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Governance interdependencies between the water & electricity sectors

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1.0 INTRODUCTION

This working paper explores the governance interactions between infrastructure sectors over three historical time periods with the aim of analysing how these might influence future transitions. The purpose is to develop an understanding of interactions between two sectors (water and electricity). The paper also offers insights into the impact of these interactions on the uptake of sustainable technologies, and draws lessons for the co-ordination of policies and regulations that cut across traditional sector boundaries. The paper investigates the case of renewable energy use in the water industry in the UK. This has developed links between the water and electricity sectors. This introductory section sets out the rationale and context of the study, and the theoretical approach used for examining the co-evolution of these two sectors.

1.1 Background context

National infrastructure is composed of a set of interconnected sectors, such as ICT, water, energy, transport, waste, etc. The interconnected nature of national infrastructure and the growing risks, uncertainties, and opportunities associated with interdependencies, point towards the need for critical analysis – and, in some cases, for policy interventions to respond to these interdependencies. Interdependencies can trigger different effects depending on the type of relationship between infrastructure sectors. A complementary or functional relationship between sectors, where various components of Infrastructure have a reliance on each other, may induce a cascade of failures if one sector experiences failure (Buldyrev, Parshani et al. 2010). For example, a failure in the electricity sector may have severe implications for the water industry, while a failure in ICT may threaten both the water and electricity sectors due to their heavy reliance on ICT. Competing decision-making processes within two sectors may also trigger trade-off effects. For example, improvement in water quality through the use of water and wastewater treatment water technology may lead to increases in energy intensity, greenhouse gas emissions, and could exacerbate some energy security risks. However, structural similarities and a symbiotic relationship between sectors may also create opportunities that allow interdependent sectors to benefit from each other. For example, waste can be used to produce energy, water efficiency can induce energy efficiency, and energy efficiency may reduce the usage of water for cooling purposes in electricity production.

Thus, the interdependent nature of infrastructures may increase the need for co-ordinated governance arrangements. Historical research shows that the physical components of infrastructure co-evolve with associated institutions, policies, regulations, organisations and social norms (Foresight 2008). Because of these evolutionary processes and interdependencies, governance arrangements cannot be analysed in isolation from other aspects of infrastructure. Thomas Hughes has illustrated this co-evolutionary process with respect to the history of electricity industries in several countries. It leads him to a broad definition of what these industries contain:

> *"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 1987)*

A large body of literature emphasises the critical nature of interdependencies between infrastructure sectors but little attention is given to governance arrangements that shape these interdependencies (Buldyrev, Parshani et al. 2010). Some recent analysis shows how an infrastructure system can be 'locked in' to a silo based governance arrangement where the regulatory regime is designed so that multiple regulating actors operate at different levels within each sector. For example, in water and electricity, Ofwat and Ofgem act as economic regulators of their respective industries, the Drinking Water Inspectorate (DWI) and Environment Agency (EA) act as environmental regulators, and the Consumer Council acts as a consumer protection body for water. Furthermore, a set of European regulations also govern the economic development and environmental impacts of these sectors (Hall, Henriques et al. 2012). DEFRA's recent review of Ofwat highlights the disjointed role of various regulators which can cause wasteful duplication or conflicts of interest, as all interested parties work in isolation (Defra 2011). This silo-based governance approach within and between interdependent sectors may have detrimental ramifications for the future because interdependencies are growing and opportunities for more integrated and sustainable service provision may be missed.

This working paper aims to understand the drivers and barriers to more integrated governance arrangements in the UK using a case study approach. The case study provides an historical account of interactions between institutions, rules, actors and technologies between two interdependent infrastructure sectors to show how these interactions influence the uptake of low carbon electricity in the water sector. The case study is also designed to explore the barriers and drivers for more co-ordinated governance arrangements between the two sectors.

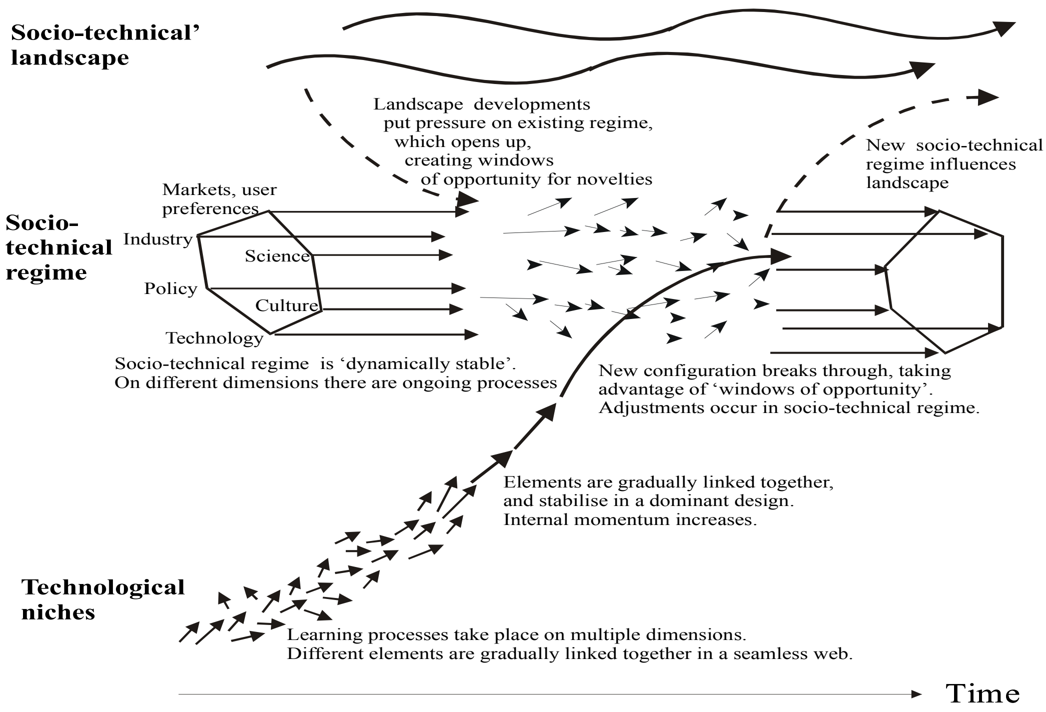
This is the first of two planned case studies of the governance of interdependent infrastructures. The second case study, which will be completed at a later date, will focus on smarter electricity grids that are likely to require integration between the electricity, ICT and transport sectors.

1.2 Conceptual Framework

Infrastructure sectors such as water and electricity are viewed in recent innovation systems literature as 'socio-technical regimes', where technical systems are embedded within the wider societal context and constitute a 'seamless web' of interaction between technical and non-technical components (Hughes 1983; Geels 2004). Geels (Geels 2006) established the term 'socio-technical regime', building on the concept of 'technological regime' from the evolutionary theory of Nelson and Winter (1982). According to his definition a regime comprises of a network of actors and social groups; formal, cognitive, and normative rules that guide the activity of actors; and material and technical artefacts and infrastructures (Geels 2006). The concept of the regime in the context of this study would thus correspond to what is often called an infrastructure 'sector' in common terms. This paper will thus analyse transitions within socio-technical regimes (sectors) drawing upon evolutionary theory and a systems innovation approach.

A growing body of literature on systems innovation has theorized the concept of transitions within socio-technical regimes. Some recent research emphasises the co-evolutionary and interdependent nature of processes which affect these systems over time (Geels, Elzen et al. 2004). For example, both Hughes (1987) and Summerton (1994) have provided useful theoretical insights about the development and transformation of large technical systems, but their theories focused most on processes of change within technical systems(Hughes 1987; Summerton 1994) . Amongst system innovation approaches, the Multi-Level Perspective (MLP) offers a broader scope in analysing changes within both technical and non-technical dimensions as well as explaining the sustainable transformation processes and patterns that shape these changes. It provides a conceptual framework for analysing system transformations by focusing on three analytical levels: (i) dynamics at the 'meso' level of a socio technical regime, (ii) dynamics emerging in niches, and (iii) dynamics within the socio technical landscape. Figure 1 below further explains the relationships between them.

Figure 1: The Multi Level Perspective (MLP)



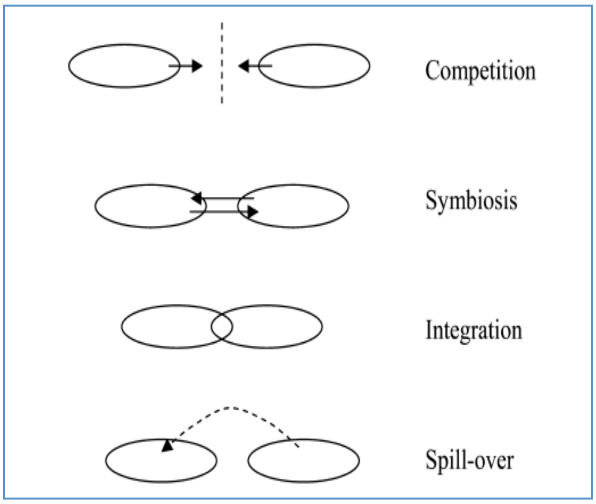
Source: Geels (2002)

Although the MLP framework has been particularly effective in analysing historical transitions resulting from interplay of these three levels, it has not been applied extensively to interactions between more than one socio-technical regime. Socio-technical transformations within one infrastructure regime may reconfigure the scope of the regime. They may also strengthen or undermine another regime.

The case study discussed in this working paper thus contributes to the existing transitions literature by drawing attention to the interactions between two infrastructure systems, each of which is characterised by its own socio-technical regime. Multi regime interactions have received some limited attention in the literature. Raven (2007) has examined how the waste and electricity regimes in the Netherlands have co-evolved, and how they have become more symbiotic and integrated due to innovation in biomass technology (Raven 2007). *Geels (2007)* has shown how interactions between two regimes contributed to the rise of a new musical style. Finally, Raven and Verbong (2007) established a typology of interactions between the gas and electricity regimes in the

Netherlands by analysing the case of emerging innovation in combined heat and power (CHP) (Raven and Verbong 2007). This typology is summarised in Figure 2.

Figure 2: Typology of interactions



Source: Raven and Verbong (2007)

As shown in Figure 1-2, these interactions can be:

- *Competitive*- when regimes start fulfilling similar functions;
- *Symbiotic*- when regimes start reaping mutual benefits from each other's existence;
- *Integrative*-when previously separated regimes more or less become one;
- *Spill over* –when regimes transfer experience to each other.

Konrad et al (2008) further investigate interactions and relationships between German utility regimes that contribute to regime transformations(Konrad, Truffer et al. 2008). They identify three types of relationship:

- When regimes fulfil a similar 'societal function' (e.g. private and public transport)
- When regimes are complementary (e.g. gas and electricity, via gas-fired power generation)
- When regimes have a similar structure, and can learn from each other (e.g. where lessons from the regulation of electricity can be applied to the water sector)

The multi regime case studies discussed above clearly show that knowledge of multi regime interactions can be useful, as changes in one regime may trigger reactions or obstruct expected changes in the other regime. This has important implications of policies or strategies designed to enable a more integrated approach to infrastructure transitions.

This working paper analyses the co-evolution of the water and electricity regimes in the UK using the Multi-Level Perspective. As shown in Figure 1, this framework includes three levels of analysis:

- The first level is the dominant *socio-technical regime,* where regimes constitute three sets of interrelated dimensions: (i) rules/institutions; (ii) actors; and (iii) technology, artefacts and infrastructure. These incumbent socio-technical dimensions provide stability within a regime and prevent radical changes from happening easily. Incremental innovations take place within these socio-technical regimes.
- Second level is the *niches* where development of radical, new technologies takes place in protected spaces.
- Third level is the socio technical *landscape*. These are deeper structural trends that shape regimes and are external to socio technical regimes and niches. The analysis examines the

interplay of actors, institutions, rules, technology and artefact with socio-technical landscapes and niches over different time periods.

The analysis of each of the two regimes is divided into three main time periods in this paper:

(1) Centralised / state control: The first time period runs before 1980s when utility regimes were characterised by state ownership.
(2) Privatisation: The second time period runs from 1980s to 2000 when most utility regimes were privatised in the UK.
(3) Post privatisation: The third time period runs from 2000 onwards when environment, climate change and resource security became a growing concern, and had significant impacts on the regulation of the privatised utilities.

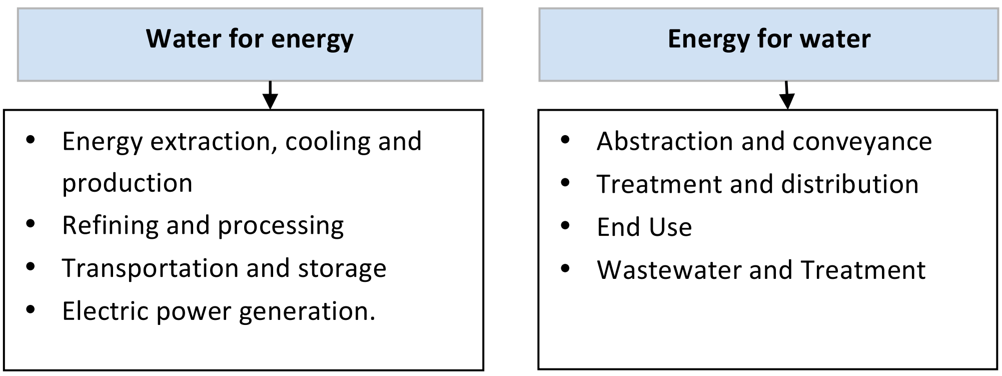
The paper also analyses the interactions between water and electricity regimes by drawing on the typology of interactions and relationships established by Raven and Verbong (2007) that are summarised in Figure 2. The case study is based on a primary and secondary literature review of academic publications, government reports, grey literature, etc. This secondary data is complemented with primary information from semi-structured interviews with water companies and other actors such as water regulator, Ofwat.

The following sections explain the rationale for studying the interactions between the water and electricity sectors.

1.3 The relationship between the water and energy sectors

The water and energy sectors are closely connected to each other. Water is used for producing energy and energy is used in water and wastewater processes (see Figure 3).

Figure 3: Water-energy interactions



Water for energy: water is extensively used in energy production for cooling processes in electricity generation, for producing electricity (hydroelectricity), in fossil fuel extraction and in bio fuels (Rothausen and Conway 2011). Fresh water is required in each step of energy production including 'energy extraction and production, refining and processing, transportation and storage and electric power generation' (WEC 2010).

Energy for water: energy is extensively used by the water industry in different stages of the life cycle and often has the highest environmental implications (Rothausen and Conway 2011). The following water-sector processes involve a high level of energy use:

- Abstraction and conveyance of water involves two main energy intensive stages: Pumping of water from source (fresh, ground and saline water) and transfer of water from source to water treatment plant or reservoir.
- Treatment and distribution processes are highly energy intensive: The more advanced the process the more energy intensive it tends to be. Processes may include filtration, oxidation, ultraviolet treatment, additives, de-nitrification, desalination, pumping etc.
- End use: May involve water heating, cooling, and the use of water in appliances etc.
- Wastewater treatment: Involves highly energy intensive processes in collection, physical treatment, chemical treatment, sludge treatment, discharge, etc.

As demonstrated, the water and energy sectors are heavily reliant on each other, and changes in one sector potentially impacts the other, either positively or negatively. Konrad et al define this relationship as one of 'functional coupling'. Functional coupling implies an input-output relationship between two regimes, where provision of one utility service (e.g. water) requires inputs from other utility service (e.g. energy) (Konrad, Truffer et al. 2008). This relationship may induce a 'symbiotic interaction' where two sectors or regimes reap mutual benefits from interdependency (Raven and Verbong 2007)

The focus of this working paper is on interactions between the electricity and water sectors, including a particular focus on renewable electricity use in the water and the wastewater sector. The three key reasons for choosing this focus are:

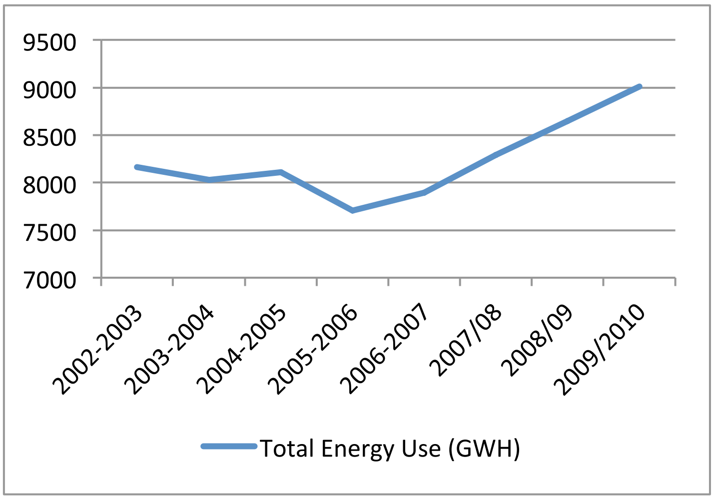
- First, the issue of energy use in the UK's water sector is under-represented in the literature. Most studies of the water-energy nexus tend to focus on water use for electricity generation (Gleick 1994; Hightower and Pierce 2008; King, Holman et al. 2008; Rothausen and Conway 2011). Some also analyse the implications of climate change for water availability and demand. But little peer-reviewed literature focuses on the implications of energy use in the water sector of the UK. Furthermore, there is a lack of literature on the governance interactions between the two sectors.
- Second, the issue of energy use in the water sector is a growing concern. The energy intensity of the water sector is growing and so is the water sector's sensitivity to climate change and climate variability. The water sector is also one of the contributors to greenhouse gas emissions due to the energy intensive nature of its processes.
- Third, whilst the water sector is starting to increase its use of renewable energy, progress has been limited so far.

The section below highlights the latter two aspects in more detail.

1.3.1 Energy use in the UK water industry

The water sector is the fourth most energy intensive sector in the UK and consumes 3% of total energy demand (CST 2009). As shown in Figure 1-4, the total energy used by the water industry in 2009/10 was 9012 GWh (Water UK 2010). The energy use has escalated by almost 8% in last 10 years (from 8160 GWh to 9012 GWh) and by 50% in past 20 years (Water UK 2005). Reports of some water companies show an increase of over 60% in energy-use since privatisation of the industry (Caffoor 2008).

Figure 4: Energy use by the water sector (2002/03 to 2009/10)



Source: Water UK annual sustainability indicators

Water treatment and wastewater treatment are the most energy intensive processes in the water sector. Whilst the industry body, Water UK, no longer reports energy intensity figures the most recent data from 2006/07 shows that the industry used 756 kWh of energy to treat one mega litre (Ml) of sewage and 559kWh to treat 1 Ml of water (Water UK 2006). When compared to the previous three years, the energy intensity for water treatment had fallen whilst the energy intensity of sewage treatment had increased. Energy costs account for almost 13% of the total production costs in the water industry. Electricity costs as a proportion of total operating costs of wastewater treatment is around 28%. The largest energy usage process in wastewater treatment is sludge aeration, which accounts for 55% of total wastewater treatment energy use (Caffoor 2008).

Two main reasons for increases in energy use over the past few years are: (a) stringent water quality requirements within EU regulations, and (b) climate variability

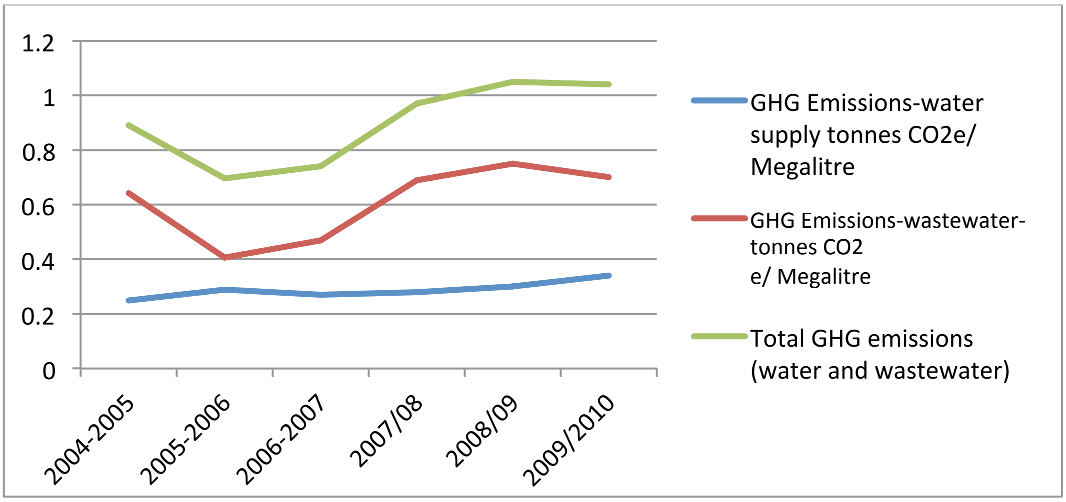
Stringent water quality regulations implemented by the EU are the major drivers for increases in energy use in the water sector, particularly attributed to water and wastewater treatment processes (Zakkour, Gochin et al. 2002). It is predicted that energy used for water production is likely to show a downward trend in future due to reduced leakage, demand reduction and energy efficiency. However, wastewater treatment is likely to show an increase in energy use due to stringent water quality requirements. Water companies predict a 60%-100% increase in energy use as a consequence of implementing EU Directives which include the Water Framework Directive (WFD) introduced in 2000 (Caffoor 2008). The WFD is focuses on the sustainable management water. The WFD requirements are transposed into national regulations in the UK by the Environment Agency. The WFD requires all surface, ground, inland and coastal waters to reach a 'good ecological status' by 2015. This is predicted to increase energy use for water and wastewater treatment by almost 100%. For example, Southern Water spends around £30 million on electricity per year. This is predicted to increase by almost 50% in the next Asset Management Plan period (2014-2019) as the company is involved in environmental improvements in the region under the National Environment Programme. The company manages a large coastal area, and is expected to invest in several schemes to improve bathing water and wastewater quality. Each time a new scheme has been established, energy consumption has increased (Southern Water 2012).

Climatic sensitivity of the water sector has also increased energy use in the water industry. Rainfall patterns in the UK have changed over the years so that winters are wetter while summers are becoming drier. These trends are likely to escalate in the future (UKCIP 2002). Energy used for pumping water during dry periods has also increased. For example, Southern Water caters for a drought prone region in the South East. As a result, the need for pumping water from reservoirs into rivers has increased over time (Southern Water 2012). Pumping is one of the major sources of energy demand within the water industry. It constitutes 60% of the total energy used for water supply in the UK (Caffoor 2008). Lifecycle assessment of water processes also show that electricity consumed for pumping has high environmental impacts (Friedrich, Pillay et al. 2007; Rothausen and Conway 2011)

1.3.2 Carbon intensity of the water sector:

The energy intensity of the water sector also makes it carbon intensive – see Figure 1-5. Estimates show that the water sector emits around 41 million tonnes of CO_2 on an annual basis (DEFRA 2009). With respect to end-use, domestic water heating accounts for almost 5.5% of the total GHG emissions, whilst operational processes in the water industry account for 1% of the total emissions, with wastewater treatment being the dominant contributor. It is estimated that the higher water quality standards required under the Water Framework Directive could further increase CO_2 emissions by 110,000 tonnes per year (EA 2009).

Figure 5: Carbon emissions from the UK water industry

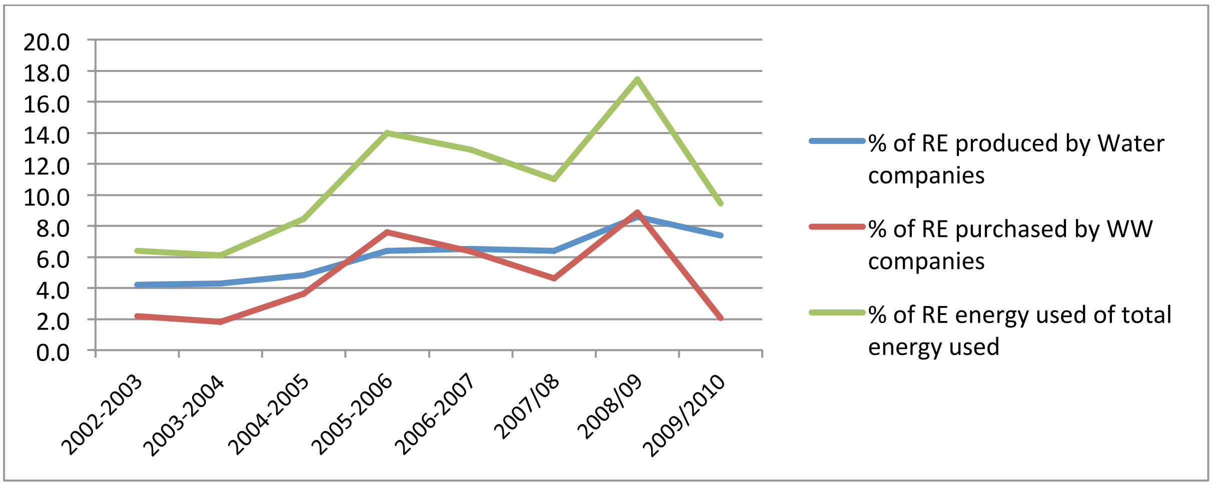


Source: Water UK annual sustainability indicators

1.3.3 Renewable energy use in the water industry

Measures to decarbonise the energy used by the water industry through renewables, and to make energy use more efficient, have had a mixed impact (see Figure 6). For example, renewable energy generated and used by the water industry of the UK increased from 6.4% in 2002/03 to 14% in 2005/06 and to 17% in 2008/09. The majority of this renewable energy has been generated and used as electricity. However, the share decreased to 9.5% of energy used in 2009/10 (Water UK 2005).

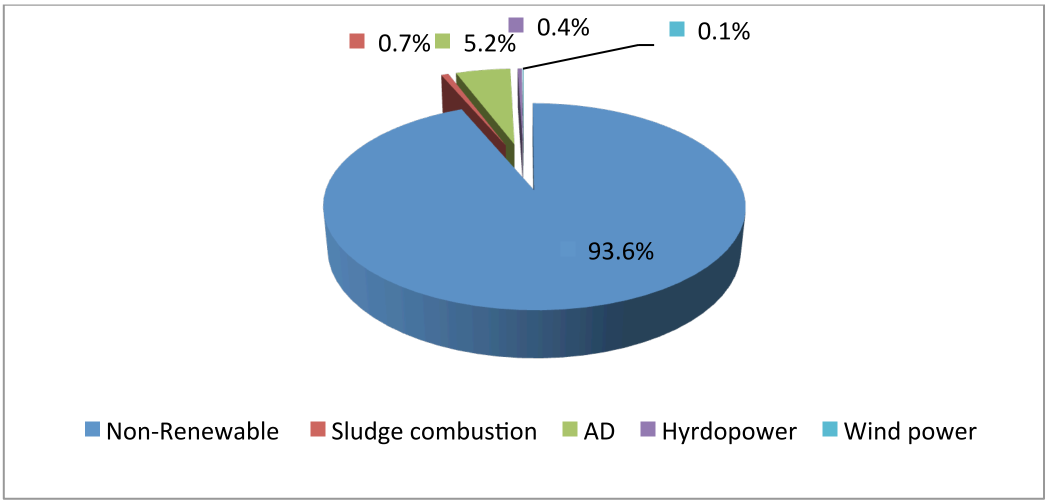
Figure 6: Renewable Energy use in the UK water industry



Source: Water UK annual sustainability Indicators

The types of renewable technologies deployed by water companies has also varied. As shown in Figure 7, 90% of current renewable energy generation comes from sludge combustion and digestion (Environment Agency 2009). Solar technology is also being deployed by some companies such as Thames Water, but it accounts for a very small proportion of electricity generated.

Figure 7: Breakdown of energy use by the water industry by technology (2009)



Source: (Environment Agency 2009)

Several economic, regulatory, and policy constraints and drivers are responsible for this observed pattern of renewable energy use. The uptake of technologies is not only influenced by changes in institutions and rules within the water sector, but also by several exogenous changes from the energy sector such as changes in energy policies and energy R&D priorities.

2.0 NATIONALISATION AND STATE OWNERSHIP

This section discusses the changes in the water and electricity regimes prior to the 1980s when infrastructure governance moved from a decentralised system (with dispersed ownership) towards a nationally centralised governance model. During this period, the perceived political and economic importance of individual infrastructures greatly determined the level of investment and political attention received by each sector, and this fluctuated over time (Marshall 2010). For example, the electricity regime received significant attention and was centralised after the Second World War (1940s) due to the strategic importance of the resource in an industrialised economy (Foresight 2008). In contrast to electricity, the localised public private control of water lasted until the late 1960s or early 1970s.

2.1 The water sector under state ownership

2.1.1 Changes in rules and institutions

The nationalisation of the water sector was implemented via the Water Act of 1973. A major driver for the nationalisation of the water sector was growing water demand resulting from 'landscape' changes, particularly demographics and industrial growth. Growing water demand also resulted from an increase in energy use. This period thus saw 'an accelerated development of the nation's water resources' to manage the growing demand (Hassan 1998). Besides demand management in the 1960s, environmental issues in late 1970s and early 1980s were also emerging concerns for the water and wastewater industries; notably the growing environmental opposition to large-scale water engineering projects. The public interest in the environmental implications of such projects underpinned the Water Act of 1973 with a focus on nature conservation and recreational use of land and water owned by the water authorities. River and ground water quality gained attention amongst public authorities due to poor performance by municipal Sewerage Treatment Works (STW). Thus the 1970s began to see an increase in the share of capital expenditure towards sewerage and sewerage disposal. But financial concerns, the global oil shocks, and the government's focus on financial efficiency, led to a reduction in investment in such projects. Other than the water quality agenda, industry incumbents continued to treat the environment as a lower priority. Not surprisingly, environmental discussions overlooked the potential energy intensity implications of large-scale water engineering projects.

2.1.2 Actors and networks

The Water Act of 1973 established 10 Regional Water Authorities (RWAs) that were later converted into private Water and Sewerage Companies (WASCs) through the Water Act of 1989. The RWAs were now responsible for integrated management of the entire water cycle. They were responsible for the work previously carried out by 157 water undertakings, 29 River Authorities and 1393 Sanitary Authorities (Hassan, 1998). The RWAs functioned as single units of operation within their respective regional areas that were delineated using a catchment based approach. They were required to perform a diverse range of tasks such as water supply and treatment, sewerage disposal, drainage, river pollution, the management of fisheries, etc.

This institutional reconfiguration gave a lot of responsibility to the new Authorities, but their performance in dealing with emerging challenges was debated. For example, drinking and river water pollution became a focus of concern amongst the public interest groups and European officials during this period. Some initiatives were undertaken by the RWAs but there was insufficient attention to tap water quality and river water quality. According to one assessment, 'the national failure to improve river water quality was basically a reflection of official priorities' (Hassan 1998). The Regional Water Authorities were more focused on de-municipalisation and cost reductions that on environmental improvements.

2.1.3 Technology, artefacts and infrastructure

National spending on water supply infrastructure increased considerably post-centralisation. Between 1955 and 1973, growing demand for industrial and domestic water were major drivers for state spending on capital-intensive supply solutions, such as the construction of reservoirs, ground water resource development and pumping stations (Marshall, 2010). Assets inherited from early periods of investment in the 19th century had suffered neglect due to previously dispersed local level ownership. New construction also had environmental implications, for example for nature reserves and for the industry's energy intensity. Energy use increased due to processes such as pumping river water into newly constructed reservoirs (Hassan 1998).

The 'landscape' pressures on the water sector changed in the 1970s. The global oil shocks of 1973/4 and 1979, coupled with declining GDP, meant a reduction in the availability of public finance to invest in the water sector (Hassan, 1998). At the same time, the UK's textile industries declined in size, thereby reducing the demand for water from the industrial sector.

The combination of investment and declining demand meant that the water sector had an excess of supply capacity during this period. The emerging challenges for Regional Water Authorities (RWA) were driven by public health and environmental concerns about water pollution. Historically, the water industry had prioritised 'supply fix' solutions over improvements in local sewerage infrastructure. Consequently, after 1973, the RWAs inherited a sewerage infrastructure that was in need of renewal (Hassan, 1998). RWAs began some capital spending from the 1980s onwards on primary treatment projects. In 1978, some environmental initiatives were implemented by the North West Water Authority, with a focus on the renewal of river systems. However, the slow progress is illustrated by the fact that some 30% of total wastewater disposals were still made into the sea during the late 1980s (Hassan, 1998). This led to further pressure from the European Commission for a reduction in the environmental impacts of the UK water sector – and for the UK government to meet the terms of European directives (House of Lords Science and Technology Committee 2006).

Although the subsequent privatisation of the water industry was primarily driven by the government's desire to reduce the size and role of the State, it also aimed to address these investment and environmental challenges.

2.2 The electricity sector under state ownership

2.2.1 Changes in rules and institutions

After the Second World War, energy and transportation were increasingly seen as strategic sectors for economic recovery in the UK. During the inter-War period, a decisive move towards an integrated system had been made. Universal technical standards were imposed by the national government after a concerted battle with local authorities. Electricity supply was ultimately nationalised after World War II in 1947. The Electricity Act of 1947 nationalised several private and municipal electricity generation and supply utilities and replaced them with British Electricity Authority (Surrey 1996). The nationalisation of the gas industry a year later in 1948 under the Gas Act in 1948 amalgamated over 1000 companies into just 12 regional gas boards (National Grid 2009). The Electricity Act of 1957 further dissolved the Central Electricity Authority and replaced it with the Central Electricity Generation Board (CEGB) and the Electricity Council. Security of supply was the main goal and private provision was replaced with public ownership and management of electricity generation, transmission and supply. The Electricity Act of 1983 attempted to introduce some competition by encouraging independent private generators but this attempt failed due to a lack of incentives and a lack of transparency from the CEGB. The incumbent CEGB was able to access capital at much lower costs (and could therefore use a 5% discount rate) than the private small scale generators (Surrey 1996).

The relative importance of energy policy in the UK has varied considerably since nationalisation (MacKerron 2009). After nationalisation, the security of coal and oil supplies lost its prominence. But the global oil shocks of the 1970s led to increases in energy prices and refocused attention on the energy security agenda, including the need for energy efficiency and alternatives to oil. This led to a drive to harness and exploit natural gas and oil from the North Sea, to plans for an expansion of the use of coal in the electricity sector, and also provided a rationale for the UK's emerging civil nuclear power programme. Civilian nuclear power was introduced in 1956 with the opening of the Calder Hall reactor – the world's first civil nuclear power station. This was followed by a significant nuclear investment programme during the 1970s and 1980s. But this source of electricity became increasingly controversial (Marshall 2010) and the programme lost momentum in the 1980s as it became clear that nuclear power's high costs and financial liabilities made it unsuitable for privatisation (Pearson and Watson 2011).

UK renewable energy policy around this time was largely based on R&D programmes and a few experimental demonstration projects. By contrast with growing support for nuclear technology during the 1970s there was very little support for renewables. Some support was provided by the Energy Act 1983. The CEGB was obliged to purchase electricity from renewable generators. However, the amount payable to renewable generators was 30% less than what CEGB received for its own electricity (Mitchell 1996).

2.2.2 Actor and networks

The nationalisation of the energy sector also led to reconfiguration and emergence of new actors and institutions. The UK Electricity Supply Industry (ESI), which primarily comprised small-scale, local, private or municipal companies, was nationalised in 1947 as the British Electricity Authority (BEA). The BEA was responsible for the generation and bulk transmission of electricity and overseeing the independent Area Electricity Boards (AEB). ESI was one of the biggest nationalised industries in the UK, and by the late 80s the combined assets of ESI were more than £42 billion (Surrey 1996).

The Electricity Act in 1957 further reconfigured the structure of the industry by creating a Central Electricity Generating Board (CEGB). The national grid emerged from a patchwork of local companies and networks. CEGB was responsible for the generation of electricity and construction, operation of the power stations, and maintenance of the national grid. At the same time, two vertically integrated state-owned companies (Scottish Hydro and South of Scotland Electricity Board) were established in Scotland. By the late 1980s, the CEGB generated and supplied 95% of all electricity in England and Wales. By the late 1980s private independent generation of electricity was almost completely displaced by the public sector and declined to 6% of total production in that year. The industry was supervised and coordinated by the Electricity Council and retail distribution of the electricity was the responsibility of 12 Area Electricity Boards (Surrey 1996).

2.2.3 Technology, Artefacts and Infrastructure:

The demand for electricity grew significantly in the first few decades of state ownership – from 42TWh in 1945 to 222TWh in 1973. Coal accounted for the majority of electricity generated throughout this period, though its proportion fell from 97% in 1945 to 63% in 1973 as the shares of oil and nuclear power grew (Fouquet 1998). The decline of coal was partly driven by high coal prices, and the relatively low price of oil. Intensified electrification on the other hand triggered growth in nuclear capacity to compensate for reduced fossil fuel usage. Nationalisation of the electricity industry also set the scene for several decades of development that was characterised by progressively larger power plants and an excess of power plant capacity (Sherry, 1984). By the mid-1960s, the capacity of individual power plant units was increased to 1000 MW.

Despite the growth of nuclear power, fossil fuels continued to constitute the majority of power plant capacity (78%) for electricity generated (80%) by the UK electricity supply industry. By the late 1980s, fossil capacity still accounted for 78% of the total (and 80% of total generation) whereas nuclear and hydro power accounted for 18% and 1.2% of generation respectively (see Table 1). The share of renewables other than hydro power was negligible.

Table 1: Electricity Generated and Supply Capacity by ESI, 1987.

Capacity by type	Capacity (MW)	Electricity generated (GWh)
Fossil fuel	50,263 (78.6%)	226,382 (80.71%)
Nuclear	6,519 (10.2%)	50,282 (18%)
hydro	4,085 (6.40%)	3,312 (1.2%)
Other	3,001 (4.70%)	512 (0.18%)
Total	**63,868**	**280,488**

Source: Handbook of electricity supply statistics, 1988, Electricity Council (Surrey 1996)

Despite the minor role played by renewable electricity technologies during this period, some attention was paid to technological development after the oil shocks of the 1970s. Total public R&D expenditure on renewables was £215 million between 1977 and 1994, with an annual average expenditure of £17m. An initially high percentage went into wave power, followed by wind, geothermal and solar technologies. Between 1981 and 1984, geothermal and wind funding increased while wave expenditure decreased significantly. Tidal and solar power received negligible R&D attention throughout the period. The practical development of RE technology in the UK prior to privatisation was only limited to hydropower. Approximately 200 plants were financed by individuals and private owners. Electricity generation by anaerobic digestion processes was also implemented in small scale individual or company level schemes (20 in number). Almost half a dozen wind turbines were also built by private investors (Mitchell 1996).

2.3 Dynamics between the water and electricity regimes

Water and electricity are functionally linked to each other. Technically, the output of one regime is an input for the other. For example, water and wastewater are energy intensive processes, where energy is used in numerous processes such as abstraction, conveyance, distribution, pumping and water and wastewater treatment. Thus, the new water supply infrastructure constructed between 1950s and 1970s also implied increase in use of energy for water processes, particularly when new reservoirs required water to be pumped from rivers. On the other hand, water is an essential input for the energy system. For example, water is used for cooling in conventional power plants and nuclear reactors, for hydroelectric power, and for some fossil fuel extraction. The growing demand for electricity due to industrial growth increased the dependence of the electricity sector on water. However, whilst the water and electricity sectors had an increasingly symbiotic relationship, they were developed and governed separately. There was little interaction between the incumbent actors, institutions and rules governing the two regimes (see Figure 8).

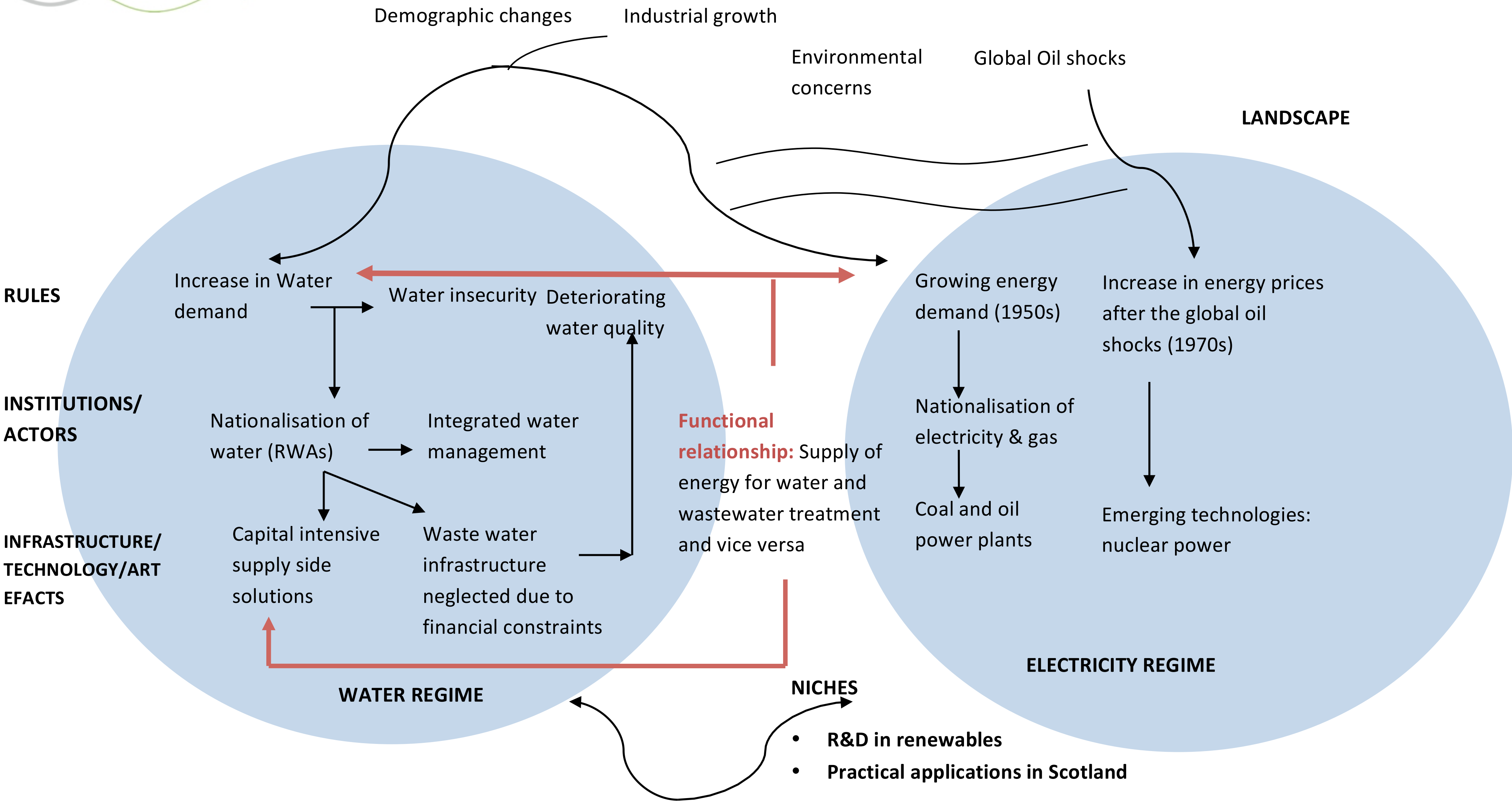


Figure 8: Interactions between water and electricity during state ownership

3.0 PRIVATISATION: LATE 1980s-2000

The 1980s saw the privatisation of both the water and electricity sectors, where central government transferred most of its state-owned assets into private hands. This privatised arrangement differed from the unregulated part-public, part-private arrangements of the early 20th century. Besides a political commitment by the government of the day to reducing the involvement of the State in the economy, privatisation was driven by the government's need to raise revenue and the perception that the State-owned utilities were inefficient. Nigel Lawson, the Secretary of State for Energy, in 1981 was one of the key proponents of privatisation. He declared that 'no industry should remain under State ownership unless there is a positive and overwhelming case for it so doing'(HC 1981).

3.1 Water privatisation and regulation (1989-2000):

3.1.1 Changes in rules and institutions

For the first time in Europe, the UK water sector was fully privatised under the Water Act of 1989. The resulting regulated private companies were expected to ensure efficiency in service provision. Additionally, they were obliged to ensure that people had access to services and the infrastructure was maintained and updated. The economic regulation of the water companies was based on the 'RPI-X' formula, which was used to controlling costs and to provide an incentive for operational efficiency. The RPI-X formula emerged from the Littlechild report on the regulation of telecommunications, which recommended price cap regulation for telecom companies in 1983 (Littlechild 1983). This formula was subsequently adopted for the regulation of many other privatised utilities. The formula restricts the companies from increasing charges for monopoly services to the retail price index (RPI) minus an efficiency factor (X) (Stern 2003). In practice, this allowed the independent water regulator, Ofwat, to set limits on the changes that water companies could make. During the initial years after privatization, Ofwat imposed lenient price controls and favourable rates of return to strengthen their balance sheets. The companies made high profits by increasing the prices they charged to their customers. The political impact of these profits led to an early review of the price control formula by Ofwat after 5 years (in 1999) instead of original plan for a review every 10 years. Following the 1999 review the companies were expected to produce economic appraisals of the options that they proposed to use to provide services to their customers. The shorter planning cycles (5 years) gave less financial certainty to water companies for longer term innovation and investment in new technologies including renewable energy (Cave 2009).

The 1980s also saw the growing influence of European legislation as a major driver for environmental policy in the UK. As a result, unlike the low environmental priorities of their State-owned predecessors, the newly privatised water industry was now expected to comply with various EC directives such as the dangerous substance directive (1967), the bathing water directive (1976), nitrates directive (1991), urban waste water treatment directive (1991), and the drinking water directive (1998). The urban waste water treatment directive (1991) was particularly important in encouraging sludge based renewables in the water industry by chance, as it required all significant coastal discharges to have secondary treatment – and it imposed controls on sewage sludge disposal and re-use and treated wastewater reuse (Colquhoun 2012).

3.1.2 Actor, institutions, networks

The Regional Water Authorities that were established by the Water act of 1973 were merged into private Water and Sewerage Companies (WASCs) through the Water Act of 1989. In addition, three main regulatory authorities were established to protect the interests of consumers and the environment. These were (a) an economic regulator (b) environmental regulators and (c) water quality regulators.

The Office of Water Services (Ofwat) was established in 1989 as the economic regulator of the water industry. As noted earlier, the main duties of Ofwat have been to regulate the revenue of the monopoly water suppliers, thereby ensuring that the companies are operationally efficient. They were also expected to encourage competition when feasible.

As outlined above, the role of European Union has become increasingly important with respect to the environmental agenda. European legislation did not allow regulatory duties (such as environmental regulations) to be discharged by private water companies. Consequently, the National Rivers Authority (NRA) was set up in the UK as an independent statutory body with a remit that included the regulation of the water industry. Hassan has argued that the NRA was very successful in performing its duties in relation to river-basin management, water conservation, pollution prevention and water quality (Hassan 1998).

During the 1990s, the NRA, Her Majesty's Inspectorate of Pollution (HMIP), Local Authority Waste Regulation Authorities and other environment related bodies were merged into a single agency: the Environmental Agency (EA). The EA was established under the Environment Act of 1995. The Agency licenses water abstraction, regulates pollution discharges, and oversees water management planning in the UK. The Agency is responsible for ensuring both water quality and quantity are adequately maintained. Besides water management, the Environment Agency also regulates other sectors including waste and energy (House of Lords Science and Technology Committee 2006).

Finally, the Drinking Water Inspectorate (DWI) was set up in 1990 as the drinking water quality regulators of the water industry. As their name suggests, they monitor the quality of drinking water by sampling and testing the water to ensure water companies comply with safe water standards.

3.1.3 Infrastructure, artefacts and technology

Following privatisation, the water companies proceeded to 'sweat the assets' they inherited, particularly the water supply infrastructure that was built during the previous era (Helm 2004a; House of Lords Science and Technology Committee 2006). However, the post privatisation period also saw improved operational efficiency and extensive investment in infrastructure to improve water quality to comply with European directives and obligations. In some ways water sector privatisation allowed the government to agree to European environmental obligations whilst meeting the costs from consumers rather than from general taxation. For example, Thames Water, which had one of the track records for sewage treatment under state ownership, reduced the number of non-compliant sewage treatment works from 86% to 47% in 1991 (Brown, 1991). The increase in investment in water and wastewater treatment in the 1990s was almost 2-3 times more than in the 1980s (Hassan 1998). The water companies invested around £50 billion in improving water services and reducing environmental impacts between 1989 and 2005.

As a result of these expenditures, the reported incidence of pollution fell significantly. River water quality improved by 26% between 1990 and 1994 and compliance with the drinking water directive improved from 94% to 97% between 1991 and 1993 (Hassan 1998). In 2000 around 27% of the population was connected to advanced tertiary wastewater treatment, in England and Wales, in comparison to 13% in 1990 (Eurostat, 2010). Although the chemical and biological quality of UK improved significantly post privatisation, the treatment technologies employed to meet EU standards were highly energy intensive. Wastewater treatment on average uses 60% of the energy used by the total water processes.

The minimal use of renewables in the water industry coincided with the low levels of attention to renewables in UK energy policy. The limited five-year price control periods introduced in the 1999 Ofwat price review process also acted as a disincentive to investment projects such as renewable energy that have relatively high up front costs which take time to pay back. For example, Thames Water investigated the possibility of investing in hydro power projects in the late 1990s. However, these projects were not economic if they were required to pay back during one five year price control period (Colquhoun 2012).

A few renewable energy projects were implemented nevertheless, such as investment in sewage gas plants to reduce wastewater disposal into the sea. Thames Water has operated combined heat and power (CHP) engines for a number of years. At the end of the millennium they introduced sludge powered generators to reduce the amount of waste they produced and to generate on site power (Colquhoun 2012). These projects were implemented before incentives for renewable energy were reformed and strengthened in 2002 (with the introduction of the Renewables Obligation). The main driver was the EU urban water and wastewater treatment directives that restricted the water companies' disposal of sewage sludge in the North Sea, and to comply with disposal standards for agricultural land. However, some of these projects were also the eligible for the National Fossil Fuel Obligation (NFFO) policy that had been in operation since 1990. The NFFO required electricity suppliers to purchase a specific amount of nuclear and renewable electricity each year (Mitchell 1996).

3.2 Electricity privatisation and liberalisation (1989-2000)

3.2.1 Changes in rules and Institutions

Within the UK energy sector, almost all subsectors (gas, electricity, and coal) were privatised between 1986 and 1995, with the exception of older nuclear power stations which remained in public ownership. The Electricity Act in 1989 privatised the 12 area electricity boards in England and Wales, each of which became a Regional Electric Company (REC). In early 1990, they were granted joint ownership of the National Grid Company that was established to manage the high voltage transmission system. They also distributed and supplied electricity to final consumers within their region. The companies purchased electricity from a wholesale market instead of a monopoly generator (which was the CEGB before privatisation). The CEGB's generation assets were split between two private companies, National Power and Powergen, and a state-owned nuclear company, Nuclear Electric. In Scotland, two vertically integrated companies were created at privatisation: Scottish Power and Scottish Hydro, with State-owned Scottish Nuclear retaining ownership of Scotland's nuclear plants. British Gas Corporation (BGC), a monopoly supplier and a vertically integrated corporation was privatised intact under the Gas Act of 1986. BGC was restructured in 1996 when its roles were distributed into 5 main divisions: domestic gas supply, business supply, transport and storage supply, service and installation, and retail. By 1997, BGC was fully demerged to form BG plc and Centrica. The liberalization of gas market was completed in 1998, with the extension of competition to all consumers. The extension of retail competition to all electricity consumers was completed in 1999.

Independent energy regulators were established to regulate the monopoly network operators and to promote competition. The Office of Electricity Regulation (Offer) was created to regulate the electricity sector whilst the Office of Gas Supply (Ofgas) regulated the gas sector. They both used the standard 'RPI-X' formula to regulate monopoly network charges over time. The role of each regulator was to reduce costs, to provide incentives for short term efficiency and to promote competition. Not surprisingly, innovation and R&D suffered during this initial period of privatisation, as the main focus was to ensure efficiency and reduced costs for current customers (Bolton and Foxon 2011). During the early years of privatisation, the electricity companies made what were seen by many as excessive profits due minimal competition in generation and retail markets, and relatively generous price controls for network businesses (Pearson and Watson 2011). Subsequently, these price controls were tightened up and action was taken to increase competition in electricity generation.

Environmental issues were important for the electricity supply industry even before privatisation. But environmental regulatory pressures became more acute over time. Three key environmental aspects received significant attention in this period. (a) Environmental targets were established by the European Union for sulphur and nitrogen emissions from large combustion plants (via the Large Combustion Directive in 1988); (b) Integrated Pollution Control (IPC) framework for combustion plants established specific requirements to acquire authorisation for discharges at power stations; and (c) the carbon emissions reductions debate became a hot topic after the earth summit of 1992. The implementation of the Integrated Pollution Control by Her Majesty's Inspectorate of Pollution (HIMP) was made possible by the Environmental Protection Act in 1990 (Surrey 1996).

Support for renewables was initially provided by the Non- Fossil Fuel Obligation (NFFO), starting in 1990. This was originally part of the post-privatisation settlement that was designed to provide economic support to nuclear power, but the European Commission insisted that the policy should also support renewable energy sources. The NFFO was accompanied by the introduction of a new Fossil Fuel levy on electricity bills to provide a subsidy to nuclear and renewable generators. During the initial stages of the NFFO the suppliers were required to purchase nuclear power at above market prices from the Non Fossil Purchasing Agency. At the time the NFFO was introduced, government expenditure on R&D and Innovation in renewable technologies was very low (Mitchell and Connor 2004). The NFFO was designed to reduce the price of renewable electricity through a series of capacity auctions, but it was not successful in substantially increasing the deployment of renewables. This was due to a relatively modest ambition coupled with the failure of many contracted projects to get planning permission or to secure finance (in some cases because they bid too low to get a contract). Renewable electricity also remained a low priority since environmental targets were being met through the construction of large numbers of new gas-fired power plants

(Pollitt 2010). Nevertheless, the NFFO helped to provide some momentum to the renewables industry in the UK (Mitchell 1996).

3.2.2 Actors and networks

As noted above, the privatisation of the electricity sector resulted in a number of new companies. The 12 area electricity boards became Regional Electricity Companies (RECs), responsible for supply and distribution of electricity in England and Wales. Assets of CEGB were split between three new companies: Powergen, National Power and the National Grid Company. The National Grid Company was initially owned jointly by the RECs. Over time the distribution and supply of electricity were unbundled to some extent as a result of EU Directives and the Utilities Act 2000.

This period also saw significant changes in the ownership of electricity and water companies, including the merger and horizontal integration of some water and energy companies (Helm and Tindall 2009). Following the demerger of National Grid Company from the RECs in 1995, there was a wave of takeovers of these companies by both domestic and foreign firms. The incumbent generators in England and Wales (National Power and Powergen) and the integrated electric utilities in Scotland (Scottish Hydro and Scottish Power) all purchased RECs during this period (Pollitt and Domah 2001).

In 1995/6, two multi-utilities were formed through mergers of water companies with their local Regional Electricity Companies. North West Water and NORWEB merged to form United Utilities in 1995. In 1996, Welsh Water took over the Regional Electricity Company SWALEC to become Hyder. Also in 1996, Southern Water was subject to a hostile takeover by Scottish Power (one of two vertically integrated electricity companies in Scotland. None of these multi-utilities lasted over the long-term. United Utilities pulled out of the electricity retail market in 2000 and sold of its electricity distribution business in 2007. Hyder was purchased by electricity network company Western Power Distribution in 2000, who sold off the water business of the company to Glas Cymru. Southern Water was sold by Scottish Power in 2002.

The original drivers for these water-electricity mergers included efficiency savings and economies of scale. They were also due to the high profits that were being made at the time by water companies, which made them attractive targets for electricity companies. Exceptionally high returns in the water industry led OFWAT to review the price control for water companies early. A review took place in 1999, after only five years rather than 10 years as planned (House of Lords Science and Technology Committee 2006). The 1999 price review was different from the previous review since it imposed a 'K factor' on the average level of price rises to 2.1% below the retail price index (RPI). Between 1990 and 1995, the K factor had been 5.0%. This adjustment stemmed from a comparison between UK water companies and companies in other sectors (Bailey 2002). A windfall tax was also imposed in 1997 by the incoming Labour government, and the early price control review was followed by tighter regulations. These changes to the regulatory regime led to lower financial returns for the water companies, and led to the withdrawal of electricity companies from the water sector (Helm and Tindall 2009).

Similarly, the privatisation of the gas and electricity sectors was accompanied by the regulation of monopoly network charges by independent economic regulators. Two regulators were initially established: Offer (for electricity) and Ofgas (for gas). They were merged to form a single electricity and gas regulator, known as Ofgem, in 1999.

Environmental regulation of the electricity sector was rather different to that for the water sector. Whist the water sector had an autonomous authority (the National Rivers Authority), regulation of the electricity sector was carried out by an integrated pollution control agency that was also responsible for other sectors (Her Majesty's Inspectorate of Pollution, formed in 1987). The HMIP was the first agency to focus on interdependency issues, prompted by the concern that pollution control in one sector may impose costs on other sectors. In 1995, the Environment Act led to further integration of environmental regulation through the merger of HIMP, the NRA and the Waste Regulation Agency into the Environmental Agency.

3.2.3 Infrastructure, artefacts and technology

The years immediately following privatisation were characterised by a large amount of investment in new gas-fired power generation. The 'dash for gas' that followed privatisation led to a rapid switch from coal to gas. The was driven by a range of factors including the desire by the government and the regulator to promote competition via new generation that was independent of the incumbent generators, tightening environmental regulations embodied in European Directives, recent advances in gas fired power plant technology that had improved its efficiency, and the relatively favourable economics of new gas generation when compared to other technologies (Watson 1997). Thus, North Sea natural gas and Combined Cycle Gas Turbine (CCGT) power plants became the dominant choice for private sector investors – including incumbents National Power and Powergen. In first five years after privatisation, coal based power generation reduced from 68% to 51%. The share of gas generation increased from a negligible level in 1990 to 21% in 1996 (Fouquet 1998). As an accidental by-product of this shift, UK carbon emissions began to fall even though specific policies and regulations to reduce these emissions were not yet significant (MacKerron 2009).

Renewable energy also received some policy support through the Non-Fossil Fuel Obligation (NFFO) from 1990. The Obligation was initially conceived to support nuclear power, but was modified to include renewables at the insistence of the European Commission (Mitchell 2000). The first round of NFFO contracts provided support for 152 MW Declared Net Capacity (DNC) of landfill gas, sewage gas, hydro, wind energy, waste-to-energy and biomass projects. The second NFFO round came in 1991 where contracts were provided for 472 MW DNC of projects - but this time on the basis of competitive bidding. Projects using similar technologies competed with each other for contracts. The third NFFO round in 1994 included an attempt to reduce economic rents available from the contracts. As noted earlier, the implementation of the NFFO led to mixed results – and only a small increase in renewable electricity (from 2% to 3% of electricity between 1990 and 2002). The main beneficiary of the NFFO policy was nuclear power. Between 1990 and 2002, nuclear power received £7.8bn in subsidies whilst renewable energy projects received £800m.

By contrast with electricity generation, there was much less investment in electricity networks. Previously high levels of investment in the state-owned era allowed regulators to 'sweat the assets', and to deliver significant efficiency savings via increasingly stringent price controls (Helm, 2009). The companies that inherited network assets therefore lacked an incentive to invest or to innovate.

3.3 Dynamics between the water and electricity regimes

Following the privatisation of the water and electricity sectors, three types of interactions can be identified between them, which are summarised in Figure 9.

(a) Symbiotic interactions: a growing interdependency between the two regimes due to their customer – supplier relationship
(b) Spill-over interactions: the emergence of structural similarities between the governance of the two regimes.
(c) Integrative interactions: the emergence of integrated delivery of services by multi utility companies.

Symbiotic functional interactions

The privatisation period once again saw the growing functional or symbiotic relationship between water and energy due to an emphasis on water and wastewater improvement. Investment in treatment technology, consequentially increased energy use in the water sector due to take up of advanced tertiary and secondary treatment processes that were highly energy intensive.

Structural similarities in regime governance

Privatisation saw emergence of structural similarities between the regulatory arrangements in place for the water and electricity regimes. These structural similarities include a common economic regulatory philosophy, and the emergence of a common environmental regulator for both regimes.

The economic regulation of monopoly networks by Ofwat and Ofgem was based on the 'RPI-X' formula that aimed to control the prices charged by companies for the use of their networks (Stern, 2003). The RPI-X formula was only applied to part of the electricity sector – generation companies and retail supply businesses (that sold electricity to final consumers) were not subject to this regulatory formula since they were opened up to competition. In addition, although structural similarities emerged, the gas, electricity and water sectors continued to be regulated separately by regulators that had little or no interaction with each other. As noted above, the gas and electricity regulators were merged in 1999 to become Ofgem (the Office of Gas and Electricity Markets).

Another structural relationship emerged through a common environmental regulatory authority for the water and electricity regimes. Emissions from the water and electricity sectors were regulated by an integrated pollution control agency formed in 1987, Her Majesty's Inspectorate of Pollution (HMIP). Water quality was regulated separately by the National Rivers Authority (NRA). The Environment Act of 1995, integrated pollution control by merging HIMP with the NRA and the Waste Regulation Agency into the Environmental agency (EA). The EA was responsible for regulating many parts of the energy sector including emissions from fossil fuel power plants, the oil industry, sites producing sustainable energy from biomass as well as gasification, liquefaction, refining and the nuclear industry. For the water regime, it was responsible for licensing water abstraction, regulating pollution discharges and water management planning (EA, 2012). Whilst the EA has a very broad remit across the water and electricity sectors, there is little evidence that environmental regulations were implemented in an integrated way. For example, regulations to improve water quality and to reduce electricity emissions were potentially inconsistent.

Integrated service delivery

Following privatisation, there were some instances of the integration of the two socio-technical regimes. Integration played an important role during initial years following the privatisation of the water industry. As noted earlier, some of the water companies merged with electricity companies operating in the same region in the mid 1990s. However, after early 1999 OFWAT price control review, the rationale for some of these mergers broke down since water companies became less profitable. Other than United Utilities no other water and energy companies continued their integrated relationship.

Despite this institutional separation between the two regimes, this period saw some more modest integration via the deployment of renewable energy. There was some investment in sewage gas plants by water companies to reduce wastewater being disposed into the sea. This was driven by the National Fossil Fuel Obligation (1990) that required the Regional Electricity Companies to purchase nuclear and renewable electricity at above market prices, and offered contracts for renewable electricity projects(Mitchell 1996).

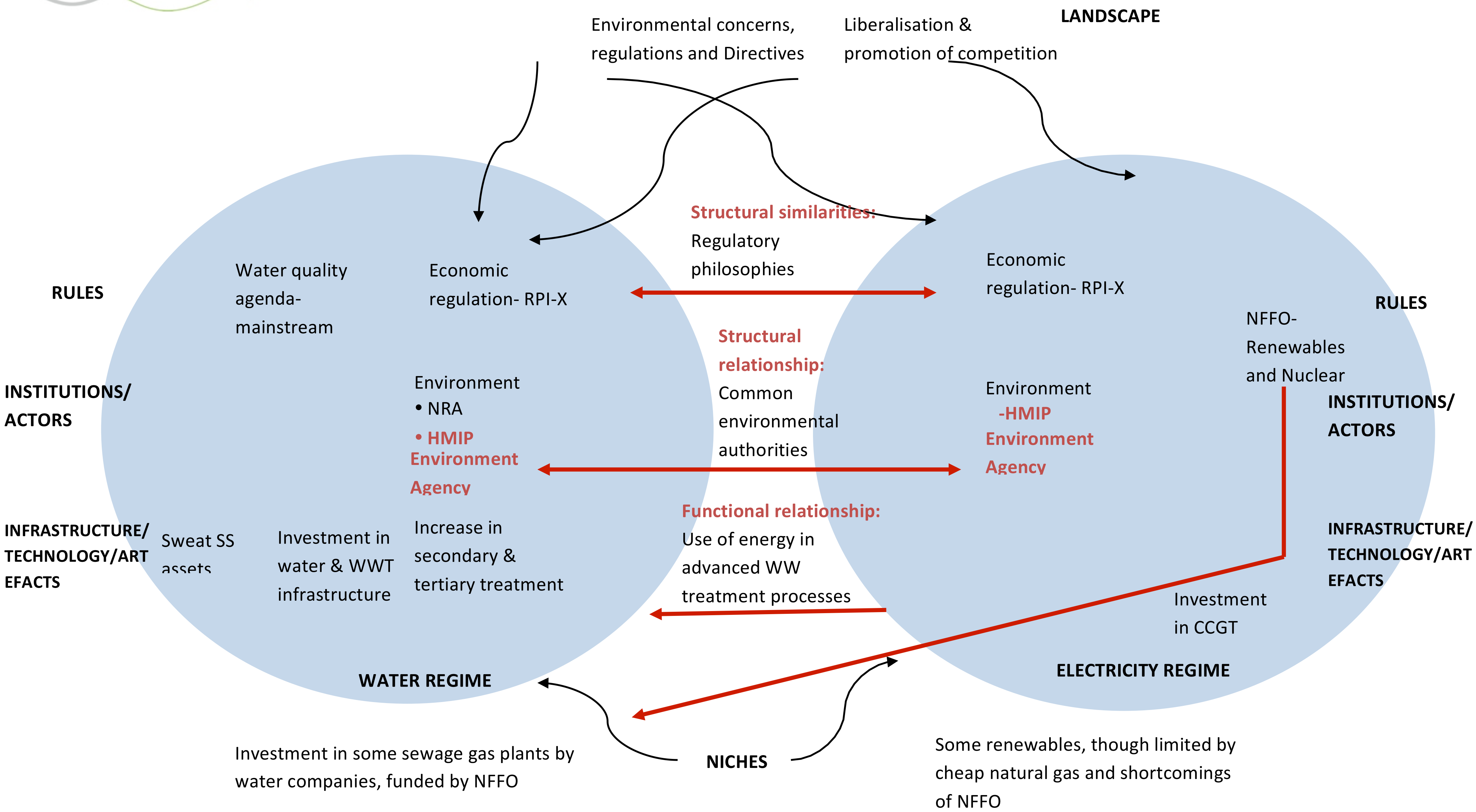


Figure 9: Interactions between water and electricity after privatisation

4.0 POST PRIVATISATION 2000-2012

Following the turn of the millennium, climate change and emissions reduction agenda became particularly important drivers for UK policy. Resource security in general – and energy security in particular - also reappeared in the policy agenda in the mid-2000s. Water security became a concern due to increasing evidence for current and future climate change while energy security concerns were driven by a number of factors including rising energy prices and a the UK's return to the status of net exporter of energy (Pearson and Watson 2011). As a result, electricity use and energy intensity in several sectors including the water sector became a more significant concern. The period also included an increase in the influence of EU Directives on national policies and regulations. As part of the response to these changes, the water sector began to expand the use of renewable energy.

4.1 The Water Regime (2000-2012)

4.1.1 Rules and institutions

Since privatisation, the prevailing focus of the water regulators (Ofwat and the EA) had been to ensure efficiency and quality of service for customers while improving environmental quality through the improvement of wastewater collection and treatment systems. During this period, the water industry was subject to some new and some re-emerging issues that had received less attention in the past. For example:

- Growing water security concerns due to climatic variability and water shortages in the 1990s and mid 2000s.
- The overriding requirement to reduce greenhouse gas emissions (GHG), and therefore to improve energy efficiency.

The Water Act 2003 was one of the most important policy changes during this period, and was designed to respond to water security concerns and other issues such as high leakage rates. The primary focus of the Act was conservation through Catchment Abstraction Management Strategies (CAMS) and time-limited licenses to water companies. It also required the water companies to develop periodic water resource plans and drought management plans with leakage reduction as a major imperative (House of Lords Science and Technology Committee 2006). In its water strategy of 2008, the Department for Environment, Food and Rural Affairs (Defra) pressed the water companies to adopt a 'twin track approach' which should include demand management measures alongside the development of supply side infrastructure if the need for it is justifiable (DEFRA 2008). In actual practice however, demand management measures did not receive significant attention.

The importance of climate change increased due to the implications for water security in the South East of the UK. The UK experienced severe drought conditions in 2004 and 2006. Projections by the UK Climate Impacts Programme (e.g. UKCIP-2002) envisaged further changes in future – including a likely increase in rainfall in the winter months and decrease of rainfall in summer. The latter changes projected for the South East were for a decrease in summer rainfall of 35% to 50% and increase in winter rainfall of 10% to 30% by 2080 (UKCIP 2002). This led to a discussion about the desirability and feasibility of supply side solutions such as interregional transfers, desalination and new reservoir construction. However, regulators highlighted concerns about the energy intensity of such solutions large scale solutions – and the possibility that they could contribute to a 'vicious cycle' of climate change. The Environment Agency also cautioned about the use of energy intensive engineering solutions to adapt to climate change (Environment Agency 2006). There was a perceptible change in institutional mindset that meant more of a focus on the energy intensity of the water sector by regulators.

Nevertheless, energy use continued to increase during this period due to strengthening water quality regulations. In 2000, several EU water quality directives were consolidated into one single directive: the Water Framework Directive. The broad objective of the Directive was environmental protection and the promotion of sustainable water consumption. The UK translated the Directive at the national Level through National Environment Programme (NEP). The Environment Agency asked the water companies to prepare five yearly environmental improvement plans to invest in water and wastewater treatment projects. The strengthening of these rules thus further reinforced the energy intensity of water regime.

Not surprisingly, the increasing energy intensity of the water sector led to concerns about its greenhouse gas emissions. According to annual sustainability indicators published by Water UK, emissions from water and wastewater increased by almost 17% since between 2004/05 and 2009/10 - from 0.89 tonnes CO_2e/mega litre to 1.04 tonnes CO_2e/mega litre. In parallel with these changes, the water sector has begun using renewable energy. The emergence of renewables as an integrating link between the water and electricity regimes was driven by common policy goals for emissions reduction. In 2009, the industry committed to a voluntary target to source 20% of the sector's energy from renewable sources by 2020 (Department for Environment 2009).

This ambition to increase the renewable energy has encountered some difficulties. Within the price control review of 2009, Ofwat decided to restrict finance for those renewable schemes that are not directly related to the regulated activities of the water companies. Ofwat's main motive was to limit the economic impacts of renewable projects on customer bills – and to reduce the profits being made by the water companies from these projects (Defra 2011). These changes led the water companies to concentrate on technologies such as hydro generation or CHP linked to sludge treatment. Prior to the changes, water companies could recover expenditures on a more diverse range of renewable technologies including solar and wind power.

Ofwat argued that the renewable projects implemented in early 2000s did not generate the significant amounts of electricity that were anticipated – and that they were less cost effective than established technologies (Ofwat 2012). Ofwat also argued that there is a competitive market for electricity generation. If water companies intended to enter this market, they should not put the customers at risk by engaging in it through their regulated business. Ofwat's approach was contested by water industry who emphasised that there was significant scope for renewable electricity generation on their sites, and that many of these technologies can be more cost effective than established technologies such as hydro (Thames Water 2012). A recent DEFRA review of Ofwat observed that the water companies tend to be 'risk averse' in their approach to such investments, and that this stems from uncertainties about how renewable electricity projects will be treated by the regulator in future (Defra 2011).

Ofwat's short five-year price control periods that were introduced in 1999 were also seen by water companies as a barrier to investing in long term projects such as renewables (Defra 2011). Ofwat argued that the water industry mistakenly believes that any investment they propose is expected to achieve a payback within a single five-year period – and that regulatory documents do not mention this requirement (Ofwat 2012). The incongruous understanding of both actors indicates that there is a divergence between stated information and implied information in government regulations, with statements that may be interpreted differently.

4.1.2 Actors and networks

The changes in regulations outlined above were driven by Defra, the Environment Agency and Ofwat. The water companies and Ofwat were required to justify new water supply schemes to Defra, while the Environmental Agency regulated any environmental impacts from these schemes.
Defra was formed in June 2001 when the Ministry of Agriculture, Fisheries and Food (MAFF) was merged with part of the Department of Environment, Transport and the Regions (DETR) and with a small part of the Home Office. In October 2008, further reorganisation led to the climate change and energy demand functions of DEFRA merge with the energy supply functions from the Department for Business Enterprise and Regulatory Reform (BERR) to create the Department of Energy and Climate Change (DECC).

The Water Industry Act 2003 bought another significant change by establishing an independent Consumer Council for Water on 1 October 2005, funded by Defra. Water UK was also established during this period to represent all of the major UK water and wastewater service suppliers at national and European level. Water UK has represented the water industry in response to policy consultations, and has been involved in the development of tools for carbon accounting for water and wastewater treatment processes.

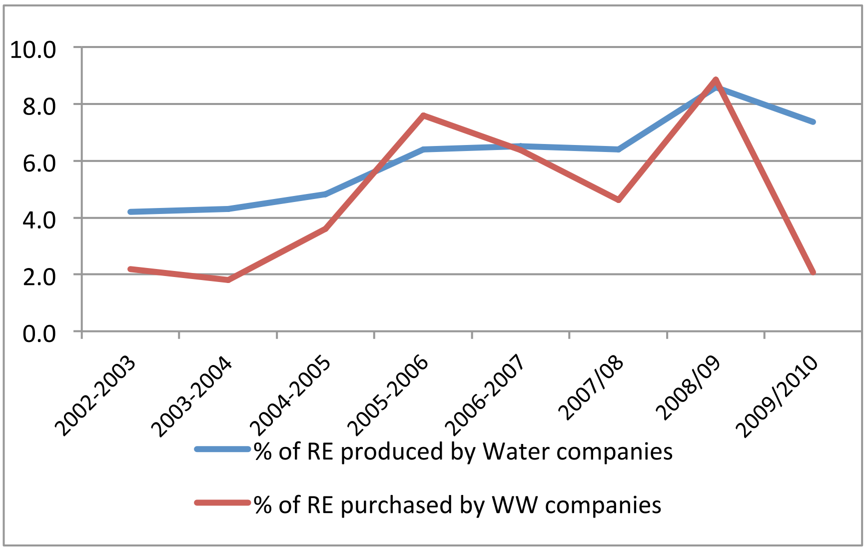
4.1.3 Infrastructure, artefacts and technology

Increasing concern about water security during this period had an impact on debates about water infrastructure and investment. As noted above, the water shortages in South East England led to a renewed discussion about investment in new sources of water supply. These discussions focused on options such as interregional transfers and desalination. However, an Environment Agency report published in 2006 discouraged these solutions on the grounds that they would be expensive, energy intensive and environmentally damaging (Environment Agency 2006). It estimated that the development of new resources in the South East would cost 4 times less than transferring water from further afield. Instead, the water industry proposed three demand management strategies in their water resource plans: (a) leakage reduction; (b) Industrial and commercial water efficiency; and (c) household water efficiency. These stated priorities suggested that water companies had responded positively to calls for a 'twin track' strategy of supply investment and demand management. However, some questioned whether this twin track approach was being implemented in practice (House of Lords Science and Technology Committee 2006).

Investment in infrastructure to improve water quality continued to be dominant during this period. The EU Water Framework Directive and the National Environment Programme further strengthened the rationale for such investment. According to the industry, they had spent £69 billion on water infrastructure by 2007 - and they were continuing to invest £3.4bn per year (Water UK 2007). This was continuing to increase the sector's demand for energy, which had risen by 10% during this period. For example, Southern Water spend approximately £30m on energy, a figure that is likely to rise due to the implementation of the National Environment Programme (Southern Water 2012).

Investment in renewable energy by the water industry took off during this period. In contrast to the small-scale developments of the 1990s, renewable energy now accounts for 10% of the energy used by the water industry. The majority of renewables generation by the industry is using sludge combustion and anaerobic digestion technologies (Environment Agency 2009). However, the generation and use of renewables by water companies has not developed in a straightforward way – see figure 10.

Figure 10: Purchase of renewable energy by water companies



Source: Water UK annual sustainability indicators

The Renewables Obligation was a significant driver of the growth in renewable energy generation by the water industry in the 2000s (see section 4.2 for details). The water company focused on the deployment of combined heat and power (CHP) plants at their treatment plants to generate electricity and heat from sewage sludge. Southern Water invested in several plants by the mid 2000s. They argue that the Renewables Obligation Certificates 'were certainly attractive but it also made technical, commercial and environmental sense to harness readily available bio gas' at these plants (Southern Water 2012). This assessment is confirmed by Severn Trent, which invested £20m on CHP plants at majority of their sites between 2002 and 2007. By contrast, Thames Water argued that the such investment was mainly due to an obligation to dispose of sewage sludge responsibly rather than the incentives offered by the RO (Thames Water 2012). They noted that any revenue from ROCs had to be shared with their customers as specified by the water regulator.

During this period, the water companies also began to explore investments in other renewable technologies. For example, Southern Water undertook feasibility studies into the use of solar and wind technologies at their smaller waste water plants. Welsh Water installed the first solar powered combined sewer overflow in Wales in the mid 2000s, whilst Yorkshire Water installed 4.3 MW of wind capacity at two sites in Howden and Saltend. Despite these examples, many water companies did not deployed these technologies more widely. As noted earlier, the key reason for this is the changes introduced as a result of Ofwat's price control review in 2009. For the new Asset Management Plan (AMP) period that applied after the review (from 2005-2010), water companies were allowed to recover the cost of renewable projects from consumers only if they had natural synergies with their core business. This implied that Ofwat would allow established technologies such as CHP linked to sludge treatment, but that expenditure on solar and wind projects would be less likely to be approved. A report by Defra concluded that this acted as a barrier to the implementation of many renewable schemes (Defra 2011).

Not all water companies viewed the regulatory changes implemented from 2010 as a constraint to renewable investment. For example, Severn Trent Water responded by setting up an unregulated business, Severn Trent Green Power Ltd, to meet its renewable targets. Severn Trent was producing 16% of its electricity from renewable sources by 2007, the majority of which came from sewage gas and hydro. In 2007, it decided to increase the amount of renewable generation to 30% by 2015. It prioritised the optimisation of existing sewage digestion plants and investments in wind power and anaerobic digestion (Severn Trent Water 2012). Other companies could have chosen to follow a similar strategy, but did not do so due to the risks involved. Whilst Southern Water began exploring investment in other renewable options in the early 2000s, it decided against taking them up (Southern Water 2012).

A further wave of renewable energy investment by water companies was triggered by the RO banding review in 2007. The proposals to reduce the subsidy available to established technologies such as sewage sludge CHP drove water companies to bring forward investments in CHP projects before the changes were implemented. For example, Southern Water constructed around 7 CHP plants by 2005 and they managed to build 6 more CHP plants before the value of ROCs for such projects was halved (Southern Water 2012). Whilst these changes made sewage sludge CHP plants less attractive, some companies took the view that many of the best investment opportunities had already been taken up prior to implementation (The ENDS Report 2010; Severn Trent Water 2012; Southern Water 2012).

At the end of the decade, there was a significant fall in the use of renewable energy by the water industry - from 17% in 2008/09 to 9.5% in 2009/10. According to industry body Water UK, this is possibly due to changes rules about the eligibility of renewables for government support schemes (Water UK 2010). There was also a fall in the amount of renewable energy purchased by water companies – from 8.9% in 2008/09 to 2.2% in 2009/10. A key reason for this fall in purchases was changes to government greenhouse gas reporting guidelines. These mean that renewable electricity bought on a 'green tariff' from a supplier could no longer be used to offset a company's greenhouse gas emissions. As Water UK notes, this purchased 'green electricity' could not be used to help companies meet their obligations under the Carbon Reduction Commitment (CRC) scheme which was introduced in 2010 (Water UK 2010). However, the government argued that there is a potential double counting issue that these restrictions are designed to address. Renewable energy generation for which ROCs have been claimed under the renewables obligation should not also be used to comply with the CRC.

Since 2010, water companies have once again turned their attention towards other renewable energy technologies. This has occurred for several reasons including increasing energy use and prices, new energy policy incentives, an emphasis on renewable energy in planning processes and technological progress. In addition, Ofwat as become more flexible in their approach to renewables as a broader range of technologies have matured and become more cost effective (Ofwat 2012; Southern Water 2012).

Thames Water made its first investment in solar PV in August 2011 in partnership with Ennoviga Solar. Through this venture the water company expects to save almost £200,000 annually in energy costs (ENDS 2011). A key driver for this particular project was the availability of generous feed-in tariffs following the introduction of this new policy in April 2010 (see section 4.2 below). Five other water companies have announced plans to invest in wind power plants. For example, Thames Water applied for planning permission to improve some of its sewage treatment works. As a condition of planning permission, the Mayor of London required onsite renewable energy generation using the most cost effective technology available. In this case, wind power has been chosen to fulfil the planning conditions (Thames Water 2012).

The new incentives for renewables investment offered by feed-in tariffs have not been wholly positive, however. The reduction in feed-in tariff rates in 2011 and 2012, and the way in which these were implemented, created significant uncertainties for investors (see section 4.2 below). Water company investment plans were negatively affected by these changes (ENDS 2011). For example, Southern Water's plans to install solar PV panels at 300 of their sites were curtailed due to the unexpected change in tariff rates (Thames Water 2012). In addition to this, there has been some difficulty in establishing the eligibility of some renewable energy schemes for feed-in tariffs, and some differences of interpretation between Ofgem and Ofwat. One example is a case where a water company pumps water into an upstream reservoirs or storage areas where they have plans to install a hydro project downstream. There has been a suggestion by Ofgem that such hydro schemes would not be eligible for feed-in tariffs which has led to bilateral discussions between the two regulators (Ofwat 2012).

4.2 The Electricity Regime (2000-2012)

4.2.1 Rules and institutions

UK energy policy continued to change significantly during this period. There were a series of reviews, White Papers and pieces of legislation. The Utilities Act introduced in 2000, modified the Electricity Act 1989 and the Gas Act 1995. Originally the Utilities Act was intended to focus on the water and telecommunications companies, but it was modified to include a major focus on energy market reform and the unbundling of distribution networks. The Act also had a major focus on the integration of environmental concerns into the economic regulation of the energy sector (Pearson and Watson 2011). It introduced new powers for the government to provide social and environmental guidance to Ofgem. Ofgem's primary goal continued to be the protection of consumers – but this guidance now needed to be taken into account. The Act also included energy efficiency provisions, and introduced a new Energy Efficiency Commitment (EEC) for electricity and gas suppliers. This policy obliged them to achieve a defined level of energy savings in their customers' homes (Ofgem 2005). A new Climate change Levy (CCL) was introduced in 2001, which taxed the use of energy by businesses alongside a system of voluntary agreements between government and energy intensive industries. With respect to renewable energy support, the Act replaced the Fossil Fuel levy and the Non Fossil Fuel Obligation (NFFO) with a new Renewables Obligation (RO).

By the early 2000s, climate change was receiving significantly more attention within UK energy policy. Following the signing of the Kyoto Protocol in 1997, the UK was allocated a new target to reduce greenhouse gas emissions by 12.5% from 1990 levels by 2008-2012. Significant progress towards meeting this target had already been made due to the 'dash for gas' in the power sector during the 1990s (Pearson and Watson 2011). The Energy White Paper of 2003 established climate change as the primary driver of UK energy policy. The White Paper was a direct response to the Royal Commission on Environmental Pollution (RCEP) report: *Energy: The Changing Climate* (Royal Commission on Environmental Pollution 2000). This report recommended that the UK should adopt a target that emissions should be reduced 60% from 1990 levels by 2050.

During the mid 2000s, climate change mitigation was joined by a renewed emphasis on energy security in energy policy. By 2004 Britain had become an energy importer after several years of being a net exporter and the energy prices had an upward trend after 15 years of somewhat low price levels. Energy policy was revisited at the instigation of Prime Minister Tony Blair, and a second Energy White Paper was published in 2007. This emphasised a role for new nuclear power stations alongside other low carbon technologies (particularly renewables) and energy efficiency (Pearson and Watson 2011).

By 2008, the UK had reduced its carbon emissions by 20% below the 1990 levels, and had met its Kyoto target. As noted previously, this performance was largely the result of the 'dash for gas' in the power industry. UK climate change policy was further strengthened by the Climate Change Act 2008 which was the result of a cross party consensus. The Act introduced more stringent long-term target for emissions reduction alongside five yearly carbon budgets over the short to medium term. The Act requires that greenhouse gas emissions should be reduced by at least by 80% by 2050 compared to 1990 levels. The Climate Change Act also established the independent Committee of Climate Change which has a remit to advise the government on carbon budgets and targets. In the same year the Act was passed, a new Department of Energy and Climate Change (DECC) was established.

These changes in energy policy that placed an increasing emphasis on climate change mitigation were accompanied by the increasing use of economic instruments to provide incentives for carbon reduction by businesses. The Climate Change Levy and system of voluntary agreements that was introduced as a result of the Utilities Act 2000 has already been mentioned. Subsequent to this, the UK established a pioneering pilot emissions trading scheme in 2002. This pilot scheme was succeeded by the EU Emissions Trading Scheme (EU ETS) from 2005. The EU ETS covered greenhouse gas emissions from large point sources, and covers around half of EU emissions. The EU ETS has not been as effective in practice as was first hoped, largely because the cap on emissions imposed under the scheme has not been tight enough (Betz and Sato 2006). The price of emissions allowances has therefore been too low to drive significant low carbon investments in industries covered by the scheme.

More recently, a trading scheme for smaller emitters known as the Carbon Reduction Commitment (CRC) was introduced in 2010. The CRC covers large public sector and commercial organisations that are not energy intensive, and are therefore not covered by the EU emissions trading scheme or voluntary agreements. Participants in the CRC are expected to monitor and report their energy use, and to buy allowances to cover the emissions from this energy use (DECC 2010). The water industry is included in the remit of the CRC and, as discussed in the previous section, there has been some controversy concerning its implementation.

With respect to renewable energy policy, this period saw significant reforms. The replacement of the NFFO with the Renewables Obligation in 2002 was an attempt by government to accelerate the rate of renewables deployment. This policy change was reinforced by a target that 10% of UK electricity should come from renewables by 2010. As a result of RO, electricity suppliers had to source an increasing share of their electricity from renewables, starting at 3% in 2002 and rising steadily each year. To comply, suppliers needed to surrender enough Renewables Obligation Certificates (ROCs) to show that they had generated or purchased the right amount of renewable electricity. The rationale for the RO was further strengthened when the UK government signed up to a new EU target for renewable energy in 2007. The EU Renewables Directive (2009/28/EC) that was agreed in March 2007 committed the European Union as a whole to source 20% of its energy from renewable sources by 2020. The UK's share of this target meant that the UK would need to source 15% of its overall energy (not just electricity) from renewables by that date (Pearson and Watson 2011).

Initially, the Renewable Obligation was technology neutral where electricity from all renewable technologies received the same level of support per MWh generated. In 2009, technology 'bands' were introduced which meant that generation from different renewable energy technologies would generate different multiples of ROCs. The introduction of banding was designed to provide a better incentive for less mature and emerging technologies such as offshore wind. Following the introduction of banding, offshore wind projects were awarded 2 ROCs per MWh. The technology bands were once again reviewed in 2012. As a result, support for onshore wind will be reduced by 10% to 0.9 ROCs for the period 2013-17, and the rate of support for offshore wind technology will also reduce due to an expected reduction in costs. Support for marine energy technologies will more than double from 2 ROCs per MWh to 5 ROCs per MWh (DECC 2012). According to the government, these changes were introduced to make renewables more competitive and less dependent on subsidies. However, uncertainties with respect to banding had some negative impacts on investor confidence, particularly for the onshore wind industry.

The Energy Act 2008 further developed UK renewables policy by introducing a Feed-in-Tariff (FIT) scheme in April 2010 for installations of less than 5MW in capacity (DECC 2012). The tariff rates available to small-scale renewables was initially generous – especially for solar photovoltaics (PV). As a result, the initial uptake of the scheme was rapid. In response, the government announced that the rate of feed in tariff for small scale solar PV would be reduced substantially – from 43p/kwh to 21p/kwh. The rationale was that costs had fallen, and that rates of deployment were higher than expected (ENDS 2012). But this decision was challenged in the courts on the grounds that the reduction was being implemented without sufficient consultation, and ahead of schedule. As a result, it had significant negative impacts on the nascent solar installation industry. Whilst the government's decision was partly reversed, tariff rates were reduced progressively from March

2012. From August 2012 the small scale solar PV tariff rate was reduced to 16p/kWh, with a further review every 3 months. Similar changes were introduced for other small-scale renewable technologies in December 2012. For example, small wind projects commissioned after December 2012 will see a drop in tariff by almost 40% (to 21p/kwh). Support for some technologies such as anaerobic digestion did not change, and tariffs for micro CHP were increased (DECC 2012).

4.2.2 Actors and networks

There were significant changes in energy sector government and regulatory institutions during this period. These were mainly driven by the increasing importance of energy policy – and the particular salience of climate change as a policy driver. In 2008, a dedicated government department for energy policy was re-established more than 15 years after the previous Department of Energy had been abolished. The new Department of Energy and Climate Change brought together energy supply competencies from the Department of Business and Regulatory Reform and energy demand and climate change policy areas from the Department of Environment, Food and Rural Affairs.

Around the same time DECC was established, the Climate Change Act 2008 led to the creation of a new independent advisory body. The Committee on Climate Change was established to provide advice on the UK's carbon budgets and targets – and on the extent to which current and planned policies would be likely to meet these targets.

As noted previously, Ofgem was established in 1999 as a result of the merger of electricity and gas regulators (Offer and Ofgas respectively). Starting with the Utilities Act 2000, Ofgem's remit was progressively reoriented to include the interests of future consumers (and not just current consumers) and to take into account social and environmental goals of energy policy. Ofgem and other regulators, including water regulator Ofwat, started to meet regularly under the auspices of the Joint Regulators Group[1]. The Group has operated as a forum for sharing experience and information between sector regulators – but has not focused on interdependency issues until very recently (2012/13).

This period also included significant restructuring within the energy industry. This resulted in the emergence of the 'big six' integrated energy utilities in the UK, many of which are part of pan-European energy companies. Most of these utilities include electricity generation, distribution and retail businesses. Two of the largest German utilities E.On and RWE took over PowerGen and National Power respectively in 2002. Scottish Power was taken over by Spanish utility Iberdrola in 2006. Electricite de France (EdF) established an integrated UK electricity company in the late 1990s and early 2000s through the acquisition of several retail and distribution businesses and power stations. Its position was consolidated through a takeover of nuclear generator British Energy in 2009. Scottish and Southern Electricity (now known as SSE) remains independent, and expanded its ownership of electricity generation in England and Wales during the 2000s. British Gas also remains independent, and is now known as Centrica.

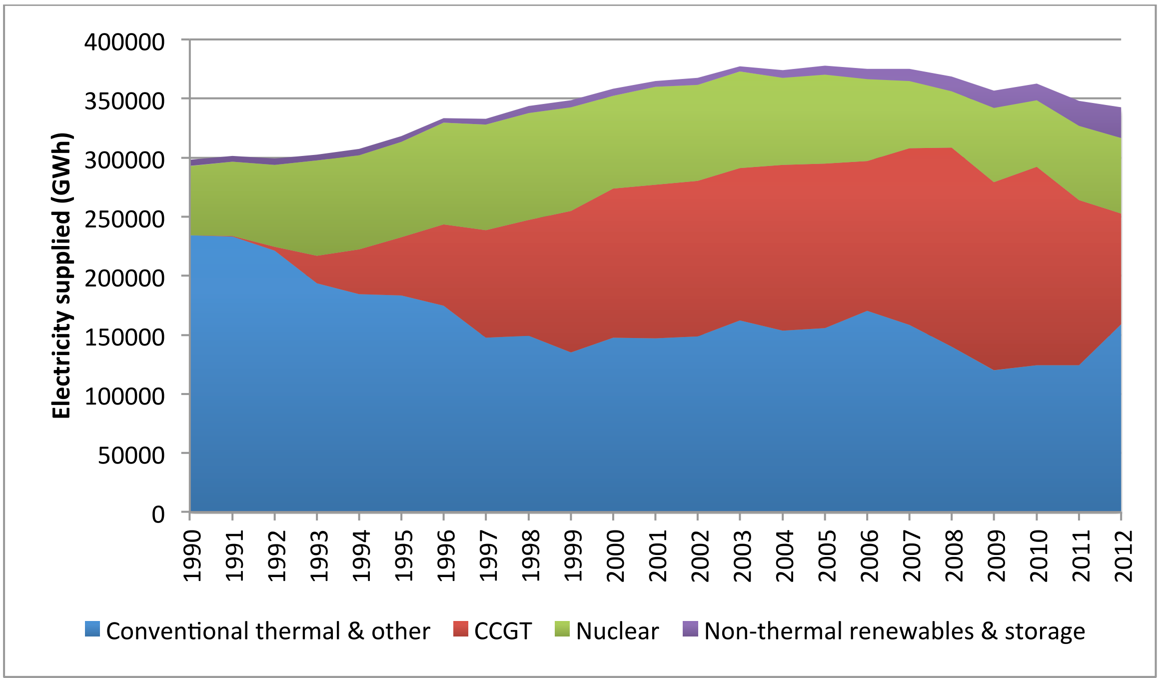
4.2.3 Infrastructure, artefacts and technology

The role of gas in the electricity sector continued to increase in this period, though in later years this growth started to level off – and in some years the share of gas declined as gas prices rose. At the

[1] See details here: http://www.ofcom.org.uk/about/organisations-we-work-with/joint-regulators-group/

same time, the share of renewable electricity has also increased as a result of the incentives provided by the Renewables Obligation. Nuclear power's share fell as a result of progressive plant retirements as well as maintenance issues at some stations.

Figure 11: UK Electricity generation mix (1990-2012)



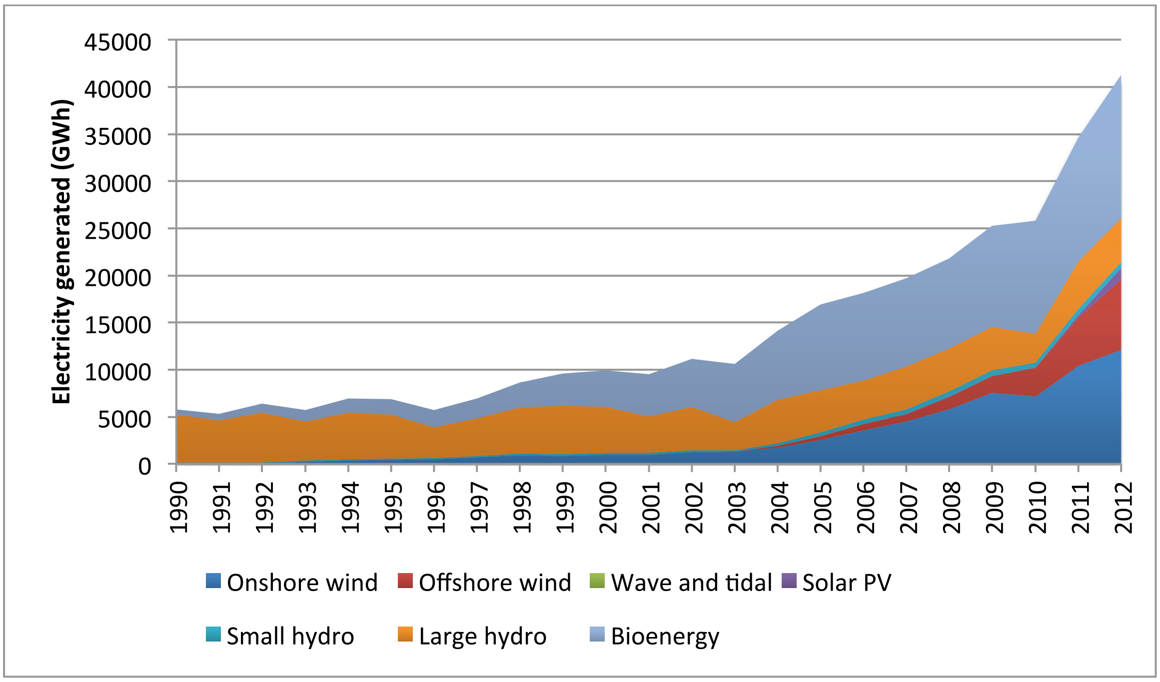
Source: Department of Energy and Climate Change historical electricity data[2].

Renewable electricity capacity increased dramatically between 2000 and 2012 – from a capacity of around 3GW in 2000 to around 15.5GW in 2012 (Department of Energy and Climate Change 2013). As shown in figure 12, the generation of renewable electricity also increased significantly during the period. Renewables accounted for 11.3% of electricity generation in 2012. The figure also shows that the technology mix of renewables has diversified during this period. Renewable generation was dominated by large hydro and bioenergy in 2000 – including some generation of bioenergy in the water sector. By the end of the period, onshore and offshore wind power were also making significant and rapidly growing contributions. Solar PV was also starting to make a small contribution due to incentives offered by feed-in tariffs.

Whilst the original 2010 renewables target was not met (the actual percentage was 6.8% rather than 10% as required by the target), the main policy focus is now on the 2020 renewables target that was agreed at EU level. The UK still has a long way to go to meet this target which is extremely challenging – and implies that around 30% of electricity should come from renewables.

[2] https://www.gov.uk/government/statistical-data-sets/historical-electricity-data-1920-to-2011

Figure 12: Renewable electricity generation in the UK by technology (1990-2012)



Source: Digest of UK Energy Statistics (Department of Energy and Climate Change 2013)

4.3 Dynamics between the water and electricity regimes

During this period, there were a number of different interactions between the water and electricity regimes (see Figure 13). The most notable of these were:

(a) The intensification of energy use in the water sector continued to reinforce the functional relationship between these two regimes. However, this relationship also included tensions between the water and electricity regimes:
- Symbiotic interaction between the regimes was strengthened when the water sector began purchasing renewable energy from energy suppliers, but policy changes in the electricity sector weakened this interaction later in the period.
- Symbiotic technological interactions coincided with policy and regulatory tensions between the two regimes due to competing priorities.

(b) Some limited integration of technologies and actors between the two regimes – largely as a result of renewable energy generation by water companies. Decision-making within the water regime was strongly influenced by policy changes within the energy regime.

Functional relationships

The functional relationship between water and electricity further intensified due to tightening regulatory requirements, particularly at the EU level. This led to the integration of all water quality directives into a single Water Framework Directive (WFD) in 2000. These standards resulted in an increase in water industry energy use by almost 10% in the last 8 years. Further significant increases are expected as regulatory requirements are tightened further (Caffoor 2008). This trend has also been driven by water scarcity in the South East of England which has led to an increased need for water pumping from rivers into reservoirs. For example, at the time the fieldwork for this paper was conducted (2011/12), Southern Water was spending £30m on energy use. They said that this was likely to rise in the subsequent five years to £50m per year to comply with the National Environment Programme (NEP) and their next Asset Management Plan (AMP6) which runs from 2015 to 2020 (Southern Water 2012).

Whilst this trend is likely to further reinforce the technical symbiosis between the water and electricity regimes, this period also included tensions between them due to competing policy priorities. Stringent regulatory requirements such as Water Framework Directive have led to the prioritisation of energy intensive water treatment processes within the water industry to improve water quality. This emphasis on energy intensive infrastructure did not fit well with the carbon reduction policy focus that has dominated the energy sector during this period. This applies to both the overall policy framework for carbon emissions reductions as set out in the Climate Change Act 2008, and to more specific policies such as the Carbon Reduction Commitment.

The Carbon Reduction Commitment (CRC) exemplifies these tensions – and the sometimes contradictory incentives on water companies from the water and electricity policy regimes. Their spending to meet Water Framework Directive goals for improved water quality has increased the costs of compliance with the CRC. In 2011 for example, Southern Water spent £2.8 million and Thames Water spent £4 million to comply with the CRC. Whilst the water industry has taken some actions to reduce emissions such as investments in energy efficiency and on-site renewable energy, these have been outweighed by increases in their energy demand. Their inability to use the purchase of 'green electricity' to help meet their CRC targets has made this job more difficult. However, the government argues with some justification that this would lead to double counting of emissions reductions if Renewable Obligation Certificates (ROCs) are issued for this purchased electricity.

In addition to these tensions, there were other specific changes to policies and regulations that destabilised some of the relationships that had developed between the water and electricity sectors during this period. A good example of this is the growth in the purchase of renewable energy by the water industry, which increased from 2.2% in 2002/03 to 8.9% in 2008/09. However, in the past few years purchases have fallen to almost zero. In the opinion of the water companies interviewed for this paper, the primary reason for this was changes in policies for greenhouse gas reporting. The water companies no longer saw a benefit from the purchase of renewable energy because these purchases could no longer be used to offset their emissions. In this case, the symbiosis identified in Raven and Verbong's typology of interactions broke down.

Partial Integration?

In Raven and Vebong's typology, they identify cases where different sectors (or regimes) start to fulfil similar societal functions (Raven and Verbong 2007). Whilst the water and electricity sectors have continued to have a primary focus on different functions (the provision of water and electricity respectively), their separation has become less pronounced as water companies began to generate renewable electricity. This has not led to competition with the electricity sector to any significant extent, but it has arguably led to a modest degree of integration between the two sectors. As this paper has shown, however, this has not been an easy process.

The key energy policy driver of this modest integration has been he introduction of the Renewables Obligation in 2002. By mid the 2000s, water companies were responding to the financial incentive offered by the Renewables Obligation. As a result, the water companies' generation of renewable energy increased from 4.2% of their needs in 2002/03 to 8.6% in 2008/09. The re-banding of the Renewable Obligation Certificates (ROCs) in 2009 led to a surge of investment in combined heat and power (CHP) and energy production from sludge digestion processes between 2005 and 2008 (Southern Water 2012). This was due to a reduction in the value of ROCs for these technologies that was implemented from 2009. After 2009, the share of renewable energy generation by the water companies declined – to 7.4% in 2009/10. This was partly because of the aforementioned changes in the CRC. These meant that renewable projects that generate ROCs cannot also be used to comply with the CRC because this would mean double counting of emissions reductions.

The introduction of feed in tariffs by the government in 2010 provided a further incentive for water companies to invest in renewables. In particular, it encouraged interest in other renewable electricity technologies such as wind and solar. A series of projects and plans followed, some of which included new partnerships with renewable energy companies. However, the changes in feed-in tariff rates in 2011 – some of which were introduced earlier than expected – had a detrimental impact on the plans of some water companies. These impacts were more widely felt by other renewables investors, and illustrate the risks of unpredictable changes in policies that were not foreseen or communicated to investors beforehand.

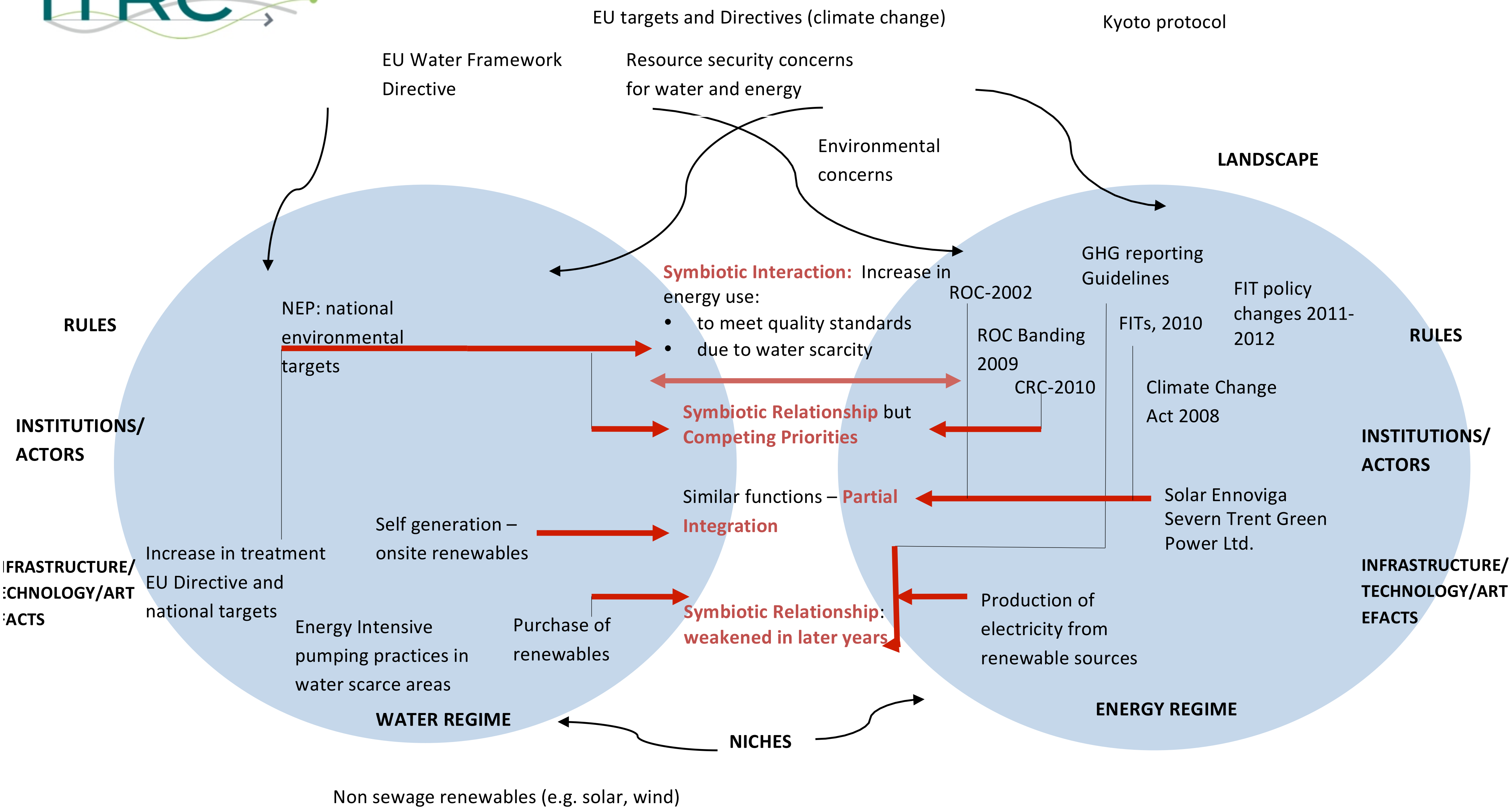


Figure 13: Interactions between water and electricity regimes (2000-2010)

5.0 Conclusions

This concluding section summarises the main conclusions from the water electricity case study, and draws some tentative lessons for the governance of infrastructure interdependencies.

5.1 Dynamics between the water and electricity sectors

This case study has shown that the interaction between the electricity and water sectors has taken a variety of forms over the past few decades. Our analysis has, in some cases, confirmed the usefulness of the typology of interactions between sectoral 'regimes' suggested by Raven and Verbong and summarised in Figure 2 of this paper (Raven and Verbong 2007). In some other instances, the interactions observed between these regimes have departed from those set out in this typology. The following sections discuss these dynamics in further detail.

Interactions before privatisation

Prior to the 1980s, the water and electricity regimes were essentially linked through a customer-supplier relationship. A substantial amount of electricity was supplied to the water industry. The demand for electricity had increased due to investments in large-scale engineering projects. The two regimes for water and electricity were therefore linked by a symbiotic relationship. Institutionally, the two sectors functioned separately (and as separate socio-technical regimes). There was little interaction between incumbent actors, institutions and rules governing them. The water industry's increasing use of energy intensive and large-scale engineering solutions set the scene for closer interactions in future time periods, where this energy intensity would prove to be challenging for the water companies after they had been privatised.

Interactions during privatisation

The number of institutional and actor level interactions increased during the 1980s and 1990s when both the sectors were privatised. The functional symbiotic interaction continued to strengthen due to the European Union's strong drive improve water and wastewater quality. A series of other interactions emerged such as the 'spill over' of regulatory rules between regimes, a common approach to the regulation of monopoly networks based on the RPI-X formula, joint environmental regulation by a common agency (The Environment Agency), and some temporary horizontal integration as a result of mergers and takeovers. This variety of interactions fits well with the assumption in the transitions literature that symbiotic relationships between regimes can lead to more complex, dynamic relationships (Konrad, Truffer et al. 2008). However, as this case study has shown, this does not necessarily ensure that these dynamics are managed or shaped in a co-ordinated way.

For example, although the economic regulation of monopoly networks was now governed by a common regulatory philosophy, both regimes continued to be regulated by agencies (Ofwat and Ofgem) with separate interests and decision-making arrangements. As a result some of the significant interactions between the two sectors during this period were short lived. For example, some of the companies from the water and electricity sectors integrated horizontally during this period. But a change in regulatory rules by Ofwat made these integrated relationships less lucrative for the electricity companies, and most of them were soon dissolved. Although the integration led to some economies of scale, the ultimate decision to dissolve most of the integrated water-energy utilities was significantly influenced by lower than expected financial returns. It is an open question whether mergers of this kind, to create multi-utility companies, would have led to more integrated decision making between the water and energy sectors – and whether they would have benefitted consumers due to efficiency gains. One rationale for such mergers was to reduce costs by sharing some functions, but as became clear, another was a perception by electricity companies that water companies were lightly regulated and would therefore be a source of increased profits. Many mergers between utility companies would have led to new challenges for regulators. Gaining access to information and analysing this information effectively could have become more difficult – an essential prerequisite for regulating effectively in the interests of both current and future consumers.

This period also saw the establishment of the Environmental Agency as environmental regulator of both sectors. It is not clear whether this integrated regulator has led to a more co-ordinated approach to the regulation of cross sectoral environmental issues. Our evidence suggests that the Agency has continued to operate with separate divisions overseeing the two sectors – and has not sought to explicitly deal with trade-offs between them. For example, the water sector has been increasingly required by EU Directives and national UK policy to invest in water quality improvements that have led to increases in energy demand. At the same time, energy policies have emphasised the need to reduce emissions from the energy sector – a goal that can be in tension with water quality improvement.

Interactions post privatisation

During the more recent post-privatisation period, the interactions between the two sectors became more complex. The increasing use of renewable energy by the water sector led to some integration between them as water companies began to generate renewable energy. According to Raven and Verbong (2007), when two regimes begin fulfilling similar functions their interactions become competitive. Our analysis does not entirely concur with this assertion. The generation of renewable energy within the water sector was driven by changes within energy policy – as well as by high energy prices and reduced renewable technology costs. Increased cooperation and the establishment of common goals between water and electricity regimes (e.g. for carbon emissions reduction and renewable energy generation) has further encouraged these changes. Policy dialogue and information sharing has improved to some extent. Ofwat and the Water industry have engaged with energy policy departments in government within consultation processes on energy policy changes.

However, this process of integration has been far from smooth. The intermittent commitment to renewable energy by the water sector can be partly explained by frequent energy policy changes. As the case study has shown, the water industry began purchasing renewable energy from accredited energy suppliers during this period – a trend that was a direct outcome of climate change policy and the opportunity for water companies to use renewable energy to offset their greenhouse emissions. However, this particular relationship soon weakened because of a policy decision in 2010 that purchased renewable energy via 'green tariffs' could no longer be allowed to offset company emissions. Furthermore, the introduction of the Carbon Reduction Commitment was accompanied by a restriction on the use of renewable generation to meet company targets due to concerns about 'double counting' of emissions reductions.

Therefore, the case study shows that the integration of the two sectors via renewable energy investment during this third time period was subject to significant pressure. This is a good example of the tensions that can be experienced when the policy and regulatory arrangements for two sectors have significant overlaps and interactions.

5.2 Lessons

This paper has provided some insights about the governance of sustainable infrastructure transitions, particularly where these transitions involve increasing interdependencies between infrastructure sectors. Clearly there is a limit to the generalizable lessons that can be learned from the single case study that has been analysed in this paper. However, in combination with lessons from further case studies, the conclusions from the paper can start to provide more general insights and policy implications.

The paper has shown that the interactions between the water and electricity sectors have become more important and extensive over time. It also shows that the interactions have a strong governance component, and that they have had some impacts on the development of the two sectors – particularly the water sector.

The privatisation of both sectors was followed by the implementation of some common approaches to economic regulation – and some learning between sectors. Both water and electricity have some 'natural monopoly 'functions that are not practical to open up to competition, and have therefore been subject to price controls to mimic the effect of competition. In the years after privatisation, comparatively lenient price controls in the water sector led to a brief window of opportunity for takeovers and the formation of multi-utilities that included both water and electricity provision. The business case for these multi-utilities did not prevail for long in most cases, once regulatory formulae had been tightened up. More co-ordination between economic regulators at the time may have meant fewer attempts to form such multi-utilities. It is also an open question whether such horizontal integration was beneficial – either to current consumers (in the form of efficiency savings) or in terms of longer-term sustainability.

Privatisation was also followed by the establishment of a common regulatory agency, The Environment Agency, to govern the environmental impacts of both sectors. However, creating such an integrated regulatory agency has not necessarily ensured an integrated approach across sectors. The Agency is only one actor amongst many, and has therefore had a limited influence over the two sectors which has arguably been less significant than that of the economic regulators.

The paper has also shown that changes in policy priorities for different sectors can lead to competing or conflicting demands on infrastructure providers. In the case of water and electricity, this has led to a complex and sometimes difficult relationship. The growth in the generation and use of renewable energy in the water sector was negatively impacted by these conflicting demands at times.

This experience suggests that it is essential for policy makers and regulators to understand the technical, economic and policy interactions between sectors - and to consider what forms of co-ordination between regulations and policies might be desirable to deal with them. Whilst such co-ordination would not guarantee that conflicts between priorities and policies could be resolved, they would make it more likely that competing incentives on infrastructure providers (in this case water companies) would be attended to.

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