Citation for published version:
Foxon, TJ & Pearson, PJG 2013 'The UK low carbon energy transition: Prospects and challenges' Realising Transition Pathways.

Publication date:
2013

Document Version
Publisher's PDF, also known as Version of record

Link to publication

University of Bath

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Download date: 07. Dec. 2019

The UK low carbon energy transition: prospects and challenges

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WP 2013/3

5 September 2013

Realising Transition Pathways

Whole systems analysis for a UK more electric low carbon energy future

Realising Transition Pathways

'Realising Transition Pathways' (RTP) is a UK Consortium of engineers, social scientists and policy analysts. The consortium is managed by Professor Geoffrey Hammond of the University of Bath and Professor Peter Pearson of Cardiff University (Co-Leaders). It includes research teams from nine British university institutions: the Universities of Bath, Cardiff, East Anglia, Leeds, Loughborough, Strathclyde, and Surrey, as well as Imperial College London and University College London. The RTP Project [www.realisingtransitionpathways.org.uk] commenced in May 2012 and is sponsored by the 'Engineering and Physical Sciences Research Council' (EPSRC: Grant EP/K005316/1). It is a renewal and development of the earlier 'Transition Pathways' (TP) project, which was initially established in 2008 with the joint sponsorship of E.ON UK (the electricity generator) and the EPSRC. This project addressed the challenge of the so-called energy 'trilemma': the simultaneous delivery of low carbon, secure, and affordable energy services for the electricity sector. It developed and applied a variety of tools and approaches to analyse the technical feasibility, environmental impacts, economic consequences, and social acceptability of three 'transition pathways' towards a UK low carbon electricity system. These pathways explore the roles of market, government and civil society actors in the governance of a low carbon energy transition.

The research within the RTP Project seeks to explore further the constraints and opportunities in realising a low carbon UK energy sector, including those stemming from European developments. This project includes studies on the horizon scanning of innovative energy technologies over the period to 2050, the feasibility of demand responses, uncertainties in economic analysis, the estimation of investment costs of the different pathways, and the implications of markets for investment decisions about energy technologies. Further work is being undertaken on conceptualising, mapping and analysing 'actor dynamics' in the contemporary UK electricity sector, historical transitions and case studies, integrated energy networks modelling and evaluation, and 'whole systems' energy and environmental appraisal of low carbon technologies and pathways. The consortium is also developing their initial work on branching points on pathways, in order to identify and explore other potential branching points on the core transition pathways.

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The UK low carbon energy transition: prospects and challenges[1]

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Abstract

Under the 2008 Climate Change Act, the UK has committed to reducing its greenhouse gas emissions by 80% by 2050. This implies a radical transformation of systems for meeting energy service demands - in particular, a transition to a low carbon system of electricity generation and supply. Despite efforts by the UK Department for Energy and Climate Change (DECC) to examine pathways to 2050, most of the focus in UK energy policy has been on the shorter term reforms needed to incentivise high levels of investment in low carbon generation technologies, embedded in the Energy Bill currently going through the UK Parliament. This chapter draws on work by the authors and colleagues on UK low carbon transition pathways for the electricity sector to 2050 (Hammond and Pearson, 2013; Foxon, 2013) to examine the drivers and consequences of alternative low carbon pathways, and reflect on the implications for current UK energy policy measures. This suggests that governance models with different roles for government, business and civil society could lead to quite different low carbon futures, so that which model dominates could have a significant influence on the direction of change and the risks and challenges to be addressed. Whilst a hybrid government-market form of governance appears to be emerging, there still seems to be a relatively small role for civil society in influencing the pathway to a low carbon future.

[1] A revised version of this working paper will appear in Bumpus, AG & Okereke, C (eds.), *Carbon Governance, Climate Change and Business Transformation*, Routledge, 2014.

1. Introduction

Mitigating the threat of climate change by reducing carbon emissions is a societal challenge that requires response by governments, businesses and civil society. It will also be an opportunity for investment and innovation in creating new industries and new jobs and for incumbent firms to develop or accommodate new technologies and business models.. However, given the fundamental role of energy provision to meeting the service needs of industry and consumers in a secure and affordable way, achieving a transition to a low carbon economy requires attention to be paid to pathways of transition, as well as the roles of the different actors. Broadly, governments need to put in place credible long-term frameworks that provide incentives for investment, businesses need to undertake that sometimes risky investment, and civil society needs to continue to support the case for change and articulate the benefits to individuals and society. However, these different actors tend to have different priorities that may lead to different visions of a low carbon future and the appropriate governance mechanisms for achieving these. This chapter draws on work by the authors and colleagues on UK low carbon transition pathways for the electricity sector to 2050 (Hammond and Pearson, 2013; Foxon, 2013) to examine the drivers and consequences of alternative low carbon pathways, and reflect on the implications for current UK energy policy measures and business responses.

2. Development of UK climate and energy policy since 2008

In October 2008, Prime Minister Gordon Brown set up the Department of Energy and Climate Change (DECC), to take over some of the functions of the Departments for Business, Enterprise and Regulatory Reform (energy) and for Environment, Food and Rural Affairs (climate change). And in November 2008, the UK Parliament passed the Climate Change Act (2008), with agreement of all the major political parties. This was in response to the scientific evidence on the current and likely future impacts of climate change (IPCC, 2005; 2011), the economic analysis provided by the Stern Review (2007) and lobbying by environmental NGOs. This Act places a duty on current and successive UK governments to act to ensure that the UK reduces its greenhouse gas emissions by 80% by 2050, relative to a 1990 baseline. The Act also created an institutional structure by which the government could be held to account for progress towards this target. An independent Committee on Climate Change, consisting of experts on science, technologies and economics, was set up to provide ongoing advice to government and specifically to recommend the level of five-yearly carbon budgets, at least 15 years into the future. If accepted by the government, these carbon budgets set a cap on total UK territorial emissions for that period. The caps which have been accepted by the government for the first four carbon budget periods, 2008-12, 2013-17, 2018-22 and 2023-27, correspond to a 34% reduction in UK greenhouse gas emissions by 2020, and a 50% reduction in emissions by 2025, relative to 1990 levels. The Low Carbon Transition Plan (HM Government, 2009) and the Carbon Plan (HM Government, 2011) were subsequently put in place by Labour and Conservative/Liberal Democrat Coalition governments, respectively, to provide a set of measures and incentives to achieve these targets.

As energy for providing electricity, heat and transport services is a major source of carbon dioxide (CO_2) and other greenhouse gas emissions, much of the focus of these measures and incentives was on energy supply and demand. Indeed, meeting the 2050 reduction goal implies a radical transformation of systems for meeting energy service demands and indeed of these demands themselves. Scenarios produced by the Committee on Climate Change (CCC, 2008) and others focused on a transition to a low carbon system of electricity generation and supply. This was because there are a range of technologies for low carbon electricity generation, including coal and gas with carbon sequestration, nuclear power and a range of renewables, such as wind, wave, tidal, solar, geothermal and biomass, and the potential for expanding the use of electricity to heating and transport, through the use of air- or ground-source heat pumps and electric vehicles. This still leaves open a wide range of potential pathways with different mixes of low carbon generation and different amounts of effort to improve conversion efficiencies and manage end-use demand.

Given the fundamental role of energy in providing the services that people and businesses need, and in contributing to economic prosperity, the appropriate pathway to follow will be politically contentious. Even though the need to achieve significant reductions in carbon emissions has been accepted by UK political leaders, it is challenging, in tough economic times, to maintain an appropriate balance between incentivising carbon reductions and maintaining secure and affordable energy supply – the so-called energy 'trilemma' (Boston, 2013). In addition, the governance of UK energy systems has already undergone significant changes in the last 25 years (Pearson and Watson, 2011). The UK moved from state-owned provision of electricity and gas after the Second World War, through a process of privatisation and market liberalisation in the late 1980s and 1990s, to achieve competitive markets in wholesale electricity generation and in supply of power and gas to domestic and business consumers. Through a series of mergers and acquisitions, the UK electricity market is now dominated by 6 international, vertically-integrated energy firms.

This process of liberalisation had the unanticipated consequence of reducing the UK's carbon emissions since 1990, as a result of a rapid expansion of gas-fired electricity generation, as new efficient gas-fired generation was built to compete with and replace old coal-fired generation (Pearson, 2000). This resulted by 2011 in gas providing the largest share (41%) of electricity supply, with 29% from coal, 18% from nuclear and 9% from renewables. Though this helped to reduce household energy bills until around 2005, since then rises in wholesale gas prices have resulted in increasing household energy bills, leading to much greater political salience of the affordability of energy. In addition, around a quarter (20 GW) of existing electricity generation plant, mostly coal and nuclear, is due to close by 2020. This has raised concerns over security of supply, meaning that up to £110 billion of investment in low-carbon generation, transmission and distribution will be needed by 2020 to keep the lights on (Ofgem, 2010). As a result, a further reform of UK electricity markets is being undertaken, embodied in the Energy Bill currently going through Parliament and expected to become law in 2013.

The Energy Bill focuses on new incentives for low-carbon and secure electricity generation, needed to achieve the UK's carbon emissions caps to 2020 and 2025 under the carbon budgets. They have been designed particularly to promote investment by private firms in new nuclear capacity and onshore and offshore wind generation. The latter is also driven by the need to expand renewable generation to around 30% by 2020, in order to meet the UK's commitment under the European Union Renewables Directive. Previously, it had been envisaged that the carbon price under the EU Emissions Trading Scheme (ETS) would provide the main incentive for switching to low carbon generation. However, due to the reduction in industrial and commercial energy demand as a result of the economic downturn, as well as the political and institutional challenges of a multi-country, multi-sectoral policy instrument, firms have found it easier than expected to achieve their caps under this scheme, reducing the demand for additional permits and so depressing the carbon price under the EU ETS to around £5/tonne CO_2 by early 2013. So, the UK government legislated under the Finance Act 2011 for a unilateral UK carbon price floor applying to the UK electricity generation sector only, rising from £15.70/tCO_2 in 2013 to £30/tCO_2 in 2020, to £70/tCO_2 in 2030 (real 2009 prices) (DECC, 2012). This effectively imposes a carbon tax to set the carbon price for this sector, on top of the wider carbon emissions trading scheme.

The other main measures to be introduced in the Energy Bill are Contracts for Difference feed-in tariffs, a Capacity Market and an Emissions Performance Standard. The Contracts for Difference (CfD) feed-in tariffs provide a guaranteed price, known as the 'strike price', for new low-carbon generation. As the name suggests, the CfD establishes a contract between a generator and a counterparty owned by the Government, which provides for a top-up to the strike price if the wholesale electricity market price is less than this price, with the generator paying back for any times that the market price is higher than the strike price (see Figure 1). The top-up is paid for by a levy on all consumers' energy bills. At the time of writing, the first CfD is currently being negotiated between the UK government and the energy firm EDF for 2 new nuclear power stations at Hinkley Point in South-West England. Unconfirmed press reports suggest that a strike price of around £100/MWh is being negotiated for this first-of-a-kind plant.

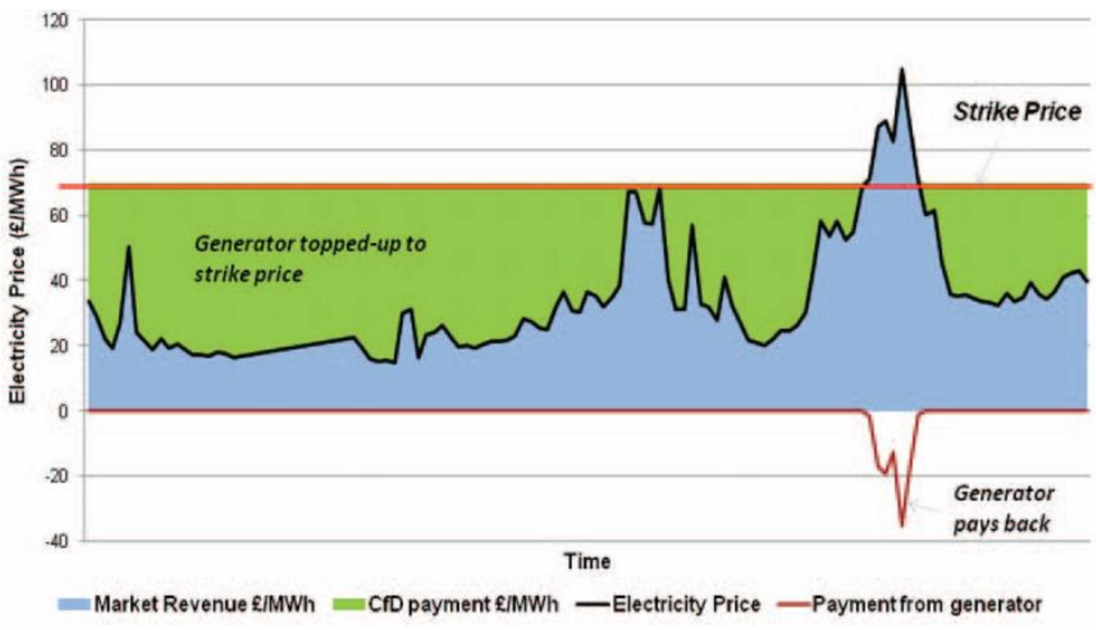

Figure 1. Operation of the Contract for Difference feed-in tariff (**Source:** DECC (2012a), reproduced under the terms of the Open Government Licence: http://www.nationalarchives.gov.uk/doc/open-government-licence/.)

The Capacity Market will provide for auctions for additional effective capacity, including storage and demand-side response options, if needed to maintain security of supply (see also DECC, 2013). The Emissions Performance Standard provides a limit on the emissions of new fossil fuel power stations, initially to be set at 450 gCO2/kWh. This would prevent the building of new unabated coal-fired power stations (i.e. without carbon sequestration), but would allow building of new unabated gas-fired power stations.

These electricity market reform proposals thus represent a significant increase in government involvement in previously liberalised energy markets. We have argued that this represents a move from a market-led approach to a hybrid government/ market-led approach (Foxon, 2013; Foxon and Bolton, 2013). The UK government envisages this as a necessary but temporary strategy, before moving back to a more market-oriented approach, in which strike prices under the CfDs would be set by a form of competitive price discovery through tenders or auctions (DECC, 2012). However, it remains to be seen if it will be possible to return to a market-led approach.

As well as policy relating to energy supply and the measures to be introduced via the Capacity market, mentioned above, the UK government has also been somewhat belatedly developing a broader set of strategies to address energy efficiency and energy demand reduction. For example, the Carbon Plan (HM Government, 2011) states that energy efficiency will have to improve across all sectors to the point where per capita energy use has fallen to between a fifth and a half of its 2011 value; and in November 2012 DECC published the government’s Energy Efficiency Strategy (DECC, 2012b). As part of this strategy, policies include the Green Deal programme, to let householders and businesses pay for the cost of energy-saving property improvements, over time, through savings on energy bills; further funding is available for some people and properties via the Energy Company Obligation (ECO), which provides a subsidy from energy suppliers. These policies offer both challenges and opportunities for incumbent and new businesses, both in energy supply and in the supply chains relating to domestic, commercial and industrial premises, appliances and controls.

Despite this wide range of policy measures, their effectiveness depends on the willingness of energy companies, investors, businesses and households to respond by investing in low carbon and energy efficiency alternatives and/or changing their practices and behaviours, and the confidence these actors place in government not to subsequently change the supporting measures in ways that would disadvantage them. The willingness of the public to accept these and potentially more stringent policy measures, especially if they are seen as contributing to higher energy costs, is likely to depend on the widespread acceptance of the need for climate change mitigation, and the perceived credibility of the measures in contributing to low carbon pathways for the UK.

3. UK low carbon transition pathways

In order to investigate the implications of different governance framings on energy choices, the authors and colleagues are undertaking ongoing research on UK low carbon transition pathways for the electricity sector (Hammond and Pearson, 2013; Foxon 2013). This work involved selecting, developing and analysing transition pathways to a 'more electric' low carbon future and undertaking integrated 'whole system' assessments of the pathways' technical, economic, social and environmental implications, in order to inform thinking and decisions on low carbon transitions. This focussed on development and analysis of pathways contributing to meeting the 80% carbon reduction target by 2050, but went beyond previous scenario work by investigating the roles of actors and, in current work, on 'who needs to do what by when' to realise these pathways.

The development of the pathways drew on interviews and workshops with energy system stakeholders from industry, government and non-governmental organizations, historical case studies of past energy system transitions (Arapostathis et al., 2013) and theoretical insights on understanding socio-technical transitions (Geels, 2002; Hofman and Elzen, 2010; Foxon et al., 2010). As the research team were interested in the role of governance framings or 'logics' in influencing the rate and direction of a low carbon transition, we developed the idea of an 'action space' for analysing the interactions between different logics[2]. The logic represents the actors' assumptions underlying the governance of the energy system, including the relative roles of regulation and market frameworks, and the relative importance attached to the objectives of carbon reduction, energy security and affordability in the energy 'trilemma'. In order to simplify and structure the analysis, we identified three key logics – a *market logic*, in which energy policy objectives are seen as best achieved by market actors freely interacting within a high-level policy framework; a *government logic*, which envisages a dominant role for the direct co-ordination of energy systems by national government actors to deliver energy policy goals; and a *civil society logic*, in which citizens are seen to take a leading role in the decisions relating to how their local and national energy systems operate. These three logics compete in a dynamic fashion to form the dominant framing for the governance of national energy systems and so strongly influence the rate and direction of future pathways (Foxon, 2013). In current work, we are exploring the competition between these logics in more depth but in the first phase of the research, we focussed on development and analysis of three pathways in which each of the logics respectively dominates. This facilitates understanding of how these different logics may influence policy and individual choices and demand, supply and technology outcomes.

In the *Market Rules* pathway, in which the market logic dominates, a high carbon price is necessary to drive market actors to invest in low carbon technologies, but there is limited interference in market arrangements, so 'government sets the framework, and then gets out of the way'. Under this pathway, large energy companies continue to play a dominant role and see the 'highly electric, low carbon future' as a strategic business opportunity. This leads to high levels of investment in large-scale low carbon generation technologies, including coal and gas-fired generation with carbon sequestration, new nuclear power stations and large-scale renewables, such as offshore wind power. As 80% of the generation capacity is still connected at the high-voltage transmission level, this implies the need for high levels of transmission reinforcement, as well as 'smart grids' to meet increasing amounts of distributed generation.

[2] The action space concept was originally developed by Jacquie Burgess and Tom Hargreaves at the University of East Anglia, UK.

In the *Central Co-ordination* pathway, a government-led Strategic Energy Agency is set up to manage a process of central contracts for tranches of low carbon generation. This enables the government to direct the mix of low carbon generation technologies, leading to co-operation but also tensions between government and large energy companies. This pathway also sees significant roles for nuclear power, coal and gas-fired generation with carbon sequestration and offshore wind, but with a greater emphasis on domestic and industrial energy efficiency measures. Again, 80% of the generation capacity is still connected at the high-voltage transmission level, implying the need for high levels of transmission reinforcement, as well as 'smart grids' to meet increasing amounts of distributed generation.

In the *Thousand Flowers* pathway, civil society, including local community groups, play a much greater role in the energy system and, together with a large number of small-scale energy service companies, develop a more diverse range of local energy solutions. In this pathway, technological and behavioural changes lead to significant end-user demand reductions, and there is commercial deployment of a range of distributed generation technologies, including biomass cogeneration of heat and power, solar photovoltaics and solar thermal, and onshore wind. This results in 50% distributed generation by 2050 requiring the development of 'smart grids' to handle two-way power flows. Nevertheless, 50% of generation capacity is still connected at the high-voltage transmission level, implying the need for significant levels of transmission reinforcement.

Through a process of technical elaboration with our engineering research colleagues and informed by their energy system modelling (Barton et al., 2013; Barnacle et al., 2013), we undertook a quantification of the above narratives for each pathway. This leads to projections of the changes to energy service demand and electricity generation mixes for the three pathways (Foxon, 2013).

4. Comparison of low carbon transition pathways with DECC 2050 pathways

As noted above, the UK government currently seems to be moving to a hybrid government-led/market-led approach to governance of a low carbon transition in the energy system. In the 1990s, a market-led approach was dominant, with a programme of privatisation of previously state-run gas, electricity and coal companies and liberalisation of energy markets to promote competition in generation and supply (Pearson and Watson, 2010). Together with access to supplies of natural gas from the North Sea, and regulatory acquiescence, this resulted in an expansion of gas-fired power generation and eventually a reduction in prices to domestic and industrial consumers, helping to fuel economic growth. However, the need to meet carbon reduction targets to 2025 and to work towards the 80% reduction targets by 2050, growing disquiet about the adequacy of infrastructure investment, and increasing concerns over energy security as North Sea gas supplies decrease, have led to growing direct government intervention in the management of the energy system. However, the pro-market philosophy still plays a significant role, with the UK government seeing itself as setting up a race between different low carbon technologies: "Rather than pick a winning technology, the Government will create markets that enable competing low carbon technologies to win the largest market share as the pace of change accelerates in the 2020s" (HM Government, 2011, p. 12).

As such, the UK government has not produced a preferred pathway to meeting the 2050 target. Instead, it has used modelling tools to explore different potential scenarios, including the MARKAL energy systems model (Strachan et al., 2011) and its own DECC 2050 pathways spreadsheet-based calculator tool (DECC, n.d). The MARKAL model optimises the mix of demand-side and supply-side measures, for example finding the least cost mix to meet the 80% reduction target by 2050, given assumptions about technology learning rates. The DECC 2050 pathways tool, on the other hand, allows the user to estimate the level of deployment of different demand-side and supply-side options, corresponding to different roll-out and build rates, and so specify plausible mixes of options to meet carbon reduction targets. The UK government's 2011 Carbon Plan (HM Government, 2011) includes four scenarios to 2050 – a core MARKAL scenario and three scenarios developed using the DECC 2050 calculator. We now briefly compare these scenarios with our low carbon transition pathways (see Figures 2-4). This comparison is discussed in more detail in a project working paper (Davies et al., 2013).

In 2010, the UK had 98 GW of electricity generation capacity, including 62 GW of gas and coal-fired generation, 11 GW of nuclear power, 9 GW of renewable generation and 9 GW of heat and power cogeneration, providing an annual total of 365 TWh of supply. Under the core MARKAL scenario, by 2050, capacity rises to a total of 106 GW, including 33 GW of nuclear, 28 GW of coal and gas generation with carbon sequestration, and 45 GW of renewable generation, providing a total of 536 TWh of supply. This is driven by the expansion of the use of low carbon electricity in transport for electric vehicles and in heating via air- and ground-source heat pumps, as well as for domestic and industrial power and lighting services. The DECC 'higher renewables; more energy efficiency' scenario sees capacity rise to a total of 135 GW, including 106 GW of renewables, 16 GW of nuclear and 13 GW of coal and gas with carbon sequestration, providing a total of 530 TWh of supply by 2050. The DECC 'high nuclear; less energy efficiency' scenario sees total capacity rise to 99 GW, including 75 GW of nuclear power, 22 GW of renewables and 2 GW of gas with carbon sequestration, providing a total of 610 TWh of supply by 2050. The DECC 'higher CCS; more bioenergy' scenario sees total capacity reach 96 GW, including 40 GW of coal and gas with carbon sequestration, 36 GW of renewables and 20 GW of nuclear power, providing a total of 490 TWh of supply by 2050. Thus, all of these scenarios envisage a massive expansion of low carbon generation to replace the current fossil fuel intensive mix, and meet additional demands for low carbon electricity in transport and heating, but with radically different generation mixes. None of these scenarios sees a significant expansion of heat and power cogeneration.

The *Market Rules* pathway has a total supply of 539 TWh by 2050, very similar to the DECC core MARKAL scenario, though with a higher proportion met by renewables (80 GW of capacity) and a lower proportion met by nuclear (26 GW of capacity). This suggests similar projections of the levels of demand-side energy efficiency improvements, but that the *Market Rules* pathway is more optimistic about the viability of investment in renewables capacity and less optimistic about the viability of nuclear power under a market-led governance arrangement with a high carbon price as the main driver of investment. The

Central Co-ordination pathway assumes greater demand-side energy efficiency improvements, leading to a total supply of 427 TWh by 2050. This requires 65 GW of renewables capacity, 30 GW each of nuclear and 30 GW of coal and gas with carbon sequestration. Both these low carbon transition pathways assume that nuclear and coal and gas with carbon sequestration operate at lower capacity factors than those in the core MARKAL scenario, with in particular the gas capacity having a greater role as back-up for intermittent renewable generation.

The *Thousand Flowers* pathway includes even greater demand-side energy efficiency improvements, arising through both technological changes and behavioural adaptations, and much higher levels of local distributed generation (up to 50% of total generation by 2050). This results in a total supply of 313 TWh by 2050, requiring 96 GW of renewables capacity, but only 5 GW of nuclear and 22 GW of coal and gas with carbon sequestration. In particular, much higher levels of electricity demand are met by renewable (biomass) combined heat and power (CHP) cogeneration by 2050. This offsets much centralised electricity generation in two ways. Firstly, by direct replacement of centralised generation and, secondly, by offsetting electricity demand for heating using heat pumps. This higher proportion of local distributed generation has implications for the rest of the power system, in the need for 'smart grids' to manage two-way power flows, including excess of supply for periods, and a need for some capacity, such as gas-fired generation with carbon sequestration, operating at low capacity factors to provide back-up to other intermittent renewables supplies, mainly onshore and offshore wind (Barton et al., 2013). However, the total capacities of both nuclear power and coal and gas with carbon sequestration in 2050 are much lower in this pathway due to the lower levels of demand and the use of flexible biomass cogeneration.

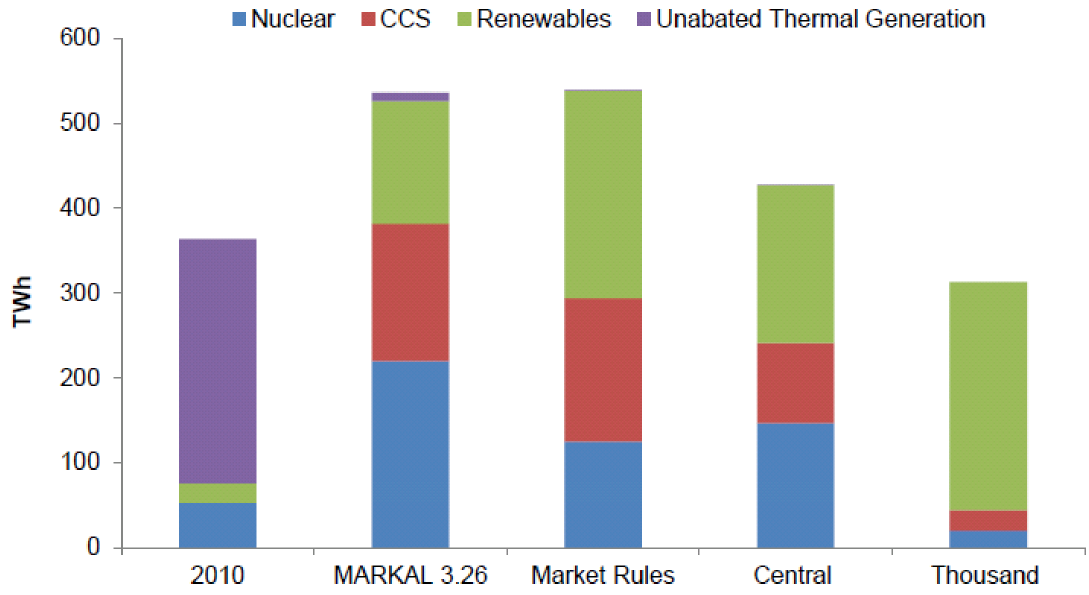

Figure 2. Annual UK electricity generation in 2010 and 2050 under different pathways (**source:** Davies et al. 2013)

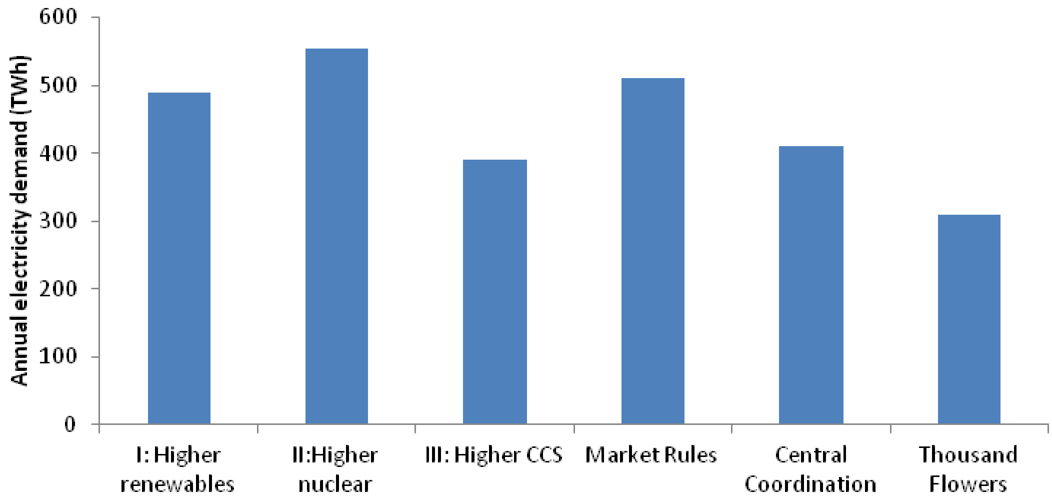

Figure 3. Annual UK electricity demand in 2050 under three DECC scenarios and three Transition Pathways (**source:** Davies et al. 2013)

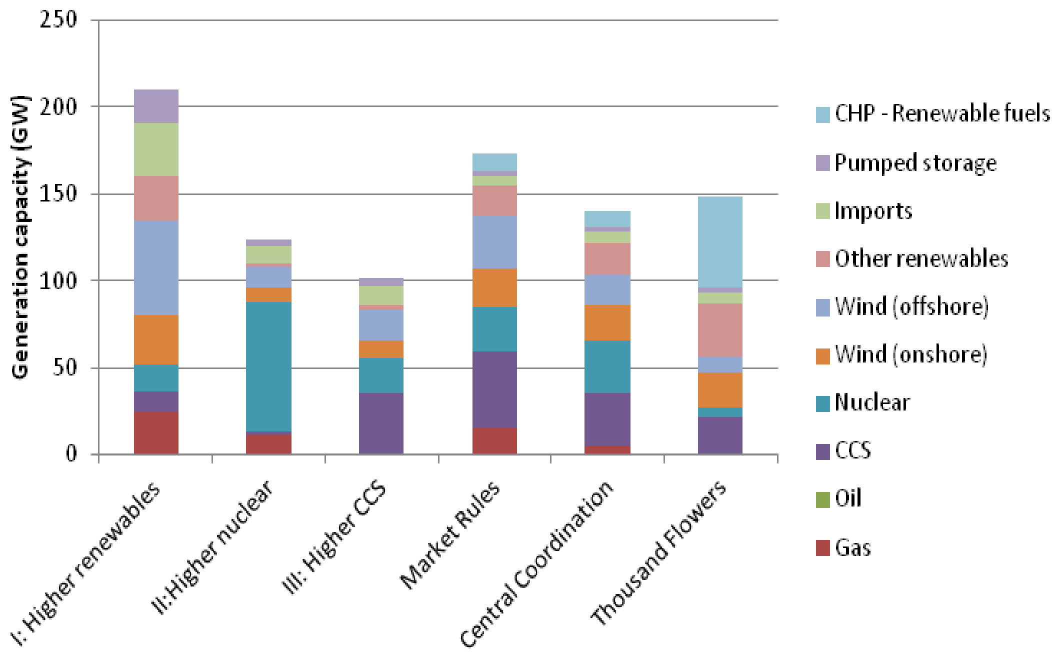

Figure 4. Total UK generation capacity in 2050 under DECC scenarios and Transition Pathways (**source:** Davies et al. 2013)

5. Implications for UK energy and climate policy

Both the DECC 2050 scenarios and our low carbon transition pathways, together with other UK 2050 scenarios (Ekins et al., 2013), demonstrate the range of possibilities for a secure and low carbon UK energy system by 2050. However, any of these pathways would be extremely challenging to achieve, and would require significant action by industry, government and civil society actors to balance low-carbon, security and affordability objectives, in the face of multi-faceted risks and uncertainties, some predictable and some not . The pathways, though, highlight different challenges for different actors and different visions for the priorities and goals for UK energy policy (Foxon, 2013). The *Thousand Flowers* pathway would require energy users and households to take a more active and demanding role in energy service provision, in relation to energy efficiency improvements and more local distributed generation. This may require broader changes in social attitudes towards focussing on 'quality of life' benefits, rather than narrow economic benefits. The *Market Rules* pathway highlights the challenges for market actors in delivering high levels of investment in large-scale low carbon generation options, given risks and uncertainties in the technical and economic feasibility and social acceptability of some of these options. Furthermore, this requires confidence in the credibility of governments to ensure a sustained high carbon price or other measures to enhance the returns on these low carbon options. The *Central Co-ordination* pathway would give government actors greater direct influence over the future evolution of energy systems. However, this would require greater political leadership than policy makers have generally been willing to show - and possibly the exercise of more authority than some market and civil society actors might be willing to tolerate.

In general, this type of pathway analysis highlights the high-level choices that need to be made in realising a transition to a low carbon energy system. It also explores the social and political means of making those choices, and informs the ways in which the objectives, thinking and actions of different actors might need to become aligned (although the 2050 Calculator does not explore the policy, institutional and societal changes that would underlie the DECC scenarios). The analysis suggests, for example, that business needs to decide to what extent and in what ways it wishes to work with national, regional and local government and with civil society in the form of community groups and individual consumers and 'prosumers'. As for governments, some would argue that they have historically been poor at picking technology 'winners' and tend to impose high levels of bureaucracy, so they should just set the framework and then 'get out of the way' to allow market actors to make those choices, as in our *Market Rules* pathway. However, as mitigating climate change is largely a public benefit rather than a private benefit or source of revenue to individual consumers and producers, the demand for this has to be articulated through government action and the rules and incentives that governments put in place often implicitly favour one technology or another. Given that different low carbon technologies are at different stages of technical and commercial development, a completely 'technology-neutral' policy framework is probably impossible.

Others would argue for a greater role for local communities, including local authorities in energy provision, as in our *Thousand Flowers* pathway. In this approach, a variety of local renewable generation and energy efficiency measures could provide more secure, low carbon heat and power supplies, reducing transmission losses and creating local economic benefits, in the form of investment and jobs. However, given the levels of local opposition seen to some forms of renewable generation, such as wind power, and the need for more behavioural changes to reduce energy demands and take a more direct role in energy provision, this will require further developments in planning and public engagement and greater social change than is currently generally envisaged. While the government has already begun to recognise the need to ensure that local communities affected by new energy installations receive appropriate benefits, it remains to be seen how successfully they and businesses will manage to strike a balance between local and national interests and yet maintain the momentum implied by the 2050 targets.

Yet others would argue for government to take a greater role in explicitly making trade-offs between low-carbon, security and affordability objectives and in consequent technology choices, as in our *Central Co-ordination* pathway. However, as noted, this requires high levels of political leadership and greater democratic accountability in relation to making these choices.

As we have seen, the UK government is currently moving to a hybrid market/government-led governance approach for the UK energy system, with relatively little role for civil society. Despite the setting into law of stringent carbon reduction targets to 2050 and intermediate carbon budgets under the Climate Change Act, and a plethora of Energy White Papers and Carbon Plans, there has still been relatively little public debate about the desired vision of the future energy system. So far, debate has centred on the desirability or otherwise of particular technology choices, such as onshore wind and new nuclear power, with little context as to how these might contribute to low carbon and secure energy supplies.

Moreover, the issue of affordability of energy services for households (Hills, 2012) and businesses is rapidly rising up the political agenda, following increases in retail gas and electricity prices, due to rising international gas prices and financial support for renewables. The prospect of increasing levels of financial incentives for renewables and new nuclear power under the Contract for Difference feed-in tariffs, which will be passed through to consumers' bills, is likely to raise the salience of the affordability issue further.

The recent conduct of energy and climate policy and the discussions around it reflect, however, an implicit and sometimes explicit reweighting by the current government of the relative priorities of the low carbon, energy security and affordability/ international competitiveness objectives that were established in the 2003 Energy White paper and reflected in the Climate Act 2008. In light of the financial crisis, rising energy prices, recent developments in the US of shale and other forms of unconventional gas and effective lobbying by climate science sceptics, this is perhaps not surprising. This reweighting, with greater emphasis on energy security and affordability/ competitiveness relative to climate change and low-carbon objectives has been signalled by ministerial changes at DECC and reports of the growing influence of the Treasury in areas from the carbon budgets to the funding of the government's Green Investment Bank. And even though the Electricity Market Reform to be enacted via the Energy Bill is designed to provide a level of certainty to businesses and investors about the direction of travel towards a low carbon electricity system and the levels of support into the future, uncertainties remain about the trajectory and durability of the explicit and implicit market value of carbon in the UK and more widely.

This and the foregoing pathway and scenario analyses suggest the need for a higher level of public debate on what type of energy system people want by 2050, how the objectives of low-carbon, security and affordability should be balanced and how and by whom they should be financed and delivered. The type of pathway and scenario analysis described in this chapter could play a role in informing this debate, which we argue is crucial for ensuring that people's private demands for secure and affordable energy service provision are met whilst achieving the socially-desirable goal of contributing to mitigating climate change and ensuring that business can play its part in delivering these outcomes..

6. Opportunities and Risks for Business

We think that there are significant opportunities for business in the low carbon area. There are a range of renewable supply and control technologies with potential for both widespread domestic deployment and generating major export markets. The growing scale of production and growth of experience in wind and photovoltaic technologies has the potential to drive several technologies down their experience curves, with lower costs and greater market penetration, though, as ever, it is not easy to foresee exactly which will be the 'winning' technologies. Smart grids and smart controls, at both national and local levels, including smart metering, will be needed both to manage the growing share of intermittent renewables but also the growth and load profiles of demand. There are also likely to be growing physical and financial opportunities relating to developments in interconnectors and the possibilities for a European 'supergrid'. As the UK (and other countries) pursue the decarbonisation of the electricity sector, renewable heat and vehicular transport will provide further opportunities relating not only to the technologies themselves but also the supply chains in both the built environment and transport. In most low carbon pathways, energy efficiency and demand management measures will have significant roles to play, especially to meet the needs of households and businesses challenged by rising energy bills. This is likely also to require the development of new business models, including energy service companies (Hannon et al., 2013) and engagement with potential new generations of 'prosumers'. Finally, consumers have a growing appetite for new electronic devices interfacing with ICT that will satisfy their demands for information, entertainment and personal management of time, assets and costs in affordable ways.

There are also, however, significant risks for businesses. Concerns about the value and durability of carbon and government commitments to it, as reflected in future national and international carbon prices, instruments and legislation, could deter low carbon investments. On the other hand, some have suggested that investors in businesses that hold high-carbon inventories of fossil fuels may face increasing risks if indeed governments, other businesses and civil society increasingly commit to carbon reduction (Leaton et al. 2013); for example, it has been suggested that reserves of coal, oil and gas held by companies listed in London could be 'sub-prime' assets that pose a systemic risk to investors and pension funds and hence economic stability). Similarly, business with a high stake in older low-carbon technologies and/or with business models that prove unsuited to a lower carbon world may find themselves facing substantial sunk costs. For example, will the traditional large electricity and gas utilities, energy suppliers and their technologies remain fit for purpose in a world where consumers want lower energy bills, the 'right' kinds of smart appliances, from companies they trust, and where others may wish to pursue more local and small-scale solutions to the challenges of energy demand and supply? Insights from previous industrial transformations suggest that a successful transition to a low carbon economy would require significant interactions between changes in practices, technologies and business strategies (Foxon, 2011; Fouquet and Pearson, 2012; Pearson and Foxon, 2012).

However, if the projections of the likely severity of human-induced climate change are as serious as the overwhelming majority of climate scientists agree, and governments can continue to command public support for the type of measures that the UK government is implementing, then businesses that seize the opportunities that a low carbon economy offers will be the ones that prosper commercially whilst contributing to a sustainable future.

7. Conclusions

Recent analyses, including those of the Transition Pathways project have shown the complexities of resolving the shifting priorities of the energy policy trilemma in a privatised and liberalised electricity system. While there are many technological routes to deliver low carbon pathways, our research shows that governance and the roles of key actors in government, the market and civil society will be of central importance in determining whether and how we 'get there from here'. Our pathways illustrate the opportunities for these key actors, not least those in business, to play significant parts in helping to resolve the tensions inherent in developing and delivering an energy system that is low carbon, secure and affordable. They also suggest that in all pathways the market sector will have a significant role to play. This will require the ability to adapt and respond to dynamically changing market and governance conditions and to develop new, robust business models that are fit for purpose, enabling agile businesses to prosper in a carbon-constrained but sustainable world.

Acknowledgements

This paper draws on research undertaken as part of a major research grant jointly by the UK Engineering and Physical Sciences Research Council (EPSRC) and E.ON UK (the integrated energy company) to study the role of electricity within the context of '*Transition Pathways to a Low Carbon Economy*' [Grant EP/F022832/1], and a follow on grant by the UK Engineering and Physical Sciences Research Council (EPSRC) on *'Realising Transition Pathways - Whole Systems Analysis for a UK More Electric Low Carbon Energy Future'* [Grant EP/K005316/1]. We are grateful to these sponsors, as well as for the interchanges with the main UK academic partners at the University of Bath (Prof. Geoffrey Hammond), University of East Anglia (Prof. Jacquie Burgess, Dr Jason Chilvers), Imperial College London (Prof. Goran Strbac, Dr Danny Pudjianto), Loughborough University (Dr Murray Thomson), University College London (Prof. Neil Strachan), University of Strathclyde (Prof. Graham Ault, Dr Stuart Galloway and Prof. David Infield), University of Surrey (Prof. Matthew Leach), and the researchers and PhD students associated with the project; see www.lowcarbonpathways.org.uk for a full list of those involved. The views expressed in this paper are the responsibility of the authors.

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