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Branching points for transition pathways: assessing responses of actors to challenges on pathways to a low carbon future

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Abstract

This paper describes initial analysis of branching points on a set of transition pathways to a UK low carbon electricity future by 2050. As described in other papers in this special issue, we are exploring and analysing a set of core transition pathways, based on alternative governance patterns in which the 'logics' of market actors, government actors and civil society actors respectively dominate. This core pathway analysis is enhanced by analyses of branching points within and across the pathways, which informs how competition between different logics plays out at key decision points. Branching points are defined as key decision points at which choices made by actors, in response to internal or external stresses or triggers, determine whether and in what ways the pathway is followed. A set of initial branching points for our three core transition pathways is identified through project and stakeholder workshops, and drawing on analysis of actors' choices and responses at past branching points in energy system transitions. The potential responses of the actors are identified at these branching points, and risk mitigation strategies are formulated for the dominant actors to reinforce that pathway, as well as opportunities for actors to move away from the pathway.

1. Introduction

This paper describes initial analysis of branching points on a set of transition pathways to a UK low carbon electricity future by 2050 (Foxon et al., 2010; Foxon, 2012, this volume). As laid down in the Climate Act 2008, the UK aims to reduce greenhouse gas emissions by 80 per cent on 1990 levels, through phased 'carbon budgets'. Moving to more efficient delivery of electricity generated from low-carbon sources is expected to play a key role in achieving these goals. This set of transition pathways has been developed by applying a multi-level perspective for analysing transitions in socio-technical systems (Geels, 2002, 2005a, 2011; Grin et al., 2010), augmented by related work on a coevolutionary framework for analysing low-carbon transitions (Foxon, 2011). This approach emphasises that pathways arise through and can be shaped by actors' decisions, drawing on insights into how the contingency of actors' decisions and coevolutionary processes can be usefully incorporated into scenario thinking (Hughes et al., 2012, this volume). These decisions are enabled and constrained by a range of structural factors, and are made under conditions of high uncertainty. This reflects the evidence from historical studies that technological systems change is path dependent, such that the state of the system at any time is sensitive to events and decisions made along the way, and is not predictable on the basis of optimality conditions (David, 1985, 1997; Arthur, 1989, 1994). The paper thus aims to inform how decision-making by actors influences whether a particular pathway is followed, or a branch to another pathway may occur, in the context of analysis of future transition pathways.

Uncertainty and path dependence present a challenge to the development and analysis of plausible scenarios or pathways towards particular futures, including a transition to a low carbon electricity system. One approach, commonly applied in techno-economic modelling, is to develop and analyse scenarios meeting some optimality condition, as 'ideal types' for comparison. Whilst this approach is valuable, there is a danger that it might lead to scenarios that underplay the path dependence and actor contingency of technological systems change, and hence give a misleading picture of how such change might occur and how the consequences of different decisions might play out. Hence, our work takes an alternative approach of first developing and analysing transition pathway narratives based on more 'realistic' decision-making processes, and then undertaking a process of quantification of the narratives. Consequently, unlike scenarios developed from cost optimising techno-economic models, our transition pathways do not assume that actors will optimise any utility function.

We have developed and analysed a set of three core transition pathways to 2050. 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. In these core pathways, we assume that the dominant logic is reinforced at decision points, giving rise to a path dependent evolution of the technological and institutional features of the pathway, as described in Foxon (2012, this volume). The branching points analysis seeks to examine in more detail the processes that give rise to the dominant logic either being reinforced or challenged at these decision points. Pathways reflect the outcomes of multitudes of decisions made by interacting actors along the way. At key decision points, actors make choices that depend on the magnitude and timing of pressures and the openness and capability of regime actors to respond to them. These key points represent major challenges, either to a pathway's dominant logic or to the ways in which that logic is pursued. Thus we define a *branching point* as a key decision point on a pathway at which actors' choices, made in response to internal or external pressures, determine whether and in what ways the pathway is followed. However, it is important to note that pathways and branching points are emergent properties, and so actors may not be consciously deciding to pursue a particular branch or pathway, but rather to address particular challenges as they see them at that point in time. The path dependence literature argues that particular choices at one point may result in later choices being constrained, giving rise to an identifiable branch or pathway.

We are interested in using these ideas to investigate the robustness of our core transition pathways. If the actors that are following the dominant logic in a pathway have the capacity to respond to pressures at a branching point, then that pathway is likely to be reinforced, as in our core transition pathways. However, internal or external events may result in the dominant logic in a pathway being challenged, leading to branching to another path or failure to realise a transition along that pathway. In this paper, we identify and analyse such branching points.

In order both to test and refine the approach and to explore the decisions made by regime actors at two periods in which significantly different logics dominated, we first apply branching point analysis to past experiences of the UK gas regime, drawing on historical case studies described in detail in Arapostathis et al. (2012, this volume). In these cases, we identified branching points at which challenges arose to the ways in which the dominant market or government logic was pursued, without necessarily challenging that logic.

The paper is structured as follows. Section 2 discusses in more detail theoretical and conceptual issues relating to branching points, drawing on the technological lock-in and historical institutionalism literatures. Section 3 looks at the lessons that can be learned from analysis of past branching points in historical transitions, through two case studies from the UK gas industry. Section 4 describes the process and methodology used to select a set of key branching points on our core pathways. Section 5 analyses the potential responses of actors and risk mitigation strategies at these selected branching points, drawing on insights from stakeholder workshops. Section 6 discusses how the analysis of branching points might inform thinking and decision making processes for actors from policy, business and civil society. Section 7 concludes and sets out the next steps for the analysis.

2. Theoretical issues – path dependence, lock-in and path creation

A range of evidence from socio-technical, historical, institutional and evolutionary economic analysis can help us to understand transitions in technological and related systems, and the implications of actors' decisions within transitions. This evidence highlights that long-term technological change is "*uncertain, dynamic, systemic* and *cumulative*" (Grubler, 1998, p. 21; Rosenberg, 1982, 1994; T. Hughes, 1983; Mokyr, 1990; Freeman and Louca, 2001; Geels, 2005a). These authors argue that uncertainty is fundamental because of the many inter-related individual and institutional decisions that affect technological change. The poor record of forecasting of even the broad characteristics of future energy systems provides strong evidence for this (Smil, 2005). Technological change is dynamic as it involves replacement over time of capital stock as stock ages and economies expand, and the injection of new technological possibilities arising from inventions and innovation. The systemic nature of technological evolution extends not only to the inter-relations between technologies, but also to the institutions, business strategies and social practices with which technologies coevolve (Nelson, 2005; Beinhocker, 2005; Arthur, 2009; Foxon, 2011). Finally, technological change is cumulative, as it builds on previous experience and knowledge, both of what works technically and of what is socially acceptable and desirable.

A key aspect of long-term technological systems change is that it is *path dependent*, i.e. the present and future evolution of a technological system depends sensitively on the particular historical sequence of events that led to its current state. In his investigation of path dependence, economic historian Paul David argued that "A *path-dependent* sequence of economic changes is one in which important influences upon the eventual outcome can be exerted by temporally remote events, including happenings dominated by chance elements, rather than systemic forces. ... In such circumstances, 'historical accidents' can neither be ignored, nor neatly quarantined for the purposes of economic analysis; the dynamic process itself takes on an *essentially historical character*" (David, 1997). This implies that a particular state of the system may be 'locked in' as a result of particular historical accidents, creating barriers to moving to an alternative state, even though the conditions that led to that lock-in are no longer relevant. He illustrated this with the famous example of the QWERTY keyboard layout design (David, 1985). This originated in the design of early mechanical typewriter keyboards, ostensibly to slow-down typists to prevent adjacent keys from jamming. Because of certain historical factors, such as most typists being trained on this layout, the switching costs to another design increased. Even though alternative layouts have been proposed and claimed to be more ergonomically efficient, the QWERTY design is still ubiquitous on nearly all modern computers and electronic information devices. Arthur (1989, 1994) identified four types of increasing returns to adoption that can lead to this type of technological 'lock-in': *scale, learning, adaptation* and *network* effects. These increasing returns can then result in technical and social advantages accruing to the incumbent technology, so delaying or preventing the adoption of a potentially superior alternative technology.

The insights from historical approaches to understanding long-term technological change are reinforced by those from evolutionary and institutional economics. From this perspective, North (1990) argued that the four types of increasing returns, identified in relation to the adoption of technologies, also apply to the adoption of institutions, understood as social rule systems. Pierson (2000) argued that increasing returns would be particularly prevalent in political institutions, such as market or regulatory frameworks. These frameworks are typically difficult to implement initially as they require co-ordination between many actors, but if this collective action problem can be overcome, then actors tend to adapt their behaviour and expectations to the new rules, and so acquire an interest in these rules being maintained. Hence, legally binding rule-systems are subject to learning, adaptation and co-ordination effects, and so become difficult to change, once implemented. In particular, actors that have power under the current rule-system will try to use this power to ensure that the rules that enhance their interests are maintained. Historical analysis of political institutions has also identified 'critical junctures' - crucial founding moments relating to the formation of institutions that send countries along broadly different political development paths (Collier and Collier, 1991; Scokpol, 1992; Ikenberry, 1994). In a perceptive review of this literature, Thelen (1999) argues that this type of historical institutional analysis could be used to examine in a coherent way both the formation of institutions and the processes that sustain and reproduce these institutions.

These insights suggest that analysis of processes of co-evolution of technologies and institutions can inform how techno-institutional systems form and the conditions under which they may become locked-in (Foxon, 2007, 2011). Unruh (2000, 2002; Unruh and Carrillo-

Hermosilla, 2006) argued that such a process of co-evolution of technologies and institutions has led to the lock-in of current high carbon energy systems, termed 'carbon lock-in', through mutually reinforcing positive feedbacks to the adoption of high carbon technologies and supporting regulatory institutions and user practices. Co-evolutionary thinking thus highlights the difficulty in moving away from a pathway that has widespread support, particularly amongst powerful actors. It also shows that rapid change is possible if increasing returns to the adoption of an alternative approach can be instigated, leading to the creation of 'virtuous cycles' of change (Stenzel and Frenzel, 2008; Suurs and Hekkert, 2009; Foxon, 2011).

Whilst historical lock-in can be eventually overcome, this is likely, but not necessary, to require strategic action by markets actors and/or governments. Indeed, while acknowledging the relevance of path dependence, Garud and Karnoe (2001) suggested it to be problematic in relation to entrepreneurship. This is because its proponents "relegate human agency to choosing to go with a flow of events that actors have little power to influence in real time." They argued instead for *path-creation,* a process of "mindful deviation" in which entrepreneurs, although constrained, may choose to depart from structures they jointly create, "in a collective effort where paths are continually and progressively modified as new technological fields emerge" (Garud and Karnoe 2001, p. 3). Historical studies also suggest that lock-in can be avoided through the formation of a diverse range of alternative technological options, whilst ensuring that promising options benefit from sufficient increasing returns and learning effects to enable them to challenge the dominant technologies (Foray, 1997; van den Bergh et al., 2006, 2007; Gross, 2008).

Nevertheless, although a range of studies suggest positive roles for entrepreneurs and other actors in overcoming lock-in, the development of low carbon pathways requires investment in risky R&D, demonstration projects and early stage commercialisation of new technologies. This is against a backdrop of uncertain revenues, including the price of carbon and the probability that many initially promising options will fail to achieve full scale commercialisation. Hence, support for option creation and testing raises dilemmas for market actors and policy-makers. The former may lack sufficent incentives to engage in socially desirable levels of risky investment and experimentation, a classic public good problem. The latter worry about overcompensating market actors from the public purse and choosing which technologies, activities and policy instruments to support, in the face of uncertain electoral backing.

Our approach to transition pathways is set within a substantial tradition of historical work on energy and emergent socio-technical transitions, particularly within the so-called Multi Level Perspective (MLP) (e.g. Geels, 2002, 2005a,b, 2006; Geels and Schot, 2007; Verbong and Geels, 2007; Shackley and Green 2005). We argue that using the concept of branching points as a tool to understand emergent transitions can enrich existing approaches, balancing micro and meso-historical approaches. MLP studies of historical transitions identify critical moments in the transition pathway when the regime experiences pressures from landscape developments or emerging niche innovations. During those situations, regime actors decide to respond, implementing changes in the regime. Despite the temporal and spatial dimension that MLP gives to those critical situations, the approach provides limited explicit focus on the decision making processes, the variety of choices, the considerations of the various actors or the relations of power that developed during the points when choices had to be made. However, Geels and Schot (2008) have argued that the agency of actors can be incorporated more explicitly within the multi-level perspective, in relation to actions leading to path creation. Drawing on these and other leading historical and sociological analyses of long-term technological change (e.g. Bijker, 1997; Cowan, 1999; Hughes, 1983), we argue that branching point analysis could offer a systematic way of looking at critical moments in transitions.

Thomas Hughes identifies five stages in the evolution of large scale technological system: invention, research and development; technological transfer; system growth; technological momentum; and, finally, planned regional systems. He introduced the concept of 'reverse salient' to denote critical junctions in system evolution, particularly at the stage of growth when components of the system are lagging and the system builder has to transform the situations into critical problems – technological, institutional, political or social – and search for solutions. During these conditions, a process involving decision making and problem solving strategies is important (Hughes, 1983: 6-17, esp. 14). Although Hughes' analysis gives due emphasis to the social processes of decision making, it does not explicitly address the issue of governance, or exactly how the identification of 'reverse salients' can act as windows of opportunity for the system builders. Sociological approaches that endorse system analysis while also stressing the importance of uses and users in socio-technical transitions have focused on 'consumption junctions'. These are places and moments "at which the consumer makes choices between competing technologies", and for which the researcher should "try to ascertain how the network may have looked when viewed from the inside out, which elements stood out as being more important, more determinative of choices, than the others, and which paths seemed wise to pursue and which too dangerous to contemplate" (Cowan, 1999:263). This approach is valuable in that it emphasises actors' choices and their contribution to the domestication of specific technologies. However, it focuses exclusively at the consumer-end of the regime and does not encompass actors from all domains and aspects of the regime.

In this paper, we seek to apply these ideas to the analysis of future transition pathways. This builds on the use of similar ideas in the scenarios literature (Hughes et al, 2012, this volume). For example, Kahn and Wiener (1967) refer to the "events and branching points [in scenarios] dependent upon critical choices", and de Jouvenel (1967) analyses "points of fulcrum" at which actors' choices can influence future outcomes. Bearing in mind the potential constraints of path dependence and the opportunities for path creation in relation to our low carbon transition pathways, we analyse in detail a small number of *branching points* along these pathways, examining the potential responses of all key actors within the system at these points. As noted, we define a branching point as a key decision point on a pathway at which choices made by actors, in response to internal or external pressures, determine whether and in what ways the pathway is followed. This analysis does not set out to predict branching points, but rather to explore plausible branching points, with the aim of informing how actors might develop strategies to prepare for potential future events, contingencies and opportunities and plan appropriate responses consistent with their long-term goals. The analysis is informed by insights provided by current actors in the energy system, and from the analysis of how energy system actors responded to historical branching points in earlier energy system transitions.

3. Application to Transition Pathways

As noted, in order to investigate how actions by actors could give rise to a transition to a UK low carbon electricity system by 2050, through the use of a coevolutionary, multi-level framework, the project has developed and analysed three core transition pathways (Foxon, 2012, this volume). We are particular interested in the governance challenges that actors face, where 'governance' here refers to the structures and processes that influence decisions made by different actors within the system, and in how their choices give rise to changes to the system (Smith, 2009). The project team developed an 'action space' approach for analysing the governance interactions between three key groups of actors – government actors, market actors and civil society actors. In this approach, as outlined earlier, different types of actors follow different underlying 'logics' that frame their view of the world and of other actors, and seek to 'enrol' others into their logic, thus giving rise to competition between logics (Figure 1).

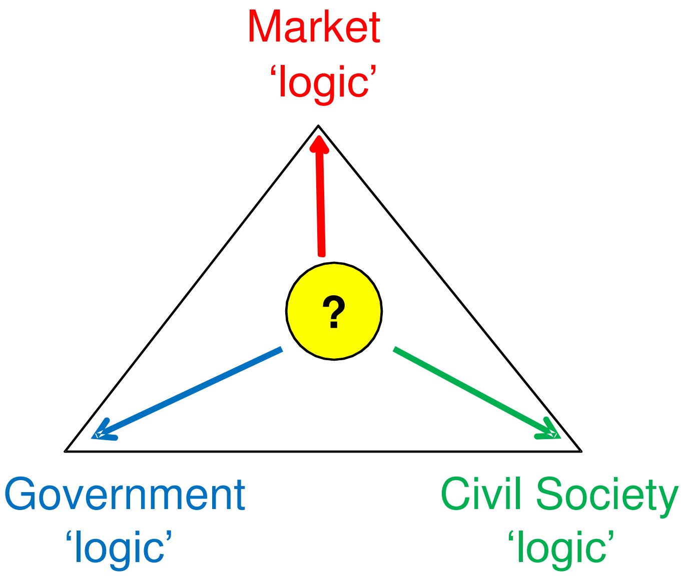

Figure 1. Patterns of governance: the action space for competing 'logics' in a transition (Source: Foxon, 2012, this volume).

In order to investigate a small number of core pathways in detail, we defined three transition pathways to a UK low carbon electricity system, in which one of each of the three competing logics dominates. Thus, we have a market-led pathway, named *Market Rules*, a government-led pathway, *Central Co-ordination*, and a civil society-led pathway, *Thousand Flowers*. However, in reality, there are messy and dynamic processes of interaction between competing logics, as path dependent processes of change play out through actors' choices and structural changes. In order to investigate this competition between logics, in Section 5 of this paper, we focus particularly on those *branching points* at which this competition leads to a challenge to the dominant logic in a pathway.

As there has been relatively little analysis of branching points in this way, and valuable insights might be drawn from a longer run perspective, we also applied and tested our approach through studying past energy transitions and branching points in them. Initial historical studies have included research on the history of the use of gas to provide lighting, cooking and heating services (see Arapostathis et al. 2012, this volume, for more detail). Here, we chose to analyse two UK transitions under contrasting governance modes/logics: an essentially market-led transition in the spread of gas to a wider range of users and services in the late 19th/early 20th century; and a government-led transition from manufactured gas to natural gas in the second half of the 20th century. In each transition, we identified branching points at which the regime actors had to make choices and had the power to take decisions which significantly shaped the pathways taken. In these cases, the branching points resulted in the reinforcement of the dominant logic, rather than its overthrow, and so contributed to specific transition pathways. Thus these historical examples shed light on the factors that enabled the reinforcement of the dominant logic at the branching points. In future work, we propose to investigate how different choices by actors might have led to different outcomes in these cases, by comparing the historical experience of the UK with that of other countries who faced similar challenges at these times. We will also explore branching points in the past development of the UK electricity regime.

3.1. Branching points on the pathway of the manufactured gas regime 1877-1914

As described by Arapostathis et al. (2012, this volume), the development of domestic use of manufactured gas to include a greater range of energy services by a wider range of British customers represents a broadly market-led transition. By around 1880, gas manufactured from coal was used by two million commercial and middle class customers, primarily for lighting. Gas was produced by private companies and municipal ‘undertakings’. Financially the municipal and private organisations behaved in broadly similar ways, both being profit-driven, albeit with different uses for those profits: as dividends for the private companies, and to pay for municipal improvements or reductions in council rates for municipal undertakings (Millward, 1991, 2000). As both sets operated within the market logic, while using it for their own purposes, they are here jointly referred to as ‘companies’.

During the decades after 1880, the companies and other actors within the manufactured gas regime faced a range of pressures, including competition from developments in electric bulb lighting (Fouquet and Pearson, 2006), low load factors due to low daytime demand and negative customer perceptions of gas. Such pressures, as well as a general search for increased profits, led to branching points, in response to which various decisions were taken by the dominant actors, the companies, which, in this case, reinforced the pathway towards the use of manufactured gas by wider parts of the population for a greater range of energy services. The Branching Points and the decisions in response to them are summarised in Table 1.

Choices made at branching points	*Key actors and their location in the governance system*	*Outcome for the transition pathway*
Branching point 1: Perceived need to promote and increase the range of energy services supplied by gas		
To organise trade exhibitions to promote gas appliances (ca late 1870s)	Private and municipal gas undertakings (central) and appliance manufacturers (increasingly important)	The beginning of increased emphasis on advertising and promotion of appliances – shift towards supplying more varied services
To organise the 1882-3 gas exhibition	Private and municipal gas undertakings (central)	Increased emphasis on advertising amongst undertakings – shift towards supplying more varied services
To introduce hiring of appliances (taken up widely in 1880s)	Private and municipal gas undertakings (central)	Continued the shift towards supplying more varied services
Branching point 2: Perceived need to broaden the customer base		

To introduce prepayment meters (from 1889)	Private and municipal gas undertakings (central) and appliance manufacturers (increasingly important)	Shifted the regime to increasingly include the working classes and continued the shift towards supplying more varied services as cookers were hired out with prepayment meters
Branching point 3: Perceived need to compete on price and quality		
To introduce incandescent gas mantles (from 1898)	Private and municipal gas undertakings (central)	Strengthened the competitive position of gas light, so regime continued supplying this energy service
Jointly mounting a legal fight against the holder of the British Welsbach mantle patent (1901)	Private and municipal gas undertakings (central)	Strengthened the competitive position of gas light, so regime continued supplying this energy service

Table 1. Choices made at branching points in the manufactured gas regime, 1877-1914

As a result of these choices and actions by the municipal and private gas companies, by 1914, the manufactured gas regime had undergone a transition to providing a wider range of services, including not only lighting but also cooking. Gas customers had more than tripled in numbers, to 7 million, and now included a growing number of working class households. The transition was led by actors operating in the market logic: the companies, whose decisions are listed in Table 1. The government had a limited role in the transition, setting the regulatory context but neither promoting nor discouraging the transition. Similarly, civil society actors do not appear to have actively argued against the companies' decisions but instead supported them by e.g., renting appliances, using slot meters or gas mantles. Some groups also encouraged the use of gas cookers amongst working class households as a way of improving health (Clendinning, 2004).

The companies usually took their decisions individually (e.g., each decided individually to introduce prepayment meters or gas mantles), but sometimes they decided to cooperate (e.g. regarding the 1882-3 exhibition). The companies took different decisions for different reasons but overall they operated within the market logic, which led to particular, profit-motivated, decisions being taken and thus gave a specific character to the transition pathway. It was shaped by the companies' desire to increase sales of gas through their choices, e.g. by promoting gas cooking and increasing customer numbers, and also to retain their share of the lighting market through the use of the more-efficient gas mantles. The decisions led to path-dependency, in the sense that future decisions were limited by the companies' choices to develop their markets in particular ways. The industry did not look back from the promotion of non-lighting uses of gas through appliance hire, nor from the introduction of prepayment meters, once these decisions had taken hold in the regime. For example, the companies continued for decades to develop their market through advertising and other promotional tactics, such as the use of lady demonstrators and prepayment meters.

Although charges for prepayment meters and appliance hire did not always cover the companies' costs of provision, requiring cross-subsidy from gas sales, the companies continued on this path, partly as there was high demand from consumers and partly because they seem to have seen no other way of doing things (Goodall, 1999:ch 9). This illustrates how decisions at branching points may lead to path-dependent trajectories that with hindsight appear sub-optimal, as discussed in section 2. The companies also took particular decisions about capital costs, which may be not unusual in market-led transitions. New machinery, offering lower production costs, was only introduced as old plant wore out (Matthews, 1983, 1987). Companies did not strand their assets even though this might have led to higher profits.

How do these historic branching points link with the prospective transition pathways? From this case, we can see that in a market-led transition with multiple players and imperfect information, heterogeneity in decision making might be expected – for example, some companies did not think it was worth selling gas to working class customers and were (at least initially) against introducing prepayment meters, whilst others wished to increase working class custom and decided to experiment with prepayment (Goodall, 1999). In a market-led transition there is the potential, in the absence of high barriers to entry, for diffusion of power amongst a wide range of actors, in this case the many hundreds of companies of different sizes and financial power, as well as other actors. The changes resulting from the decisions of many actors operating within the market logic may differ, both in form and content, from change that happens when fewer actors in a different governance logic make choices. For example, having a range of actors with potentially different approaches enables the creation of more options and more diverse choices, although such diffusion may also mean that increasing returns develop less rapidly.

3.2. Branching points on the pathway of manufactured to natural gas regime 1948-1977

Arapostathis et al. (2012, this volume) also show how the transition from manufactured gas to the use of natural gas for energy services in the second half of the 20th Century was a more government-led transition. A small number of players and a dominant government logic drove through a major transition in technology, institutions and infrastructures. In this case, the prevalent 'logic' prioritised state planning, fuel policy, capacity building, energy security and consumer safety, as well as security of investments. The regime was able to achieve, in a relatively short time, a transition that required a high level of co-ordination. This led to the emergence of a four fuel economy in the UK, with large roles for petroleum, coal, natural gas, and primary electricity from hydro and nuclear power (Geels and Turnheim, 2010).

In 1948, the UK gas industry was nationalised, because of its perceived strategic importance and socio-cultural and political changes after World War II that favoured greater state intervention. In the post-1948 period, the gas industry experienced exogenous and endogenous challenges: the high cost of manufacture of gas from coal and market competition from other energy sources, particularly electricity (Curwen, 1986: 25-26, 28; Millward, 1997; Williams, 1981: 89-119). While economies of scale were pursued through the centralisation and concentration of production, this was deemed inadequate to ensure the continued dominant role of gas for energy services. Regime actors, which were by then state-owned companies and agencies, responded by introducing niche technologies at the end-use and the production side, helping to determine the character of this transition. Several niche technologies were tried in order to improve the economics and the competitiveness of manufactured gas, leading to Branching Point 1 identified in Table 2.

In the political and institutional setting established from the nationalisation of the gas industry, the relation between the Gas Council and the Area Boards was characterized as an 'experiment in cooperation by consent' (Gas Council, 1951: 6). While the Area Boards had sufficient independence to manage and develop the gas networks and set regional fuel policy, the Gas Council acquired the jurisdiction, authority and power to make major decisions for the system as a whole. Thus they were able to plan, develop and coordinate R&D initiatives and activities for the production of gas from alternative sources, to assess the relevant technologies and to establish the setting for the economic, political and technological trend away from coal as the core feedstock in the manufactured gas regime.

Table 2 Choices made at branching points in the transition from manufactured to natural gas regime, 1948-1977

Choices made at branching points	*Key actors and their location in the governance system*	*Outcome for the transition pathway*
Branching Point 1: Perceived need to expand the market and diversify sources of gas in response to pressures from higher coal costs and competition from electricity, coal and oil		
Promotion of central and space heating (1960s)	Gas Council, Area Boards, Appliance manufacturers (e.g. Shell). Decision mostly at the level of Gas Council & the local Boards	Reinforcement of the incumbent regime, creation of new markets; increase of inherent pressures on the production side particularly for the Metropolitan Boards
Introduction of the Lurgi process (1960s)	Gas Council and Area Boards, National Coal Board, Ministry of Power. Decisions made both by Gas Council & the local Boards. Ministry of Power followed their policy suggestions	Niche technology for local problems. Internal adaptation, renewal & reconfiguration
Introduction of oil gasification processes (1960-1970)	Gas Council, Area Boards & Ministry of Power. Decisions made both by Gas Council & the local Boards. Ministry of Power followed their policy suggestions	Re-alignment of the regime/dominant technology in the late 1960s
Early experimental LNG transportation (1957-1960)	Ministry of Power, Gas Council, London Boards (North Thames Board, South Eastern Board,), Constock International Methane Ltd. Centralised decision making process	Experimental phase important for the enrolment of key actors to the use of LNG in a wider scale
LNG pipeline (1961)	Gas Council, Area Boards, Ministry of Power. Centralised decision making process	Niche technology for local problem & critical infrastructure. Reconfiguration of the pathway through hybridisation
North Sea Exploration and search for natural gas (mid 1960s and 1970s)	Combination initiatives by the state & private oil/gas companies; Gas Council key actor through involvement both in the production & the exclusive supply of gas nationwide.	Landscape pressure on the incumbent regime. Technological substitution
Branching Point 2: Perceived opportunity to respond to the discovery of North Sea gas		

Establishment of monopsony by the Gas Council in the UK natural gas regime (mid 1960s)	Government & Gas Council	Reinforced the centralisation of the regime & the state-led transition
The decision of the conversion as a single operation with no intermediate phase or period (1966)	Government, Gas Council & to a lesser degree the Area Boards. Centrally taken decision	Conversion to natural gas (1967-1977). Facilitated & provided a fast pace to the 'technological substitution'
Pilot Schemes for local conversion (1967-1977)	Gas Council and Area Boards. Decisions were made both centralised and at local level. Local Boards played important role in successful implementation of the pilot schemes.	Facilitated the 'technological substitution': developing expertise(s) & enrolling new actors. There were pressures in the new regime and reaction by actors of the incumbent regime – almost exclusively by the public. The schemes were established among other things as demonstrations to persuade the general public to support the new regime.
'Guaranteed Warmth' campaign (1969)	Gas Council & Area Boards. National promotion campaign	Important for the enrolment to the new regime
Commissioning of the Morton Report (1970)	Government & Gas Council	Important for the enrolment of new actors (the general public)
Gas Act 1972	Parliament, Government, Gas Council	Reinforced the centralisation of the regime & the state-led transition

The Lurgi process for manufacturing gas from lower grade coal was introduced by local Area Boards. The process did not progress beyond a niche technology, however, because its scaling up was assessed as economically infeasible and the Gas Council and the National Coal Board chose not to recommend further development. Despite the stake that the coal industry could have had as fuel supplier for the Lurgi process (Posner, 1973:66), the assessment informed the transition pathway by delineating the scale and the scope at which the process could contribute to gas production (Gas Council, 1964: 19-20; Williams, 1981: 121-125). The oil based processes proved more economic and quickly replaced coal based processes and related infrastructures in the 1960s, providing what proved to be an intermediate solution to maintaining the gas supply industry and opening up opportunities for further changes.

In the same period, imported liquefied natural gas (LNG) became a hybrid niche technology. It was introduced to solve local problems in London, but the scaling up and the establishment of a natural gas pipeline, which linked eight Area Gas Boards with the terminals for imported LNG, was promoted by the Gas Council as a planned transition. It aimed to provide high quality gas for the next fifteen years to regional systems, thus enabling the Area Boards to reduce the cost of gas supply (Gas Council, 1962:9). While the decision was made in order to reinforce the incumbent gas supply regime and address the cumulative pressures it faced, the natural gas pipeline constructed for imported LNG facilitated the integration of North Sea natural gas into the British energy mix, following the discovery of large gas reserves there in the 1960s.

The new LNG grid was the critical infrastructure that, along with the expectations surrounding the exploration for natural gas in the North Sea, provided the conditions for the existing gas regime's response to the window of opportunity that the natural gas discovery offered, leading to Branching Point 2 in Table 2. This enabled a decision by the state-owned gas industry actors to formulate a 10-year plan for the conversion of gas supply and all domestic appliances from manufactured gas to natural gas. The decision to convert all appliances to natural gas rather than reforming it to resemble manufactured gas was determined by several factors: the aspirations for a national fuel policy based heavily on natural gas; the initial positive indicators about the extent of the North Sea gas resources; the existence of the nascent LNG grid; and the regime's economic gains through avoiding the operating cost of the reforming plants and investments in the upgrading of the existing gas manufacturing plants (Tiratsoo, 1972: 211-212; Posner, 1973: 69-70). The change involved the stranding of existing infrastructure assets, the enactment of strategies for the enrolment of more actors to the new regime, and the requirement for domestic actors to allow members of an army of newly-trained technicians to enter their homes to convert their appliances to run on natural gas. In this case, the government-led nature of the transition enabled a high level of co-ordination between different actors and the imposition on some unwilling actors, such as householders, in order to achieve a transition that both government and industry - natural gas companies, appliance manufacturers, gas engineering institutes - agreed would be beneficial for society as a whole. However, at key points, the nature of the government-led system had also allowed experimentation in niches as to the most desirable alternative source of gas, which then helped to enable the chosen transition pathway to natural gas. In our view, moreover, the willingness of the gas regime to undertake a new, more intrusive form of engagement with its domestic customers, offers insights into the challenges likely to be faced by the introduction of smart meters and controls.

While future branching points will of course not be like those in the historic cases described here, there will be some similarities. For example, the role of different actors will be complex. While logic-leading actors dominate, other actors, such as the local authority town gas corporations in the early case, are enrolled into the dominant logic and behave accordingly, operating as profit-motivated entities and taking decisions accordingly. At the same time, some actors do not behave according to the dominant 'logic'. The historical cases show that real transitions are far from being linear and well structured as those in idealised pathways of future scenarios. They are characterized by uncertainties, ambivalences, competing 'logics' and heterogeneity as well as acts for the establishment of one specific 'logic' and the achievement of homogeneity. It is crucial to integrate historical transitions in the analysis because they not only highlight the complexity and the messiness of the past but they make clear that relations and acts of power defined dominant 'logics' and social orders. Power was enforced by substantial institutional change (as in the second case) or through new strategies of social marketing that attributed the meanings to specific technologies and constructed their trustworthiness. Relations and networks of power are existent yet different under different governance regimes. The branching point analysis stresses the importance of developing policy scenarios that take into account existing path dependencies, while the analysis maintains the dynamism to integrate the variety of futures and the heterogeneity of behaviours developed by different actors. In this way policy scenarios can acquire more depth, reflecting the reality that the appraisal and validation of technological solutions are social processes and that governance patterns are permeated by relations of power.

4. The identification of branching points on the core pathways

The historical cases summarised above provide examples of branching points at which the continuation of the dominant market-led or government-led logic helped to enable a specific transition. Also while the civil society logic was largely absent from these examples, the agency and role of civil society and consumer groups were important considerations for the decision takers who wished to enrol them. In these two cases, the dominance of a particular logic was mainly determined by wider landscape-level socio-cultural and political factors that influenced the perceived roles and agency of markets, governments and civil society, so the logic of the pathway was not fundamentally challenged at these branching points. Nevertheless, they demonstrate how actors responded to challenges or opportunities that arose which had significant implications for the transition then underway.

As described in section 2, for our three core transition pathways, we aimed to identify particular branching points at which the dominant logic in each pathway might be challenged at various levels. We identified an initial set of branching points for our transition pathways through several workshop sessions with project team members and external stakeholders, as well as through feedback from other stakeholders to presentations at other project meetings and conferences. In particular, branching points were proposed and discussed at a workshop with project team members and employees of the energy firm E.On at Loughborough in May 2010 and at a workshop for the project Research Associates and PhD students in Bath in July 2010. The Loughborough workshop identified branching points for the three pathways, and examined criteria for assessing how actors within the pathways might respond at these branching points. The Bath workshop identified branching points for the three pathways, and discussed potential measures for managing the risks associated with them. A draft approach and initial set of branching points were discussed in a small project group meeting at the RSA in London in January 2011. The insights from the historical case studies summarised above have helped to flesh out the branching points, and a further workshop was held in September 2011 at Imperial College, to identify analogues for use in the analysis of past branching points in electricity regime pathways and to explore typologies of branching points. From these workshops and discussions, a small set of branching points for more detailed analysis were developed. Finally, two workshops with industry, academic, policy and NGO stakeholders were held in November 2011 to reflect on the proposed branching points and actors' responses and mitigation strategies.

As noted, we define a *branching point* as a key decision point on a pathway at which choices made by actors, in response to internal or external pressures, determine whether and in what ways the pathway is followed. In some circumstances, the choices made at such a point could give rise to a coevolutionary sequence of increasing returns that would result in systemic changes, such that the original pathway would no longer be followed. As each pathway is characterised by the logic that defines the dominant form of governance in that period's action space, this would imply a breakdown in the dominant logic at the branching point. It is worth emphasising that at a key branching point a pathway's logic can be challenged at different levels, including its choice of technologies and/or policies with which to pursue that logic. While responses to these challenges can significantly reshape a pathway and its technology and policy mix, only some challenges will prove fundamental for its logic.

In order to simplify the analysis, we assume that the choices made by the actors could lead to one of the following responses:

a) Logic of the pathway is reinforced, and pathway continues on the same trajectory;

b) Logic of the pathway is challenged, and pathway branches to a new trajectory with a mixed logic, more similar to another of our core pathways;
c) Logic of the pathway is severely challenged, and transition fails.

Firstly, we explore branching points specific to each pathway. Reflection on the pathway narratives in stakeholder workshops has highlighted potentially significant branching points within each pathway. For each branching point, we identify the choices made by actors that could lead to responses of type (a), (b) or (c), and examine strategies for mitigating the risks and exploiting the opportunities associated with these branching points. This informs our understanding of the plausibility and internal consistency of the pathways, as well as their sensitivity and resilience to internal challenges. Secondly, we identify and examine a limited set of key branching points across all three pathways. This analysis examines how each pathway might be perturbed by an external stimulus, which might include, for example, political factors leading to a lower than expected carbon price, or economic factors affecting the gas price. The focus in this case, will be how external factors ('non actor contingent' factors (Hughes et al., 2012, this volume)) could affect the pathways in different ways. This will examine the robustness of pathways, and compare and contrast responses across pathways. The proposed branching points and actors' choices and response strategies were tested at the workshops with project team members and external stakeholders in November 2011. This aims not only to identify not only defensive strategies for mitigating risks, but also strategies for taking advantage of windows of opportunity and stimulating virtuous cycles of positive feedbacks, associated with 'path creation'.

5. Analysis of branching points

As described above, through workshops with internal and external stakeholders, we have selected and begun to analyse several initial branching points on our low carbon transition pathways, which we discuss in this section. These obviously represent a subset of the possible branching points on these pathways, but are ones that the project team and the external stakeholders regarded as particularly interesting and relevant for UK energy policy debates.

5.1. Branching points specific to each pathway

(1) **Branching point** for the *Market Rules* pathway: Carbon capture and storage (CCS) is assessed in 2020 to be commercially unviable, triggered by failure of costs to fall, technology to perform or public to accept, without strong action by central government to overcome these.

The logic of the *Market Rules* pathway is that market mechanisms are the main driver of investment in new technologies, and branching points will relate to the perceived failure of these mechanisms to deliver outcomes that benefit market actors and keep the pathway on track to play its part in meeting the UK's 80% UK greenhouse gas reduction target. Branching points can be stimulated by other actors challenging the legitimacy of the market-based logic, if it is seen as not delivering for climate change or other reasons. If decision makers decide that a technology which had been expected to play a crucial role in delivering a low carbon transition, such as CCS, is not viable, then this could give rise to an existential challenge to the dominant market logic, if this is held to be incapable of delivering the low carbon technologies needed. (While a CCS branching point might also occur in the other pathways, we suggest that the more significant role of CCS in *Market Rules* makes this case specific to this pathway. This does not rule out examining elsewhere the somewhat different

CCS-related branching point that might occur in the *Central Coordination* pathway, for example.)

So, this branching point envisages CCS being assessed in 2020 by large energy firms to be commercially unviable. This would create severe challenges and potential conflicts between different actors, as the large energy firms consider whether they are willing to invest further in the development of this technology and, if so, what further types of support mechanisms from government, such as equity stakes in companies pursuing this technology, and/or changes to regulatory frameworks, e.g. some form of Emissions Performance Standard (DECC, 2011), would be required.

Some potential responses at this branching point are then:

a) Market actors decide to continue investing in CCS development, in order to achieve future costs reductions, driven by expectations of large export markets for successful CCS technology;
b) Market mechanisms judged to be incapable of delivering large-scale low carbon technologies, so branch to Central Co-ordination pathway;
c) Widespread scepticism of achieving carbon reduction targets and concerns about energy security lead to renewed investment in unabated coal and gas-fired generation.

Participants at the November workshops argued that, in some ways, this branching point is already occurring, with the announcement in October 2011 that the final CCS demonstration plant to be supported under the UK government's CCS competition, at Longannet in Scotland, was not going ahead, due to concerns over the returns on investment. Other proposed CCS for coal-fired generation demonstration projects, such as E.ON's plant at Kingsnorth, had already been shelved because of investment and planning concerns. It was felt that the private sector will not provide the investment needed (about £1 billion for CCS) without major government incentives to make it financially reasonable. The absence of a properly functioning worldwide carbon market meant that first mover advantage and IP issues were not really seen as significant incentives. Consequently, it was suggested that the risk-reward ratio for UK investment in CCS was not good.

How might market actors prepare for and so mitigate the risks associated with this branching point? They could undertake a number of strategies. For example: (i) they might invest earlier in a larger number of demonstration plants, in order to achieve cost reductions, improved performance and greater public acceptance; (ii) they might reduce unrealistic expectations of CCS technologies by having a slower pace of demonstration programme, which key actors judge to be more realistic; or (iii) they might undertake greater and earlier public engagement, which might help to improve public awareness of CCS technologies and acceptability of the negative impacts. This could highlight, for example, how local communities could benefit from the introduction of CCS technologies either financially or through the creation of jobs. Alternatively, market actors might be stimulated to consider technological and market-related alternatives to substantial investment in CCS, and to engage with the adoption of proactive exit strategies from this technology. More broadly, they could evaluate any windows of opportunity opened by the lowered commercial prospects for CCS and seek to exploit them.

(2) **Branching point** for the *Central Co-ordination* pathway: the Strategic Energy Agency fails, due to ineffectiveness and lack of stakeholder 'buy in'.

The logic of the *Central Co-ordination* pathway is that strong action by central government is needed to persuade other actors to take actions to keep the pathway on track to meet the 80% target. In this pathway, this is facilitated by the creation of a powerful Strategic Energy Agency that issues and manages contracts for tranches for centralised generation. Branching points could arise from the perceived failure of government and/or its market partners to deliver, or if the wider social and economic costs of government action are perceived to be too high. In this case, a branching point is associated with the failure of the Strategic Energy Agency (SEA) to keep the energy system on track to achieve the Government's carbon reduction targets for the fourth carbon budget period 2023-2027. This could arise through a combination of events, only some of which would be under the SEA's control, e.g. voter discontent with the failure and passed through costs of particular low carbon technologies, or industry discontent with a perceived meddlesome, high tax regime. The negotiation of long-term contracts with electricity generating firms could present a key information asymmetry challenge for the SEA, as the industry actors are likely to have more information about likely future generation costs and technology performance, and so be able to negotiate contracts that are more favourable to the firms than to the SEA, electricity customers or the taxpayer.

Some potential responses at this branching point are:

a) Government proceeds to a new form of nationalisation of key electricity industry assets, driven by public concerns over meeting carbon reduction targets and maintaining energy security;
b) 'Bureaucratic interference and incompetence' blamed for failure – move back toward market mechanism, but delays in investment decisions and time lost in moving towards carbon targets;
c) Lack of co-ordination and failure to deliver appropriate low carbon capacity and demand reduction gives rise to power shortages, which leads to a 'two-tier' price-driven electricity system, in which richer customers get better service and poorer customers face intermittent black-outs.

Participants at the November workshops argued that it is unlikely that the UK would move towards the re-nationalisation of key electricity infrastructure assets, as in response (a). They thought it more likely to move towards a more regulated electricity industry, which also would have important repercussions. The government would contract for specific tranches of low-carbon generation and the state would introduce more control over the industry but would not move towards ownership. In general, it was argued, private companies prefer markets, as through market processes, they can establish their interests and can secure higher risk but higher return investments. Through this new regulatory regime, a new investment regime might be established, based on long-term contracts with a low but guaranteed return on investment. This would be less attractive to private energy companies, but might attract investment from insurance and pension companies. This would imply a change in the make-up of the ownership of the assets in the electricity industry, but could potentially tap into significant sources of finance needed for new low-carbon generation.

This could be a significant branching point, as it is hard to see how to branch back to a commercial market for generation, if branching reinforces the central co-ordination pathway, unless a sufficiently high carbon price were later imposed in order to stimulate low carbon investment by market actors. Several energy industry participants felt that there was a danger that this type of regulated market for generation would be less innovative, as arguably was the case in the regulated market for distribution networks following privatisation in the UK.

Government actors could undertake a number of strategies, in order to prepare for and so mitigate the risks associated with this branching point. For example, (i) lack of delivery on the SEA's aims could lead government actors to consult with the market generation and supply actors to see whether and how the issues around incentives to invest might be resolved; (ii) public discontent could lead them to undertake much earlier public engagement, well before large measures are planned and they could strive to ensure that policies are clear, well presented and transparent; or (iii) government actors could take strategic actions to try to avert this branching point by promoting the benefits of this pathway to the public, e.g. through promoting the creation of local "Green Jobs" for the future. Other risk mitigation strategies suggested by stakeholders include:

- Strategies to increase the capacity and security of the system, in order to guarantee the resilience of the system to avoid blackouts.
- Policies for securing the affordability of electricity and for even distribution of energy consumption; policies for overcoming fuel poverty, by economic transfers from outside the energy industry.
- Political stability regarding incentives for investment in low carbon generation.
- Stable and transparent energy market prices.

(3) **Branching point** for the *Thousand Flowers* pathway: 'Too much to carry', in terms of the range of actions that need to happen to keep the pathway on track, e.g. the growth and performance of Energy Service Companies (ESCOs), the satisfactory development of distributed generation (DG), increased prices, improving the energy saving performance of the building stock, and the challenges that households might experience in engaging with and managing multiple technologies, initiatives and incentives.

The logic of the *Thousand Flowers* pathway is that civil society actors become convinced of the need to act on climate change and decide that neither central government nor market actors are likely to deliver sufficient action to keep the pathway on track to meet the 80% target. As this would represent a significant change from current pathways, branching points could arise from failure of this pathway to take hold, as well as the perceived failure of this pathway to deliver sufficient action. The branching point identified here is that this pathway faces 'too much to carry', i.e. there are too many mutually dependent things that need to happen for this pathway to be realised, and so actors become disillusioned with this pathway when some of them fail to occur.

Some potential responses at this branching point are:

a) Community groups take active ownership of local electricity networks to work together to overcome problems – much higher level of social engagement in energy provision.
b) (i) National government steps in to manage problems, and moves back towards centralised generation – branch to *Central Co-ordination*.
   (ii) Large energy companies step into manage problems and take over community-led energy schemes – branch to *Market Rules*.
c) No-one in control of system, and patchwork of different local problems, resulting in targets being missed.

Several participants at the November workshops argued that Thousand Flowers represents a radically different pathway to that of current market-led or government-led pathways. It necessitates changes in the production and usage patterns that challenges the 'big is beautiful' approach in the production side and changes the role of DNOs. By giving emphasis to local grids, the architecture of the regime in this pathway is very different both technologically, institutionally, economically and socially. Technologically, the physical infrastructure would change drastically, as it would resemble more closely the development of virtual networks on the internet rather than the current technological infrastructure, in which the ‘super grid’ provides the core of the problem solving strategies. Due to the different architecture of the physical infrastructure that the Thousand Flowers pathway would necessitate, it is likely to be difficult to branch to this pathway because existing technological infrastructures have momentum. This would require deliberate acts of path creation in order to create virtuous cycles of social and technological change needed to go down this pathway, as discussed in Foxon (this volume). However, once on this pathway, the significant changes occurring would mean that it would then be difficult to branch back to another pathway, because the whole architecture of the regime would have changed. This raises challenges of the extent to which this pathway would then be ‘locked in’, creating barriers to realising responses (b(i)) or (b(ii)) at this branching point. The different physical infrastructure would require a distribution of production as well as different governance models and institutional arrangements, not only locally but nationally. The Thousand Flowers pathway requires new interface institutions and would challenge the roles of Ofgem and National Grid. It was suggested that energy services might become like platforms on the internet rather than commodity delivery services. The concepts of ownership and control infrastructure networks would change. Local control and local ownership might become more important than centralised ordered regimes. Transnational networks could get more difficult in a Thousand Flowers pathway. New finance schemes with hybrid finance (market and local government investments) would be necessary. The Thousand Flowers pathway is more compatible with a de-industrialised future and more focused on consumer based energy services (domestic, transport, heating etc.) than the other pathways. This pathway would involve a significant degree of community leadership. The vision and aspiration that local communities would bring to climate change mitigation solutions would influence activities and social practices, while local authorities would identify climate change mitigation targets. The local authorities could start to acquire new and crucial roles in the sociotechnical transition by coordinating the variety of actors that a Thousand Flowers pathway would involve.

In relation to the potential responses to the branching point at which the range of actions needed for the *Thousand Flowers* pathway might become too much to carry, industry participants tended to agree that these potential responses were all plausible to some degree, though they all required major regulatory and behavioural changes, as well as new ways of providing technical and financial assistance to the civil society actors involved. However, they tended to favour response (b(ii)), in which large energy companies would change their business model to work within a Thousand Flowers framework. Here the companies would move towards investing in distributed generation, through providing technical help in partnerships with local groups or individuals. Alternatively, small or medium sized companies might pop up doing this. However, the pathway in general, and option (b(ii)) in particular, would require changes to governance and regulations, to create the possibility for new business models and new ways of doing things.

Civil society actors could undertake a number of strategies, in order to prepare for and so mitigate the risks associated with this branching point. For example, (i) local community groups could establish ways of sharing knowledge and insights with other groups through social networks, in order to disseminate more widely local solutions to particular problems to take advantage of any opportunties that may have arisen; and (ii) they could lobby for active government support to be given to local community groups, rather than to large energy firms.

5.2. Branching point across the three pathways

Branching point across the three pathways: Disputes about the development of 'smart grid/smart control', e.g. do benefits go mainly to producers or consumers, triggered by competing visions of smart grids, and do consumers interpret such developments as unwarranted intrusions or infringements of liberty by market or government actors?

Potential responses at this branching point are:

a) Current market actors (large electricity companies) perceive the benefits to them of the smart grid, in relation to more effective management of the electricity system and so invest in smart grid control technologies – while consumers are still seen in relatively passive roles;
b) The smart grid is seen more as an enabling technology to incorporate distributed generation, microgeneration and demand side developments, led by new entrants to industry, such as ICT companies and user interface companies;
c) Discordant visions of the smart grid and smart controls slow down developments and prevents the realisation of their benefits.

Participants at the November workshops argued that the current UK government targets for every home to have a smart meter by 2020 creates an incentive for using current designs for smart meters, which could lead to a possible lock-in into a minimal definition of 'smart', with benefits primarily to market actors. This might lead to a possible backlash against the perception of the market as the key beneficiary, as well as against issues of control and invasion of privacy. This might especially be an issue on the *Market Rules* pathway.

The role of different actors was also argued to be significant. Distribution network operators were said to be conservative and might not see any benefit from a smart grid, as a higher use of the network, 'sweating their assets', might not be attractive to them. Customers might consider that who is promoting and selling 'smart' would be important in terms of trust and perception. If the state were to play this role, it might be viewed to be intrusive, as was the case with the subsequently scrapped proposal for national ID-cards. If the energy companies play the role, it might be viewed more like a reward card offered by major supermarkets, which consumers might more readily accept, as it would offer identifiable benefits to them. If a major IT firm were to play this role, it might be seen as an innovative way of using energy. Thus, it was argued, who sells will affect how it is received. An aspect of 'smart' is that a more advanced or complex tariff will be needed and people would then need to sign up to this. The issue concerns not just a piece of 'kit' but also regulatory frameworks, again providing space for different perceptions of who might lose or win.

For 'smart' to work in terms of reducing the need for expensive peaking plants, it was suggested that it must work technologically. Government software projects often have not delivered, so an important issue would be whether either government or companies could deliver. Power companies might not know their customers well enough, so a major retailer or IT firm might perhaps be more likely to deliver successfully.

The risk mitigation strategies were said to depend on how the problem might be perceived. If 'smart' were initially seen negatively or apathetically as just showing how customers much money they spent and not allowing them to do anything about their spending, this perception might be changed by increasing what the system offered. The possibility of doing this might differ between pathways. It was suggested that another approach might be to give customers a strong choice between smart technology or increased investment for which they would have to pay. This was said to be more likely in *Central Co-ordination* or *Thousand Flowers*, while quite unlikely in *Market Rules*.

Leading actors could undertake a number of strategies, in order to prepare for and so mitigate the risks associated with this branching point and/or to take advantage of any opportunities that might arise. For example, (i) government actors might ensure that a wider public debate is undertaken around visions of the smart grid, leading to agreements that enable greater accord among different actors about how benefits and costs are to be shared; or (ii) they might actively work to achieve greater public acceptance of and engagement with smart control processes.

The branching points discussed in this section illustrate that steps along a low-carbon pathways matter, and that 'getting there from here' is a path-dependent process in which progress can be challenged by events and pressures, and shaped or re-shaped by actors' agency in relation to their logics and to the threats and opportunities they perceive. In the next section we discuss how insights from this branching point analysis could inform proactive thinking and decision-making.

6. How might branching point analysis inform decision making?

The above examples of the analysis of branching points along our core transition pathways illustrate how they may be used as a tool to elicit stakeholder reflections on potential responses of actors and risk mitigation strategies at these points. Here, we examine the extent to which this type of branching point analysis can begin to incorporate the path dependent and actor contingent nature of energy systems change into future pathways or scenarios. As described in Foxon (2012, this volume), our transition pathways approach aims to more explicitly incorporate social structures and agency, including institutions and politics, into future energy studies (cf. Wangel, 2011; Nilsson et al., 2011). The approach thus aims to provide insight into how actors' decisions enable changes to happen and how institutions constrain or enable this decision making.

This builds on thinking about different potential uses of long-term socio-technical scenarios. Hughes et al. (2012, this volume) argue that while reflection on long term futures is a complex activity with an uncertain epistemology, scenarios can usefully distinguish 'actor contingent' elements that reflect developments which are within the power of systems actors to change or bring about, from 'pre-determined elements' within the system, arising from fixed actor motivations, and external 'non-actor contingent elements', which system actors cannot influence. Pre-determined and non-actor contingent elements prompt the need for *protective* decision making, in which scenario users take action to increase robustness of pathways against internal and external threats; whilst actor-contingent elements suggest the need for *proactive* decision making, in which scenario users identify opportunities to intervene on and influence the system, or for *consensus building*, in which diverse actors come together to engage in moving towards a common goal (Hughes et al. 2012, this volume). The analysis of branching points on the pathways is intended to offer insights that will inform actors of opportunities for the kinds of proactive and protective decision making and societal consensus building that Hughes et al. have described.

For example, the branching point associated with the failure of carbon capture and storage

(CCS) technologies in the *Market Rules* pathway may be argued to have both actor-contingent and non-actor contingent elements, as the success of these technologies will depend both on the investment and effort applied to their development in the UK, and on physical and institutional factors affecting their viability in the UK and the investment and effort applied to their development by actors outside the UK energy system. This suggests that the likely success of this pathway will then depend on proactive decisions by large energy firms to invest in technology demonstration and on efforts to build a public and political consensus for institutional and financial support for this technology, as well as the need for protective decision making for the development of alternative technologies, should CCS not prove viable in the UK context. Similarly, the branching point associated with the failure of the Strategic Energy Agency (SEA) in the *Central Co-ordination* pathway illustrates the need for building a consensus around the aims and functioning of this Agency, if this pathway were to be followed.

The reaction of different actors to the 'too much to carry' branching point associated with the *Thousand Flowers* pathway is likely to depend strongly on their views of the feasibility and desirability of this pathway. Civil society actors might reflect on proactive decisions needed to strengthen the resilience of this pathways and the need to enrol a wider range of actors in order to build a consensus for support amongst publics, policy makers and new entrant ESCOs for the actions needed to realise this pathway. Government and market actors might reflect on the need for protective decision making to enable government or market actors to step in to address problems that may arise if other actors choose to follow this pathway.

Reflecting on these specific examples thus illuminates the potential of this type of branching points analysis to inform actors' thinking and decision making in relation to future transition pathways. Firstly, an understanding of historical branching points in the energy services sector helps to appreciate the complexity and the dynamic processes of decision making at critical points on a transition pathway, as well as issues of path dependence. By studying the processes of enrolment and network building that actors undertook at past branching points, we can better understand the process of governing transitions and explore how competing 'logics' were debated, finally established and maintained during past transitions. This can provide a richer reconstruction of the 'logics' of market, state and more participatory governance patterns as they developed in the past. It informs our understanding of the structure and dynamics of transitions and draws helpful insights into processes of lock-in or lock-out, as well as path dependence and path creation. Secondly, the study of potential future branching points matters because decisions taken at them can exert significant influences on the nature, magnitude and timing of transition pathways. Thirdly, in positing future transition pathways, we try to anticipate and understand key choices, opportunities and constraints that different actor groups might face along a pathway. So, government, market and civil society actors will want to scope the potentially significant pathway-influencing pressures and responses that they and other actors might experience. In this way, they might be better prepared to understand both the opportunities and the constraints that could influence progress along (and the nature of) a pathway, and hence be able to address them more effectively than they otherwise would have done. This relates to areas ranging from policy strategies and the choice of instruments, to technology development and deployment and to participation in market or non-market activities and behaviours.

Thus it matters to understand how a pathway might develop, the pressures and tensions that potentially significant actors could face and their responses in the face of them. The literature on lock-in, path dependence and path creation has shown how future pathways and the options and choices on them can be shaped and constrained by decisions made at past branching points. Similarly, other parts of the innovation literature have shown the importance of windows of opportunity and the possibilities of virtuous and vicious cycles. We argue that analysis of branching points could help actors to take better account of these aspects of the dynamics of pathway development.

7. Conclusions and next steps

In this paper, we have shown how, through the development and socio-technical analysis of transition pathways (taking account of governance, agency and the interactions between different actor groups) and undertaking a series of stakeholder workshops, we identified and analysed a set of plausible branching points in order to illuminate the dynamics and choices along those pathways. We have also shown how understanding the steps along pathways through this kind of analysis can enable actors more effectively to anticipate and shape them.

This paper has argued that the study of branching points can add theoretical understanding and policy relevance to the investigation of low carbon transition pathways. We have shown how an understanding of historical branching points in the energy services sector informs understanding of the complexity and dynamic processes of decision making at critical points in transitions. It shows how key actors try to enrol other actors and build networks to reinforce their ‘logic’ or framing of issues. This highlights how, under the right circumstances, both market-led and government-led transitions can achieve a balance of co-ordination and freedom for experimentation needed for a successful transition. The historical evidence also suggests that it is useful to explore potential future branching points, as these could exert significant influence on the nature, magnitude and timing of transition pathways. Doing this should help to anticipate and understand key choices that different actor groups may face along a pathway, and by exploring the possible choices and the pressures that motivate and lead to them, enable these actors to better understand how to prepare for and address them. Our analysis shows that the governance of successful transitions relies on both the overall framing or logic that is dominant, and the decisions of actors following these logics at key branching points. Thus our approach incorporates significant roles for both agency and structure, and aims to provide a balance between action and reflection in the governance of socio-technical transitions.

In future work, we aim to further develop the relevance and usefulness of the branching points approach described here, and to identify and explore further potential branching points on the core transition pathways. We will also identify and examine other past branching points, in search of patterns, insights and typologies that might inform understanding of, and agency in relation to, prospective branching points on pathways to a low carbon future.

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