).

The manner in which CHP-DH interacts with the electricity markets highlight the persistent barriers to the development of local energy schemes in the UK since nationalisation (Russell, 1993) and which has continued under BETTA and liberalisation. The example of Denmark which was briefly discussed here shows how CHP-DH can be successfully integrated into a national energy system by rewarding its potential environmental and system benefits.

Licensing Regimes

As has been discussed, heat distribution systems, unlike gas and electricity networks, are currently unregulated by Ofgem and this is also the case for small scale supply companies who generate and sell electricity to customers under a certain threshold. Under the current regulatory arrangements governed by Ofgem, medium and large scale generators and suppliers along with the network operators must hold a licence which sets out the legal obligations a company has to its customers. For example, in the case of network operators, companies must ensure that they supply electricity within certain statutory limits, and electricity supply companies must allow a customer to switch within a certain time period, depending on the contractual arrangement in place.

Due to the fact that many decentralised energy schemes are too small to operate as licensed suppliers there are a number of exemptions to the licences which are set out in the 1989 Electricity Act and the 2000 Utilities Act[118]. The 2001 class exemption order (HM Government, 2001) sets out the qualifying criteria: The class exemption order grants ‘both individual and class exemptions from the requirement to hold a licence’, in order ‘to save small-scale generators costs arising from compliance with the electricity licensing regime’ (DTI, 2004). Generation, distribution and supply licences are included in this exemption:

- The exemption applies to a generator which does not provide more than 10 MW of output at any one time and to generators which do not provide any more than 50MW where the net declared capacity is less than 100 MW.
- An exemption applies to generators who supply a single customer or ‘customers up to a maximum of 5 MW of power - of which up to 2.5 MW may be to domestic customers’ (DTI, 2004) – this translates to 1-2,000 domestic customers depending on their end-use efficiency (interview - 31). This has the effect of CHP-DH schemes having to build a number of energy centres which can be inefficient (LEP, 2007).
- The exemption from holding a distribution licence applies to those who ‘do not distribute more than 2.5 MW of power to domestic customers’ or for the case of local networks, those who ‘distribute electricity from generating plant… located on their network provided they distribute no more than 1 MW of power from any such station to domestic customers located on the same network’ (DTI, 2004).

There is also discretion for the Secretary of State to grant licence exemptions by application. These exemptions have direct relevance to CHP-DH schemes as the following quotes from a DTI explanatory note outlines, arguing that it will reduce the costs of transacting in the market for small generators:

[118] Under section 5 of the 1989 Act and amended by section 29 of the Utilities Act 2000

> *The requirement to hold a generation licence restricts the level of flexibility in terms of how to operate under the new electricity trading arrangements. Licensees have to sign and be directly subject to the Balancing and Settlement Code (BSC). Without the proposed measure, the ways in which such generators and suppliers could aggregate their output and so benefit from such aggregation would be limited. In particular, it would prevent small generators from simply selling their output to local suppliers. Exemption would minimise the commercial and trading arrangements into which they would have to enter directly.(DTI, 2004)*

And reduce the costs of linking small scale distribution systems with the national grid and allowing them to create private wire distribution systems:

> *"The requirement to hold a distribution licence means, for example, that operators of networks based on industrial estates would have to establish a range of administrative services that are appropriate for the national networks, such as a meter point administration service; provide an infrastructure capable of supporting competition in electricity supply; and adhere to a range of accounting requirements from the regulatory regime. Alternatively the person would have to arrange for the network to be taken over by another licensee – if that were possible." (DTI, 2004)*

However, a 2007 Ofgem consultation on these issues raised the fact that due to the expectation that decentralised energy (DE) schemes are likely to proliferate in the future; 'the development of larger-scale district and city-wide DE projects that fall outside of the 2001 Class Exemption Order and will need to be licensed' (Ofgem, 2007). The consultation raised concerns regarding how customers can be protected under such schemes, i.e. the ability to switch between suppliers, and particularly those who are connected to private wire electricity systems. The aim of the consultation was to address the issue of protecting customers without putting further barriers in place for decentralised energy schemes. A key concern has been that under these exemptions a growing number of schemes have been either installing private wire systems or considering it and this has raised legal issues regarding access to private networks and customer protection.

This issue was brought to the fore in the wake of a European court ruling known as the Citiworks case[119] which involved a large German utility company who successfully sued a private wire operator in Leipzig Airport; it was argued that the supply monopoly breached EU competition law. Following this, as part of the EU's third energy package, Article 3(5) of the Internal Market in Electricity Directive stated that 'Member States shall ensure that the eligible customer is in fact able to switch to a new supplier' (Ofgem, 2007).

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[119] European Court of Justice: Case C-439/06

This ambiguity has raised concerns amongst a number of the CHP-DH schemes regarding the legality of private wire networks (interviews – 25, 28, 30, 33, 34, 37, 38). For example, one interviewee makes the point that the uncertainty regarding private networks will result in schemes tending to feed-in to the grid directly and accept the inferior price for their electricity:

> *"If we put the standalone unit [in] then there would have to be some serious thought given to how the connection would operate, it would probably just go straight to grid" (interview - 25)*

Another interviewee involved in a scheme which has already invested in a private wire system discusses the potential for assets to become stranded:

> *"It's a disadvantage when you have to put millions of pounds in to do something and you're not totally clear whether that's ok or not" (interview - 26)*

Whilst another commented on how this uncertainty is affecting the financial viability of future investments, in particular for large infrastructure investments as it is crucial to secure customers and bind them to long term contracts (interview - 34). An interviewee from a decentralized energy company argues that this can inhibit funding:

> *"At the moment you have to open it up to competition and there is an issue that you can't 100% guarantee 100% of the revenue, regardless if it is the most complicated or not, and therefore the banks cannot fund against that revenue" (interview - 29)*

As a result, there is an emerging conflict between the regulatory imperative of enabling customer switching, which Ofgem sees as central to its primary duty to protect the interests of customers (Mitchell, 2008, SDC, 2007), and the requirement for long term contracts which are put in place to reduce the risk of large scale infrastructure investments . One interviewee from a council which is currently considering developing low carbon infrastructure projects notes that this conflict may mitigate against such investments:

> *"Because you can't afford to plough out millions of pounds into pipes and boilers and whatever if (…) the potential customer is going to turn around and say; 'actually we have changed our mind and we are going to buy it from someone else'. So there are huge challenges there" (interview - 38)*

This issue has been most prominent in Woking, where private wire is most extensive amongst the schemes. In Woking the approach which has been taken is to adopt the licence terms which apply to regulated energy companies where possible e.g. customers connected to a private wire can switch on demand but the new suppler must pay Thamesway (the ESCO) 'third party distribution and use of system' charges (interview - 31). For domestic customers they also guarantee prices '5% below the duel fuel basket' and this is made possible by the fact that they are a vertically integrated entity, they therefore have a 'retail margin that [they] can flex' (*ibid*). For commercial customers they 'do market comparable pricing so if they have got a written offer of a price [Thamesway] will match it' (interview - 31).

Liberalising access to private wire systems is also a potential concern for private network operators themselves as there is a possibility that the larger utilities will engage in predatory pricing in order to reduce the market share of the CHP-DH scheme – as one interviewee notes:

> *"The big problem with the Citiworks case and what the government is currently wrestling with is that a massive utility provider could come in and say to my customers 'I will give you free electricity if you sign up to me', and if they do, they can give them free electricity for two years and put me out of business and buy my assets for pound" (interview - 31)*

The interviewee goes on to refer to the outcome of the Ofgem regulatory consultation:

> *"If Ofgem do not constrain the ability of the utilities to flex their prices below what I can meet then I have got problems because I can only take my retail margin down to a point and below that I lose money" (interview - 31)*

The 2007 Ofgem consultation did propose a number of options such as enabling DE schemes to trade in the wholesale markets, selling to third parties, 'Operating as an Exempt Supplier on the Licensed Distribution Network', and 'Becoming a Licensed Supplier'. Following a further consultation in 2008 (Ofgem, 2008), a final proposal document was issued by Ofgem in 2009 (Ofgem, 2009a). Under the proposals Ofgem 'will allow small suppliers to become licensed suppliers in a way that is proportionate to their size and impact, while protecting consumers' rights to switch energy supplier' (Ofgem, 2009a: p.1). They proposed one licence modification which would allow small scale suppliers who exceed the exemption limits to operate as licensed suppliers while providing 'an option for a derogation from the requirement to be a direct party to the industry codes in the electricity supply licence[120]… as long as alternative arrangements are in place with a third party licensed supplier that is a signatory to the industry codes for the scheme to operate in the competitive market and allow consumers to switch energy supplier' (Ofgem, 2009a: p.1).

This removes the obligation for potential licensees to engage in 'wholesale market trading, real time system balancing, retail competition and consumer protections' (Ofgem, 2009a), these services are intended to be made available by the third party licensed supplier which in theory

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[120] Standard electricity supply licence condition 11.2 – costs relating to the BSC and the Master Registration Agreement

would allow the small scale licensee holder to operate more effectively on the public network. While this solution does not alter the basic issues surrounding the functioning of BETTA, it does clear up some of the legal ambiguities which might develop if CHP-DH schemes grow and would allow them to at least get the retail price for their electricity whilst not having to invest in private wires. It also clears up much of the uncertainty surrounding private wire. However, as there is no obligation on the third party licensed supplier to provide the necessary services, it is unclear whether incumbent energy companies will be receptive to these arrangements.

On the specific issue of access to private wires; under the DECC proposals legislation will be amended to oblige operators to allow access to private networks where an operator will be 'obliged, when asked, to provide third party energy suppliers with network access in order to supply energy customers, and Ofgem having powers to take enforcement action against those in breach of this obligation' (DECC, 2010b). Also, the operator must publish a set of tariffs for system use which must be approved by Ofgem (DECC, 2010b). Once put before parliament in 2012 as part of the implementation program for the EU Third Energy Package, this will see a retention of the distribution licence exemption (DECC, 2010d). This solution is broadly in line with the Woking approach outlined above where the scheme has use of system charges in place, and as long as it does not exceed 1MW, can distribute power to customers if they are not prohibited from switching between suppliers.

6.3.6 Conclusion to Interventions and Interactions Section

This section outlined how CHP-DH schemes hare being shaped at the local level due to various interventions and interactions which are taking place between a wide array of actors within the organisational field. It has been observed that local energy schemes are shaped by a number of issues such as local authority responses to issues and priorities within their own localities, e.g. addressing fuel poverty, but also by responses to external drivers such as the long term security and resilience of the UK energy system. Due to the fragmented nature of the sector and the lack of a coherent policy landscape for heat networks in the UK, the schemes are taking quite different approaches to how they structure their systems and finance investments. As the systems develop and expectations surrounding the proliferation of small scale energy systems grow, the sector, which had previously operated in a largely unregulated space, has begun to confront and in some cases alter the regime structure, particularly in relation to the licensing regime for electricity suppliers. The following section will synthesise the outcomes of the interventions and interactions described above.

6.4 Outcomes

The following section explores the outcomes of the interventions and interactions which have taken place regarding local authority involvement in CHP-DH across the UK. This utilises the dimensions of infrastructures approach which was introduced in chapter 3 where the physical, relational and structural analytical categories characterise the interplay between actors, institutions and technologies in energy distribution sectors as a the outcome of a governance process. It was argued that institutions can be considered as embedded in each of the infrastructure dimensions and analysed in a systematic fashion where actors within the organisational field simultaneously seek to strive for notions of technical efficiency and legitimacy for their actions.

6.4.1 Physical Dimension

In the physical dimension, institutions *coordinate physical flows within a network which can be measured, monitored and controlled*. Key analytical variables which were outlined in chapter 3 include the changing relationships between nodes, links and flows, how system economies are being achieved, and how system reliability and integrity is maintained. For the case of CHP-DH the following table synthesises the main outcomes in this respect:

Table 6.7: Characterising the changing flows within CHP-DH systems

Flows	Heat Distribution
Material (Energy)	• Heat is distributed within a locality from a central node which is typically connected to the gas distribution network • Different types of interplay between electricity and heating systems depending on the organisation of the scheme and the approach to electricity sales • Some schemes are developing an interplay with other material flows within the locality such as different sources of renewable energy e.g. waste and biomass • The reduction of carbon emissions was a key motivating factor behind the design of the schemes
Information	• Lack of information on the density, diversity of heat loads within localities • Heat demand mapping techniques increasingly being deployed by leading councils to improve information e.g. identify anchor loads • Little information on heating usage patterns on a real-time basis
Revenues	• Longer term ESCO contracts needed to reduce investment risks. • Revenues not regulated as in traditional/incumbent sectors • Capital costs are front loaded but securing upfront financing is a major barrier to developing schemes • Different approaches to the retention of profits. Some schemes have revolving investment funds while others have private sector involvement

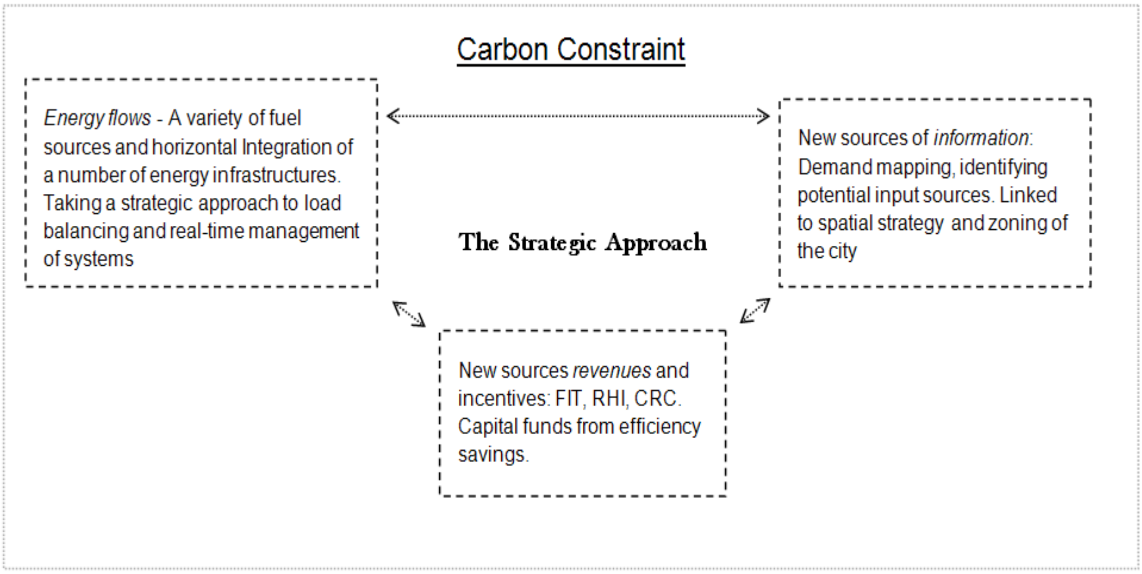
As a consequence of the development of local energy systems, a more complex set of flows and interplay between a number of different types of infrastructures are taking place. In a conventional heating regime, gas is transported from the national transmission grid via a local distribution network to individual domestic boilers. However, a different picture emerges with CHP-DH schemes where an energy centre, i.e. a CHP plant, operates as a central node within a locality which mediates between internal and external flows. In some cases flows of energy within localities are becoming more bounded and less reliant on external national and regional energy networks; investment in private wire networks and the use of locally sourced biomass and EfW as energy sources are examples of this. There is also a more transactive relationship emerging between localities and external flows, in particular following the introduction of feed-in tariffs for micro-generation and the potential for CHP-DH operators to develop virtual trading arrangements for biomethane which is fed into the gas networks.

In terms of achieving system economies, the key advantage that CHP-DH systems have is the ability to achieve economies of scope by bundling together a number of energy services including heating, cooling and electricity provision. Also, local systems can benefit by developing an interplay between a number of different infrastructures which can be integrated at particular nodes e.g. using waste or biomass from a local supply chain as fuel in a CHP plant. However, the discussion above regarding the structure of electricity trading arrangements in the UK suggests that there are significant institutional barriers to achieving economies of scope. In some cases these barriers have incentivised operators to invest in private wire networks.

As a system expands, economies of scale can be achieved in heat provision by balancing and sequencing a diverse set of loads, thus achieving more efficient fuel utilisation than would be the case with individual boilers which often operate at part load (Roberts, 2008). In order to improve capacity management and achieve these economies of system, schemes need to connect to a diverse set of customers and particular types of loads which can help to smooth out the peaks in demand, thus allowing the operator to size the system more efficiently. Examples include theatres and other entertainment venues with evening and night time demands, along with swimming pools and ice rinks which will have a consistent demand throughout the winter and summer months and which will reduce the requirement for investment in expensive back-up boilers.

Proximity to loads and knowledge of the locality are key competitive advantages which the operators of local schemes can develop, however, there is often a lack of long term strategic thinking taking place prior to large scale investments as schemes often develop on an ad-hoc basis. A more strategic approach, e.g. through using heat mapping and zoning of the city, would enable the most suitable types of loads to be identified and flows of heat to be directed towards sites of demand in the expectation that revenues can be maximised and more informed investment decisions regarding how best to decarbonise energy use within a locality can be made. This can be through the expansion of a CHP-DH network or other energy efficiency measures e.g. loft insulation (interview - 36). This more strategic approach to local energy planning, which is currently being carried out by a small number of councils, e.g. Woking who have embedded CHP-DH within their long term climate change and sustainability strategies, is illustrated in the diagram below.

Figure 6.9: An emerging strategic approach to CHP-DH within cities



As one interviewee notes, the fact that local energy systems are fully integrated across the value chain from generation through to end use, allows the focal organisation to impose a long term carbon constraint across a locality; ‘interlinking all of these buildings it gives you the opportunity to draw in whatever energy you want because you have already got the infrastructure in place and the network in place and whatever happens in the future you can put it in’ (interview - 30), making the system future-proof.

6.4.2 Relational Dimension

The relational dimension address the issue of ‘independent but autonomous organisations, each controlling important resources’ and the role of institutions is ‘to *coordinate their actions to produce a joint outcome which is deemed mutually beneficial*’ (Jessop, 1995). From the preceding discussion it is evident that despite the development and expansion of a small number of successful schemes, the broader institutional framework for the development of CHP-DH in the UK is currently underdeveloped.

Developing Local Energy Institutions

At the local level it was described how distinct ‘multi-organisations’ are being created in order to coordinate a range of actors with the aim of delivering energy services at the local level. These institutions can vary in terms of the technologies deployed, the types of interactions taking place between both public and private actors, and different approaches to the financing of schemes. Within these local institutional arrangements, local authorities, as focal actors who typically coordinate a network of actors, take on a number of roles from directing investment strategies to promoting a scheme within a particular locality. Increasingly LAs are seeking to utilise CHP-DH infrastructures in order to meet their long term strategic economic and environmental aims and are increasingly engaging with a wider array of parties in order to achieve this.

In the case of CHP-DH, what has been observed is that following the liberalisation of the energy sector in the UK, councils were initially motivated by efforts to achieve energy efficiency within their own council buildings. However, in the context of concerns over climate change, rising energy prices, and resource security, councils have begun to expand the scope of their energy management programs to more explicitly consider social housing units and the wider locality involving a more diverse set of customer and building types. As systems begin to expand and expectations behind decentralised energy grow, local authorities are taking a more long term perspective where CHP-DH becoming a key component in cities’ climate change and energy strategies (interviews – 25, 26, 28, 30, 31, 33, 34, 36, 37, 38, 39, 40, 41). As a result, with the development of ESCOs, there is a trend towards some local authorities becoming a ‘strategic deliverer’ (interview - 38) of energy services rather than a direct service provider, similar to a traditional utility. This reflects Wilson and Game’s (1998) observation that there has been an ongoing trend towards local governance i.e. away from a more hierarchical, direct service provision model. As a result councils ‘find themselves increasingly working alongside a range of other service-providing agencies in their localities’ (Wilson and Game, 1998: p.82).

This change ‘from provider to commissioner’ (Wilson and Game, 1998: p.83) is manifested in a number of areas across the different cases surveyed:

- Reducing investment and fuel price risk by tendering contracts to private sector parties who act as statutory utilities within a locality.

- Attracting and working with developers in order to meet building standards and requirements for 'allowable solutions'. Allows them to implement planning policies which are increasingly required to take into account energy and carbon.
- Attracting private sector/commercial customers who are seeking to increase their energy efficiency by incentives such as the CRC.

Using these relationships, LAs are seeking to act to purposively shape local energy institutions by coordinating an increasingly diverse network of actors, rather than merely act as sites where private actors can shape the energy transition within a locality. They coordinate these local institutional arrangements by using their (formal) role as a local service provider and enforcer of statutory legal obligations (e.g. street-work licences), by exploiting their own position as a large energy customer, using local knowledge to identify suitable loads, using public procurement mechanisms to develop a public sector customer base (interview - 30) along with using their ability to leverage investment funds such as publically funded capital grants. These local institutional arrangements rely on the local authority as an anchor tenant both in terms of creating demand for CHP-DH output but also in coordinating a network of actors and providing legitimacy for the development and expansion of schemes.

Developing Sector Level Institutions

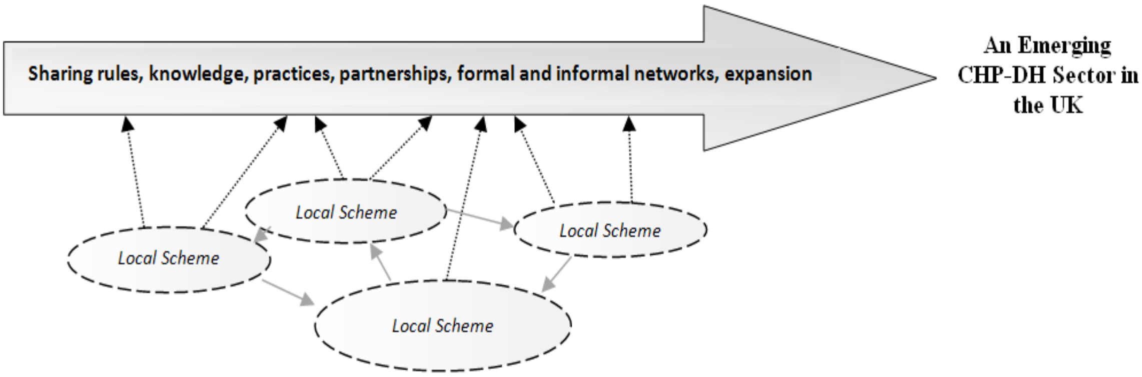
The CHP-DH sector in the UK can be characterised as a patchwork of localised spaces of agency which, through a process of structuration, are beginning to form a more coherent organisational field at the national level. This fragmented sector structure can be attributed to the fact that heat networks are by their nature organised on a local basis, but also due to a lack of national level coordinating institutions e.g. little regulation of small scale energy systems and a fragmented policy environment with the EST, Carbon Trust, Ofgem, DECC and DCLC all governing aspects of the CHP-DH regime. As a result, the interactions and knowledge sharing activities taking place within the organisational field tend to be informal professional links between individuals – often the technical or political champions of a scheme. In many cases, this lack of sector level institutions has been a barrier to the development of CHP-DH as local authorities often lack the necessary in-house capabilities (technical, institutional/legal and organisational/financial expertise) and are therefore reliant on expensive consultancy firms to provide such services (interview – 27, 36).

Although a number of organisations - the CHPA[121], LGA[122], the Decentralised Energy Knowledge Base (DEKB)[123], the Core Cities Group (interview - 37), and DECC's Community Energy Online website[124] - are beginning to create more formalised sector structures and provide forums for interactions and knowledge sharing to take place, this is in its infancy. The following quote from a local authority employee outlines the need for more formalised sector structures and the rationale for setting up the DEKB, which is an association of a number of the larger city-wide district heating schemes in the UK:

> *"We felt that we didn't really have a voice collectively, a political voice. You've got the CHPA but there is a sort of feeling, and no disrespect to them, they were sort of the widget makers if you like, they were the people who made micro-CHP and stuff like that, but we weren't really voicing the district energy market (...) So we have sort of come together collectively to establish an association that will give us a lobbying voice in government to DECC. So we can say this is Nottingham, [this is] Southampton and this is Birmingham [this] is Sheffield [and] Aberdeen, we have been talking collectively and this is what we say government should be doing"* (interview - 30)

The structuration of the CHP-DH organisational field, as represented in the schematic below, is also being enabled by the expansion of Cofely DE (Southampton, Manchester, Leicester, Birmingham, London) and Thamesway Energy (Woking, Milton Keynes) who have begun to develop and operate schemes in a number of localities by replicating a successful business model.

Figure 6.10: The Emerging CHP-DH sector



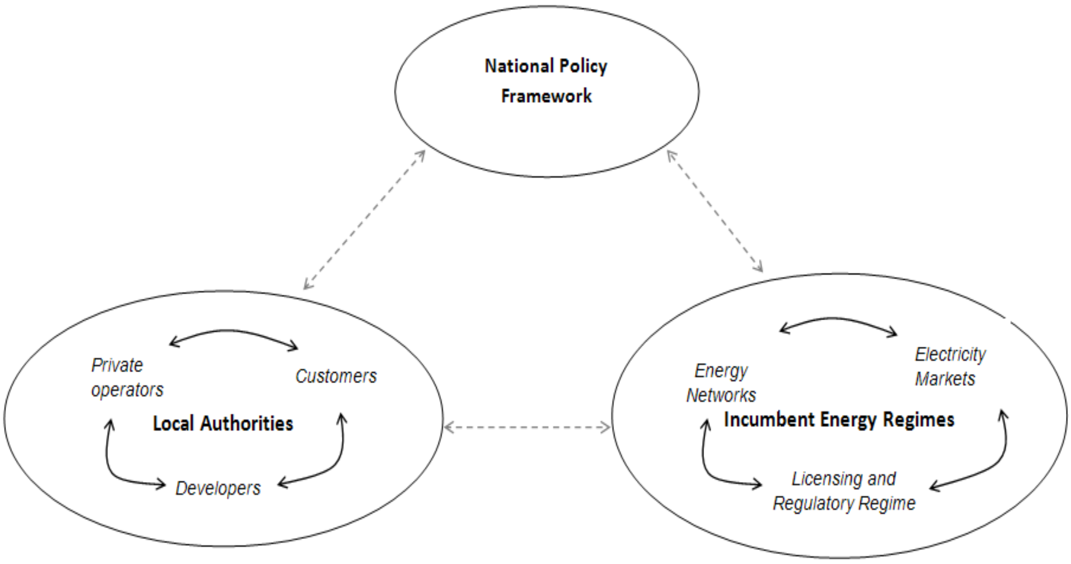
Source: Adapted from (Coenen et al., 2010)

[121] Combined Heat and Power Association: http://www.chpa.co.uk/
[122] Local Government Association: http://www.lga.gov.uk/lga/core/page.do?pageId=1
[123] http://www.dekb.co.uk/
[124] http://ceo.decc.gov.uk/

National-Local Interactions

As the diagram below illustrates; local energy schemes are part of a triumvirate of regimes including national level policy frameworks which influence planning and energy policies and the existing energy regime including regulations and market structures, which are instituted at the national level.

Figure 6.11: National-Local Regime Interactions



It has been observed that increasingly a number of local authorities are seeing CHP-DH as a technology which can align their long term strategies and interests with national level policy drivers in relation to the promotion of local governance, achieving emissions reductions targets and complying with new planning guidelines. However, as has been discussed in the interventions and interactions section, significant barriers to the development and success of CHP-DH emerge as they encounter incumbent energy regimes such as regulations and markets, which are institutionalised at the national level. Therefore, although government policies may seem to favour the development of CHP-DH, the reason why this is failing to stimulate a greater degree of investment in heating infrastructure is because energy policies and regulations continually reinforce the incumbent, largely centralised energy regime rather than promote alternative solutions such as local energy infrastructures (Mitchell, 2008).

For example; the focus on achieving the decarbonisation through supply side measures e.g. the all-electric future, the use of macro-economic modelling techniques which do not take into account local circumstances and opportunities (Speirs et al., 2010), and incentives for energy efficiency which are based on a market failure arguments and which treat customers on an individual basis, thus neglecting the potential economies of scale and scope which can be achieved through CHP-DH. This reinforces the argument that policies designed to support energy efficiency and heat tend to funnelled through this energy policy paradigm (Mitchell, 2008). For example, although the RHI may incentivise fuel switching in a small number of existing schemes, it will not provide the 'uplift to pay for the pipe network' (interview - 39) which is necessary to develop heating infrastructure more widely across the country. The following quote from a district heating developer summarises these concerns regarding the introduction of the RHI:

> *"The government has proposed the RHI (...) that would be fine if there was already a highly developed distributed heat network capability within the UK, but there isn't. Going from no heat incentive to a renewable heat incentive is absolute nonsense because this technology is starting to get developed around the place but it is a sustainable technology. If they went to an RHI immediately I would get levied on the gas that I have used, which is complete nonsense. So what they should do is go to a HI [heat incentive] to start with, then go to an SHI [sustainable heat incentive] after about five years, I'd go to a renewable after about maybe 10 years (...) At the moment is there is a disincentive [for] me to invested heat network because I am going to get clobbered by the RHI, it is absolutely crazy"* (interview - 31)

It will be proposed in the final chapter that more specific policies which support the development of local energy infrastructures and CHP-DH sector level institutions are required.

6.4.3 Structural Dimension

Network logics represent the underlying rationality behind the system which shape field level interactions and act as a source of legitimacy for action. Two 'ideal type' network logics were identified; the competitive model – where competition and prices promote efficient system planning and operation and the primary goal is to deal with the market externalities - and the public services model - where utility services are seen as a social good and risks are socialised. Similar to the electricity distribution case study, each of these network logics have influenced the various interventions and interactions which were described in the previous sections.

At the local level, the rationale behind the development of CHP-DH largely draw from a public services model as local authorities seek to address issues such as fuel poverty and the provision of public goods such as sustainability and energy security within their localities. The 'well-being' role and the introduction of prudential borrowing following the 2003 Local Government Act has given some scope to LAs to invest in local energy infrastructure. Although the means by which they go about achieving these goals are different and context dependent, in each of the schemes councils are drawing legitimacy from the view of energy services as a public utility and the need for local authorities to take on a greater degree of responsibility for dealing with climate change and sustainability issues within their localities. Also, in a number of the cases, interviews cited concerns of over the long term sustainability of the liberalised energy regime in the UK as a motivation for developing low carbon infrastructure (interview – 25, 26, 30, 31, 32, 33, 34, 37, 38).

However, as has been discussed above, as decentralised energy increasingly comes under the radar of mainstream energy policy and regulation, a number of conflicts have emerged between the competing network logics. For example, the technology and fuel blind approach to the design of electricity markets at the national level means that small scale decentralised technologies face high transaction costs and their environmental and system benefits largely go unrecognised (Mitchell, 2008). Also, as CHP-DH increasingly comes under the regulatory spotlight there is a mismatch evident between the regulator's agenda of promoting short term retail contracts and customer switching, and the necessity of long term contractual arrangements for investment to take place in low carbon infrastructure.

6.5 Chapter Conclusions

This case study discussed the interplay between actors, institutions and technologies in the emerging CHP-DH sector in the UK. The nationalisation of the energy sectors in the UK after WWII saw the end of direct provision of energy services by local authorities, and although liberalisation encouraged local authorities to develop more sophisticated energy management plans for their own estates, councils have largely taken a minor role within the mainstream energy regime. This chapter has shown how in more recent years a relatively small number of local authorities have begun to engage more directly in energy services provision, in particular by (re)investing in local district heating infrastructure. This has been occurring in the wider context of a national policy regime which is seeking to promote low carbon energy supply, sustainable development in the built environment, and efficient end use of electricity within businesses and domestic dwellings. Also, recent legislation regarding the relationship between national and local government has granted a degree of autonomy to local authorities to address 'well-being' and sustainability issues within their localities.

Individual local authorities have begun to articulate these national level policy drivers in the context of their own localities with responses being shaped by their own resources, capabilities and longer term energy and climate change strategies. In the cases surveyed, CHP-DH has become a key response which can negotiate between local and national policy drivers and is an increasingly important tool to achieve longer term strategic aims such as addressing fuel poverty, promoting sustainable development and ensuring long term energy security within the locality. Due to the fragmented and unstructured nature of the emerging CHP-DH sector in the UK, schemes differ greatly in how they are organised and financed and the nature of the interplay between public and private actors. The more advanced schemes are taking a strategic approach where CHP-DH is but one element of a long term energy and climate change strategy within the locality. The nature of the interaction between these dispersed niches and the energy regime has been a significant factor in their social shaping.

However, similar to the electricity distribution case study, conflicts and mismatches are observable between the governance regime and efforts to develop a more substantial CHP-DH sector in the UK. Regime structures such as the electricity markets and energy regulations tend to be instituted at the national level which means that there are higher transaction costs for small scale CHP plants relative to large scale centralised technologies, while at the same time energy policy and regulation tend not to provide an overarching supportive framework for investment in local energy infrastructures. Specific issues include the difficulties in transacting in the national level electricity markets, uncertainty surrounding the regulation of decentralised energy schemes and private networks, the lack of financial support for district heating, and poor coordination and coherence in the wider governance regime which is spread across a number of policy areas and government departments. Unlike electricity distribution however, these tensions and have not emerged in recent years but have been a feature of the sector throughout the nationalised and privatised periods (Russell, 1994, Russell, 1986).

7 An analysis of the interplay between actors, institutions and technologies in infrastructure sectors

7.1 Introduction

The purpose of this chapter is to look across the two case studies to seek out generalizable theoretical insights about the process of change in energy distribution networks. Although the cases differ in a number of important respects (types of technologies, institutional composition of the sectors), it is proposed that a comparative analysis which is sensitive to these differences can help to develop more generalizable knowledge regarding the contemporary dynamics of distribution networks. As was discussed in chapter three, a case study method allows for the identification of causal mechanisms or 'recurrent processes generating a specific kind of outcome' (Mayntz, 2004: p.237) which influence the dynamics between actors, institutions and technologies. The aim of this chapter is to identify and elucidate the most significant causal mechanisms which illuminate various aspects of this dynamic in each of the cases with a view to informing the existing literature and developing novel theoretical insights. The first part of the chapter discusses the outcomes of the empirical section through the lens of the existing literatures on infrastructure dynamics which were introduced in chapter two. Following this, a number of additional causal mechanisms are discussed which were identified using the analytical framework outlined in chapter three.

7.2 A Discussion of Causal Mechanisms from the Literature

Chapter two introduced the existing literature which broadly addresses the main research question regarding the changing relationships between actors, institutions and technologies in contemporary energy infrastructures. Two strands of theory were discussed; institutional and evolutionary approaches which highlight the importance of institutions - both as mechanisms of coordination and as sources of inertia in technical systems – and perspectives from the science and technology studies literature which, to different degrees, stress the role of actors and the interplay between agents and structures in processes of technical change. Table 2.2 summarised these different approaches by identifying the key causal mechanisms which describe various aspects of the interplay between actors, institutions and technologies in these sectors. Using this as a platform, the following section explores some of the main concepts in these literatures and discusses how each illuminates processes of change in the case studies.

7.2.1 Vertical dynamics

As discussed in chapter 2, analysing vertical dynamics between different parties along an infrastructure value chain has been a key theme in the different literatures. In particular, the NIE approach proposes that vertical dynamics along a value chain can be analysed in terms of the relative costs of organising transactions through markets or hierarchies (Williamson, 1985). This has been criticised by economic sociologists amongst others on the grounds that it neglects the fact that agents are socially embedded (Nee, 2003, Granovetter, 1985). Also, new-institutional sociologists propose that such notions of economic efficiency or rationality are in fact socially constructed and context dependent (Meyer and Rowan, 1977). By applying the analytical framework described in chapter 3 to the case studies, it was found that although there were instances where vertical dynamics seem to be in the interests of achieving system economies, they more often than not were shaped by broader political and societal influences rather than purely techno-economic notions of rationality or efficiency.

It was observed by a number of interviewees that in the case of electricity distribution networks, the unbundled structure of the sector has in some instances acted as a barrier to the utilisation of information regarding demand side behaviour and the 'efficient' control of flows within the network (interview – 5, 12, 16, 20). Smart grid and ANM concepts and visions have re-opened debates regarding the most 'efficient' form of sector organisation and the potential trade-offs between short term asset sweating, achieved through specialisation (unbundling) and market based incentives, and notions of overall system efficiency which are achieved through integration and closer coordination. More complex flows of energy (for example due to the connection of DG) and revenues along with the growing importance of information flows are undermining traditional sector boundaries. However, rather than seeing a smooth and predictable governance transformation involving a new set of vertical relationships, institutional change is more complex and influenced by the interpretations, motivations and strategies of a range of actors at the organisational field level. Debates surrounding the smart metering roll out and their functionality illustrate how notions of efficiency can be defined and interpreted by electricity retailers and distribution companies in entirely different ways. According to many of the distribution companies interviewed, a regulated roll out process which would involve a hierarchical institutional arrangement with a distribution led process designed to achieve economies of system is a technically 'rational' way to proceed. On the other hand, the retail led approach views rationality in terms of enabling 'efficient' customer behaviour by facilitating switching between suppliers. What emerged was a hybrid solution involving some levels of hierarchical coordination but the approach is underpinned by the prevalent network logic of competition, switching and unbundling.

For the case of CHP-DH, there tended to be less debate surrounding the vertical dynamics taking place as the schemes operated in an integrated fashion with no separation of retail, distribution, and generation. This is because the heat sector is a largely unregulated space therefore there is no licensing regime which would compel the unbundling of different system functions. This points to the view that, rather than being a process where actors choose the most efficient governance arrangements, unbundling is largely a political choice based on ones notion or framing of a networks logic (Graham and Marvin, 2001). By considering the influence of broader network logics one can see how framings of efficiency and how to govern vertical relationships within an infrastructure sector draw from competing values and ideas of what a network should be whilst involving a process of political negotiation as these compete - rather than solely concerns over efficiency and transaction costs.

7.2.2 Innovation

The evolutionary based literature emphasises the importance of innovation in processes of economic change. This is theorised at the sector level – where industries are characterised by different types of innovation processes –and at the firm level – where organisations possess unique capabilities and are constituted by sets of organisational routines which are difficult to change. For each of the cases, these issues relating to innovation at both the firm and sector level have been an important explanatory factor in processes of technical and institutional change.

Prior to the period of this study the electricity distribution sector could have been categorised as a typical Schumpeter Mark I type sector with ‘large established firms and the presence of relevant barriers to entry’ (Malerba, 2002). During the period of study a number of developments have altered this to some degree. For example, politically motivated efforts to promote DG challenged existing sector boundaries and prompted a series of institutional realignments designed to adapt existing sector or regime structures (Smith et al., 2005) e.g. changing the charging regime for the use of distribution networks by DG operators. Also, uncertainty surrounding how to utilise demand side information from smart metering technology have challenged to some extent the structure of the sector which emerged following the processes of liberalisation and privatization during the 1980s and 1990s. These examples show how the diffusion of potentially disruptive technologies such as these need to be considered in a dynamic or co-evolutionary way where sector structures adapt to a changing selection environment whilst also seeking to shape new technologies. Within highly institutionalised organisational fields such as distribution sectors, potentially disruptive technologies which alter value networks (Christensen and Rosenbloom, 1995) can be in a sense pacified (perhaps to a greater degree than conventional, non-regulated industries) as sector structures and institutions, rather than firms, adapt and incorporate them. At a firm level, although firms do not possess dynamic capabilities due to the mutual interdependence between the regulator and the companies and the resulting incremental nature of regulatory change, their routines tend to be shielded from external shocks and harsher selection environments. Also, the asset specific nature of the transactions taking place grants a degree of power to network operators which otherwise would not be the case.

The failure of the RPZ scheme can be partially attributed to the fact that the incentive was aimed at the firm level, rather than at the sector level where, as discussed above, many of the barriers to innovation persist. The innovation systems literature emphasises innovation as an interactive and complex process involving a range of public and private actors, and stresses the importance of collaboration and learning processes. Although the LCNF program does address some of the deficiencies of RPZ, in particular by de-risking innovation and actively promoting collaboration, it is questionable whether it alone can be adequate to address the systemic barriers which are deeply entrenched in field level interventions and interactions. The regulator must show a long term commitment to promoting technological innovation through incentive schemes which can develop capabilities at the firm level, whilst also incorporating innovation into the wider selection environment for innovation, rather than simply as a means to achieve CAPEX efficiencies. This may change the short-term efficiency and price focused field level rationality which pervades.

The analysis of CHP-DH schemes showed that, as one might expect, a less institutionalised organisational-field is more receptive to new innovations and practices. In the electricity case, although the RPZ and LNCF schemes have begun to bring about some differentiation amongst the different firms, it is difficult to distinguish between firm strategies and capabilities in this regard. Because CHP-DH systems are not interconnected and operate in a less structured selection environment, each of the schemes is unique in the technologies and practices being adopted and manner in which a scheme is organised. A potential explanation for this difference in the nature of the sector innovation system is that when designing and developing schemes, local authorities are more concerned with context specific local priorities and issues, and because they operate in an emerging field, their resources and capabilities are more differentiated. For example, the scheme in Woking has developed in isolation from the wider national level energy sphere but within its own context the scheme can be categorised as an architectural innovation; private wire in this respect is a disruptive innovation. Therefore, as will be discussed in a later section, the notion of a selection environment should be considered in a more multi-dimensional or multi-scalar way than has previously been the case and a lack of coherence between selection environments, e.g. at the local and national scale, can be a significant barrier to the diffusion of innovations in certain circumstances.

7.2.3 Path Dependency and Lock-in

Path dependency refers to a view of institutional and technical change where previous events within a system influence contemporary decisions and can result in a lock-in which results in potentially sub-optimal outcomes and development trajectories. Paul David (David, 1985) has argued that actors cannot simply switch between alternatives in order to achieve an efficient outcome and, developing these insights, Gregory Unruh proposes that large scale technical systems such as energy infrastructures are prone to inertia as technical and institutional systems coevolve due to increasing returns to produce lock-in (Unruh, 2000).

For the case of CHP-DH, processes of path dependency must be viewed as a process of 'lock-out' rather than 'lock-in' to a certain trajectory. Russell's study of CHP-DH in the pre-privatisation period highlights two key reasons for this; 1) the failure to interact with the electricity markets in an effective way because 'producer industries have generally sought to consolidate and maintain the structure of the sector in vertically integrated chains' (Russell, 1993: p. 48) and 2) the fragmented nature of the CHP-DH sector and its failure to pursue its interests and become institutionalised at the national level. It is interesting to observe that these issues which have been present since the nationalised period have been largely unresolved for the CHP-DH sector, therefore implying that decisions made in the nationalised and pre-nationalised periods are shaping the trajectory of the sector in the UK today. This is highlighted by the difficulties that different schemes have encountered transacting in the wholesale electricity market and the fact that policies which seek to promote a low carbon energy system often neglect or under-explore the potential role that CHP-DH can play (Speirs et al., 2010). The development of private wire can perhaps be seen as a strategy to break-out of this path by disengaging from the national level energy policy regime and promoting local autonomy.

Unsurprisingly the electricity distribution case shows signs of significant lock-in and path dependent institutional and technical change. Dominant modes of governing ('sweat the assets', 'open access', 'protect the customer') which emerged from the liberalisation and privatisation processes have been a significant factor in shaping responses to demands for the networks to facilitate DG and more flexible demand side behaviour. Also, it is questionable whether the current unbundled and fragmented structure of the sector which was designed to exploit the large capacity margins which were built during nationalisation, is necessarily the 'optimal' configuration for the transition to a low carbon electricity system where distribution networks will need to play a more active role in system operation. This perhaps illustrates a form of political (Pierson, 2000) or regulatory path dependency where the pace of change is incremental and paradigmatically structured rather than adaptive and responsive to contemporary needs (Mitchell and Woodman, 2010, Mitchell, 2008).

7.2.4 Processes of Social Construction

Constructivist approaches emphasise the contested nature of technical change and view innovation as a process involving interpretive flexibility and conflicts between different actors and groups of actors (Edge and Williams, 1996). Although actor based approaches such as SCOT and ANT have been criticised for having a shallow ontology which underplays the influence of structures and institutions in long term change (Geels, 2007, Russell, 1993), constructivist approaches provide a useful toolbox of theories and concepts which can be utilised to analyse the relationship between technologies and actors.

One such concept which describes the electricity distribution case is that of closure. In their famous bicycle example, Pinch and Bijker (1987) outline how, following a process of negotiation between different social groups, closure was reached as actors converged on a shared interpretation or meaning of a particular technological configuration. A similar process has taken place in the evolution of the ESI throughout the 20th century where a centralised system based on AC technology emerged as the dominant design following competition between a number of alternatives (David and Bunn, 1988). However, it has also been noted in the literature that closure is not permanent as conflicts and interpretive flexibility can re-remerge (Murphy, 2006b). The analysis of contemporary dynamics in the UK electricity distribution sector suggests that this undoing of closure is occurring to some extent where the stable system configuration of passive distribution networks which emerged following nationalisation is being undermined by a range of technical and institutional changes relating to the connection of DG and integrating with the demand side. This is opening up the system to interpretive flexibility as different groups of actors e.g. DNOs, the regulator, suppliers etc., seek to understand the implications for their particular interests. In this respect visions and scenarios of the future play an important role in this negotiation process and often represent the interests and values of the actors who forward them (Berkhout, 2006). The different visions of a smart grid future which have emerged illustrate how actors are seeking to make sense of the future; for example many of them propose to situate a low carbon energy system within a liberalised context.

The CHP-DH case illustrates examples of conflicts and processes of interpretive flexibility which are taking place as less established technologies and approaches emerge and seek to gain legitimacy. The example of private wire clearly illustrates how different groups of actors view a particular technology in different ways. This is illustrated in the following quotes – the first is from a consultant who works in the electricity distribution sector and throughout the interview tended to be a strong advocate of liberalisation and market based incentives. The second is from a local authority official who has been closely involved for many years in developing one of the largest CHP-DH schemes in the UK:

> *"I would feel unhappy if genuine private wire systems emerge, that's a sign of some inefficiency somewhere (…) or uneconomic pricing of the public wires" (interview – 19)*

> *"Putting in a private wire (…) makes a lot of sense. The council gets lower electricity costs, a guaranteed lower electricity cost than we are getting (…), and [we] make more profit off the sale of that electricity because they have no use of system charges" (interview - 34)*

As the quotes suggest, the issue of private wire is contested with some seeing it as a threat to the established order or a sign of inefficiency, whilst others, who frame the issue within their local context, see it as a rational and economic investment which can make a particular CHP-DH scheme more economic as the revenue from electricity sales can be increased.

7.2.5 System Evolution

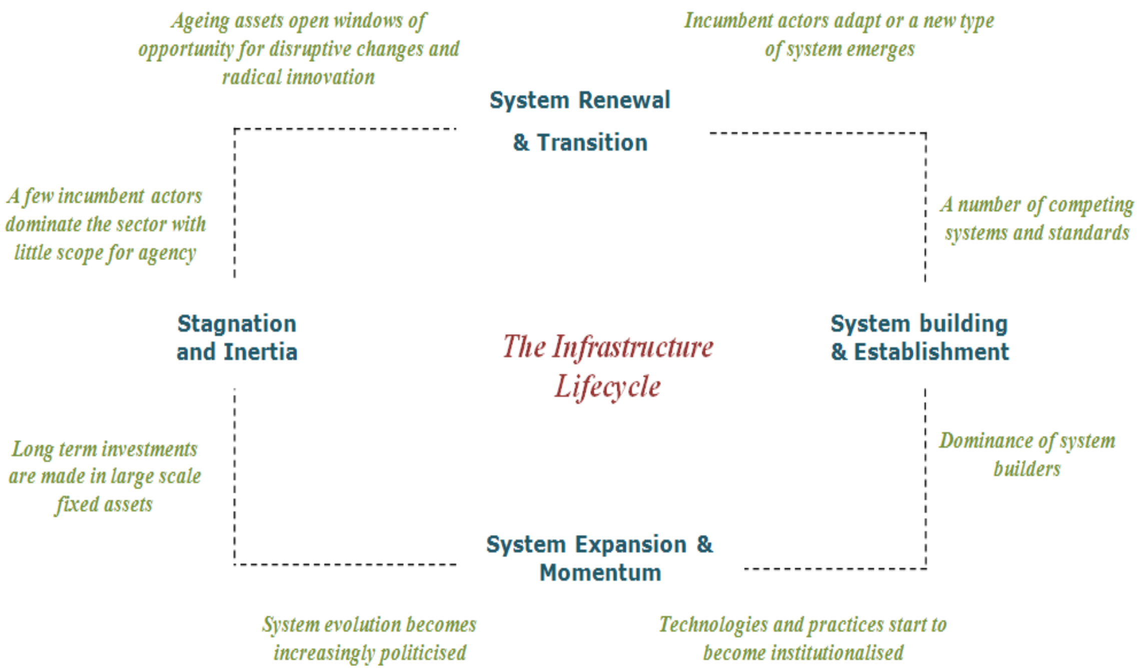
Systems approaches stress the interconnectedness of the social and technical components of large scale infrastructures. The approach developed by Thomas Hughes in his analysis of early electricity networks highlighted how the technical systems interacted with their external environment and over time developed momentum as dominant technologies and practices became institutionalised (Hughes, 1983). Hughes outlines a number of concepts and analytical tools for the analysis of the socio-technical dynamics of infrastructures such as a reverse salient – a breakdown in system momentum due to a critical problem – technical styles – the context dependent diffusion of technology - and system builder – influential actors who shape systems in their early stages, similar to engineer sociologists in ANT.

The electricity distribution case in particular highlights the relevance of the reverse salient and technological momentum concepts. Throughout the periods of nationalisation and privatisation the ESI in the UK has displayed significant technological momentum with the persistence of a supply side dominated system and passive distribution networks. However, developments in DG and DSM provide examples of technologies which have challenged this momentum and have created critical technical problems on an area of the system which was not designed to be managed in an active manner – the distribution networks. These examples show how developments in the generation and demand side are creating bottlenecks in the networks areas of the system and this has been amplified by the fact that different parts of the value chain operate under different governance regimes with natural monopoly and competitive segments. Because Thomas Hughes' work focused on early stage and expanding systems which were by and large vertically integrated, many of the reverse salients he pointed to tended to be technical in nature, however, in a liberalised context the evolution of a system as a whole can no longer be treated as a unified entity with a singular system goal. The DG issue in particular shows how reverse salients do not only involve technical solutions (changes to the energy flows) but also institutional realignments such as changing revenue streams and regulatory incentives (revenue and information flows). Also, within highly institutionalised sectors such as electricity supply, responses to reverse salients and associated outcomes are more likely to be shaped by incumbent institutions and organisations such as large energy companies (Stenzel and Frenzel, 2008) and regulators, rather than individual technologists or entrepreneurs as Hughes suggests.

The CHP-DH case does however show that the Hughesian model of system building and actor-network concepts remain relevant. The development of local energy schemes undoubtedly provides individual actors with more autonomy to shape systems and enrol other actors thus developing their own technical styles e.g. different approaches to interacting with electricity markets. The case also showed how the organisational 'style' or model that is adopted is also a key differentiator between schemes. If and when the sector becomes more structured and institutionalised it is likely that dominant designs and more powerful actors will emerge who begin to influence and shape CHP-DH schemes in other localities. There are already early signs of this with the emergence of Cofely DE and Thamesway Energy who are both operating a number of schemes and looking to expand their influence over the evolution of the sector as a whole. The CHP-DH case also shows that for a scheme to be successful two types of individual system builder are necessary – a technical and a political champion. This dual role is required in CHP-DH schemes due to the politicised nature of energy networks which require actors to show long term commitment and to address a number of institutional barriers. The function of the political champion is to enrol influential actors within the council to provide resources to the technical champion who operates in a similar way to a traditional Hughesian system builder.

It has been argued elsewhere that the systems approach is less applicable to contemporary energy systems because Hughes 'credits the system-builders themselves with too much authority' (Winskel, 1998: p.282). However, the selection of two sectoral case studies of networks which are at different stages of development – electricity systems being mature and institutionalised with CHP-DH at an earlier stage – shows that systems approaches can be still relevant and the role of the system builder is not redundant. It is argued that rather than reject the systems approach, a more dynamic perspective to the analysis of infrastructures based on a lifecycle approach allows one to form a better understanding of the interactions between structure and agency as systems evolve. The figure below draws from Arne Kaijser and Thomas Hughes' work on the evolution of large technical systems over time (Kaijser, 2004, Hughes, 1983). This lifecycle model is a stylised account of the temporal evolution of infrastructures and represents a novel heuristic framework to think about the interplay between structures and agents over time as a system evolves.

Figure 7.1: The Infrastructure lifecycle



This avoids the pitfalls of an over emphasis on structures or agency as explanatory variables; rather it shows that both actor-centric/constructivist and more structural or institutionally orientated approaches need not be mutually exclusive but each provide useful tools to analyse the dynamics of energy systems at different stages of their lifecycle.

7.2.6 Landscape, regime and niche interactions

Transitions theorists argue that structural changes in production and consumption systems can be explained according to the multi-level perspective with different types of interactions taking place at the landscape, regime and niche levels. The multi-level framing is similar in many ways to the analytical framework which was developed as part of this thesis as it not only considers agency and practices at the micro-level but also how this is shaped by institutions which are structurally embedded at the regime and landscape levels.

The CHP-DH case in particular illustrates the utility of such a multi-level framing (Geels, 2004, Verbong and Geels, 2007). As has been previously noted, the application of solely actor-centric approaches - such as ANT - to the analysis of CHP-DH has been critiqued on the grounds that they fail to describe the structural preconditions and context for agency (Russell, 1994). The MLP allows micro-level activities within niches, such as the development of local energy schemes, to be analysed in the context of sector level structures – which are predominantly instituted at the national level in the UK – and external landscape influences such as concerns over international resource security. To illustrate these multi-level dynamics the following two quotes from local authorities illustrate how ongoing developments at the landscape level have influenced their approach to the provision of local energy services:

> *"And then you have got the political issues [if] Mr. Putin or whoever decides to turn your gas off (…) If we get to a stage where we are self-sufficient in terms of energy, that we are not importing all of this energy which is having a massive export in terms of our economy"(interview - 30)*

> *"(...) yet we are entirely reliant on deals that are struck for the supply of gas and coal and oil at a national level, and yet we also recognize that we have got significant natural resources in the city, and man-made resources that we can exploit far more effectively" (interview - 37)*

These examples show how perceived threats to energy security and the long term sustainability of the current energy regime are prompting new forms of response where cities and localities seek to 'strategically protect "themselves" from climate change and resource constraint'; this has been referred to as 'urban ecological security' (Hodson and Marvin, 2011). The evolution of the CHP-DH niche in the UK should therefore be viewed within this broader context.

The electricity case highlights changing regime dynamics as a result of landscape (e.g. climate change) and niche (e.g. DG) pressures. Transition theory outlines three patterns of regime dynamics; reproduction – where dominant actors reinforce regime structures through incremental innovations – transformation – where incumbent actors change and adapt by developing modular innovations – and transition – where new variations become institutionalised and replace the incumbent regime. It is clear in the electricity distribution case that a transformation pattern is currently taking place as existing modes of governing are being adapted rather than fundamentally reformed. The RPI-X@20 and RIIO proposals, where fundamental reform to sector structures was ruled out before the process began, illustrates how incumbent actors such as Ofgem are seeking to strategically select new variations which conform to their interests and existing sector structures (through innovation incentives aimed at DNOs) whilst ruling out radical alternatives. Within such a regulated sector it is highly unlikely that a transition pattern will be observed due to the natural monopoly characteristics of networks and the strong independencies between the regulator and network companies.

7.2.7 Scalar Dynamics

The Splintering Urbanism literature argues that the socio-technical dynamics of infrastructure networks should be viewed within the wider context of the post- Keynesian state which has seen a move away from nationally integrated energy systems towards more spatially disaggregated forms (Graham and Marvin, 2001). As a result, new types of dynamics are likely to emerge between different spatial scales resulting from processes of de-nationalisation, de-statization and internationalisation (Jessop, 1997). Although it was argued in chapter 3 that the Splintering Urbanism literature tends to downplay the role of the nation state in infrastructure governance, its emphasis on scalar dynamics does shed some light on the processes of institutional change that have been observed across the two cases.

In the electricity case, due to the liberalisation of the generation and retail markets and efforts to promote DG and demand side integration, a process of the localisation of flows can be observed across the networks. The traditional passive/one way flow model of distribution networks is being supplanted by a more complex and dynamic set of energy, information and revenue flows and this is necessitating more site-specific responses to issues such as voltage imbalances and fault levels. Emerging from the nationalised era, network planning and operation had tended to be carried out at a highly aggregated level and components were bought ‘off the shelf’ from large scale multi-national manufacturers and rolled out across the networks (interview – 6). The diffusion of DG in particular has created problems both for the incumbent operators and the governance regime for electricity networks because the resulting localisation of flows is requiring innovative and location specific solutions depending on the geography, and the location and density of loads on the different networks. Issues surrounding smart metering and uncertainty over how system economies can be achieved in a highly fragmented sector are also challenging the centralised model where electricity markets and network oversight take place at the national level whereas emerging issues on the distribution networks increasingly require decentralised decision making at the sub-network level (Jamasb and Marantes, 2011). The development of cost reflexive pricing regimes for new connections and incentives for innovation which are giving autonomy to companies to solve particular issues on their networks show that scalar dynamics are an increasingly important aspect of institutional change.

The CHP-DH case shows how dynamics between scales clearly affect the interplay between actors, institutions and technologies in energy systems and how incoherencies between scales of governance influence infrastructure dynamics. The failure of national level markets to properly value the electrical output of CHP is creating uncertainty around the economic viability of CHP-DH (interview – 25, 26, 27, 29, 31, 34, 36). Depending on the context, a number of different responses have emerged from this scalar dynamic between local energy systems and national level electricity markets - drawing from Coutard and Rutherford (2011) two such responses can be characterised: The first is going *off-grid* which Coutard and Rutherford (2011) describe as being ‘based on a deliberate policy or strategy of bypassing to some extent traditional centralised networks and developing services on a local level, increasingly over decentralised, local infrastructures. Such policies or strategies are founded on desires or obligations of autonomy or independence’ (P.112). A prominent example in the UK CHP-DH case is that of Woking Borough Council which uses a private wire electricity network thus by-passing the public distribution network and creating a sense of independence from the incumbent regime. The second response is *feed-in to grid* where there is more interaction between the local scheme and the centralised energy system. Rather than using private wire electricity networks, these schemes feed electricity back into the distribution network and sell the heat locally - examples include Aberdeen, Birmingham and Nottingham.

These cases of scalar dynamics show how selection environments are multi-dimensional and can differ across scales with certain technologies such as CHP-DH and ANM benefiting from circumstances and opportunities which are specific to a geographical location or a particular local context but do not align with the broader national governance regime.

7.2.8 Summary of key findings

The purpose of this section was to explore the interplay between actors, institutions and technologies across the two cases through a number of different theoretical lenses which were introduced in chapter 2. Throughout the discussion it was found that, to different degrees, these theories and concepts can illuminate different aspects of this interplay. Therefore rather than present them as being in conflict or as mutually exclusive, it is more useful to allow room for a number of approaches and models to help explain these complex socio-technical processes. This is particularly important for large scale infrastructure systems as they involve technologies and institutions which are embedded in broader societal and political structures with processes of path dependent change and multiple interactions taking between a wide array of both public and private stakeholders who have different and sometimes competing motivations and strategies. A similar conclusion was arrived at by Winskel in his analysis of technical change in the ESI during the early years of privatization:

> *"… No single model or conceptual framework has proved capable of a fully-satisfying explanation. Electricity generation technologies are the result of the complex interaction of a range of technical, economic, institutional, regulatory and political forces, operating at various level of social aggregation, whose analysis ultimately requires a broad based social shaping perspective. As the British ESI case demonstrated, technological dynamics retain a distinctive quality and an essential unpredictability within the broader process of economic and social change. In exploring these relations, the insights offered by technology studies concepts and models, whilst being necessarily limited, are of continuing value." (Winskel, 1998: p.310)*

A key insight was that perspectives which emphasise structures and institutions need not be in conflict with more actor-centric perspectives, particularly if one considers the long term evolution of infrastructures in terms of a lifecycle where the relative importance of each changes over time. It is argued that the analytical framework which was developed in chapter three of this thesis proved to be a useful and ontologically coherent platform whereby a number of models and concepts could be deployed to elucidate the transformation and reproduction of distribution networks. In particular the analytical separation between the physical and relational dimensions helped to elucidate the emerging vertical and horizontal relationships that are between actors within meso-level organisational fields, but also how these dynamics are grounded in the micro-level physical realities of the system. Contextualising this using the macro-level network logic concept enabled a critique of notions of efficiency as the sole driver for institutional and technical change because actors draw from these logics in different ways to legitimise their actions.

7.3 Additional Causal Mechanisms

Having discussed the similarities and differences across the two case studies with respect to the literatures introduced in chapter 2, the second section of this chapter explores in more detail a number of additional causal mechanisms which it is argued can further elucidate the underlying processes of technical and institutional change in infrastructure sectors. These mechanisms have been identified as significant contributors to the socio-technical dynamics of energy distribution sectors in each of the case studies and thus represent novel theoretical and/or empirical insights. Three such underlying causal mechanisms and their influence on each of the cases are discussed.

7.3.1 Strategic Selectivity of the State

In chapter three it was proposed that the influence of state transformation is a neglected aspect of the infrastructure governance literature. Following Jessop (2001, , 2007b, , 2009) it was argued that the governance of energy networks is institutionally embedded within national level socio-political dynamics such as the evolution from a Keynesian welfare state towards a Schumpeterian competitive state. These macro-level dynamics bring about a ‘tendency for specific structures and structural configurations to reinforce selectively specific forms of action, tactics, or strategies and to discourage others’ (Jessop, 2001: p.1224). For the case of energy networks, it was argued that this can be analysed in terms of national level governance regimes which in turn influence meso and micro level interventions and interactions within infrastructure sectors.

This section explores in more detail how specific modes of governing energy networks which are situated at the national level have influenced the uptake of different technologies and practices and shaped the nature of interactions taking place within organisational fields. To illustrate the influence of this strategic selectivity on the evolution of the electricity distribution sector the following table shows a sample of technical and organisational innovations which were encountered during the case study. It shows the level of ‘fit’ between the innovation and the modes of governing electricity distribution networks which constitute the governance regime in the UK (- is a poor fit or a conflict, 0 is neutral, + is a good fit or an alignment).

Table 7.1: Strategic selectivity in the Electricity Distribution Sector

Innovation	Sweat the assets	Open access	Protect the customer
Smart metering	+	+	+
RIIO	0	+	+
Innovation incentives	-	0	-
DG	-	-	-

What can be seen is that the introduction of smart metering technology to the UK ESI is unsurprising as it aligns well with existing modes of governing the sector. Smart metering reinforces the dominant liberalised rationality which underpins the current governance regime, in particular it promotes the idea that prices and incentives can promote efficient and rational decision making by individuals regarding their own energy use. Ofgem have proposed that this will facilitate competition in the retail market which will promote more efficient dispatch of generators and further reduce capacity margins. Smart metering has also become central to debates surrounding the smart grid i.e. as key enabling tool for the development of more active distribution networks. However, as the debate surrounding the smart metering roll out has shown, there remains a degree of uncertainty as to how coordination can be achieved between customers, retailers, DNOs, DG operators and the system operator.

RIIO, seen here as a regulatory innovation, also aligns well with the governance regime. The proposals reinforce a number of overarching trends which have been taking place in regulation since 2000-2005. For example, the fourth and fifth price control reviews have begun the introduction of output based incentives as a means of avoiding a damaging trade-off between incentives to reduce costs and the end customers' quality of service. RIIO has expanded this agenda in an effort to promote stakeholder engagement and transparency and efficiency in the delivery of network services e.g. connections. This further reduces the autonomy of network operators in determining how they achieve efficiency savings. Also, due to the recognition that CAPEX expenditure will rise in the future, RIIO has extended the price control period and proposed more detailed scrutiny of companies' business plans. RIIO is an evolution of the previous RPI-x framework which is broadly in line with existing regulatory practices and modes of governing.

One significant area where the governance regime for electricity distribution networks has largely failed to adapt is in efforts to promote innovation within the sector. Although there is a recognition that innovation incentives will need to be removed over time, the RIIO proposals continue the approach to innovation set out in previous price controls i.e. having a separate incentive mechanism which operates outside of the mainstream regulatory process. This difficulty stems from the fact that the original rationale behind RPI-x was that the job of the regulator was to incentivise efficiency and that innovation would be an outcome of the process. Although this was largely the case for OPEX, the short term time horizons that the process engendered negated against significant technological innovation and throughout this process the regulator has promoted risk averse strategies. Although the LNCF is likely to be more successful than RPZs in promoting the deployment of new technologies because it covers the majority of the upfront capital costs for the DNO, thus reducing the risk, it is as yet unclear how innovation can become embedded into the wider regulatory regime – the final chapter contains a proposal on how this might be achieved.

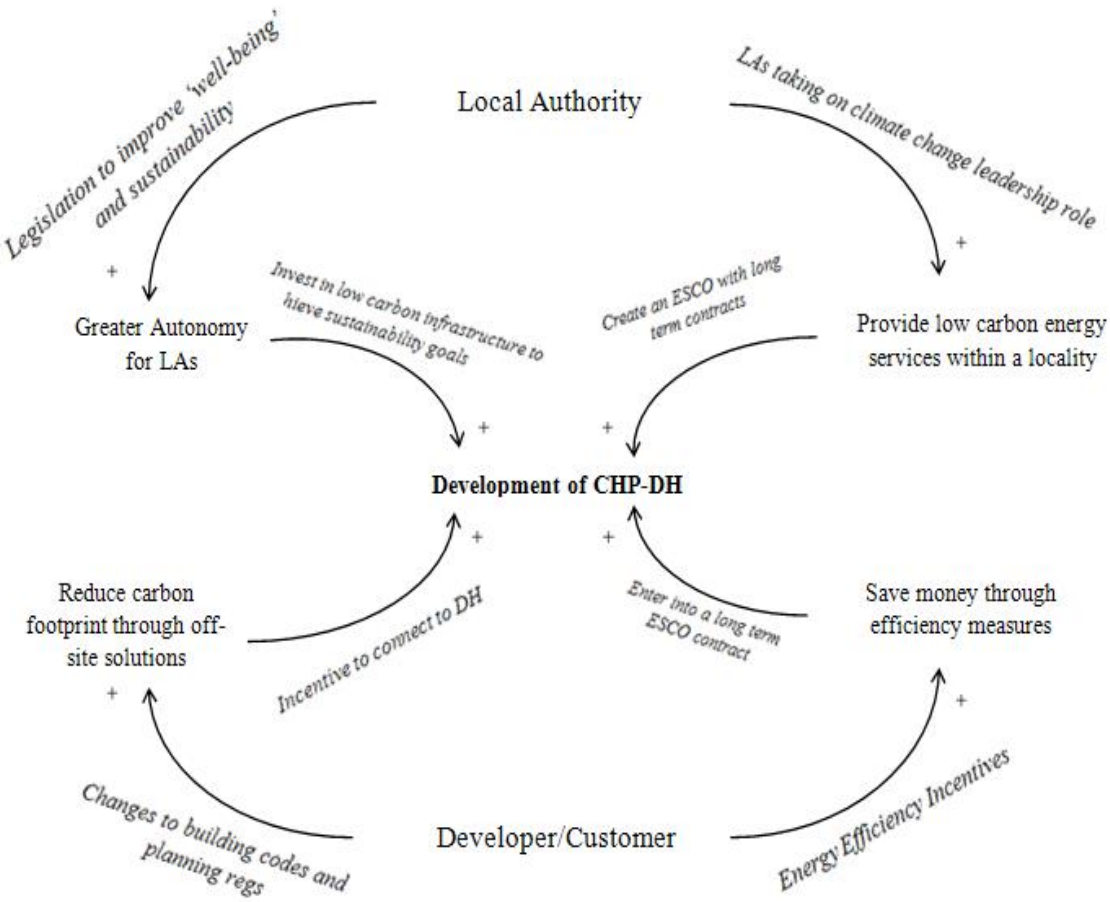
The final example in the electricity distribution case is that of the connection of distributed generation. As outlined in the case study chapter, the integration of DG into existing modes of governing within the sector has been a difficult process and has largely been a piecemeal process. DG has led to conflicts within the sector as it undermines the traditional approach to network operation that has prevailed since nationalisation i.e. that distribution networks are passive systems and any generators that wish to connect can be accommodated through reinforcing the network, thus placing a large upfront capital cost on DG developers and increasing the costs of running the networks. Efforts to increase the levels of DG connected to the networks have necessitated changes to the charging and connections regime. However, because these responses have been shaped by the existing paradigm of short term and piecemeal solutions and within the confines of existing sector structures, there are few examples of a coordinated approach being taken with regards to DG which would see the more active management of distribution systems.

Table 7.2: Strategic selectivity in the Electricity Distribution Sector

Innovation	Local Governance	Sustainable Built Environment	De-carbonise Heat
Investment in heat networks	+	+	-
Private wire networks	0	+	-
ESCO contracts	+	+	-

The table above outlines a number of innovations associated with local energy schemes in the context of the broader governance regime for CHP-DH in the UK. As discussed, investment in heat networks has formed part of a number of leading councils' strategies to address well-being and sustainability issues within their localities; thus forming part of an emerging local governance agenda in the UK. The changing nature of the relationship between the national and local tiers of government is evident in a number of key areas, e.g. the 'well-being' function and climate change mitigation, and this has created spaces of agency for local authorities and enabled them to invest in low carbon infrastructure. Similarly, changes to the building codes and planning regulations are enabling LAs to develop Local Development Frameworks which promote the expansion of low carbon infrastructure within their areas and allows them to work with developers to provide allowable solutions in order to comply with the code for sustainable homes. This virtuous circle (see figure below) between local autonomy, efficiency incentives for companies, building and planning regulations and the development of district heating networks is evident in a number of the leading councils such as Woking who have begun to develop a specific local energy policy and embed it within a wider set of strategies relating to sustainability and climate change. Also, depending on the context of the particular scheme, laying private wire networks and developing long terms ESCO contracts can enhance the financial and economic viability of CHP-DH by a) allowing operators to get the full retail price for their electrical output and b) securing long term stability which reduces risk and allow infrastructure investments to take place.

Figure 7.2: Example of virtuous circles in the development of CHP-DH



However, in each of the three innovations listed in the table above, there are incoherencies with national level decarbonisation policies. For example, measures which have recently been put in place to promote renewable heat, the RHI, fails to take into account the upfront capital cost of investing in distribution pipes. Also, issues surrounding the interaction between CHP-DH systems and the electricity markets have been discussed above, along with the ambiguities surrounding private wire networks and ESCO contracts. Both private wire networks and long term ESCO contracts directly conflict with current regulatory practice, particularly in relation to facilitating customer switching; this in particular has been interpreted by Ofgem as central to their primary duty to protect the interests of customers.

The central reason for this viscous circle between many of the UK decarbonisation policies and the development of CHP-DH is that policies which are designed to promote renewables and other low carbon energy technologies along with demand side energy efficiency are typically channelled through the incumbent energy regime which is dominated by a small number of vertically integrated energy companies and governed by Ofgem, who, it has been argued, tend to implement policies and design regulations which engender a conservative approach to the evolution of the energy system in the UK and favour incumbent actors rather than new entrants (Mitchell, 2008). Looking at it from a CHP-DH perspective, this points to a second underlying mechanism which is shaping change within infrastructure sectors – structural overlap between governance regimes.

7.3.2 Structural Overlap

Thornton and Ocasio see structural overlap as occurring ‘when individual roles and organizational structures and functions that were previously distinct are forced into association’ (2008: p.116). They identify this as a key source of institutional change as it can expose ‘competing institutional logics’ which has the potential to lower ‘constraints and embededness of actors’ (Thornton and Ocasio, 2008: p.116). Raven and Verbong (2007) and Konrad et al. (2008) have argued from a transitions perspective that similar processes, which they term multi-regime dynamics, are at play in infrastructure sectors. Raven and Verbong discussed the interactions which took place between the natural gas/heating and electricity regimes in the Netherlands which influenced the successful diffusion of CHP technology since the 1970s. They outline four interaction types (2007: p.503); competition – ‘when regimes start fulfilling similar functions’ – symbiosis – ‘where two regimes can reap mutual benefits from cooperating’ – integration – ‘when previously separated regimes more or less become one’ – and spillover – ‘refers to the transfer of rules from one regime to another’. In the case of the Netherlands, during the 1970s there was little uptake of CHP-DH as the gas and the highly fragmented electricity regimes were in competition; however, following liberalisation, there was a consolidation within the electricity industry and this (combined with the introduction of energy efficiency legislation) led to a more symbiotic relationship between the two regimes and over time resulted in integration with the large scale uptake of industrial CHP and CHP-DH to a lesser extent.

In the case of CHP-DH in the UK it is clear that there has been little symbiosis or integration between the gas/heat and the electricity regimes. The current regulatory structure for electricity and gas in the UK treats the electricity and gas/heat regimes as silos and there is little scope within the institutional framework to explore how different forms of integration such as CHP-DH could support decarbonisation. This governance regime for energy networks has largely been reinforced by decarbonisation and energy efficiency policies which are underpinned by a rationale that the provision of price signals and incentives to individuals will promote an efficient and optimal decarbonisation pathway. The result is that although individual components of the system may change (incremental and modular innovations), there has been little consideration of how changes to the structure of energy systems and the role of networks in particular can support long term decarbonisation (architectural innovation).

Two particular examples of structural overlap from the case studies highlight this. The first is from the CHP-DH case study where the electricity and heat regimes have been shown to be incompatible. It is widely recognised that the CHP and CHP-DH in particular can offer environmental, economic and system benefits if deployed in locations with appropriate load types (Kelly and Pollitt, 2010), however, unlike countries such as Denmark and the Netherlands, this is not explicitly recognised in the electricity governance regime. Instead, there has been a competitive dynamic between the emerging niche level regime of CHP-DH and the incumbent electricity regime since the days of nationalisation (Russell, 1993). This is largely due to a lack of strong sector level institutions for decentralised energy which has a loosely coupled and fragmented governance regime.

Structural overlap has also been a feature of the electricity distribution case, particularly in debates surrounding the active management of distribution systems. ANM requires the operation and management of the networks to become more closely aligned with other segments of the value chain (demand, DG and the system operator) in order to achieve system economies. This however has clashed with incumbent institutional arrangement and modes of governing which are based on isolating the networks from the competitive segments of the value chain in order to deal with the market failure of natural monopoly. This means that existing regulatory structures are largely incapable of distributing the risk and benefits of investing in such architectural innovations. Once again, this siloed approach to energy governance often does not take into account the potential environmental and system benefits of achieving greater vertical and horizontal integration in infrastructure sectors.

These two cases highlight that structural overlap in energy infrastructures often reflects power imbalances between the niche and regime levels which can close off avenues for radical institutional and technical change and also highlights the inherent inflexibility of the UK governance model for energy networks.

7.3.3 Institutional entrepreneurs

The socio-technical systems literature which was introduced in the literature review chapter highlighted the role that individuals can play in shaping infrastructures in their early phase. It was argued that the concept of the system builder, which was proposed by Thomas Hughes to describe the important role that influential individuals have had in shaping systems, is still relevant with technical and political champions in UK local authorities influencing the development of CHP-DH. However, there is little understanding of the role of agency in shaping change in incumbent infrastructure sectors such as electricity distribution. Within incumbent organisational fields such as this, it is clear that there is much less scope for entire systems to be reshaped through the action of motivated individuals because actors are constrained within an existing techno-institutional complex (Unruh, 2000) - Granovetter (1985) refers to this as embedded agency. Within institutional theory the concept of the institutional entrepreneur has been forwarded as a means to explain the role of agency in more structured organisational fields (Garud et al., 2002, Leca and Naccache, 2006, Tracey et al., 2011). An institutional entrepreneur, although embedded within highly structured organisational field, 'can play a critical role in perceiving institutional differentiation, fragmentation, and contradiction by virtue of the different social locations they may occupy in the interinstitutional system and in taking advantage of the opportunities it presents for institutional change' (Thornton and Ocasio, 2008: p.115). Thus by exploiting perceived inconsistencies and conflicts between competing network logics for example, institutional entrepreneurs can affect change in incumbent infrastructure sectors.

It is evident from the electricity distribution case that within infrastructure sectors with natural monopoly characterises, network companies will not engage in innovative or entrepreneurial activities without an incentive to do so, and this incentive must come from the regulator. The empirical case shows that efforts to incentivise focal organisations, such as DNOs, to become institutional entrepreneurs have been problematic because it runs contrary to the competitive network logic which has shaped the organisational field. In particular, the DNO specific RPZ incentive did not promote significant deployment of ANM solutions. This is because innovation and change is by and large not in the interests of focal actors in established organisational fields who benefit from the status quo. An interviewee who has worked both within the industry and as a regulator notes that entrepreneurial activity can only come about through collaboration.

> *" These ideas are going to come up from other companies, they're going to come from the entrepreneurs who are never too interested in getting that long run marginal cost down, they want to see their idea working don't they - completely different set of drivers. And I think what we have got to get smarter as a country and a sector in linking, making the relationships with universities and industry, manufacturers and industry, and trying to get that kind of food chain working because then the incentives can align" (interview - 6)*

This is why the LNCF has been welcomed within the industry because apart from providing a large fund which reduces much of the innovation risk for DNOs, it seeks to promote 'collaboration between DNOs and other parties in the energy supply chain [a]s a central objective of the LCN Fund' (Ofgem, 2010a: p.46). Although concerns have been expressed regarding the fact that the fund is DNO-centric (only DNOs can apply) (interview – 2) and it remains to be seen whether the projects will lead to meaningful learning outcomes, making collaboration a central criterion for funding is to be welcomed. This is because it is highly unlikely that regulated network operators will adopt strategies which radically reshape their institutional environment and become institutional entrepreneurs in the conventional sense.

Evidence from the RPZ scheme has shown the importance of more peripheral actors within the organisational field, i.e. small scale engineering consultancies and equipment manufacturers. These companies such as Econnect, Smarter Grid Solutions and EA Technology have specialised in developing site specific solutions to different network constraints, for example brought about by DG. This supports claims made in the literature on institutions and transitions; that entrepreneurship is 'more likely to emerge from less embedded organizations at the periphery of a field'[125] (Greenwood and Suddaby, 2005). As was discussed in the empirical chapter, these companies have an increasingly important role to play in aligning incentives as distribution systems become more active, and also in enabling DNOs to develop more innovative relationships with a wider range of equipment manufacturers. This example points to the potential role that small, flexible, and specialised companies can play in influencing institutional and technical change within increasingly complex organisational fields.

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[125] Greenwood and Suddaby note that 'Central organizations do, sometimes, act as institutional entrepreneurs' however this is 'not typical'' (Greenwood and Suddaby, 2005: p.30).

In the CHP-DH case, many of the local authorities who have successfully been involved in low carbon infrastructure projects have developed partnerships with external parties on a formal basis in order to benefit from their knowledge and capabilities. For example, in the early stages of their project Woking council partnered with the Danish company, Xergi, by incorporating them into their ownership structure. Of particular influence within the emerging CHP-DH sector in the UK is the specialist decentralised energy company Cofely DE[126] who have entered into contracts with a number of councils to operate and extend their schemes on a long term basis (interviews – 25, 27, 30). Such firms have a key role to play in diffusing new knowledge across this fragmented sector and act as 'mobile' carriers of knowledge between cities. Cofely DE, in particular is emerging as a key actor in shaping the emerging sector due to the fact that many of the local authorities do not possess either the resources or capabilities to develop projects on their own.

Referring back to the functions of innovation systems that were introduced in chapter two[127], the role of these specialised firms or innovation intermediaries – actors who act as institutional entrepreneurs by mediating between a focal actor and an innovation - is highlighted for each of the cases:

Table 7.3: The role of intermediaries in shaping energy network innovation systems

System Function	Electricity case	Heat case
'The creation and diffusion of 'new' knowledge'	Intermediaries can act as a bridge between the ambitions of the regulator in incentivising innovation and the capabilities of the network companies	Intermediaries can bring knowledge and experience from different contexts to the UK, particularly Scandinavian countries where CHP-DH is more developed
'Guide the direction of the search'	Smaller more specialised firms can identify value chain dynamics and help to spread the risks and benefits of innovative network investments	By offering a well developed business model, specialised CHP-DH companies can encourage reluctant LAs to develop schemes within their

[126] Formerly Utilicom
[127] 'The creation and diffusion of 'new' knowledge', 'Guide the direction of the search', 'Supply Resources', 'create positive external economies', 'formation of markets' (Jacobsson and Bergek, 2004)

		localities
'Supply Resources'	-	Local authorities can outsource the development and operation of schemes to intermediaries thus reducing risk and helping to secure financing
'Create positive external economies'	Mobile intermediaries can apply knowledge to different locations across the networks, thus helping to create linkages and reducing uncertainty	Intermediaries can work across a number of different schemes thus helping to bring coherence to a fragmented organisational field. This will help to reduce transaction costs and in bringing about economies of scale in the procurement of equipment
'Formation of markets'	Intermediaries can help to identify opportunities and 'find the value' for DNOs in investing in innovation	Specialised CHP-DH firms can identify load dynamics and use more sophisticated modelling techniques to plan network investments

In each of the cases these innovation intermediaries have helped to create virtuous circles in infrastructure innovation systems.

7.4 Chapter Conclusion

This chapter identified a number of underlying causal mechanisms which help to explain the interplay between actors, institutions and technologies in each of the cases. It was found that to various degrees the existing literatures can help to illuminate different aspects of these processes. For example, it was found that vertical dynamics across the electricity value chain are as much influenced by politically motivated decisions which were made in the past as notions of marginal technical or economic efficiency. It was also found that ongoing debates within the literature regarding the relative weight which should be attached to structure and agency in processes of technical and institutional change in technical systems can be reconciled if one views the nature of this interaction as changing in different phases of an infrastructure lifecycle. In the early phases of development, such as CHP-DH in the UK, influential and motivated individuals can play a key role in shaping change, however, as systems grow and become institutionalised this scope for agency diminishes. The electricity distribution case shows however that over time, systems enter into a new phase where subtle windows of opportunity open up for agency which pose challenges to incumbent actors and present opportunities to actors such as small, specialised equipment manufacturers to have an increasingly influential role. These types of actors have been identified as institutional entrepreneurs; unlike the conventional framing of system builders these are not focal actors within organisational fields but can play a key role in developing sector innovation systems and developing value networks for innovations. Identifying this dynamic relationship between different types of agents of change and their environment was aided by the choice of case studies; with electricity distribution being a highly institutionalised organisational field and CHP-DH being less structured.

Additional causal mechanisms which were identified focused on the structural determinants of change in infrastructure sectors. In chapter 2 it was argued that existing literatures tend to down play or under theorise the role of the nation state in the governance of energy systems. Using insights from the governance and governmentality literatures it was shown how structures at the nation-state level strategically select certain types of technologies and practices. For example, in the case of CHP-DH it was found that decarbonisation policies which tend to be channelled through incumbent energy institutions tend to act as a barrier to investment in local energy infrastructures. In the electricity case, network regulations which emerged from a market based logic and political program of liberalisation and privatisation have favoured short term investment time horizons and incremental change. It was also shown that interaction between different governance regimes, or structural overlap, can play an important role in enabling and constraining change. This has been highlighted by the case of active electricity distribution networks which involve interactions between different segments of the value chain, this has not been facilitated due to the fact that networks are governed as non-competitive natural monopolies which are separated from the retail and generation functions, this creating a barrier to ANM.

The table below summaries each of the explanatory causal mechanisms which it is proposed provide generalizable insights into the nature of the interplay between actors, institution and technologies in contemporary energy distribution networks – thus addressing the main research question:

Table 7.4: Synthesis of Literature Review and Identification of Causal Mechanisms

Causal Mechanism	Insights from the case studies
Vertical Dynamics: The nature of transactions taking place determines the dynamic between integration (hierarchies) and de-integration (markets) in a network industry value chain	Governance transformations are not smooth and predictable, rather institutional change is path dependent and political in its nature.
Innovation: The nature and pattern of technical change - whether this is incremental or disruptive - and the response of firms strongly influences sectoral dynamics	The institutional density and adaptive capacity of the organisational field in question influences the pattern of innovation and whether new technologies are likely to disrupt existing structures.
Path Dependency and Lock in: Institutional change is not a process of optimisation at the margin but is influenced by the historical trajectory of change.	The governance regime which emerged from privatisation and liberalisation during the 1980s has a strong influence in shaping responses to the decarbonisation of the electricity and heat sectors.
Social Construction: Technical change is a contested process which is characterised by the multiple framings and interpretations of different actors and groups of actors.	The process of technical change is characterised in particular by conflicts between the competitive and the public services network logics which actors draw upon in different ways to frame and legitimise their actions.
System Evolution: Technical systems evolve with their environment initially being shaped by influential system builders but over time develop momentum and become prone to inertia.	The infrastructure lifecycle heuristic can be used to frame the interplay between actors and institutions as a system evolves.
Multi-level dynamics: Interactions between niche, regime and landscape levels lead to different types of socio-technical patterns or pathways – reproduction, transformation or transition.	Patterns of reproduction, transformation and transition are taking place in energy distribution sectors. Incumbents sectors are more likely to undergo processes of transformation while niche level sectors draw on landscape dynamics to develop radical and architectural innovations but face barriers at the regime level.
Scalar Dynamics: In the context of liberalisation and globalisation the notion of nationally	Scalar dynamics are an increasingly important feature due to the localisation of flows and changes in the

integrated infrastructures has been diminished and new spaces of agency are being opened up at different scales	governance regime. Different selection environments at different scales are emerging leading in some cases to inconsistencies between local and national priorities.
Strategic Selectivity of the State: Macro level processes of state transformation act as a selection environment for meso and micro level sector dynamics.	The re-emergence of long term energy policy goals is beginning to change the governance regime of infrastructure sectors. In incumbent sectors regulatory change is a slow process due to the price control review process. In niche sectors this has opened a window of opportunity but existing decarbonisation policies tend to favour incumbent technologies and actors.
Structural Overlap: Interactions and overlaps between different governance regimes can influence institutional change	Sector structures which emerged from liberalisation are proving to be inflexible and often act as a barrier to radical and architectural innovation in incumbent and niche sectors.
Institutional Entrepreneurs: Motivated actors draw on broader institutional logics to reshape organisational fields and influence technical change.	Institutional entrepreneurs play an important role in both incumbent and new sectors. They can help incumbent actors to adapt their organisational routines and to build capacity within niches by acting as innovation intermediaries.

The next chapter will draw upon these insights to answer the research questions outlined in the introductory chapter.

8 Discussion and Conclusion

8.1 Introduction

The previous chapter looked across the two case studies in order to identify similarities and differences along with the causal mechanisms which have characterised the dynamics of change in each of the sectors. This final chapter of the thesis will draw upon these insights and answer the research questions which were outlined in the introductory chapter. Following this, there is a discussion of the policy implications of the research and recommendations for future work in this area. The chapter begins by outlining the empirical and theoretical contributions of the study.

8.2 Contribution of the Thesis

The contribution to knowledge that this thesis makes has been to uncover the socio-technical characteristics of energy distribution systems which tend to receive less attention than the generation and demand sides, and in doing so the thesis develops a conceptual understanding of the dynamics of these sectors which have unique technical and institutional characteristics. This contribution can be divided into its empirical and theoretical parts:

Empirical Contribution

On the empirical side, the key contribution that has been made is in understanding the complex socio-technical dynamics of two energy distribution sectors in the UK. In the introduction it was argued that the network component of energy systems – the pipes and wires – are often black-boxed or treated as purely technical objects in analyses of energy system transformation. As the development of more flexible systems of energy distribution become increasingly important in enabling the diffusion of low carbon forms of energy generation and more efficient end use practices, it is argued that by making the networks central to the analysis the study provides novel insights for the broader transition to a low carbon energy system more broadly.

The empirical chapters outlined that in a liberalised environment networks have been treated as natural monopolies and largely separated from the competitive areas of the energy value chain. In the electricity case the underlying rationale behind this was to reduce the costs of operating the networks and to discourage large scale capital investment. While this may have been appropriate in the phase immediately following liberalisation when long term energy policy was not a significant part of the political agenda, it is clear that a more integrated and long term perspective is required in order to achieve system economies and to develop smarter and more intelligent ways of planning and operating the distribution systems. The UK case in particular highlights that although technologies such as CHP-DH offer potential environmental and economic benefits in certain circumstances, they tend to have different attributes and requirements than incumbent systems and therefore face a number of structural barriers to their wider scale diffusion. It is proposed that in developing and adapting our distribution networks, current regulatory and energy policy frameworks need to take into account in a more systematic way the distinct financial, regulatory, institutional and technical characteristics of infrastructure networks. This is necessary in order to develop more coherent and synergistic relationships between infrastructure networks and other parts of the energy value chain.

Theoretical Contribution

The introductory chapter outlined the general characteristics of infrastructure networks – natural monopoly, public good features, technical complexity and scale – which mean that these systems do not operate as conventional market based sectors. This posed a number of conceptual challenges which needed to be addressed in order to uncover the socio-technical dynamics of distribution networks in a theoretically coherent manner. In order to do so two main avenues of theoretical discussion were explored and elucidated:

- The nature of institutions and institutional change in shaping energy networks became a central concern in developing the analytical framework. Following the literature review it was proposed that a more ontologically coherent perspective on the role of institutions in shaping socio-technical change in infrastructure networks is required. Using insights from the science and technology studies and new-institutional literatures, a framework was developed which showed how institutions are embedded in the physical, relational and structural dimensions of infrastructures, rather than being a variable which facilitates or acts as a barrier to technical change in a linear fashion.
- The second theoretical area that was highlighted was how the socio-technical dynamics of energy systems are influenced by and aligned with the changing role of the state in the governance of the economy. It was pointed out that due to the public good characteristics of infrastructure networks, the state will always have some form of influence whether this is direct ownership or is outsourced to a quasi-independent sector regulator; however this is often under-represented in the literature. Drawing on the governance and governmentality literatures it was argued that the role of the state should not be thought of in binary terms such as ‘interventionist’ vs. ‘non-interventionist’ or ‘markets’ vs. ‘hierarchies’, because this masks the true nature of the

state which should be viewed in relational terms; reflecting different strategies, interests and capacities.

These theoretical insights were incorporated into a coherent analytical framework which was outlined in chapter three and was then operationalised for the empirical sections. In each of the cases a governance regime was characterised where it was shown how specific policy tools and regulatory instruments have been shaped by the re-emergence of energy policy and the changing relationships between local and national tiers of government. The chapters discussed how these broader governance regimes influence meso and micro level interventions and interactions and explored the outcomes in terms of the interplay between actors, institutions and technologies. The choice of two contrasting case studies – a regulated and a non-regulated sector – enabled the study to capture the broad range of these socio-technical dynamics occurring in both incumbent and developing infrastructure sectors. Across the two cases it was observed that technologies and practices which align with the broader governance regimes tend to be favoured and reinforced whilst other options are often marginalised. Chapter seven outlined how the empirical results and approach adopted could inform existing literatures but also lead to novel insights regarding the interplay between actors, institutions and technologies in infrastructure sectors.

8.3 Answering the Research Questions

The research questions are answered in turn below:

1. *What is the nature of the interplay between actors, institutions and technologies in reproducing and transforming contemporary energy distribution systems?*

In chapter three, an approach to the analysis of infrastructure networks was developed which distinguished between the physical, relational and structural dimensions of infrastructure networks. In particular, an analysis of interactions between the physical – where institutions coordinate physical flows within a network which can be measured, monitored and controlled – and the relational – where institutions coordinate interactions between actors 'to produce a joint outcome which is deemed mutually beneficial' (Jessop, 1995) – dimensions have helped to elucidate the interplay between actors, institutions and technologies across the two cases.
In the electricity distribution case it was found that mechanisms which have been identified in the literature on infrastructure governance, namely path dependency and techno-institutional lock-in, provide a good overarching description of the sources of inertia in contemporary energy systems. The ex-ante/price-cap regulatory regime which has been in place since liberalisation has incentivised network companies to adopt short term investment time horizons and achieve

operational efficiencies rather than develop innovative network solutions to problems such as the connection of DG and integration with the demand side. The failure of the RPZ scheme to lead to a significant deployment of innovative technologies and practices has highlighted how a conservative approach to network planning and operation has become deeply embedded in the organisational routines of large scale energy companies.

In addition to firm level barriers to the uptake of innovations which has been addressed in the existing literature on energy systems (Stenzel and Frenzel, 2008), this analysis has shown that the incremental process of change within the sector can also be attributed to the structure of the sector itself and the nature of the company-regulator interactions. The inherent inflexibility of the governance regime for monopoly electricity networks in the UK means that architectural innovations such as ANM and smart grids, which require new types of interaction between different actors across the value chain, have not been facilitated. The structure of the organisational field and the rationality which underpins it has been based on a competitive network logic which means that energy systems are siloed into competitive and non-competitive segments in order to enable the creation of wholesale and retail markets. This has meant that new types of physical flows of energy, information and revenues are not aligned with existing institutional arrangements which govern incentive structures and regulator-company interactions. The regulator's job, which is broadly to balance the interests of shareholders and customers (present and future) in investment decisions, and to distribute economic rents, has traditionally been achieved through reducing the marginal costs of operating the networks and aligning this with a pricing regime. However, it is increasingly apparent that the need for networks to facilitate the broader transition to a low carbon energy system will require the regulator to embed innovation into the mainstream regulatory process, recognising that it will become increasingly difficult to set prices in an ex-ante fashion due to the uncertainties involved in innovation – this will require a more flexible approach. The nature of the price control review process which brings about incremental change has to date precluded this from happening.

The analysis does show however that there are spaces for agency within this highly structured organisational field. As physical flows within the networks become more localised and specific to geographical location, the role of specialised and flexible engineering companies who can work with DNOs to create the value proposition of investing in radical and architectural innovation has been highlighted. Unlike incumbent network operators these are potential institutional entrepreneurs.

In the CHP-DH case, it was observed that a number of local authorities have begun to reshape local energy institutions by investing in and expanding district heating within their localities. This has been in response to local level drivers such as a desire to reduce fuel poverty and to address broader concerns regarding the long term sustainability of centralised energy provision. District heating has (re)emerged as a key technology which can negotiate between these local and national level issues and is increasingly being seen by LAs as a way to achieve their strategic long term aims. In order to develop and operate schemes, councils coordinate a network of actors, both public and private, and have adopted financial and organisational arrangements according to their own strategic aims, resources and capabilities.

As one might expect, due to the unstructured nature of the organisational field there has been a greater degree of scope for variation and a more prominent role for system builders than in the electricity distribution case. This has led to the development of increasingly complex and diverse physical flows within these networks as CHP-DH schemes begin to expand and interact with other infrastructures such as waste and bioenergy. It was found however that this scope for agency and innovation is largely confined to localised selection environments because when CHP-DH systems begin to interact with the broader energy regime (incumbent electricity regulations and markets which are instituted at the national level) they face structural barriers to their diffusion and expansion. Therefore, while technologies and practices such as private wire electricity networks and long term ESCO contracts may make sense in the context of the CHP-DH scheme, if viewed from a more structural perspective, they conflict in a number of ways with incumbent institutions and practices. These scalar dynamics and structural overlaps in the evolutionary process of technical and institutional change have played an important role in constraining the CHP-DH sector in the UK. As has been argued in chapter three, in analysing transitions in infrastructure sectors it is therefore important to consider the wider governance regime within which processes of change are contextualised.

In order to synthesise some of the above insights which were drawn out in the previous chapter, the infrastructure lifecycle diagram was proposed as a useful heuristic to think about the interplay between actors, institutions and technologies in energy networks. It was argued that this framing can address the deficiencies of approaches which emphasise the role of agents in shaping change rather than structures and institutions, and vice versa.

2. *How do the liberalisation and climate change agendas interact to influence this interplay?*

The purpose of asking this question was to explore how the dominant liberalisation paradigm which has influenced energy governance since the 1980s is shaping and being shaped by the climate change agenda. The analytical framework outlined in chapter three proposed that network logics are the organisational principles behind infrastructure sectors and are drawn upon by actors within organisational fields in order to frame and legitimise their actions. It is clear that in the electricity distribution case a number of areas of conflict have emerged between competing network logics or conceptualisations of how an energy system should be configured. A key rationale behind the competitive/unbundled logic which emerged following the privatisation of the ESI in 1989-2000 was to isolate the natural monopoly segments of the value chain in order to allow competition in the wholesale and retail markets and to promote the efficient exploitation of the networks asset base. Beginning with the issues surrounding DG connection and later DSM, the ridged sector boundaries which resulted from this logic have begun to be challenged as efforts to promote the active management of distribution networks have encountered structural barriers. It is apparent that due to the importance of electricity distribution networks to enabling low carbon production and consumption practices, networks can no longer be isolated from the mainstream energy policy. However, to date decision making by Ofgem continues to be framed according to a competitive logic and in particular measures which improve competition in the markets tend to have more legitimacy.

In the CHP-DH case, the emergence of the climate change issue has prompted a number of local authorities to invest in and redevelop district heating schemes. A key legitimating factor behind this has been a desire to provide a public good e.g. reduce fuel poverty or ensure the long term energy security of a locality. This public services network logic is rooted in the view that local authorities have an obligation to improve the well-being of residents and increasingly they feel obliged to take a lead on reducing carbon emissions and contribute to the national level targets. In a number of ways these schemes, which are in the early phases of development, need to isolate or protect themselves from the competitive arena as they require long term contracts and upfront capital investments which have a long payback period. It has been shown that a conflict between this rationale and the competitive logic have surfaced following the emergence of institutional issues surrounding the legality of private wire networks and questions over the future regulatory regime for decentralised energy and local infrastructures.

These conflicts between competing networks logics are likely to become more prominent in the future and will shape the evolution of infrastructure sectors. This is because decarbonisation is largely a public good where the time horizon of policy outcomes tends to be decades, while the rationale behind liberalisation was to promote economic efficiency at the margin and to design pricing regimes which would incentivise private actors and individuals to behave in an economically rational manner.

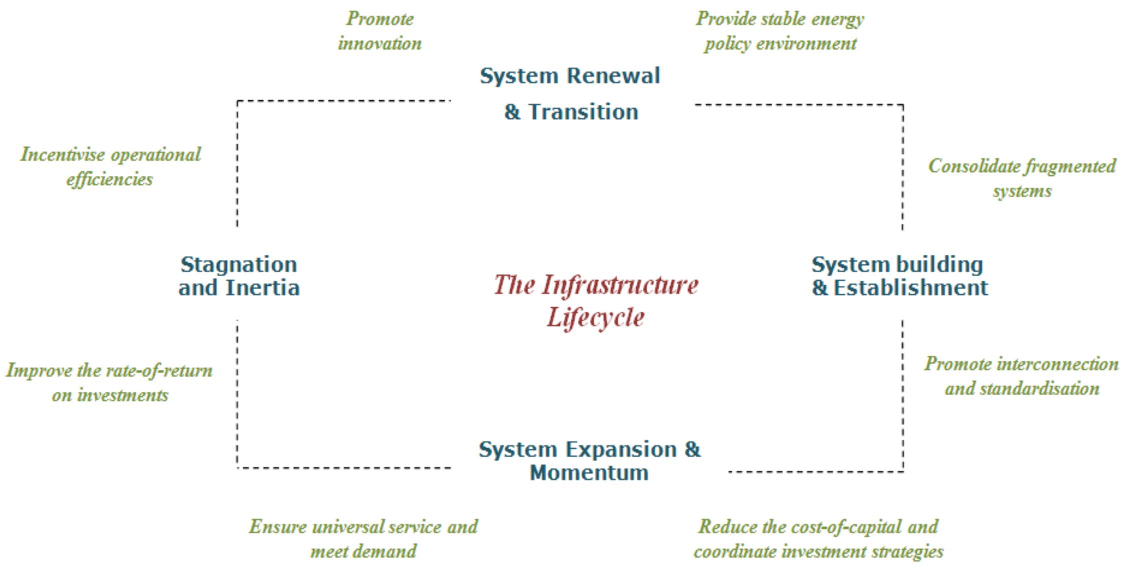
3. *What is the role of the state in the governance of energy networks and how is this changing?*

The role of the state in the governance of energy networks has been cited in chapter two as a neglected or under theorised aspect of the literature. It was argued that the role of the state should be viewed as fluid and dynamic rather than in binary or linear terms and that micro-level policy instruments and tools of regulation are not neutral but reflect and reinforce broader political rationalities. The design and application of RPI-x regulation is a case in point. Emerging from a neo-liberal political rationality, price based regulation was seen as an apolitical and mathematical way of governing networks by framing natural monopoly as an externality which can be priced. The RPI-x model was designed to discourage investment in capital assets (CAPEX) and shift the focus of licensed network operators towards short term operational efficiencies (OPEX) whilst maintaining open access to the networks, thus enabling competitive retail markets according to the liberalisation agenda.

However, in more recent years, energy policy and demand for investment are once again becoming part of the political agenda due to concerns over energy security, an ageing asset base and the need to decarbonise energy supply. The institutionalisation of long term energy policy goals has seen the formation of a new department of energy, DECC, along with proposals to re-regulate wholesale electricity prices to provide a stable investment environment and attract international capital. Ofgem is increasingly taking on the function of an implementation body for the longer term orientated energy policy goals of the state i.e. decarbonising the electricity supply industry. An example of this is efforts to promote innovation through competitive funds which are designed to incentivise network operators to engage in experimentation and learning and to overcome some of the institutional barriers to the deployment of smart grid technologies. This strategy allows the sector to proceed along its current trajectory of avoiding substantial capital investment whilst facilitating low carbon generation and new types of demand side behaviours. Under the RIIO framework these adapted regulatory instruments are seeking to strategically select collaboration across the value chain, integration with the demand side, real-time active management of distribution systems and innovation - as opposed to the conventional network planning and management techniques. Also, an extension of price control period to 8 years (from 5) reflects the wider changes in state strategy towards providing longer term stability for investors in the electricity sector.

Using the infrastructure lifecycle heuristic, the figure below outlines the evolving role of the state in the governance of electricity networks. It is argued that the main functions of network regulation since privatisation have been to improve the rate of return on investments and to promote OPEX efficiencies, this led to the formation an independent regulator whose decisions have been framed and legitimised by a neo-liberal/market based rationality. What has been observed in this study is that although recent changes to the regulatory framework still draw from this logic, there is an increasing emphasis being placed on experimentation to deal with uncertainty and the provision of a stable and long term policy framework to attract private capital. However, there remains uncertainty as to how incentives for investment in innovative networks technologies can be embedded within the mainstream regulatory regime.

Figure 8.1: The roles of the state in the infrastructure lifecycle



Of course, CHP-DH is in the system building and establishment phase. Experience of district heating in Scandinavian countries and the early stages of electricity systems in the UK show that the state has a key role to play in developing sector level institutions; e.g. reducing transaction costs by promoting standardisation and interconnection and by consolidating fragmented systems. Analysis of CHP-DH in the UK shows that central government is seeking to promote localism and greater levels of autonomy for local authorities in bringing about sustainable development. However, it is largely the case that in the energy sphere agency at the local level and amongst small scale actors is being constrained due to the state strategy of achieving long term energy policy goals through incumbent actors (vertically integrated energy companies) (Mitchell, 2008). The following remarks made by Russell in his history of CHP-DH in the UK during nationalisation largely hold true today:

> *"Most state policy and action has been concerned with primary energy supply; intervention in energy use and conservation has been weak, and mostly achieved through prices. This structure, reinforced by relatively closed decision-making and a powerful and coherent ideology" (Russell, 1993: p.48)*

In order for CHP-DH to become a more prominent part of the energy sector in the UK clear direction and support from state level institutions is required as it is likely that local level initiatives will remain fragmented and uncoordinated.

4. *How are socio-technical transition processes in energy systems likely to be affected by the specific dynamics of distribution networks?*

This study has shown that in a liberalised energy environment energy networks should be treated as sub-systems of an overall socio-technical system which have unique institutional characteristics e.g. network regulation, system complementarities, and natural monopoly. It was argued that in many cases the literature on the governance of transitions in the energy field tend to treat energy systems as a whole and typically concentrate on the supply and/or demand side whilst neglecting infrastructure networks. As a result the focus of much of the transitions research in the energy field tends to be at the national level and focusing on supply side technologies. Policy recommendations emanating from this research therefore run the risk of neglecting a key aspect of energy systems.

This is particularly the case for the electricity sector in the UK due to the highly unbundled structure of the ESI. Since privatisation the governance of networks have largely been treated separately from the generation and demand sides. As a result, there is a risk that the networks will become a reverse salient (Hughes, 1983) which holds back the transition to a low carbon energy system e.g. by failing to adequately integrate DG. This is likely to be amplified because, due to market forces, the competitive segments of the value chain will change at a different pace than the regulated segments. This thesis argues for a move away from the siloed approach to energy governance where networks are black boxed, instead a more integrated and long term transformation agenda is required – this is expanded upon in the policy recommendations section.

Analysis of district heating showed the potential that local distribution networks can have in promoting energy efficiency and delivering a more flexible energy infrastructure which can produce synergistic relationships between a range of generating technologies e.g. CHP, biomass, EfW, micro-generation etc. A key governance challenge is to develop infrastructure networks which can promote flexibility and which are future proof against new developments in low carbon generating and demand side technologies and practices. District heating has these attributes however is neglected in the UK as it does not sit well with the incumbent regime as it is an inherently local technology which gives a central role to new entrants i.e. local authorities. Also, policies aimed at decarbonising heat supply such as the RHI do not take into account the need for significant upfront capital investment to develop infrastructures in their establishment phase such as low carbon heating networks. A number of policy recommendations aimed at addressing these issues are made in the section below.

8.4 Policy Recommendations

The main aim of this thesis was to open up the black box of distribution networks in socio-technical transition processes in energy systems and in doing so to propose a number of useful policy recommendations. In an overall sense it has been argued that the UK's energy infrastructure policy is deficient in a number of respects:

The primary focus of energy infrastructure governance in the UK over the past twenty has been on reducing the marginal costs of operating incumbent gas and electricity networks. The analysis of electricity distribution networks shows that although there have been efforts to bring about more innovative approaches to planning and operating the networks with longer term decision making horizons, this has largely been shaped by the liberalisation agenda and has yet to be integrated into the mainstream regulatory process. Also, because the focus of energy policy and regulatory attention has been on incumbent networks at the national level, the development of local heat infrastructure has remained on the fringes. The strong emphasis on privatisation and liberalisation in UK energy policy has left a legacy where energy networks have largely been black boxed and siloed off, resulting in a situation where policies which seek to promote the transition to a low carbon and sustainable energy system tend to treat networks as afterthought or secondary to the main business of negotiating between different energy generation technologies.

In order to value the contribution that more flexible distribution networks can make in enabling the diffusion of low carbon generation and achieving demand side efficiencies, the analysis of both incumbent and non-incumbent sectors highlights that two broad governance strategies should be pursued – this draws from the infrastructure lifecycle heuristic presented in figure 8.1.

The first is concerned with reorienting incumbent systems which are entering into a system renewal and transition phase. This thesis has argued that government can no longer outsource the governance of sectors such as electricity distribution to an economic regulator which is a legacy institution of the liberalisation programme - rather a more integrated and long-term orientated approach is required for this phase. As is shown in figure 8.1, this should involve a closer alignment between the functions and strategies of the regulator and the broader set of energy policy goals, particularly decarbonisation targets. This can provide a clear and long term regulatory/policy environment for investors and will help to overcome the institutional mismatches which are a result of incoherencies between the liberalisation – emphasising cost reductions and marginal efficiencies - and climate change - emphasising long term transformation - governance agendas. Aligned with this there needs to be a means of incentivising innovation in these non-competitive sectors and incorporating this into the mainstream regulatory process. In the sub-section below, a more specific policy recommendation is made in this regard which argues for the formulation of long term network transition plans.

The second governance strategy which should be pursued addresses how to facilitate the expansion of new low carbon infrastructures which are at the early stages of the infrastructure lifecycle (see figure 8.1). As has been illustrated in the CHP-DH case, this process of emergence tends to take place in specific local contexts with fragmented and dispersed systems developing in niches which are removed from mainstream energy institutions. The consolidation and interconnection of such fragmented systems will not only require resources and capacity development within local authorities, but also the development of a more coherent set of sector level institutions which promote standardisation, expansion and the diffusion of best practice. In the section below a proposal is outlined for the development of heat planning involving a statutory role for local government in developing local energy strategies - this draws from experience in front-runner Nordic countries.

8.4.1 Specific Policy Recommendations

Network Transition Plans

A key issue that was encountered during the electricity distribution case study was how to extend the time horizons of investment decision making. The proposal here is to place a requirement on network operators to publish Network Transition Plans for the next 25-30 years where the DNO outlines their expectations for the future evolution of the network in their particular region. Although the price control review period will be extended from five to eight years from 2015, it is still relatively short in the context of the long life of network investments. The presence of price control reviews acts as a disincentive for companies to make long term risky investments. Under the proposal a new category of investments would be created which are shielded from the normal price controls and can be assigned an increased cost of capital by the regulator. This would see a de-linking of these long term investments from the WACC[128] which would allow network companies to raise finance on terms which reflect the greater risk of these longer term investments[129].

Network investments are of course dependent on a number of variables such as economic growth, future population dynamics and the likely demand for DG connections; therefore a central aspect of the proposal is that the network plans would be developed and reviewed in consultation with range of stakeholders such as DG developers, local authorities, consumer advocacy groups, energy suppliers and transmission operators. The job of the regulator would remain to balance the interest of shareholders and customers and to distribute economic rents, however, this would be achieved by providing a transition arena (Rotmans and Loorbach, 2008) or a platform whereby a range of actors can negotiate on as equal terms as possible. Plans should be formulated and revised in line with the higher level policy work of DECC and the CCC. The criteria for selecting this category of investment would need to set by the regulator and this should include a requirement to deploy innovative technologies and practices, to connect renewables in an integrated way, produce learning outcomes, and to develop long term collaborations – similar to the LNCF criteria. In order to protect customers, the performance of these investments would be assessed against the outputs incentives which have been laid out in the RIIO proposals.

Local Heat Planning

As has been noted, the nature of heat demand is tightly coupled with the built environment and as such differs in each building, street and area. For example, the nature of demand in densely populated inner city districts will be quite different from outer suburban areas; it therefore follows that the most suitable low carbon heating solutions will differ also. This local dimension of heat decarbonisation is currently not recognised in UK energy policy as it places all of the emphasis on incentives for individuals to become more energy efficient or invest in particular

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[128] WACC sets an average cost of capital for financing existing and new investments

[129] Similar arguments regarding investment ahead of need have been made by Baker et al. (2010) who propose that ‘Network owners could be offered an enhanced rate of return in cases where investments undertaken without full user commitment ultimately proved to be fully justified, but a reduced rate of return if those assets remained under-utilised’ (p. 32)

technologies; this does not take account of the economies of scale and scope which can be achieved through local energy service provision. In fact recent changes to regional policy have actually diminished the obligations on LAs to reduce emissions in their areas[130] (Travers, 2011). It is proposed that local authorities need to be given a greater implementation role for the decarbonisation of heat due to their greater knowledge of localities and their potential to take up a coordinating role. It is proposed to place a statutory requirement on local authorities to develop heat decarbonisation strategies for their areas. This would begin by characterising the nature of loads in an area by developing detailed heat maps and identifying opportunities. By coordinating a local heat planning forum consisting of the DNO, suppliers and community groups, the local authority could zone an area and identify suitable low carbon heating solutions in line with their own planning guidelines and the building codes and standards. If necessary, contracts could be tendered through the public sector procurement process.

It is not proposed that heat networks be regulated as natural monopolies; however some degree of national level coordination is necessary to enable sector level structures to evolve. As CHP-DH is currently in a system building/establishment phase, a learning-by-doing approach will likely be the most effective route to developing sector institutions such as technical standards and legal and contractual arrangements. This would eventually lead to an appropriate licensing and regulatory regime as systems begin to expand across cities. DECC's proposal for a national heat market forum[131] would be a suitable arena for actors to come together and develop a more coherent governance regime for CHP-DH. Experience from the success of district heating in Denmark also shows that strong legislation which imposes a ban on waste heat and mandates connection to a heating network where it exists is also important[132]. A more coherent national and local framework for heat decarbonisation, along with changes to the electricity market trading arrangements which reward CHP for its environmental and system benefits, will likely improve the ability of local authorities to access finance and reduce their cost of capital. This should be supplemented by the inclusion of premium payments for distribution pipes in the RHI.

[130] In 2011 Comprehensive Area Assessments (CAAs) have been abolished and 'The existing local government performance framework, which contained a number of provisions on local action on carbon reduction and environmental protection, has been abolished. The Government has not yet demonstrated how its new system will deliver on legally binding commitments such as the Climate Change Act'. 'According to DECC, in July 2008 101 out of 152 local area agreements (LAAs) contained targets against the then-existing National Indicator 186 (NI 186) on reducing per capita emissions in their communities, while 35 LAAs also included targets against National Indicator 185 relating to reducing emissions of CO2 from local authority operations', however many of these have been abolished (Travers, 2011)

[131] The proposal was made in the 2010 'Warm Homes, Greener Homes' strategy (DECC and DCLG, 2010)

[132] The Danish 'Heat Law' was introduced in 1979

8.5 Limitations and Avenues for Future Research

Concerns were expressed in the research design section relating to the sector level approach which was adopted in this study. It was decided not to take a firm or project level approach so as to capture the influence of structural and political processes which are institutionalised at the national level. On reflection, while this level of aggregation provided valuable insights into the meso-level governance processes taking place in the two cases and has been a useful starting point for transitions related research in this area, it perhaps has down-played the influence of micro-level agency. This was particularly so in the electricity distribution case where there was relatively little discussion of the differences between network operators in terms of capabilities and strategies. Through the semi-structured interviews it was found that as flows on the networks become more complex and geographical differences between networks become more prominent, it is likely that companies will develop more divergent strategies and approaches to issues such as innovation and collaboration with other actors. These emerging network operator strategies and potential changes to their business models could be analysed in more detail by perhaps paying closer attention to the LNCF projects as they become materialised over the next number of years. In order to do this an analysis of the relational dimension of infrastructures would have to pay closer attention to specific actors rather than the sector as a whole and trace the changing relationships between focal and peripheral actors within an organisational field in more detail, for example by using social network analysis tools.

An issue was also raised regarding the functional equivalence of the case studies and whether this would limit the generalisability of the findings. It was found that the strategy adopted has been justified as choosing cases at different stages in the infrastructure lifecycle made the findings more relevant to an analysis of a long term transition process in the UK and illustrated the depth and range of interplay between niche and regime level actors, institutions and technologies in infrastructure sectors. However, the policy related empirical findings along with the analytical framework itself could be further developed and refined by making a comparison between the evolution of energy networks in different countries. Suggestions include a study of how smart grid developments in the UK compare to those in less liberalised jurisdictions such as France or certain states in the US. Also, a study of the institutional context within which CHP-DH became successful in Scandinavian countries and exploring what this might mean for the prospective decarbonisation of heat supply in the UK would be relevant. Another suggestion would be to analyse in a more systematic way the emerging scalar dynamics which are increasingly beginning to influence energy network governance in the UK, particularly the changing role of the EU energy and common market policies. Also, during the course of the study a number of important areas, which were not explored in any great detail, warrant further study; for example how to improve access to capital for low carbon infrastructure projects, how synergies between different infrastructure networks can be promoted, and how demonstration projects and trials on the electricity networks can be evaluated. A final area for future work would be to explore how the framework which has been developed in this thesis could be operationalised as part of a wider interdisciplinary project. Of particular relevance would be whether researchers from different disciplinary backgrounds could draw on it to address real world problems relating to the transition to a low carbon energy system. This would be a true test of the validity and robustness of the approach which has been developed in this thesis.

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ZERO CARBON HUB (2009) Defining a Fabric Energy Efficiency Standard for Zero Carbon Homes. *Task Group Recommendations*.

10 Appendices

Appendix A: Summary of Policy and Regulatory Documents Reviewed

Document Name
BERR (2008a) Current Technology Issues and Identification of Technical Opportunities for Active Network Management.
BERR (2008b) UK Renewable Energy Strategy consultation document
CLIMATE CHANGE COMMITTEE (2008) Building a low-carbon economy – The UK's contribution to tackling climate change
CLIMATE CHANGE COMMITTEE (2010) The Fourth Carbon Budget Reducing emissions through the 2020s.
DCLG (2000) Local Government Act 2000.
DCLG (2006) Building A Greener Future: Towards Zero Carbon Development - consultation document.
DCLG (2008a) The Community Infrastructure Levy.
DCLG (2008b) Improving the energy efficiency of our homes and buildings Energy Certificates and air-conditioning inspections for buildings.
DCLG (2008c) Sustainable Communities Act 2007: A Guide.
DCLG (2011a) A plain English guide to the Localism Bill, Update
DCLG (2011b) Planning, building and the environment
DECC (2009a) A Consultation on Smart Metering for Electricity and Gas
DECC (2009b) A Consultation on Smart Metering for Electricity and Gas.
DECC (2009c) Extending the Carbon Emissions Reduction Target: Consultation on a CERT framework for the period April 2011 to December 2012.
DECC (2009d) Heat and Energy Saving Strategy Consultation.
DECC (2009e) Smarter Grids: The Opportunity.
DECC (2009f) The UK Renewable Energy Strategy.
DECC (2010a) Allowing Local Authorities to Sell Electricity.
DECC (2010b) Consultation on the provision of third party access to licence exempt electricity and gas networks.

DECC (2010c) Digest of United Kingdom Energy Statistics 2010.
DECC (2010d) Implementation of the EU Third Internal Energy Package: Government Response
DECC (2010e) Renewable energy: Statistics used for the EU 2020 renewables target.
DECC (2010f) Smart Metering Implemnentation Program Prospectus.
DECC (2010g) Warm Homes, Greener Homes: A Strategy for Household Energy Management Supporting Paper VIII: An Enabling Framework for District Heating and Cooling.
DECC (2011a) Consultation on Electricity Market Reform.
DECC (2011b) Renewable Heat Incentive.
DECC (2011c) Smart Metering Implementation Program: Response to Prospectus Consultation.
DECC & DCLG (2010) Warm Homes, Greener Homes: A Strategy for Household Energy Management Supporting Paper VIII, An Enabling Framework for District Heating and Cooling.
DEFRA (2007) Analysis of the UK potential for Combined Heat and Power
DTI (2004) Class Exemption Order: Explanatory Memorandum.
EGWG (2001) Report into Network Access Issues Volume 1: Main Report and Appendices.
ENSG (2009) Electricity Networks Strategy Group: A Smart Grid Vision.
HM GOVERNMENT (2001) The Electricity (Class Exemptions from the Requirement for a Licence) Order 2001: Explanatory Memorandum.
HM GOVERNMENT (2010a) The Coalition: our programme for government.
HM GOVERNMENT (2010b) The Sale of Electricity by Local Authorities (England and Wales) Regulations 2010
OFGEM (2001a) Embedded generation: price controls, incentives and connection
charging: A preliminary consultation document.
OFGEM (2001b) Ofgem's strategy for metering: A consultation paper.
OFGEM (2002) Electricity (Connection Charges) Regulations: A consultation documen.
OFGEM (2003a) Innovation and Registered Power Zones Discussion paper
OFGEM (2003b) Introducing Comeptition in Smart Metering.
OFGEM (2004) Electricity Distribution Price Control Review: Final Proposals.
OFGEM (2005) Further Details of the RPZ Scheme: Guidance Document

OFGEM (2006) 'Our Energy Challenge': Ofgem's response.
OFGEM (2007) Distributed Energy - Initial Proposals for More Flexible Market and Licensing Arrangements.
OFGEM (2008) Distributed Energy - Further Proposals for More Flexible Market and Licensing Arrangement.
OFGEM (2009a) Distributed Energy - Final Proposals and Statutory Notice for Electricity Supply Licence Modification.
OFGEM (2009b) Electricity Distribution Price Control Review: Final Proposals
OFGEM (2009c) Innovation in energy networks: Is more needed and how can this be stimulated? Regulating energy networks for the future: RPI-X@20 Working paper 2.
OFGEM (2009d) Next steps in delivering the electricity distribution structure of charges project.
OFGEM (2010a) LCN Fund Governance Document v.3.
OFGEM (2010b) Low Carbon Networks Fund winning projects: Second Tier decision.
OFGEM (2010c) Regulating energy networks for the future: RPI-X@20 Emerging Thinking.
OFGEM (2010d) Reports by Distribution Network Operators (DNOs) on Innovation Funding Incentive (IFI) and Registered Power Zone (RPZ) activity for 2008-2009.
OFGEM (2010e) RIIO: A new way to regulate energy networks, final decision.

Appendix B: List of Interviewees [133]

Interview 1: Energy policy researcher, July 2009
Interview 2: Energy policy researcher, July 2009
Interview 3: Professor of electrical engineering, July 2009
Interview 4: Head of business modelling for an R&D subsidiary a 'big six' energy supplier, July 2009
Interview 5: Electrical engineer with an R&D subsidiary of a 'big six' energy supplier[134], July 2009
Interview 6: Director of network innovation at an energy consultancy, Aug 2009
Interview 7: R&D manager with a transmission operator, August 2009
Interview 8: Strategy manager with a transmission operator, August 2009
Interview 9: Strategy manager with a power engineering consultancy, 2009
Interview 10: Managing Director of an engineering consultancy who specialise in grid connection, Jan 2010
Interview 11: Electrical engineer with an R&D subsidiary of a 'big six' energy supplier and technical advisor to a DNO, Feb 2009
Interview 12: Managing Director of UK operations of a large multi-national energy technology manufacturer, Feb 2010
Interview 13: Low Carbon Projects Manager at a DNO, Feb 2010
Interview 14: Technical advisor to the UK energy regulator, Feb 2010
Interview 15: Renewables Development Manager at a DNO[135], March 2010
Interview 16: Strategy Manager at a DNO, March 2010
Interview 17: Technology Manager at a DNO, March 2010
Interview 18: Operations Director at a consultancy specialising in ANM solutions, March 2010
Interview 19: Independent consultant specialising in network regulation and connections, April 2010
Interview 20: Head of future networks at a DNO, May 2010
Interview 21: Policy Manager at a DNO and 'big six' energy supplier, May 2010
Interview 22: Policy advisor at DECC specialising in electricity networks, Nov 2010
Interview 23: Regulation manager at a DNO, Jan 2011
Interview 24: Utilities consultant specialising in business models and network innovation[136], Jan 2011
Interview 25: Sustainability Manager at a local authority, June 2010
Interview 26: Chief Executive of a local authority, June 2010
Interview 27: Head of new business and economics at a government housing agency, June 2010
Interview 28: Consultant specialising in carbon management and local energy systems, July 2010
Interview 29: Services Manager with a district energy utility company, June 2010
Interview 30: Sustainability/Energy Manager at a local authority, July 2010
Interview 31: Managing Director of a council owned ESCO, July 2010
Interview 32: Principal Designer & Energy Engineer of a local authority (retired), Aug 2010
Interview 33: Director of environmental services at a local authority, August 2010
Interview 34: Energy manager for a local authority, August 2010

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[133] Interviews 1&2 covered both cases, interviews 3-24 covered the electricity distribution case and interviews 25-41 covered the heat distribution case
[134] I was unable to record this interview due to a technical issue with the recorder. Extensive notes were taken however
[135] Interviews 13-15 were conducted as part of a group discussion held over two hours
[136] I was unable to record this interview due to a technical issue with the recorder. Extensive notes were taken however

Interview 35: Deputy Head of community-led policy making at DECC, August 2010
Interview 36: Senior policy officer at a lobbying organisation for local government, August 2010
Interview 37: Director of Sustainable Development at a local authority, Sept 2010
Interview 38: Head of Sustainable Development at a local authority, Sept 2010
Interview 39: Deputy Director of a lobbying organisation for the CHP industry, Dec 2010
Interview 40: Head of community energy for a 'big six' energy supplier, March 2011
Interview 41: Head of Decentralised Energy Delivery at a local authority, March 2011

Appendix C: A coded extract from an Interview

The following are extracts from an interview from the CHP-DH case. For each of the interviews across both cases relevant sections of the interview were highlighted and assigned a code with additional explanatory notes added. Codes that were used to analyse the interview were as follows:

- **A**: Local Authorities role, background, organisational change, motivation, strategies
- **B**: Structural issues @ the regime level: Regulation, contracts, incumbency, lock-in, history & path dependency, constraints
- **C**: The CHP-DH Sector: Links between councils, knowledge development, interactions between council and stakeholders, CHP-DH advocacy
- **D**: Governance regime, policy and transitions: Energy policies, national-local interactions, grants, scales, policies , grants, schemes, the future
- **E**: Technology Choices: Generation, scheme design, loads, fuels, carbon abatement, benefits, modelling techniques
- **F**: Capital and Finance: Issues surrounding the funding of schemes

- *In this excerpt we are discussing the different ways councils structure their schemes. The interviewee begins by outlining the advantages of councils having direct ownership –*

Q: That gives you more flexibility?

R: Yes, because we can decide ... the investment rate, the minimum investment rate of return is, the council can decide what its minimum rate of return is, so if the Council is borrowing money of 3.2% let's say, on a fixed interest 50 years from the public works finance facility, they can decide to have a trigger rate of 4% on investment... and because we have thet the delivery capability we are not looking for an external commercial company to come in who would war to see a return much higher than we are prepared to accept, under which the infrastructure can't deliver that rate of return on investment, because sustainable infrastructure doesn't return money at that level of investment. So there are two things; you have got to get finance right, it has got to be either long-term low interest rate, and obviously all local councils have that capability, or it has got to be short term project finance which you then roll over when the time comes into asset finance, but most banks even on asset finance won't look beyond a seven-year horizon even at commercial rates. So there is a big fight between commercial money and the capability of debt for local councils. And then within the political bubble debt is bad!! So councils need to go into debt to be entrepreneurial and they can do at low interest rates for 50 years fixed but electorally debt is bad. So they are between a rock and a hard place, they know that they have got to spend money, they have access to cheap funds, but electorally it is dangerous to borrow money and go into debt.

F: Risk and ownership

F: Public vs. private debt

F: Politics & debt

[The ESCO] is setup so that all the profits of the … group can only be spent within the boroug on sustainability, that is the very reason on which they are set up. And that money, those profits are bounded, so they are not used to subsidize lower council taxes, that is the basis on which th … group is setup. So the profits are spent within the borough, with negotiation between stakeholders within the Borough, on improving energy efficiency. On energy efficiency in residential property, what we have done is matching government grants so that they are virtually free grants for people to upgrade their houses, we have achieved from what we have put in about a 21%'s CO2 emission reduction on housing throughout the borough, and we have had contact with between five and 6000 households within the borough on energy efficiency and that there is 26,000, no 36,000, households in the borough, so [the] profits and help engender sustainability within the borough and that is all it is intended to do. [The ESCo] is a CO2 reduction entity - not a profit-making entity for the purpose of Council tax reduction.

A: ESCO aim

D: Efficiency policies

A: ESCo aim

Q: Very different business model from Utilicom?

R: oh yes. Totally.

Q: You mentioned stakeholders what kind of groups?

R: [The] Council is a stakeholder in the outcomes of expenditure. You have the church groups, the faith groups, you have place making groups, you have community groups, so they are stakeholders, and you have climate change groups that includes all of those stakeholders; that is chaired by one of the counsellors and the idea is that effectively spends [the group's] profits on sustainablity within the borough. It is the same scenario as Utilicom in that [the ESCo] is a commercial entity but what is done with a profits is completely different... the other thing is that [the council] is obviously very attractive to developers because we are half an hour outside of London, we know what kind of development which is going to occur here, is going to be high rise's and mixed-use office accommodation buildings. We know roughly where developers are going to be interested over the next 25 years, there are parcels of land where we have existing old property that is not going to be redeveloped; and so we want to open up a dialogue between developers as early as possible, so that first of all they don't pay too much for the land, so that there is still a margin available for them to spend on sustainability, and that we are going to get holdings that we are not going to be embarrassed about in 100 years time. So we interact very early what the developers, as soon as they walk through the door …they get one of these things that says; this is what we would like to see the developments look like … and if you do this, in inverted commas, you might get through planning easier - so it is not a statutory thing, but it is encouragement to developers; saying to them that these are the kind of buildings that we want and we will do our best - a) to make sure that you build them and we can support you in building i.e. that we can have sustainable energy facilities available to you to support your

A: ESCO aim

C: Planning, developers & energy

development, and then we have got the ESCO that will be around for at least 25 more years in order to support those sustainability technologies... so it is an integrated whole.

- *In the next excerpt from the same interview we discuss the issue of regulating local energy schemes –*

Q: What is your best case scenario?

R: Our best case … is that it is the situation that it is. That if you are regulatory open, if you model yourself on a current utility in terms of the ability to protect their networks and customers, which is what we do, we are just as friendly or unfriendly as your local utility company, then status quote reins and that would be ideal for me. If Ofgem do not constrain the ability of the utilities to flex their prices below what I can meet, then I have got problems, because I can only take my retail margin down to a point and below that I lose money.

B: Private wire and regulation

- *In the next excerpt from the same interview the respondent describes the scheme and the technologies being deployed –*

R: … This is the town centre energy station; that provides heating cooling and electricity within the CBD. And also we provide electricity to carparks, advocacy and heating to the Holiday Inn conference centres etc. etc. This is the technology we use; marine diesel modified to run on gas and the reason why we used that technology is because a) you can put the machines anywhere in the because there is a good gas grid, and b) within 15 years we hope to be putting them on anaerobic digestion gas that has been injected into the gas network; so that a sustainable gas.

E: Scheme technologies

Appendix D: Map of the GB ESI

Figure 10.1: The Electricity Supply System in Great Britain in 2009

Source: (DECC, 2010c)