Innovation and Policy for Bioenergy in the UK: a Co-evolutionary perspective

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Abstract

This paper analyses the role of niche innovation and regime interaction in the field of renewable energy in the UK. Adopting a co-evolutionary approach and a dynamic multi-level perspective on system innovation, the paper investigates niches development in UK in the field of bioenergy and its interaction with the current energy regime. Contributing to the debate about spatial scales at which sustainability transitions can be conceptualised, the paper utilises the case of niche development in the region of Wales to provide supporting evidence of the importance of context-specific social and political relations that may foster or hinder regime transformation.

Key words: systems innovation, institutions, co-evolution, bioenergy, transition studies

1.0 Introduction

As the most recent policy documents at international, national and regional levels stress, there is incontrovertible evidence that climate change - is an issue that must be tackled if planetary environmental conditions are not to be further jeopardised. Although the environmental performance of the energy sector has improved over the past 30 years (e.g. reduction of SO2, NOx and particle materials), policy makers as well as other actors in society increasingly acknowledge the limitations of end-of-pipe solutions and the need for more structural change. Such change is aimed at placing the energy sector, as many other sectors in contemporary societies, in confrontation with serious structural issues.

In the UK, for example, as stressed in the Stern Review of the *Economics of Climate Change* (2006), experts agree that the opportunities offered for the deployment of relatively affordable renewable energy solutions to tackle global warming exist. Moreover, the rise from a low base of renewable energy innovation, notably in biofuels, biomass power, wind, marine and solar energy, and, particularly, photovoltaics, is welcomed. Nevertheless, attention needs to be given to current driving forces, obstacles and policy challenges to the diffusion of green innovation and the shift to low carbon economies. The challenge is directly and indirectly to address such *transformation* which involves changes in a variety of elements, including technology, regulation, user practices and markets, cultural meaning and infrastructure (Elzen et al., 2004). These types of meta-changes are referred to as 'transitions' or 'system innovations' (Kemp & Rotmans, 2005). Adopting a co-evolutionary perspective, the aim here is twofold. Firstly, drawing from research recently undertaken in UK and Wales, based upon case studies, it reports examples of niches development in UK in the field of bioenergy and its interaction with the current energy regime. Secondly, contributing to the debate about spatial scales at which sustainability transitions can be conceptualised, the paper utilises the case of niche development in the region of Wales to provide supporting evidence of the importance of context-specific social and political relations that may foster or hinder regimes transformation.

The paper starts with an overview of the theoretical perspective adopted and follows reviewing the energy regime in the UK. The paper turns to discuss niche developments in green innovation and investigates how the bioenergy niche interacts with the current regime. Providing evidence from niche development in the region of Wales, the paper highlights that grounding niche development and niche-regime interactions in a specific spatial context offers a better explanation of geographically uneven transitions pathways. Concluding remarks also elaborates on lessons learnt and core propositions of the paper.

2.0 Theoretical perspective: co-evolution, innovation research, and transition

Co-evolutionary thinking offers a dynamic multi-level perspective on system innovation and, although originated from the synthesis of ecology and evolutionary biology, has found applications in a variety of disciplines; among these evolutionary economics and innovation studies (Geels 2006; Foxon, 2010) and sustainable development (Kemp, Loorbach and Rotmans, 2007).

Co-evolution (Norgaard, 1984) is defined as a process of change between practices, values and the environment and offers an insight into the complexity of evolutionary systems (Van den Bergh et al., 2007).

Traditional neoclassical economic concepts of rationality, efficiency and optimisation are considered unsuitable given the systemic nature of technological innovation (Kemp, 1997) and the themes of systems and adaptability, from evolutionary approaches, are recurrently adopted to facilitate more pertinent innovation research. Innovation systems (Lundvall, 1992, Freeman, 1987, Nelson, 1993, Braczyk et al. 1997, Edquist, 1997, Breschi and Malerba, 1997) involve a combination of technological, organisational and institutional novelties and the involvement of a multitude of actors at different scales (national, regional, local and sectoral). Innovation systems are therefore seen as part of broader socio-economic processes and, as argued by Foxon (2006), evolutionary economics offers a bridge to the social shaping of the technology approach.

Recently, social science research has extended beyond the study of the development and diffusion of individual cleaner technologies to incorporate a wider discourse on sustainable development and a climate change perspective. This emphasis on climate change demands a broadening of perspective in innovation studies (Smith, et al., 2010) that goes beyond the promotion of cleaner technologies moving towards an interest in innovating entire systems of production and consumption.. Geels (2006) defines these heterogeneous configurations with elements such as technology, regulation, user practices, markets, cultural meaning, infrastructure, maintenance networks, science and supply networks as 'socio-technical systems'. Co-evolutionary approaches are therefore used in the literature to understand the transition from one socio-technical system to another. Foxon (2011) also suggests that co-evolutionary arguments have provided an explanation on how the co-evolution of technologies and institutions have led to the lock-in of current high-carbon technological systems (see for e.g. Unruh, 2000 and 2002; Foxon, 2007) and shows how the co-evolutionary perspective is useful for examining how more sustainable low carbon developments could overcome this lock-in.

Described as a co-evolutionary approach (Geels, 2004), transition studies rather than using evolutionary concepts of variation, retention and selection, use the sociological concepts of *alignment* between different or heterogeneous elements (Foxon, 2011); new innovation is therefore analysed as a co-construction or alignment process that gradually links heterogeneous elements together into a working configuration (Geels, 2004).

The literature on socio-technical transitions uses the interaction between three 'levels' to analyse transitions: the landscape, regime and niche. These three levels, often referred to as multi-level perspective (MLP) according to Geels (2002), are analytical and heuristic concepts that help in understanding the complex dynamic of socio-technical change. While earlier work characterised the three analytical levels as nested hierarchies, a more recent contribution by Geels (2011) argues that the different levels refers to different degrees of stability. The socio-technical level of landscape refers to aspects of the exogenous environment; this includes the conditions and the pressures for transitions but also issues such as economic growth, political cultures, macro economic trends, resource scarcities, infrastructure and cultural and normative values (Geels, 2006). Landscapes are beyond the direct influence of actors and therefore changes at this level can take place slowly[i].

The concept of regime relates to existing or incumbent technologies and practices. In details regimes consist of technological artefacts, users' practices, markets structures, regulatory framework, skills and procedures and scientific knowledge. Regimes tend to develop incrementally and cumulatively along trajectories and are path-dependent. The regime represents the core concept, the 'deep structure' (Geels, 2011) in MLP as it consists of a strong alignment between technological artefacts and institutional structures, that accounts for the stability of an existing socio-technical systems. The niche level consists of protected spaces in which radical innovations emerge through co-construction processes. The niche level provides a context for developing innovations shielded from mainstream market selection (Geels, 2006; Smith and Raven, 2012) (they may operate as small niche markets, in the form of experiments and/or through by public subsidies or private investments). Niches provide places for learning processes to take place and they are recognised as significant sites for network building relevant for sustainable innovation. The main contribution of the multi-level perspective is that transitions are produced by interaction processes that occur between all the three levels[ii]. Changes in the regime are triggered either by increasing pressures from the societal context or landscape forces or by upcoming, rivalling socio-technical configurations or niche developments. The latter initially suffer from poor alignment of their various components (technologies, institutions, user practices) to the overall system configuration. When the new socio-technical regime expands, competition with the incumbent regime increases to the point where niche rules and regime rules can no longer be separated (Raven, 2006). For instance, energy practices and technological innovations such as renewable energy technologies emerge in protected spaces or niches evolving over time, scaling up and starting to compete with the dominant regime, and, in the long term, replacing it.

It follows that understanding niche experimentation and development plays a crucial role in transition research. Borrowing from a combination of two theories of technological change- social constructivism and evolutionary economics- transition studies often utilise the Strategic Niche Management (SNM) approach as a conceptual framework to understand niche innovation dynamics (Verbong et al., 2008). SNM refers to the understanding of the processes of technological (and market) niche creation and development that enable regime-shifts. The current niches literature focuses on niches as a product of agency (Schot and Geels, 2007) and argues that nurturing processes operates across the articulation of expectations; social network processes and learning processes (Hoogma, et al., 2002, Verbong et al., 2008). The interrelation between technological innovation, the social environment and regime changes requires specific learning modes and institutional embedding (Hoogma et al., 2002). On the one hand, niche development builds upon valuable lessons being learnt, in which conceptions about technology, users demands and regulations are not just tested but questioned and explored (second order learning) (Hoogma, et al., 2002). On the other, niche success ultimately rests upon the enrolling commitments from a wide array of actors, more robust expectations, a better articulated supportive institutional requirements and the development of complementary technologies.

The burgeoning and quickly evolving literature on socio-technical transitions and the MLP developed in recent years has provided researchers with an alluring framework (Smith et. al, 2010) that has served both in terms of organising analysis and ordering policy interventions. Nevertheless, the existing literature has raised a number of cautionary criticisms and some responses (for a review see Smith et al., 2010; Geels, 2011). Two of these critical issues are worth emphasising in the context of this paper. On the one hand, scholars have highlighted some vagueness in the transition literature, as Smith et al. (2010) emphasises, and, although the MLP may help people simplify and intervene reflexively, it risks becoming counter-productively simplistic in its abstraction. On the other hand, within the literature, there is a lack of an adequate conceptualisation of space (Coenen et al, 2012) and understanding of the role of place in processes of transition (Hodson, and Marvin, 2009).

The paper is set to address these two critical issues; firstly, focusing on the processes through which innovation occurs at the level of niches, it contributes to understand the pressures and challenges in niche/regime interactions in the bioenergy sector. The case study investigates how these niche developments interact with the regime(s) highlighting internal conflicts and alignments, regime's stability and multi-regimes interactions (cf. Raven, 2007). In drawing attention to niche development in the UK bioenergy sectors and its differences and similarities in Wales, it seeks to ascertain the importance of context- specific social and political relations that may foster or hinder regime transformation.

3.0 Setting the scene

This section starts with the identification of the socio-technical regime structure. It then considers the emergence of alternatives at niche levels in the bioenergy sector, emphasising the favourable openings in regime selection environments. The paper draws from i) 20 interviews with entrepreneurs and policy makers involved in the bioenergy sector in 2008 conducted by the author; ii) from primary sources including government publications, research reports, annual reports, specialised publications and iii) secondary data sources including publications in scientific journals and dissertations.

3.1 Regime dynamics

The literature on transition has often been criticised for been too ambiguous in the definition of regime. Smith et al. (2010:441) note that socio-technical regimes are structures that are constituted from a co-evolutionary accumulation and alignment of knowledge, investments, objects, infrastructures, values and norms that span the production- consumption divide. So defined, socio-technical regime encompasses institutional and material interdependencies as institutions and rules persist through re-enactment by networks of actors engaged in material practices. These processes tend to be path dependent and incremental. Nevertheless, it is the operationalisation and specifications of regimes that is often considered ambiguous in the research community (Geels, 2011). Berkhout et al. (2004:54) claim that 'it is unclear how these conceptual levels should be applied empirically' and argue that a socio-technical regime could be defined at one or several levels. This criticism is also coupled with the lack of attention to multi-regime interactions[iii] (Raven, 2007; Konrad et al., 2008; Geels, 2011). Markard and Truffer (2008) suggest that there is no unambiguous regime definition and list the features of the regime that should be taken into account such as 1) the regime structure that stabilise certain technological trajectories and 2) the different dimensions such as technology, user practices, application domains, symbolic meaning of technology, infrastructure, industry structure, policy issues and particular stocks of knowledge. Following Markard and Truffer (2008) regimes, therefore, can be defined at different level of aggregation and from different perspectives and the choice of a particular level depends to a large extent on the research question. While the aim of this paper is to investigate the dynamics and tensions that rise within a regime and how these may open windows of opportunities for niche alternatives to compete for attention and exert influence, it is relevant to define in more details the topic of analysis in order to draw boundaries to make operational the regime concept in this empirical research.

Bioenergy technologies have developed against the backdrop of different regimes, i.e. the electricity and/or heating regimes. For the purposes of this paper, attention will focus on the UK electricity regime and the pressures for change. The starting point is a brief account of how the electricity regime in the UK has undergone major changes.

From the 1880s the electricity systems in the UK evolved from small scale, unconnected networks towards a more integrated and centralised system. The construction of a national grid started in 1926 (Lehtonen and Nye, 2009) and, just after the Second World War, the industry was nationalised under a centrally planned regime that saw the creation of a vertically integrated statutory monopoly (Bonneville and Rialhe, 2005): a single vertically integrated company, the Central Electricity Generating Board,responsible for electricity generation and transmission in England and Wales, and twelve regional boards for the distribution and supply of energy. The Board steered the direction of development, R&D activities and actively supported the goals of national energy, employment creation and regional policies (Lehtonen and Nye, 2009). In the late 50s, the predicted continued growth rates in electricity demand impacted significantly on electricity system planning and on project finance, resulting in new power stations being constructed -‘the bigger the better’ (Butler, 2001). The period from 1970 also saw a shift from coal to gas as the main source of primary energy, and towards greater use of gas and electricity in final consumption as generating technologies developed to include the combustion of oil and natural gas and the first nuclear powered electricity generation appeared.

The main mechanism of control of the nationalised industry was through government and parliament (Pond, 2006).

In the early 80s the energy system in UK started to change dramatically, removing barriers to entry in the sector and encouraging the growth of independent power producers. The Electricity Act (1989) laid the foundation for the privatisation of the industry.

The electricity system that has emerged following privatisation is remarkably different. There are about 52 new generating companies in England and Wales, with the 10 biggest generating companies owning about 80% of the total UK generating capacity (Pond, 2006). The gas and electricity sectors have also converged and multi-utility groups have been established, providing a range of gas, electricity, water and telecommunication services. The transmission system is now operated by National Grid, an independent company, which is also responsible for developing and maintaining an efficient and economic transmission system, facilitating competition. The 12 distribution networks in England and Wales are now run by seven companies (Scottish Power in North Wales and Western Power Distribution in South Wales) and over 70 companies are licensed to supply electricity to domestic and/or non domestic consumers. However, the wholesale market is still dominated by 6 powerful incumbent vertically integrated players (Centrica, E.ON, RWE npower, SSE, Scottish Power and EDF).

3.2 Exploring new trajectories

However, since the late 1980s, the combined impact of the liberalisation of electricity markets, technological innovation, financial constraints, security of supply and increased environmental concerns prompted consideration and development of alternative generating technologies and energy storage.

It could be argued that the ongoing liberalisation and increasing awareness for climate change has put pressure on the dominant UK electricity regime providing windows of opportunities for niche development and alternative technologies. The UK has had a specific delivery programme for the generation of electricity from renewables since privatisation began in 1989 and many subsequent Government strategies, Energy White papers and Energy Bills stressed out the bold vision for the UK to achieve a sustainable energy future with ambitions to obtain an 80% cut on greenhouse gas emissions by 2050 and to meet 15% of the UK demand from renewable sources by 2020.

In the 1990s, the main financial mechanism to support renewable electricity generations was the Non-Fossil Fuel Obligation (NFFO) introduced in 1990 to support, primarily, the UK's existing nuclear industry and initiate growth in renewable energy. The NFFO, which consisted of a fossil fuel levy, facilitated the award of long term fixed price power purchase contracts to particular projects in different renewable technologies, including bioenergy (Thornley, 2006). The new Renewable Obligation (RO), which replaced NFFO in supporting renewables since 2002, consists of a tradable green certificate and quota system that places a mandatory requirement on licensed UK electricity suppliers to source a specified and annually increasing proportion of electricity from eligible renewable sources. Both mechanisms have, however, been underperforming, particularly with regard to set targets. NFFO and RO have not been successful in promoting diversity, whether technological or by actors involved: they only supported technologies that were already close to the market and favoured large vertically integrated companies over new entrants or smaller players (Wood and Dow, 2011).

A series of reforms have taken place and are planned to bring changes to the RO aimed at tackling the diversity issue. Some changes include the introduction of bands of supports and suppliers' cap to limit renewable energy deployment for some technologies (for example co-firing as discussed below) in order to encourage the development of emergent technologies. These changes have, however, caused an increased uncertainty which has prevented projects from 'getting underway'[iv].

4.0 Unfolding Bioenergy developments in UK

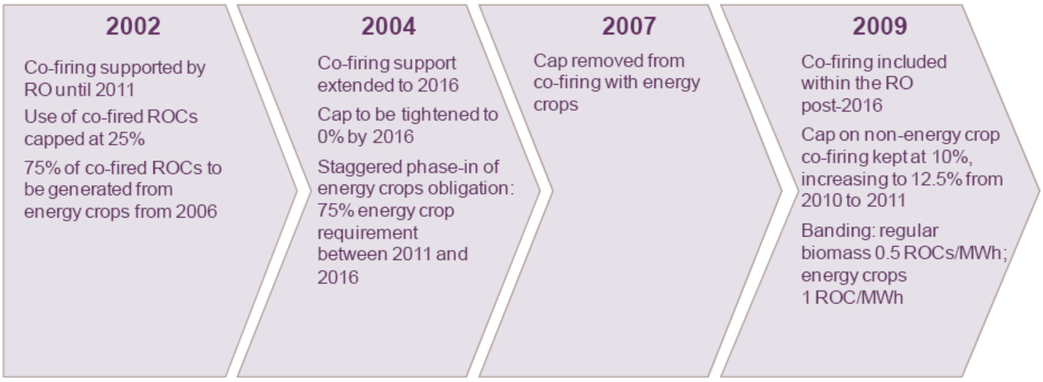
Biomass[v] is regarded as one of the most important energy sources after fossil fuels and has been used as a source of fuels for heat and power for many years. Currently however, biomass supplies only a small proportion of primary energy demand in the UK (3% of total primary energy consumption, with an expectation to grow up to 8-11% by 2020, DECC, 2012) and most other developed countries[vi].

In the UK, a burgeoning industry and limited transport infrastructure resulted in a shortage of wood fuel in the 17th century, resolved by an increase in mining activities and supply of coal, which resulted in the dominance of coal and gas in the UK energy supply (Thornely, 2006). Nevertheless, nowadays, due to its potential to service all three major demand sectors for heat, electricity and transport fuels and its likely contribution in reducing greenhouse gas emissions, increasing attention has revolved around the development of the bioenergy niche in Europe[vii].

In 2010, the UK Renewable energy Roadmap suggested that the UK had around 2.5 GWe of biomass electricity capacity, accounting for 11.9 TWhe of output, thereby making the single largest contribution to the UK's renewable electricity generation. The major contributors are co-firing (21%) and dedicated plant (17% of the total). The remaining 62% derives from waste/landfill gas. There are currently 18 existing electricity plants that are co-firing in the UK. Co-fired fuels are often imported and only one plant is using Miscanthus and Short Rotation Coppice (SRC) amongst their co-fired fuels. There are also seven operational biomass electricity plants with only three of these designed for bioenergy crops.

According to IEA Bioenergy (2009) government support has been the main driver in the development of bionergy. A complex regulatory framework has been put in place in recent years to create an interest and promote energy production from biomass and new bioenergy projects. Bioenergy developed slowly in the 1990s. From 1990 to 1999, biomass accounted for 6% of the total MWe awarded in NFFO contracts (Perry and Rosillo-Calle, 2008) and only a fraction of NFFO contracts resulted in the eventual commissioning of a biomass facility. In 2003, only seven from a total of 22 projects awarded under the NFFO were active. Following the introduction of the RO, there has been an increase in the number of bioenergy projects. However, as the RO was specifically designed to be 'technologically blind', leaving price and technology choice to the market (Wood and Dow, 2011), mainly cheaper and more mature technologies have benefited. This has led to the expansion of co-firing and, in 2004-2005, co-firing accounted for 25% of the total RO certificates issued. Since its introduction in 2002, several changes to the RO have attempted to stimulate indigenous biomass production, setting up an obligation that at least 75 % of feedstock would come from energy crops from 2006. The measure aimed at providing a clear signal to energy crop developers that there would be a secure source of demand for energy crops and at promoting the development of the supply chain. Technology bands were also established in 2009 (1 RO certificate for energy crops and 0.5 RO certificate for regular biomass per MWh). The changes that have been introduced to the RO, summarised in fig. 1 have, however, unquestionably brought uncertainty to the decision making of operators considering investing in co-firing and bio-energy projects.

Fig.1 Evolution of changes related to co-firing and energy crops within the RO



Source: Oxera, 2009

4.1 Dynamics in bioenergy niche innovation: protecting the core of the socio-technical regime?

The following section unfolds the long-term dynamics of niche-innovation trajectory associated with bioenergy. This analysis is inspired by the theoretical discussion presented earlier and focuses on the social networks, the expectations and learning processes, as well as the relationships to regime actors that characterises bioenergy niche innovation in the UK.

Expectation dynamics and social networks: The UK delivery programme for renewable electricity since the 1990 has provided moments of optimism and high expectations for the British renewable community (Mitchell and Conner, 2004). Although the NFFO was developed primarily to support nuclear power, it proved to be a powerful incentive to a small renewable industry. Nonetheless, the highly competitive system behind the NFFO awarded contracts of near-market technologies which benefitted energy power plants that were already producing renewable energy and attracted primarily ex-nationalised companies rather than new independent entrants. Smaller-scale projects and independent generators experienced difficulties in obtaining contracts (Mitchell, 1995). The early experiments supported through the NFFO were largely problematic and only a limited number of projects were developed. The reality of delivery became hampered by problems with obtaining planning permissions as projects were highly contested by environmental and civic groups. The lack of a penalty for those companies which did not take up their contract also showed a lack of interest in achieving deployment on the ground. While at first only projects based on 'established' technologies were successful in obtaining contracts, electricity from energy crops and biomass gasification were first included in the

NFFO in 1994. However, the high expectations set around the first 'flagship' project to demonstrate electricity generation from dedicated energy crops (ARBRE), driven by a partnership between an established technology provider and a large utility company, with the buy-in of farmers to grow and supply biomass, subsequently collapsed (Piterou, et al., 2008; van der Horst, 2005). The failure of ARBRE, following a series of technological and organisational problems, caused a loss in the technical knowledge and expertise but also diminished the confidence of other actors, especially the farming community, in investing in energy crops (Mitchell and Connor, 2004). Conversely, it is argued that energy crops, at that time a technological niche, were placed in the market mechanisms without any other support (Mitchell and Connor, 2004). Planting grants for instance did not start until later on and the chosen technology in the eligibility criteria (gasification) together with issues associated with the energy crops (for instance size of the plants, cutting and transportation) were unknown (Mitchell and Connor, 2004).

Contrary to electricity from dedicated energy crops, the production of electricity from co-firing biomass was linked closely to the electricity regime from the start. Co-firing started to gain importance with power generators as an opportunity to contribute to an emerging green electricity market and as a promising option for producing energy in an environmentally friendly way. The support provided through the RO, research evidence that showed that co-firing could lead to substantial emission reduction (DTI, 2006), the lack of any considerable opposition (especially when confronted with the contested nature of the development of dedicated bioenergy plants, see for instance Upreti and van der Horst, 2004) allowed co-firing to expand quickly.

The social network, developed around co-firing, consists mainly of representatives from the incumbent energy regime. Regime actors could build upon existing competencies with coal combustion and dominated this niche as co-firing biomass developed around already established large power stations, with energy companies replacing part of their coal with a range of fuels including wood (virgin and recycled), olive cake, palm kernal expeller, sewage sludge and energy crops. Often a portfolio of biomass suppliers is contracted, located either domestically or internationally. Due to the type of co-fired fuel, however, a limited number of suppliers are located in the UK. These tend to provide smaller volumes of feedstock and have a greater focus on energy corps. Even though, a number of environmental non-governmental organisations (NGOs) and the public have raised concerns and resisted co-firing experiments, as these are often seen 'as a distraction' rather than a transition away from the use of any fossil fuels, network alignment was relatively high. This has allowed co-firing to develop into one of the largest renewable niches, becoming embedded in the electricity regime as dominant solution to climate change.

Despite the early negative experiences with electricity generation from dedicated energy crops, bioenergy crops are however deemed to play an important part in achieving long-terms ambition for energy policy in cutting carbon emissions and contribute to energy supply (DTI, 2006). The dynamics in visions and expectations around indigenous biomass production re-emerged, promoted by a renewed emphasis on using sustainable feedstock in co-firing and in dedicated biomass power plants in the late 2000s. In particular, these related to:

- the set up of a Biomass Task Force in 2005 - to contribute research and help the Government and the industry to develop bio energy;
- the set up of a Biomass Energy Centre- to act as a central information hub for farmers, industry and the public;
- the biggest ever single UK public investment (£27M) by the Biotechnology and Biological Sciences Research Council (BBSRC) in 2008- to provide the science to underpin and develop the important and emerging UK sustainable bioenergy sector and
- the new UK Bioenergy strategy (DECC, 2012).

Since the failure of the ARBRE project, of the seven operational biomass electricity plants, only three are designed for bioenergy crops and only one plant is co-firing using Miscanthus and SRC amongst their co-fired fuels (Bellarby et al., 2010) representing a very limited market for the energy crops.

Although, co-firing of indigenous biomass has been seen as a major outlet for energy crops and a means to help and support the strategic development of a supply chain for energy crops, the contributions of co-firing to foster the development of the energy crops niche have been limited. Firstly, the possibility of co-firing with little modification to the plant, the little capital investment required[viii], a positive policy environment (a system of co-firing ‘cap’ and a band on energy crops was only introduced in 2009, see fig. 1), the ease for generators to currently obtain imported stocks and to still benefit from RO has meant that imported feedstock is still a preferred option to indigenous energy crops (RCEP, 2004; IIED, 2010).

Secondly, establishing a market for energy crops has been proven to be particularly challenging. Energy crops tend to be higher in costs and commercial generators have often been reluctant to reduce their margins by paying higher prices for feedstock (Thornley, 2006) and have failed to sign up to long-term supply contracts with farmers (Sherrington et al., 2008). Conversely long-term security is a key issue for the development of energy crops and, there are assumptions (Sherringthon et al., 2008) that farmers will diversify into energy crop production if the energy industry can provide long term contracts to growers (IIED, 2010).

Thirdly, the use of energy crops for electricity poses many challenges as it requires the establishment of a dedicated supply chain with efficient linkages of several stages from planting through harvesting, storing, processing and its final burning (through gasification or other final technological treatments). Given the fragmented supply chain and the uncertainties which beset investment in any part of that chain, the developments around energy crops failed to results in a stronger and more aligned network among the participating actors (such as farmers, research communities, power generators, government actors, utilities, technology providers, environmental and civic groups).

Learning experiences: The expansion of co-firing activities in the UK has been partially a result of technical learning, made it relatively easier by the fact that co-firing actors could build upon existing technical knowledge around coal combustion. However, co-firing in the UK[ix] is substantially less than the existing technical potential and shows that learning processes have progressed more slowly than expected. The lack of willingness to make modifications to current plants to increase the proportion of biomass fired coupled with practical, legislative and commercial factors) and the difficulties experienced in addressing technical problems in the industry (Thornley, 2006) explain the reasons why experiments with more radical co-firing options have been limited. The limited numbers of demonstration projects and R&D investment in more radical innovations have hampered successful innovation and commercial development [x](Foxon, 2006). The results from these experiments could have helped broadening the composition of the social networks, change actor expectations and contribute to some deeper forms of learning (e.g. second order).
Foxon’s analysis (2006) of the biomass innovation system highlighted that biomass also suffered of a lack of interaction between research and commercial actors within the system and there has been a limited knowledge flows, especially technical knowledge and understanding of environmental and economic implications of bioenergy.

Nonetheless, learning has also been limited in the case of demonstration projects.The bankruptcy deal of the ARBRE project had confidentiality agreements and the lessons around possibilities and shortcomings could not be publicly disseminated.

Both the NFFO and RO have been unsuccessful in fostering innovation and diversity (Mitchell and Connor, 2004). Institutional learning has taken place; however, the emphasis is on promoting mainly technologies nearer to the market with policies failing to promote new entrants and the creation of a mentoring base. Changes to the RO have also brought uncertainty to the decision making of actors that are considering investing in co-firing and bio-energy projects.

Some authors argue that a critical mass of both biomass R&D and demonstration projects is still needed, as these would allow learning-by-doing and improving the commercial viability of energy crops and stimulate successful innovation and commercial development (Foxon, 2005). However, the controversy associated with the development of dedicated biomass energy plants shows that public acceptance is very contested. While acceptance of small-scale schemes could be higher, the promotion and development of this type of projects remains poor or negligible.

The long-time frame that brings uncertainty associated with the application and preparation process in establishing energy crop demands focussed and specific technology support that the UK had never attempted for renewables (Mitchell, and Connor, 2004).

The potential benefits associated with energy crops includes several benefits for local and regional economies and the recognition of these socio-economic benefits has led the government to specifically provide farm-level support to make energy crops economically viable for farmers (e.g. the arable payments for growth on non-food crops, the energy crops schemes; the Woodland grant schemes and the bionergy infrastructure schemes). This has led to an increased complexity in the funding framework in support of niche development, with different schemes and government departments involved with growers, developers and utility companies (Thornely, 2006). As a consequence, the take up of these schemes has been poor and has not led to the development of biomass projects that could provide wider socio-economic benefits (Thornely, 2006). The development of energy crops has brought together a variety of actors (for instance the farmers' community, DEFRA and the Forestry Commission, agricultural research institutes, newly established cooperatives that formed energy supply companies- ESCOs and independent developers) however, learning, often, occurs in farmers' networks and in collaboration with agriculture research institutes. Hence, technical difficulties are more difficult to address due to the limited participation from energy regime's actors.

4.2 Discussion

The core idea developed within the paper is that through experiments with new technologies, niche development and new socio-technical arrangements, processes of co-evolution can be stimulated. The literature suggests that some niches have the potential to contribute to a regime-shift; whereas others are most likely to reinforce the existing regime (Hoogma, et al., 2002). In the case study analysed in this paper specific national policies have created *protective spaces*, which have enabled shielding, nurturing and empowerment (Smith and Raven, 2012). However, as argued in Mitchell and Connor (2004), the main outcome of the market mechanisms promoted encouraged large-scale developments of the cheapest technology by ex-monopoly energy companies. This stimulated the growth of renewable electricity that come from options closer to the existing regime; options that showed a 'fit' with existing rules, practices and principles (Smith and Raven, 2012; Verbong, et al., 2008). Learning and articulation processes have been relatively neglected and lessons have not been internalised (e.g. lack of societal embedding and societal acceptance, technical learning around more radical technologies and practices around energy crops, policy learning and uncertainty). The network developed around bioenergy seems to be predominately narrow and closed. An exception perhaps is found in the case of electricity generation from dedicated (indigenous) energy crops. However, renewable energy contribution from energy crops is still very small.

The example of co-firing can be read as an evasive strategy of incumbents protecting the core of the socio-technical regime. Paradoxically, the processes and protections that empowered bioenergy development in the UK have also shown that pressures for sustainable innovations to become competitive and improve alignment with existing industrial norms and/ or structures have been actually quite disempowering in terms of sustainability.

5.0 A 'devolved' energy system: Regional specificities in Wales

There is a growing consensus that sustainability transitions need to be conceptualised at different spatial scales as neglecting the importance of a spatial perspective may hinder the explanatory power of transition studies (Coenen, et al., 2012; Bulkeley, et al, 2010; Hodson, and Marvin, 2019, Cooke, 2010; Späth and Rohracher, 2010; 2012).
What follows is an account of niche development in the region of Wales to provide supporting evidence of the importance of context-specific social and political relations that may foster or hinder regimes transformation. This section aims at grounding the niche-regime interactions discussed above with reference to bioenergy niche in a specific spatial context.

Wales is a relatively small country located in the western periphery of the United Kingdom with a population of fewer than three million people. Wales produced 9% of electricity generated in the UK between 2004 and 2010 and is considered a net exporter of electricity. As argued, the electricity regime, since liberalisation, is organised through private regional utilities, national transmission and power producers and, given the level of integration with the rest of the UK and the limitations of responsibility devolved to the Welsh Government (WG)[xi] there is an inherent complexity in isolating and defining system boundaries within the Welsh energy system (Georgakaki, et al., 2013). In Wales, electricity is generated primarily through a combination of large plants but also through medium-sized CHP plants and smaller embedded generation of renewables.

As shown, policy intervention has been a key driver in the UK in order to articulate regime tensions and pressures for change. Similarly, policy intervention has been quite an important driver in Wales too. Two important features are worth emphasising that illustrate the inherent complexity that characterises the energy system and policy intervention in the devolved administration of Wales. Firstly, energy policy is a reserved function that is not devolved to the WG. Policies within the energy sector are set within the UK context and key strategy documents for Wales underpin the broad UK government strategy (WAG, 2010a; WAG, 2010b; WAG, 2009a; WAG, 2009b; WAG, 2011). Similarly, the market mechanisms in support of renewable energy highlighted above are also available to the devolved administrations (with differences in Scotland and Northern Ireland).

Secondly, all the devolved administrations in the UK- Scotland, Wales and Northern Ireland- have full responsibility for spatial planning policy and decision making in other areas such as transport and economic development. This has had a twofold effect. On the one hand, it has played a pivotal role in the development of a regional strategic approach to planning and targets for renewables at regional level, which has translated into the emergence of a regional level governance for renewable energy (for the English regions see Smith, 2007). Local planning authorities in Wales have responsibility for determining planning applications for renewable projects under 50 MW and requests to devolve planning authority over large energy projects (>50 MW) situated in the region have been repeatedly rejected (Georgakaki, et al., 2013). On the other hand, the fact that energy is not a devolved matter but planning is, has added a strain of complexity to energy policy that, particularly in Wales, has somehow hampered and slowed down the effective achievement of targets in renewable energy (Stevenson, 2009).

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5.1 Co-firing and energy crops in Wales: expectations dynamics, social networks and learning

In Wales, similarly with the rest of the UK, policy intervention has been a key driver in order to articulate regime tensions and pressures for change. The WG has actively supported biomass development and this is reflected in a number of recent bio energy related documents, 'The Renewable Energy Route Map for Wales' published in 2008, the 'Consultation on a Bioenergy Action Plan for Wales', published in 2009, the Bioenergy Action plan for Wales- Progress Report (2010) and the Energy policy Statement (2010). These documents set out specific actions on how Wales can meet the renewable electricity self-sufficiency objective, increasing renewable energy generations from different bioenergy related technologies. The Energy Policy Statement argues that the WG aims at delivering by 2020 up to 6 kWh/d/p in Wales of electricity from biomass. In order to achieve this, a combination of indigenous and imported biomass is considered necessary; nevertheless, it is argued, that the WG will promote the use of waste wood and the local supply of biomass and it will require that any larger scale plant needs to demonstrate that it is supplied by fuel from sustainable sources (WG, 2010).

As one may expect, co-firing developed quite quickly in Wales too, following the support available from the RO and the presence in the region of two large coal-fired power stations in Uskmouth (380MW), and Aberthaw (1,500MW). Only small proportions of the biomass utilised are sourced locally, raising concern among the bioenergy community for the environment case of such way of energy production and co-firing is often seen as *'a very short term fix to keep statistics on renewable growth in the UK (and Wales) high and to meet some short term policy objectives' (anonymous interviewee)*.

As in other parts of the UK, it could be argued that the availability of a local supply of energy crops has become a key issue for key stakeholders and policy makers in the bio energy niche. The presence of two dedicated biomass power plants in the region could have been beneficial in attracting local farmers to respond to the opportunities presented by energy crops. On the one hand, the development of the first commercial-scale biomass plant in Wales (based in Margam, Port Talbot), that generates 14MWe, was successful in creating a market for wood-type biomass.. The Forestry Commission is the largest single fuel supplier to the plant and discussions are also under way with local farmer cooperatives to enter into long term supply arrangements. However, as the plant was built with £9.3m of grant aid from the European Union's Objective One programme and £4.65m of aid from the former DTI under the Bioenergy Capital Grant Scheme there is not commercial benefit in burning energy crops that are more expensive- '*we cannot get the premium price to pay for energy crops that other projects can get because it would be double aid as we have had Priority 1 funding'*. .

On the other hand, the second biomass power plant in the region, a £400 million investment from *Prenergy Power* has been further delayed following a lengthy and difficult process of obtaining planning permission. The plant, when operational, will represent the UK's largest biomass (350MW wood chip-fuelled plant) power station but most of the feedstock will be imported raising concerns over its sustainability. The resistance shown from environmental groups and local residents to the construction of the plant has had the effect of limiting the embedding of the biomass niche in the societal context. Interestingly, one interviewee suggested that the WG could have played a more proactive role in supporting the emergent energy crop niche through setting conditions for the provision of biomass from local farmers:

> *'The WG could easily have said that, for example, 2.5% has to be full local energy crops; it would have been a really easy condition for the Government to put on, but did they do anything? No' (Anonymous Interviewee).*

Experiments and niche developments are often conducted through research projects run in collaboration with university departments, firms and government. A key role is played by the Institute of Biological, Environmental and Rural Science (IBERS) (formerly the institute of Grassland & Environmental Research-IGER). The institute, that has been for seventy years the UK’s main specialist grassland research institute, has since 2004 opened up a bioenergy division to further exploit biofules research and commercialisation. This utilises expertise in understanding and improving the calorific content of feedstock plants by experimenting with ryegrass, short rotation willow, M*iscanthus* and SugarGrass[xii].

IBERS’s research also encompasses the scientific community and supports learning-by-doing processes with the farming community in the region. One example of this is provided by the ‘Willow for Wales’ project that run from 2004 to 2008 and aimed at demonstrating the potential of short rotation coppice willow as a biomass crop in Wales. The project involved local farmers as partners in establishing crop test sites. These test sites were used as demonstration areas to encourage interest and develop ‘grower groups’. After the 1st year 3 farms were planted and a further 4 farms followed with a total of 40 hectares. Contracts were developed with some power company suppliers but also opportunities were identified in co-firing in Aberthaw Power Station (Valentine, et al., 2009). A group of pioneering farmers, involved in the Willow project, started experimenting also with Mischantus. The cooperative grew from the initial 3 farmers to 11 energy crop growers, providing 1000t of energy crops from local farms. The farmers’ cooperative set up an ESCO to supply heat and power to 350 holiday chalets and a large 'waterworld' complex in Pembrokeshire[xiii]. These niche developments have provided spaces:

- for learning processes to occur and for sharing experiences on establishment, management, harvesting, processing and marketing of the crops and collective purchasing of the required machinery and
- to build up the networks that support innovations, such as supply chains and user–producer relationships.

In 2007, there were 40ha planted with SRC and 72ha of miscanthus, while the Bioenergy Action Plan (2009) argued that, approximately, 600,000 ha of land could grow dedicated energy crops and the amount of energy crops planted will depend on Welsh farmers’ confidence of long term market opportunities. This confidence is however undermined by the lack of availability of establishment grants in Wales to cover the high upfront costs and uncertainties over resulting net income (cfr. Sherrington, et al., 2008). While in England, the Energy Cops Scheme under the England Rural Development Plan Programme (2000-2006) and the Rural Development Programme for England (2007-2013) offers establishment grants to farmers, in Wales there is currently no financial support available, making Wales an unfavourable area for cultivation [xiv] (Tattam, 2009).

This echoed the concerns raised by many niche actors that the WG, while setting up ambitious targets for Renewable energy delivery, has failed to provide clear signals to the market

5.2 Discussing the issue of space in transition

Often, the national scale is described as the preferred geographical delineation for understanding sustainability transitions as highlighted by Raven et al., (2012); this contrasts with innovation and economic geography studies, in which, the notion of scale and space are used recurrently. According to Archibugi and Michie (1997) in order 'to understand technological change, it is crucial to identify the economic, social, political and geographical context in which innovation is generated and disseminated. This space may be local, national or global'. Indeed Coenen et al (2012) have recently argued that "transition research would do well to take a closer look at the global networks and local clusters of transition pathways in conceptual, methodological and empirical terms." In responding to this call, some authors have focussed more specifically on the conceptualisation of cities in the MLP (e.g. Hodson and Marvin, 2010, 2012) and some others (e.g. Lawhon and Murphy, 2012) on the role of power relations and social processes in influencing geographically situated regime and niche dynamics. Contributions from Truffer (2008) and Truffer and Coenen (2012) and Coenen et al (2012), have recently argued that commonalities and complementarities between territorial system of innovation concepts and the multi-level approach can offer a spatially more explicit framework to understand transition. These authors emphasise the importance of local/regional diversity and local/ regional institutional contexts in explaining why niches emerge in one place and not in others. Following from these arguments, Raven et al. (2012) highlight that a more spatially sensitive MLP leads to new questions, arguing that empirical research needs to pay more attention on regional differentiation between national boundaries in combination with the role of local/regional institutions and transnational networks. In their example of biomass gasification in India, the authors start highlighting the importance of spatial heterogeneity in the dynamics of niche development, stressing that within particular localities, networks and other conditions- such as natural, economic, institutional and other *relational assets*- influence the emergence and reproduction of niches and their interaction with regime and landscape levels.

This paper, in particular, supports these arguments providing critical insights into this emerging literature. The case study presented here emphasises the importance of institutional embeddedness of socio-technical development processes within specific territorial space. The empirical research highlighted how different institutional structures and institutions enable and/ or constraints innovation in a spatially differentiated way. The case of bioenergy in Wales shows that the local institutional environment has shaped and mediated the bioenergy niche differently from the rest of the UK. While on the one hand, the lack of availability of establishment grants in Wales has had the effect of undermining confidence and expectations around energy crops development, on the other hand, established localised networks of research establishments and farmers' communities in the region have encouraged experimental learning, collaboration practices and knowledge sharing. This paper focuses primarily on the regional scale in unpacking the spatially bounded ways in which institutions work. This is not to say that regional actors and institutions in the bioenergy niche are not crossed and connected with national and transnational networks and flows of resources. Both Raven et al. (2012) and Coenen et al. (2012) argue that global-local networks and institutions that cut across and link different geographical scales produce complex flows of knowledge and resources. These are significant to the emergence and reproduction of niches and their interaction with regimes and need to be taken into account in sustainability transition research. Further empirical work will need to provide a more encompassing account of the issue of space focussing on addressing the question of capacity to draw on resources in networks across multiple scales. In order to unfold multi-scalar interdependencies, there is a need to take a closer look at the range of actors active across multiple scales, stressing the feedbacks from the regional to the national level or even beyond, highlighting the issue of power and uneven power relations across scale (Lawhon and Murphy, 2012). In the context of Wales, for instance, a starting point would be to investigate the interaction and the feedbacks between the UK energy regulatory system that provide framework conditions for the activities of the bioenergy and energy sector, Wales and the international level. Moreover, acknowledging the limitations of responsibility devolved to the WG and the complexity in isolating and defining system boundaries within the Welsh energy system, there is further scope to explore which decisions regional actors are able to influence and to what extent regional actors are able to control their own destiny.

Concluding remarks

This paper has analysed the role of niche innovation and regime interaction in the field of bioenergy in the UK. The aim of the paper was twofold. Firstly, it discussed examples of alternative niche developments and analysed how these have interacted with the current electricity regime in the UK, highlighting internal conflicts, alignments and regime stability. In the past, the cognitive routines, the shared beliefs, the capabilities and competences, user practices, institutional arrangements, regulations, actors and technologies that have characterised the electricity regime in the UK, have developed stability, resistance to change and, as discussed, promoted specific technological trajectories. More recently, the effect of a liberalised market, technological innovation, security of supply and environmental concerns have brought increased instability in the electricity regime allowing opportunities for niche development and alternative technologies to emerge. The paper has shown that the growth of renewable electricity, in the UK, has come from options closer to the existing regime, which developed around existing designs and markets, without transforming the regime.

Secondly, the paper aimed at providing evidence from niche development in the region of Wales as a way of highlighting that grounding niche development and niche-regime interactions in a specific spatial context offers a better explanation of geographically uneven transitions pathways. The empirical evidence shows that specific local contexts are not just a simple convenient site within which niches are developed. Introducing a geographical element in studying niche development and niche-regime interaction offers an opportunity to capture how a combination of institutional, entrepreneurial and innovative processes and heterogeneous networks co-evolve and combine into more or less stable configurations that can interact with existing regimes in different ways.

The dynamics of innovation and transformation of the energy sector towards sustainability can be better understood by considering the importance of spatial heterogeneity in terms of local networks, local institutions, natural assets, economic conditions and other *relational assets* that influence the emergence and reproduction of niches and their interactions with regime and landscape levels. Research will need to provide further comparative evidence of regional differentiation between national boundaries. The development of a conceptual framework for studying niche innovations and networks at different scales becomes, therefore, an essential prerequisite in this direction.

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References

Archibugi and Michie (1997), Technological globalization and national systems of innovation: an introduction, in Archibugi, D. and Michie, J., eds., Technology, globalisation and economic performance, Cambridge: Cambridge University Press, 1–23

Aylott M.J., Casella E. , Farrall K. & Taylor G. (2010). Estimating the supply of biomass from short-rotation coppice in England, given social, economic and environmental constraints to land availability. Biofuels 1, 719-727.

Bellarby, J., Wattenbach, M., Tuck, G., Glendining, M., J., Smith, P., (2010), The Potential Distribution of Bionergy Crops in the UK under present and future climate, in biomass And Bioenergy, vol. 34 (12), pp.1935-1945

Berkhout, F., Smith, A.,Stirling, A. (2004), 'Socio-technical regimes and transition contexts', in Elzen, B., Geels, F.W. and Green, K. (eds), System Innovation and the Transition to Sustainability. Theory, Evidence and Policy, Edward Elgar, Cheltenham

Bonneville, E., Rialhe, A., (2005), Impact of Liberalisation of the Electricity Market on Energy Efficiency, Quality of Supply and Environmental Performance, discussion paper available at http://www.leonardo-energy.org/repository/Library/Papers/Impacts%20of%20liberalization%20on%20EE.pdf

Braczyk, H.J., Cooke, P., Heidenreich, M. (eds) (1998), Regional Innovation Systems: The Role of Governance in a Globalized World, UCL Press, London

Breschi, S., Malerba, F., (1997), Sectoral Innovation Systems: Technological Regimes, Schumpeterian Dynamics and Spatial Boundaries, in Edquist, C., (ed.) System of Innovation, Pinter Publishers, London

Bulkeley, H., Castan Broto, V., Hodson, M., and Marvin, S., (eds) (2010), Cities and Low Carbon Transitions, London: Routledge

Butler, S., (2001), UK Electricity Networks, The nature of UK electricity transmission and distribution networks in an intermittent renewable and embedded electricity generation future, Imperial College of Science, Technology and Medicine Centre for Environmental Technology, London

Coenen, L., Benneworth, P., Truffer, B., (2012) Towards a Spatial Perspective on Sustainability Transitions, Research Policy, 41(6), pp. 968-979

Cooke, P. (2010): Regional innovation systems: development opportunities from the 'green turn', Technology Analysis and Strategic Management, Vol. 22/7, pp 831-844

DECC, (2011), Renewable Electricity in Scotland, Wales, Northern Ireland and the Regions of England in 2010, Energy Trends, Special Feature- sub-National Renewable Electricity, Department of Energy and Climate Change, London

DECC, (2012), UK Bioenergy Strategy, Department for Transport, London available at http://www.decc.gov.uk/en/content/cms/meeting_energy/bioenergy/strategy/strategy.aspx

DTI, (2006), The Energy Challenge, Energy Review Report 2006, Department of Trade and Industry, London

Eduquist, C., (ed.) (1997) System of Innovation, London

Elzen, B., Geels, F.W., Green, K., (eds.) (2004), System Innovation And The Transition To Sustainability, Theory, Evidence and Policy, London, Edward Elgar

Euibia, (2005), Bioenergy Deployment potential and resources, available at http://www.eubia.org/116.0.html

Foxon T; Gross R; Chase A; Howes J; Arnall A; Anderson D (2005) UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures, Energy Policy, 33, pp.2123-2137.

Foxon, T. J. (2011), "A coevolutionary framework for analyzing a transition to a sustainable low carbon economy", Ecological Economics (under review).

Foxon, T., (2006), The Rationale for Policy Interventions from an Innovation Systems Perspective, in Murphy, J, (ed.), Governing Technology for Sustainability, Earthscan, Sterling

Freeman, C. (1987), Technology Policy and Economic Performance: Lessons from Japan, Frances Pinter, London

Geels, F. (2004) From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory, Research Policy, 33, 897-920

Geels, F. (2006) Co-evolutionary and multi-level dynamics in transitions: the transformation of aviation systems and the shift from propeller to turbojet (1930-1970), Technovation, 26, 999-1016

Geels, F., (2002), Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study, in Research Policy, vol.31, pp.1257-1274

Geels, F., (2011) The multi-level perspective on sustainability transitions: Responses to seven criticisms, Environmental Innovation and Societal Transitions, vol.1, pp 24-40

Georgakaki, A., De Laurentis, C., E. and Eames, M., (2013) The importance of regional scenarios for low carbon transitions: the case of Wales, in press, *International Journal of Critical Infrastructures*

Hodson, M. and Marvin, S. (2009), 'Cities Mediating Technological Transitions: Understanding Visions, Intermediation and Consequences'. *Technology Analysis & Strategic Management*. Vol.21/4. pp. 515–534.

Hodson, M., Marvin, S., (2010), 'Can cities shape socio-technical transitions and how would we know if they were?', *Research Policy*, 39 (4) , pp. 477-485

Hodson, M., Marvin, S. (2012), Mediating Low-Carbon Urban Transitions? Forms of Organization, Knowledge and Action, *European Planning Studies*, Vol. 20, pp. 421-439.

Hoogma, R., Kemp, R., Schot, J., Truffer, B, (2002), *Experimenting for Sustainable Transport. The approach of Strategic Niche Management*. Spon Press, London. pp. 212.

Lawhon, M., Murphy, J.T., (2012), Socio-technical regimes and sustainability transitions: Insights from political ecology. *Progress in Human Geography*, vol. 36, 3: pp. 354-378.

Raven, R. Schot, J., Berkhout, F. , (2012). Space and scale in socio-technical transitions. *Environmental Innovation and Societal Transitions*, Volume 4, September 2012, Pages 63-78.

Truffer, B., Coenen, L., (2012) Environmental innovation and sustainability transitions in regional studies, *Regional Studies*. 46 (2), 1-22.

IEA Bioenergy, (2009), 'Bioenergy - a sustainable and reliable energy source. A review of status and prospects', International Energy Agency, report prepared for IEA Bioenergy by the Energy Research Centre of the Netherlands (ECN), E4tech, Chalmers University of Technology, and the Copernicus Institute of the University of Utrecht

IIED, (2010), the UK's biomass Energy Development Path, International Institute for Environment and Development, available at www.pubs.iied.org/pdfs/G02921.pdf

Kemp, R., (1997), Environmental Policy and Technical Change: A Comparison of the Technological Impact of Policy Instruments, Cheltenham, Edward Elgar

Kemp, R., Loorback, D., and Rotmans, J., (2007), 'Transition management as a model for managing proceses of co-evolution towards sustainable development', International Journal of Sustainable Development and World Ecology, 14, 2007, 78-91

Kemp, R., Rotmans, J., (2005), The Management of the Co-Evolution of Technical, Environmental and Social Systems, in Weber, M., Hemmelskamp, J., (eds.), Towards Environmental Innovation Systems, Berlin, Springer

Konrad K,Truffer B, Voss J, 2008, "Multi-regime dynamics in the analysis of sectoral transformations potentials: evidence from German utility sectors, in Journal of Cleaner Productio, vol. 16, pp. 1190-1202

Lehtonen, M., Nye, S. (2009) History of electricity network control and distributed generation in the UK and western Denmark. Energy Policy, 37 (6). pp. 2338-2345.

Lundvall, B.A, (1992), National Systems of Innovation, London, Printer

Malerba, F., (2002) Sectoral Systems of Innovation and Production, Research Policy, 31/2, pp.247-264

Markard, J., Truffer, B. 2008. Technological innovation systems and the multi-level perspective: towards an integrated framework. Research Policy, 37, 596–615.

Mitchell, C. and Connor, P., 2004. Renewable energy policy in the UK 1990-2003. Energy Policy 32: 1935-1947

Mitchell, C., (1995), The Renewables NFFO: A Review, in Energy Policy, vol.23/12, pp. 1077-1091

Nelson, R., (1993), National Innovation Systems: a Comparative Analysis, Oxford, OUP

NNFCC, (2010) UK Operational Biomass Processing Facilities, NNFCC Publication, York

Norgaard, R.B., (1984) Coevolutionary Agricultural Development, Economic Development and Cultural Change 32 (3), pp. 525–546

Oxera, 2009, What is the impact of changes to the co-firing cap, Prepared for the Department of Energy and Climate Change, Oxera consulting, Ltd, London available at www.decc.gov.uk/.../1_20090921145439_e_@@_implicationsofchangestothecofiringcap2.pdf

Perry, M., Rosillo-Calle, F., (2008), Recent trends and future opportunities in UK bioenergy: Maximising biomass penetration in a centralised energy system, in Biomass and Bioenergy, vol. 32 (8), pp.688-701

Piterou, A., Shackley, S., Upham, P., (2008), Project ARBRE: Lessons for bio-energy Developers and Policy Makers, in Energy Policy vol. 36/6, pp.2044-2050

Pond, R., (2006), Liberalisation, Privatisations and regulation in the UK Electricity Sector, Working Lives Research Institute, London Metropolitan University, London

Raven, R., (2006), Towards Alternative Trajectories? Reconfigurations in the Dutch Electricity Regime, Research Policy, vol.35, pp.581-595

Raven, R., (2007), Strategic Niche Management for Biomass, A comparative study on the experimental introduction of bioenergy technologies in the Netherlands and Denmark, Dissertation Thesis, Eindhoven University Press

RCEP, (2004), Biomass as renewable energy resource, report by the Royal Commission on Environmental Pollution, Royal Commission on Environmental Pollution, London

Sherrington, C., Bartley, J. & Moran, D. (2008) 'Farm-level constraints on the domestic supply of perennial energy crops in the UK' Energy Policy, 36 (7):, pp. 2504-2512

Smith, A. (2007) Emerging in between: the multi-level governance of renewable energy in the English regions, Energy Policy, 35, 6266-6280

Smith, A. and Raven, R. (2012), What is protective space? Reconsidering niches in transitions to sustainability. Research Policy, 41 (6). pp. 1025-1036.

Smith, A., Voß, J.P. and Grin, J., (2010), Innovation studies and sustainability transitions: The allure of the multilevel perspective and its challenges. Research Policy, vol. 39, 435-448.

Späth, P. and Rohracher, H. (2012). "Local demonstrations for global transitions - Dynamics across Governance Levels Fostering Socio-Technical Regime Change Towards Sustainability." European Planning Studies 20(3).

Späth, P., Rohracher, H., (2010), 'Energy regions': The transformative power of regional discourses on socio-technical futures, Research Policy, vol. 39, pp. 449–458

Stern, N. (2006) Stern Review on the Economics of Climate Change, London, Cabinet Office & HM Treasury

Stevenson R, 2009, "Discourse, power, and energy conflicts: understanding Welsh renewable energy planning policy" Environment and Planning C: Government and Policy 27(3) 512 – 526

Tattam, C., (2009), The Biorefining Opportunities in Wales: From Plants to Products, Chemistry Innovation Knowledge Transfer Network

Thornley E P. 2006. "Increasing biomass based power generation in the UK". Energy Policy. Vol. 34. Issue 15. pp 2087-2099

Unruh, G C (2000), 'Understanding carbon lock in', Energy Policy, vol. 28, 817-830

Unruh, G. C. (2002), 'Escaping carbon lock-in', Energy Policy, Vol. 30, 317-325.

Upreti B.R. and van der Horst D. (2004). National Renewable energy policy and local opposition in the UK: the failed development of a biomass electricity plant. Biomass and Bioenergy 26 (1), 60-69.

Valentine J, Duller C J, Hinton-Jones M, Tubby I, Fry D A, Slater F M, Sherborne A, Jones E, Heaton R, Farrell J, Horne B, Green C G, Powell H, (2009); The development of sustainable heat and power fuelled by biomass from short rotation coppice in Wales. Aberystwyth University Report of the Helyg i Gymru / Willow for Wales 2004-2008 project. 92pp. http://www.willow4wales.co.uk/

Van den Bergh, J., Faber, A., Idenburg, A., Oosterhuis, F, (2007), Evolutionary Economics and Environmental Policy, Survival of the Greenest, Cheltenham, Edward Elgar

Van der Horst D. (2005). UK biomass energy since 1990; the mismatch between project types and policy objectives. Energy Policy 33(5), 705-716

Verbong, G., Geels, F.W., Raven, R., (2008), Multi-niche Analysis of Dynamics and Policies in Dutch Renewable Energy Innovation Journeys (1970-2006): Hype-cycles, Closed Networks and Technology focused learning, in *Technology Analysis and Strategic Management*, vol. 20/5, pp.555-573

WAG (2006), Science Policy for Wales, Welsh Assembly Government

WAG (2007), Energy Developments- Government policies perspective, Welsh Assembly Government, unpublished

WAG (2008) 'Renewable Energy Route Map for Wales' Welsh Assembly Government

WAG (2009), Consultation on a Bioenergy Action plan for Wales, Welsh Assembly Government

WAG (2009a), One Wales: One Planet, The sustainable Development Scheme of the Welsh Assembly Government, May 2009 Welsh Assembly Government

WAG (2009b), Capturing the Potential: A Green Job Strategy for Wales, July 2009 Welsh Assembly Government

WAG (2010b), Climate Change Strategy for Wales, October 2010 Welsh Assembly Government

WAG (2011), National Energy Efficiency and Savings, March 2011 Welsh Assembly Government

WAG, (2010), Technical Annex 1, Wales' electricity Generating Capacity over 10 MW, annex to A Low Carbon Revolution –The Welsh Assembly Government Energy Policy Statement March 2010 Welsh Assembly Government

WAG, (2010a), A Low Carbon Revolution –The Welsh Assembly Government Energy Policy Statement March 2010 Welsh Assembly Government

Wood G., Dow, S., (2011), What Lessons have been learned in Reforming the Renewables Obligation? An Analysis of Internal and External Failures in UK Renewable Energy Policy, in Energy Policy, vol.39 (5), pp. 2228-2244

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[i] Geels (2006) also argues that in some circumstances these changes can occur rapidly for example in the case of rapid increase in oil price or war.

[ii] The literature distinguishes between purposive or emergent transitions (see for instance Elzen et al., 2004).

[iii] The transition to a low carbon energy system supported by bioenergy innovations, for instance, requires interactions between two (or more) regimes (for example co-generation of heat and power links heat, electricity and waste regimes, biofuels link agriculture and transport regimes).

[iv] The introduction of the Feed-in Tariffs scheme (FITS), in 2010, on the other hand, has aimed at promoting small-scale (less than 5MW) low-carbon electricity generation, particularly by organisations, businesses, communities and individuals that were not traditionally engaged in the electricity market. However, as this research was undertaken before the introduction of the FITs, these will not be considered in the paper. Furthermore, a more recent measure, the Renewable Heat Incentive (RHI), will, when fully implemented, support generation of heat from renewable sources at all scales and will have a greater impact on bioenergy.

[v] Bioenergy is energy (electricity, heat) produced from organic sources like wood, energy crops or manure. These sources are called biomass. The words bioenergy and biomass are used interchangeably in the paper.

[vi] According to EUBIA (2005) biomass already provides approximately 11-14% of the world's primary energy consumption (with data varying according to sources). This rises to approximately 35% in developing countries.

[vii] For a study of niche development and regime interaction in biomass in Denmark and the Netherlands see for instance Raven, 2005.

[viii] Co-milling is utilised in most plants and only a few have invested in direct injection mechanisms

[ix] The co-firing ratio used is below 5% on a heat-input basis (Oxera, 2009).

[x] A large co-firing demonstration project has been proposed by Innogy. The project would be designed and built by British manufacturers and would provide a solid basis for replication at other large boilers in the UK and abroad.

[xi] Devolution in Wales took place after the 1997Welsh Devolution referendum with the first National Assembly for Wales being elected in 1999. The WG controls over 20 areas of devolved responsibility for which direct law-making power were also transferred after a further referendum in March 2011.

[xii] The prospect of growing grass for livestock with the flexibility of channelling surplus production into energy processing is a key area in which IBERS is focusing on.

[xiii] Nevertheless, it is the local heat market that presents the most cost-effective use of biomass and the ideal opportunity for farmers to get involved in energy crops. Measures to support and create a local demand for renewable heat represent the most profitable future outlet for energy crops (Sherrington, et al., 2008)

[xiv] In England there are subsidies of £1000/ha for SRC and £920/ha for miscanthus. In Wales, previously the Forestry Commission provided grant for SRC willow, but at £600/ha were much lower than those available elsewhere and when the grant closed in 2006 no more establishment grants were available to Welsh farmers.