Transition pathways for a low carbon electricity system in the UK: Key findings and policy messages

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Abstract

This paper describes the key findings and policy messages from an inter-disciplinary project developing and analysing transition pathways for a UK low carbon electricity system in the UK to 2050. The project is a collaboration between leading UK engineers, social scientists and policy analysts, supported by the Engineering and Physical Sciences Research Council (EPSRC) and the energy company E.ON. Three core transition pathways explore alternative future pathways for the evolution of the UK electricity system under different governance arrangements, dominated by market, government and civil society logics respectively. The paper outlines these three core transition pathways, and briefly summarises insights from demand side, supply side, and whole systems appraisal analyses of the pathways.

The pathways demonstrate that governance and regulatory frameworks will have a significant influence on the mix of low carbon generation options, the level of future energy service demands (including additional demand from electrification of heating and transport services) and mix of centralized and distributed generation. The paper also highlights the significant challenges facing market actors, energy users, social movements and policy-makers in realizing any of these pathways. The adoption of low-carbon generation and energy efficiency technologies will depend on changes to market and regulatory frameworks, to strategies of large and small firms, to practices of how households and businesses use energy. How these changes interact or 'co-evolve' will determine the nature of the pathway and the risks in realising it. Finally, the paper summarises how analysis of and reflection on these pathways could help to inform decision-making by government, firms and wider society on steps needed to realise a transition to a low carbon electricity future.

1. Introduction

Under the 2008 Climate Change Act, the UK has set an ambitious goal of reducing its greenhouse gas emissions by 80% by 2050 (from 1990 levels). Scenarios developed by the UK Department for Energy and Climate Change (DECC, 2010a), the Committee on Climate Change (CCC, 2008) and the UK Energy Research Centre (Skea et al., 2011) suggest that the most effective way to achieve this goal would be for the UK to rapidly decarbonise its electricity system by around 2030, and gradually move towards the use of low carbon electricity for heating and transport, as well as other power and lighting services. Under these scenarios, low carbon electricity would be generated from some combination of renewables, nuclear power and coal and gas with carbon capture and storage (CCS), and natural gas for heating and power generation would be used as a transitional fuel. To achieve such a transformation of the UK energy system is extremely challenging, not least because the low carbon objective needs to be balanced against the objectives of maintaining energy security and affordability of energy services – the so-called 'trilemma' (Boston, 2012).

The recent history of UK energy policy (Pearson and Watson, 2012) shows that the framing and relative importance of different objectives has evolved significantly over the last 30 years. In the 1990s, the focus was on the privatisation of previously state-owned electricity and gas industries and the liberalisation of energy markets, in order to promote competition, aiming to improve industry efficiency and reduce costs to business and household consumers. Since the early 2000s, an increasing focus has been on reducing carbon emissions from electricity generation, initially through measures to promote innovation and take-up of renewables, as well as energy efficiency measures, and more recently through government approval for building new nuclear power stations, without direct financial support. The current UK government proposals for Electricity Market Reform (DECC, 2011) aim to provide further support for all low carbon generation options, through a set of measures including 'contract-for-difference' feed-in tariffs, a carbon price floor, a carbon emissions performance standard and a capacity support measure. It can be argued that these measures represent a move away from a pure market framework to more of a hybrid government-market framework (Foxon, 2011).

In the light of these changes and challenges, the authors and colleagues, together a consortium of engineers, social scientists and policy analysts from nine UK universities, undertook research developing and analysing transition pathways for a UK low carbon electricity system to 2050. This paper describes the key findings and policy messages from that research. The research described here was supported by the UK Research Councils Energy Programme and the energy company E.ON.

The paper is structured as follows. Section 2 describes the core transition pathways developed and the key risks and uncertainties identified for each. Section 3 describes research undertaken within the consortium on the demand side, analysing patterns of energy use and behaviour under the pathways. Section 4 describes research undertaken on the supply side and implications of the pathways for electricity networks and smart controls. Section 5 describes the 'whole systems' energy and environmental appraisal of the pathways. Section 6 discusses the policy implications and further research to be undertaken by the consortium.

2. Transition pathways to a UK low carbon electricity system

The research aimed to explore three 'transition pathways' towards a UK low carbon electricity system, to understand the changing roles of large and small 'actors' in the dynamics of these transitions, and to learn from the successes and failures of past transitions. An innovative, robust, and 'whole systems' evidence base was developed that is distinctive from those devised elsewhere in the UK energy research community.

As noted, the 2008 Climate Change Act committed the UK to reduce greenhouse gas emissions by 80% by 2050. Achieving this target will mean a transition in the systems for producing, delivering and using energy that is not only low carbon but also secure and affordable, thus resolving the energy policy 'trilemma'. The research investigated pathways towards this 2050 target, based on increasing use of low carbon electricity for power, lighting, heating and transport services. Unlike previous scenarios that focussed primarily on the technological mix of supply and demand options needed to achieve the target, the pathways research also focused on the choices and actions needed to 'get there from here', and their technical, socio-economic and environmental implications. The pathways are not predictions or roadmaps; rather they are a way of imaginatively exploring future possibilities, to inform proactive and protective decision making and enhance the potential for building consensus towards common goals (Hughes et al., 2012).

Unlike many scenario-building exercises, our starting point is that the governance framings or 'logics' of key actors will be a crucial influence on any pathway towards a future low-carbon energy system. We have distinguished the logics of three core sets of actors: those of the market, government and civil society. Accordingly, in our three core transition pathways, named *Market Rules*, *Central Co-ordination* and *Thousand Flowers*, each pathway is dominated by a single group's logic (Foxon, 2012a). The researchers first developed narrative storylines for each of these pathways, based on initial workshops and interviews with energy industry and policy-makers. They then undertook a process of technical elaboration of the pathways, to elaborate the changes to energy service demands and mix of power generation technologies needed to meet them, under the implications of the different governance logics set out in the pathway narratives. The broad outline of the three core transition pathways is as follows:

- ***Market Rules*****:** this pathway envisions the broad continuation of the current market-led governance pattern, leading to a concentration on large-scale low carbon technologies: coal and gas CCS, nuclear power and offshore wind, under incentives from a high carbon price.
- ***Central Co-ordination*****:** this pathway envisions greater direct government involvement in the governance of energy systems, leading to greater reductions in energy service demands, but still a focus on centralised generation technologies. This is achieved through a government-created 'Strategic Energy Authority' that uses contracts with large energy companies to reduce the risks of low-carbon investments.
- ***Thousand Flowers*****:** this pathway envisions more local, bottom-up diverse solutions, driven by innovative local authorities and citizens groups, such as the *Transition Towns* movement, and energy service companies (ESCOs) becoming key actors, developing local micro-grids and incentivising reductions in energy

service demands. Small-scale renewable technologies emerge from niches, as positive feedbacks lead to ‘virtuous cycles’ in deployment of these technologies.

The pathways demonstrate that governance and regulatory frameworks will have a significant influence on the mix of low carbon generation options, the level of future energy service demands (including additional demand from electrification of heating and transport services) and mix of centralized and distributed generation. While the analysis shows that all the pathways involve challenges for national and local government, energy companies and household and business energy users, and have some common elements, there are significant differences between them. *Market Rules* and *Central Co-ordination*, for example, show two main risks and uncertainties. The first relate to the technical, economic and financial challenges of delivering the large-scale low carbon generation technologies of carbon capture and storage, nuclear power and offshore wind and the grid enhancements to support them. The second relate to the uncertainty of whether concerns about security of supply and climate change would outweigh public resistance to the nature and costs of any or all of these technologies. In the *Thousand Flowers* pathway, however, the main uncertainties relate to the technical and economic feasibility of locally distributed generation technologies, and to the realisation of the behavioural and technological changes needed to achieve and sustain the high levels of energy demand reduction that characterise this pathway. This, of course, is the pathway for which we have least prior experience on which to draw.

The researchers also investigated potential branching points on the pathways (Foxon et al., 2012), drawing on historical analysis of the processes and actors involved in past energy system transitions (Arapostathis et al., 2012). Branching points are points at which decisions may be taken to diverge from the existing trajectory, towards another pathway or a hybrid, or to return to a pathway after deviating from it. Branching points may be negative, e.g. the failure of a low carbon technology to come on stream as expected or more fundamentally a loss of faith in the prevailing logic, such as a move away from the market towards greater central coordination or local action. Or they may be positive, as in unexpectedly successful developments in technology or infrastructure. Understanding the pressures, tensions and processes that lead to branching points means being better able to anticipate and address – or even precipitate – them. Drawing on workshop with energy industry, policy and NGO stakeholders, the researchers indentified possible branching points and analysed potential responses at these. These included the failure of CCS to be commercially viable for significant scaling-up by 2020 under the *Market Rules* pathway, the failure of the Strategic Energy Agency in the *Central Co-ordination* pathway, and failure of actors to be able to deliver the level of system changes needed in the *Thousand Flowers* pathway, as well as a branching point across all three pathways relating to different potential developments of ‘smart grid/smart control’ technologies. It was argued that this type of branching point analysis could inform energy system actors’ thinking and decision making in at least three ways (Foxon et al., 2012). Firstly, by informing understanding of the structure and dynamics of transitions, including how different options may be locked-in or locked-out. Secondly, by informing how decisions taken at key points can exert significant influences on the nature, magnitude and timing of pathways. Thirdly, by anticipating key choices, opportunities and constraints that different actor groups may face along a pathway, and how these are influenced by the dominant governance framing, as well as detailed technological and social factors.

Valuable insights are also provided by the historical analyses, such as of the market-led C19-C20 transition towards increased use of gas for heating and cooking in the face of new competition from electricity, and the government-led 1960s transition to replace town gas by LNG and North Sea gas (Arapostathis et al., 2012). These can inform understanding of the governance, social and technical challenges of previous transitions and branching points. They illustrate the co-evolution of technologies, infrastructures and institutions, the power of incumbents and the complex challenges of rapidly scaling-up new technologies. They suggest that while multi-actor market-led transitions offer valuable chances for experimentation and novelty, government-led transitions with fewer actors and more centralised decisions may be easier to achieve. This helps to explain why recent governments have moved towards a hybrid pathway with greater government involvement in a broadly market dominated system. However, achieving an appropriate balance between centrally co-ordinated and market-led approaches and finding an appropriate role for civil society in decision-making remain significant challenges for current and future energy policy makers.

3. Demand side, patterns of energy use and behaviour

As part of the technical elaboration and analysis of the pathways, the researchers analysed the evolution of electricity demand and the role for demand side participation measures in each of the pathways (Barton et al., 2012). The demand for energy at the building scale arises from multiplicity of lifestyles, service needs, end-use devices, the building fabric and local energy conversion/storage. There is potential for emissions mitigation in all of these facets, and a range of opportunities exist for reducing the energy needed to satisfy basic energy services in existing and the new build stock over the transition period. The electrification of transport is evident in all pathways, as is growth in the use of electricity for heating, via heat pumps. With these new users of electricity, *Market Rules* sees continued growth in absolute levels of electricity use, despite continued efforts at technical improvement in appliances and building fabric; peak demands also grow, to some 83GW by 2050. Enhanced efforts for energy efficiency contribute to lower trends in *Central Coordination* and *Thousand Flowers*, and greater use of non-electricity sources for heating, notably CHP, within *Thousand Flowers* drives demand down further, such that peak demand is only 38GW. However, this reduction comes at a price, with significant ‘excess’ generation locally at times of low electricity demand, as CHP follows heat demands, exacerbating the problem of low capacity factors for central generation caused by growth in the role of intermittent renewables. Load shifting through greater use of Demand Side Management is shown to contribute effectively to this problem, but will require widespread acceptance of automatic control of appliances and/or deep behavioural changes. However, the response of end users needs to be taken into account. Further work undertook a longitudinal (12-24 month) study analysing energy use by households in response to information on their real-time energy use provided by visual energy displays (Hargreaves et al., 2010, 2012). This showed how rapidly households returned to pre-existing energy use levels. Most early adopters used the displays to help picture their household’s ‘normal’ pattern of energy use, and they tended often angrily to resist exhortations from external agencies (government, energy companies, NGOs) to change it. The closer engagement of endusers with governance of the energy system in *Thousand Flowers* could offer one means to overcome these barriers.

4. Supply side, networks and smart control

Researchers also elaborated the mix of increasingly low-carbon generation options needed to meet the annual and hourly electricity demand profiles for the three core pathways, and developed models to analyse the implications of these for networks (Barnacle et al., 2012) and smart control systems (Pudjianto et al., 2012). The intermittency and inflexibility of low-carbon generation mean that fossil-fuelled generation must be replaced to an even greater extent than suggested by annual average figures, in order to be able to achieve required carbon reductions. The hourly modelling undertaken indicates massive requirements for peaking plant, such as back-up gas generation, or energy storage, even after the optimistic application of automated demand-side flexibility, especially in the *Market Rules* pathway. The increasing electrification of transport and heating in the pathways also has significant implications for networks. Rapid growth in the electric vehicle market could require significant changes to power system operation. Under our current 'predict and provide' approach, the increasing electrification of transport and heating will lead to an increase in peak demand that is disproportionally higher than the increase in energy consumption. Significant generation, transmission, and distribution network reinforcements, operating with much lower utilisation factors, will be needed, including tens of billions of pounds of investment for the distribution networks. However, a coordinated application of smart demand technologies such as smart EV charging, smart heat pump control and active distribution networks with the use of voltage regulators can significantly reduce network reinforcement costs (Pudjianto et al., 2012). Two electricity system models were developed to analyse the networks implications in more detail (Barnacle et al., 2012). The *MOTRiP* (Multi-Objective Transmission Reinforcement Planning) model analysed multi-objective optimal reinforcement plans for future years, simulating for different pathways the optimal future cost of active power reinforcement associated with reinforcing the UK network, to ensure security against thermal overloading and other contingencies. The *SiTIESS* (Simulation Tool for Integrated Energy Systems Studies) model was developed to represent and interrogate a multiple energy carrier and highly interconnected energy system, at a local, regional or national level. It informs the operational changes and the necessary levels of technology (transport, transmission, storage and generation) needed to support a system over different pathways. These models have been used to analyse the network reinforcement and infrastructure implications of the pathways, including the additional peak demand requirements in *Market Rules* and the significant expansion of distributed generation in the *Thousand Flowers* pathway.

5. Whole systems energy and environmental appraisal

The whole systems appraisal of energy technologies and the transition pathways was undertaken within an overarching sustainability framework, together with a set of evaluation criteria for specific energy technologies and pathways (Hammond and Jones, 2011; Hammond et al., 2012). This assessed the impact of the three pathways, using energy analysis and environmental life cycle assessment (LCA), on a 'whole systems' basis: from 'cradle-to-gate'. This analysis highlights the significance of 'upstream emissions' and their technological and policy implications. Upstream environmental burdens arise from the need to expend energy resources in order to deliver, for example, fuel to a power station. They include the energy requirements for extraction, processing/refining, transport, and fabrication, as well as methane leakage that occurs in coal mining activities – a major contribution – and from natural gas pipelines. The impact of upstream emissions on the carbon performance of various low carbon electricity generators, such as large-scale combined heat and power (CHP) plant and carbon capture and storage (CCS), and on the pathways themselves distinguish the present findings from those of other UK analysts, such as DECC (2010a) and Committee on Climate Change (CCC, 2008) scenarios. This analysis indicates that it is not possible to decarbonise the UK electricity supply industry by 2030 (as advocated by the CCC), unless the whole economy adopts low carbon energy sources – an unlikely prospect on a 2030 timescale. Taking account of upstream emissions also suggests, for example, the striking result that CCS is likely to deliver only a 70% reduction in carbon emissions on a whole system basis, in contrast to the normal presumption of a 90% reduction. These results suggest that, if UK carbon emissions targets are to take into account the upstream emissions associated with UK electricity supply, then even more dramatic carbon reductions will be required by the electricity supply industry. Many industrialists see existing targets as a challenging aspiration, and so actions by government to show a credible commitment not to weaken the targets in the face of difficulties are likely to be necessary to persuade industry and the public to make the necessary investments on the supply- and demand-sides to realise any of the pathways.

6. Policy implications and further research

The analyses of transition pathways summarized in this paper highlight the significant technological, social and environmental challenges associated with any potential transition pathway to a UK low carbon electricity future, and the key decisions that market actors, energy users, social movements and policy-makers will all face in realizing any of these pathways. The adoption of low-carbon generation and energy efficiency technologies will depend on changes to market and regulatory frameworks, to strategies of large and small firms, and to practices of how households and businesses use energy. How these changes interact or 'co-evolve' will determine the nature of the pathway and the risks in realising it. The dominant political philosophy in recent years has been that, given the right incentives, markets and market actors will deliver socially beneficial outcomes, but the UK government is increasingly moving towards a hybrid government/market-led framework in order to deliver solutions that will meet the social objectives of low carbon, secure and affordable energy services. The need for the acceptance of these solutions by civil society and potentially the greater involvement of civil society in energy decision-making suggests that need for a deeper public debate on the desirable features of a low carbon energy future and the relative priorities of these different objectives.

The consortium is now undertaking further research, supported by the UK Research Councils Energy Programme, on 'realising transition pathways'. This will research the dynamics of a transition to a UK low carbon electricity system by:

- Analysing actors' choices and decisions within past, current and prospective dynamic changes in electricity supply and demand systems, including learning from analogous socio-technical systems;
- Undertaking detailed analysis of the social, behavioural and technical drivers and implications of demand side responses and their integration into electricity systems;

- Undertaking techno-economic systems modelling and energy and environmental assessments of the developments in electricity supply (including transmission and distribution networks) required to meet this responsive demand.

These elements will be drawn together to form a detailed whole systems analysis of the technical, environmental, economic, and social implications of a set of transition pathways and associated technologies, through quantitative modelling and analysis of electricity systems and infrastructures, and qualitative assessment of the roles of government, market and civil society actors.

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