12. The use of computerized models in different policy formulation venues: the MARKAL energy model

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INTRODUCTION

At a particular point in time, a policy formulation tool may provide real opportunities for learning or serve to rationalize pre-existing decisions (Hertin et al. 2009). This chapter examines the varying uses to which a particular energy system model – MARKAL – has been put in the UK. We define the scope of policy venues to include all policy-salient institutions using the model: academic-consulting research groups, government departments and non-departmental government bodies. We view MARKAL as a boundary object (Star and Griesemer 1989) that has served the differing but intersecting needs of academic, consulting and policy communities over a sustained period of time, helping both to inform and justify major and innovative climate and energy policy commitments. We suggest that the model has functioned to bind mutually supportive epistemic communities across academic and policy worlds, helping to develop and maintain, both materially and cognitively, a networked and influential community with shared assumptions and goals in which economic and technical models are privileged.

We reflect on how the model has both been advantaged by changing understandings (images) (Baumgartner and Jones 2002) of the energy policy problem, as climate objectives have increased in salience, while also playing a role in policy path creation, that is by supporting significant new climate policy commitments. In seeking to explain the above, we connect literatures on boundary objects in policy formulation and on the way in which changing images of a policy problem can allow new analytic and policy options to enter political and policy spaces. We observe how MARKAL has played a transformative role in this context, while itself also being transformed, as the modelling process has become more target-oriented, as the objectives of UK policy venues have evolved in response to changing political objectives and as new policy formulation venues have emerged.

In the remainder of this chapter, we begin by describing how the use of MARKAL in the UK has evolved from a focus on informing research and development (R&D) priorities in a public research organization to a much more prominent role in justifying major strategic energy policy choices. In examining the use of MARKAL across UK policy venues and over time, we suggest that it is an example of how a scientific model and its output may function as a boundary object that persists despite and because of the changing images of a particular policy problem. Finally, we comment on both the apparent hegemony and limits of technical energy policy modelling, in the light of possible future policy developments.

Our analysis of the ways in which the MARKAL model has been used across different policy venues draws on an examination of some 70 policy documents and presentations, of which 21 items were selected for closer inspection using qualitative analysis software. The selection of themes was guided by the theoretical considerations summarized below and the personal experience of the author team. The grey literature examined includes government policy documents, Parliamentary committee documents and also expert critiques of MARKAL. Changing use over time was evidenced and tracked; evidence for the changing policy image of the energy problem is inferred from the change in policy objectives, which are external to (though supported by) the model. Inference of the functioning of MARKAL as a boundary object is primarily based on observation of: (a) its value to the small academic-consultancy modelling community based at AEA Technology (now Ricardo-AEA) and originally at the Policy Studies Institute, then Kings College London and currently University College London; (b) its use in support of key energy-climate policy documents; and (c) its use in support of recommendations by the UK Committee on Climate Change regarding greenhouse gas (GHG) emissions budgets (sectoral and temporal).

THE CHANGING USE OF MARKAL IN UK POLICY DEVELOPMENT

During the late 1970s, the UK took part in the early development of MARKAL through the involvement of scientists from the UK Atomic Energy Authority (UK AEA) (Finnis 1980). Much of the early MARKAL modelling used scenarios that considered the trade-off between price (measured as the total cost of the energy system) and security of supply (represented by the quantity of imported oil) under different assumptions about the availability and rate of deployment of a range of new energy technologies (Altdorfer et al. 1979). Despite the early participation of the UK in its development and application, it would appear that there was little further use of the model to inform UK policymaking over the subsequent decade, perhaps reflecting the UK government's withdrawal from direct involvement in the energy sector and reliance on a market framework (Department of Energy 1982).

In the early 1990s, the MARKAL model was completely reconfigured and updated, and used to underpin an appraisal of energy technologies and the implications for associated R&D programmes (ETSU 1994a; 1994b). Nonetheless, the model remained at the periphery of mainstream energy policymaking at this point. Indeed, between 1998 and 2001, the UK government suspended active participation in the Energy Technology Systems Analysis Programme, which licences the use of the model generator that underpins all MARKAL models, retaining only an official observer status. Only in 2001, after several years without any substantial MARKAL-related analysis for the government, but with climate change shooting up the political agenda, was AEA Technology plc commissioned by the Department of Trade and Industry (DTI) to undertake its first project using the model specifically to examine energy-related CO_2 emissions. The aim of the work was 'to develop a range of bottom-up estimates of carbon dioxide emissions from the UK energy sector up to 2050, and to identify the technical possibilities and costs for the abatement of these emissions' (DTI 2003b). This work was featured in the Energy White Paper of 2003, in which MARKAL was used to estimate the costs of reaching deep emissions reduction targets.

The above notwithstanding, until 2005, the use of MARKAL in the UK was confined to government agencies or consultancies working under contract for government, rather than academia. This changed with the advent of the UK Energy Research Centre (UKERC), funded by the UK Research Councils' Energy Programme. During the early 2000s, it was clear that the UK's capacity to undertake energy research had become very limited. Overall research funding had fallen in response to two major trends: liberalization of energy markets and privatization of state-owned energy companies, which led to a decline in in-house R&D undertaken by energy companies, while low oil prices during the 1990s and the UK's status as an oil and gas exporter had ensured that energy was not a policy priority for R&D spending. As concern over the long-term security of supply rose, and climate change emerged as a pressing policy problem for future energy systems, UKERC was established as a cross-research council initiative. A key priority, identified early on, was the need to enhance the UK's ability to conduct analyses of the UK energy system as a whole, through an energy system modelling capacity (Strachan 2011). UKERC negotiated access to the UK MARKAL model with the DTI and funded the capacity to conduct a significant revision of it.

Following the major overhaul of the model beginning in 2005, led by the Policy Studies Institute, MARKAL took a prominent role in the analytic work underpinning the 2007 Energy White Paper (Strachan et al. 2009). It was subsequently used to inform the impact assessment for the Climate Change Bill, the 2008 White Paper on nuclear power, and the Committee on Climate Change's work on carbon budgets. In recent years, MARKAL's monopoly as an analytic tool for thinking about long-term (2050) energy system evolution has begun to be challenged by the emergence of other models. The Energy Technology Institute has developed the ESME model, a similar bottom-up, technologically explicit, cost-optimization framework for examining 2050 energy futures. The Department of Energy and Climate Change (DECC) itself developed an in-house tool, the 2050 Calculator, another technologically detailed, bottom-up framework that enables users to examine the implications of different choices in a number of abatement options.

These newer frameworks – which required considerable resources to develop – are very similar to the MARKAL paradigm. Like MARKAL, they focus on the detailed technology pathways to achieve 2050 emissions targets. There is a relative absence in policy processes of other types of tool for thinking about long-term energy systems change, such as highly disaggregated general equilibrium models, or various types of hybrid model. This suggests that the paradigm underpinning MARKAL (defined by technologically explicit whole-systems approaches focused on supplying energy at acceptable or least cost to meet carbon targets) has become so dominant in energy policy discourse that alternative frameworks struggle to achieve policy influence.

THEORETICAL PERSPECTIVES

In this section, we connect the idea of scientific models and their output as boundary objects to the theory of changing policy images as a facilitator of policy change. External pressures give issues greater political and policy salience, enabling policy change (Baumgartner and Jones 2002). We also see the punctuated equilibrium theory of policy change as being particularly relevant. This perspective views policy change occurring as a result of the interaction between policymakers and society (Baumgartner and Jones 1993; 2002; Princen 2000), with this change taking the form of relatively long periods of stasis being 'punctuated' by shorter periods of change (ibid; van Egmond and Zeiss 2010), also reminiscent of Kingdon's 'policy window' (Kingdon 1995) concept. Policy stasis is explained by the dominance of closed groups of policy experts, but can be interrupted by a changing image or idea of the nature of the policy problem. Driving these changes are competitive processes, both between government departments and in wider society, in which actors seek to achieve policy change that is consistent with their agendas (van Egmond and Zeiss 2010).

Our argument is, first, that MARKAL's changing use through the period circa 1990–2011 reflects a change in the prevalent image of the energy policy problem, from one in which the government saw its primary role as structuring and facilitating the market to provide for future energy demand, to a policy image of a climate-constrained world in which radical changes to the energy system would be required, with the attendant need for the government to identify how this transition could be achieved and which technologies might require support. MARKAL has been well positioned to allow consideration of new goals and configurations for the energy system. Second, we argue that this changing use has been strongly supported by the way in which MARKAL and its outputs have successfully functioned as a boundary object, connecting needs in different policy communities.

As van Egmond and Zeiss (2010) observe, the concept of a boundary object has proved useful in explaining the hybrid nature of scientific models used in policy – that is, the way in which such models are not only based on mathematical representations of the world, but are also shaped by, and play a role in shaping, the social world in which they are embedded (MacKenzie and Millo 2003). Scholars have previously studied the relationship between modelling practices and policy practices (for example, van Daalen et al. 2002; Evans 2000; Mattila 2005; Shackley and Wynne 1995), in general observing that models play a role in co-ordinating policy practice, specifically by providing 'discursive spaces' in which shared understandings are created between modellers and policymakers (Evans 2000). Previous understandings (in other words, shared perspectives) are made tangible in the form of numbers and their implications. Depending on their mode of use, models can define the terms in which policy questions are posed and answers given. Through the process of their use, the different parties involved retain their own norms and natures but are connected by the model, which satisfies needs in both (Star and Griesemer 1989).

In summary, we can see that scientific models may support, through their role as boundary objects, the entry of new ideas and perspectives into policy discourse, facilitating and reinforcing new policy images and hence policy change.

VARIATION AND CHANGE IN THE USE OF MARKAL

Changing images of the energy policy problem have enabled MARKAL to shift from an initial role in technology assessment, driven by concerns about oil import dependency; to a new context of liberalized energy markets in which different technologies competed to meet demand; to a key role in target-oriented climate policy, as the need to reduce greenhouse gas emissions increased in policy salience through the 2000s. This shift involved a change from using the model to focus on the relative prospects of specific technologies in order to inform R&D priorities, towards a focus on the costs and possible evolution of the entire energy system to meet carbon targets. Even more particularly, it came to involve the use of MARKAL to envisage radical changes in that system: MARKAL as a quantitative visioning, scenario generation tool. Throughout these changes, the model continued to play a valuable role for the key parties involved.

Use by Academic Policy Modellers

For UK academic policy modellers, MARKAL provides a means for examining a series of issues in energy system evolution and, in the case of some model variants, for exploring a (limited) set of interactions between these developments and the wider economy. The development of a UK version of the MARKAL–MACRO model in 2007 was a major experimental test of the importance of macroeconomic feedbacks on energy system development (Strachan et al. 2009). Subsequent model experiments have examined the importance of spatially constrained infrastructures by linking MARKAL to a geographical information system (Strachan et al. 2009), enabling representation of demand responses to price rises through the use of MARKAL–ED (Ekins et al. 2011), examining regional representation (Anandarajah and McDowall 2012), testing the importance of uncertainty and assumptions about foresight with Stochastic–MARKAL (Usher and Strachan 2010), and in ongoing work, testing the importance of consumption-based emissions accounting through linking MARKAL to a multi-region input–output model.

Use by UK Government Departments

During the 1990s, UK energy policy was supported by quantitative analysis from econometric models used by the Department of Energy and later the Department of Trade and Industry. These models principally relied on the historical analysis of drivers and trends in energy markets to provide insights about how they may evolve in the future and the implications for CO_2 emissions (DTI 1992; 1995; 2000). Policymakers were mostly interested in understanding how future energy supply and demand would evolve, rather than asking questions about how it could or should develop. Econometric models are well suited to analysing relatively stable energy markets, such as those seen in the late 1980s and early 1990s, when past trends and relationships could reasonably be expected to continue. They are not, however, suitable for envisaging large, long-term transitions in the technological make-up of an energy system, such as the kind that would be needed to seriously tackle the problem of climate change.

Since 2000, the environmental goals of energy policy, particularly in relation to climate change, have come to prominence in UK energy policy discourse. Policymakers have looked to the energy systems modelling community to provide answers to two major types of questions. First, they have asked 'what are the expected costs of meeting a given emissions reduction target?' Only a small number of model types are suitable for asking this question (particularly bottom-up energy systems models like MARKAL, and so called 'top-down' macroeconomic and general equilibrium models). Second, policymakers have asked 'what technologies are necessary for meeting the targets?' MARKAL-type models are uniquely well suited to providing an answer to the latter question. MARKAL thus provides a platform for meeting two basic government needs. First, it provides a way of justifying action in the face of climate change in terms acceptable to the bureaucratic norms embodied in the Treasury Green Book (HM Treasury 2011), that is, those of cost-effectiveness.[1] Second, it provides a way to imagine, understand and explore the dynamics of the complexity of the energy system and to identify potential technological pathways to meeting targets.

Use in the 2003 Energy White Paper

It was the publication of the 2003 Energy White Paper, *Our Energy Future,* that marked a clear transformation in the way that energy issues were approached in UK policy. The document noted that: '[e]nergy can no longer be thought of as a short-term domestic issue' (DTI 2003a, p. 3) and went on to state that: '[i]t will be clear from this white paper that we believe we need to prepare for an energy system that is likely to be quite different from today' (DTI 2003a, p. 16). The driving force behind this change was a growing awareness of the threat of climate change. The 22nd report of the Royal Commission on Environmental Pollution, *Energy – The Changing Climate*, published in 2000, played a highly influential role in this process, urging the government to 'adopt a strategy which puts the UK on a path to reducing carbon dioxide emissions by some 60% from [2000] levels by about 2050' (RCEP 2000, p. 28).

While our argument is that the changing image of the policy problem provided an opportunity for MARKAL's use (in other words, for MARKAL modellers), at this relatively early stage in the development of interlinked UK climate and energy policy, the extent to which MARKAL was used to support the 2003 White Paper is unclear. The White Paper states that it 'is based on a large amount of analysis and modelling' (DTI 2003a, p. 20). However, the only MARKAL results cited in the White Paper itself relate to the economic costs of the transition, including its impact on future levels of GDP and the costs of carbon abatement per tonne. It is worth noting that the figures for GDP loss were not a direct output from the model (the version of MARKAL used at this point simply reported total energy system cost, with no representation of the rest of the economy). Rather, they were calculated 'off-model' using MARKAL output and other simple assumptions and are noted by the modellers in the supporting material (DTI 2003b, p. 76) as being a 'ball park estimate'.

Furthermore, a memo published by DTI on the use of MARKAL modelling for the 2003 White Paper noted that 'there is great uncertainty about the forecasts which [MARKAL] provides' and that 'this type of approach is better suited to consideration of long-run impacts than transitional costs' (DTI, no date, p. 5). The fact that these GDP figures are given such prominence reflects the extent to which the economic cost of emissions reductions was central to the policy debate. Indeed, in an evaluation of the RCEP report, the Institute for European Environmental Policy (IEEP 2005, p. 51) explains that:

> DTI carried out a parallel modelling exercise using the MARKAL model, and concluded from this that the technology required could be installed at a relatively modest cost . . .. It is understood that this exercise overcame a key barrier to acceptance of the 60 per cent target, and appears greatly to have helped develop a positive attitude to carbon reductions in government.

The findings of the White Paper, and the role played therein by MARKAL, were not without their critics – although some of these perhaps credited MARKAL with more influence than it actually had. For example, during a House of Lords Select Committee hearing, Dr Dieter Helm noted:

> It is very important in this context to bear in mind that one of the advantages of MARKAL is to show you that if you pick certain assumptions you get particular answers. It turns out the government was deeply interested in a solution to the climate change problem which was largely based on wind and energy

> efficiency and not much else, particularly not nuclear power . . . *I am not at all clear in the policy process that the people making decisions fully understood how dependent they were on the nature of the assumptions that were going into the answer*. (House of Lords Select Committee on Economic Affairs 2005b, Q264–279, emphasis added)

Helm's evidence and that of other critics of the model led to the House of Lords concluding that '[w]e are concerned that UK energy and climate policy appears to rest on a very debatable model of the energy-economic system and on dubious assumptions about the costs of meeting the long-run 60% target' (House of Lords Select Committee on Economic Affairs 2005a, para 94). Despite this and, we would suggest, drawing strength from the increasing policy salience of climate change and the dearth of alternative models, MARKAL continued to play an important analytical role as the government further developed its more pro-active energy policy.

Use in the 2007 Energy White Paper

In 2007, MARKAL was used to support the government's subsequent White Paper *Meeting the Energy Challenge* (DTI 2007a). The Stern Review (Stern 2007) also added to a growing body of literature that underscored the urgency of reacting promptly to climate change. In addition to this, however, rapid rises in gas and oil prices which had occurred led to the issue of energy security joining carbon mitigation as a priority for energy policy (Pearson and Watson 2012). Following the Stern Review, the likely costs and benefits of a low-carbon transition continued to be an important element of the policy debate. In response, *Meeting the Energy Challenge* made use of the newer version (MARKAL–MACRO), which links MARKAL to a simple macroeconomic model. Unlike the standard version, MARKAL–MACRO can directly estimate the impacts on GDP of emissions reduction. However, use of this new model did not dramatically change the estimates of GDP impacts and many of the limitations associated with the 2003 MARKAL version, such as the omission of transition and behavioural costs, were still relevant.

Perhaps as a result of the earlier criticism, the 2007 White Paper discusses in some detail the cost estimates and their limitations, making clear how and why MARKAL results can 'be expected to produce lower-bound estimates of the costs of carbon abatement' (DTI 2007a, p. 292). Additionally, the 2007 document compensates for some of the weaknesses of MARKAL by also drawing on the results of other models. Yet the use of MARKAL to support the 2007 White Paper went far beyond calculating GDP impacts. *Meeting the Energy Challenge* explains its use of MARKAL–MACRO in the following terms: 'for the period to 2050, we have used a model of the entire UK energy system (UK MARKAL–Macro model) to explore the changes to the amount and use of energy required if we are to deliver our goal of reducing carbon emissions by 60% by 2050 at least cost' (DTI 2007a, p. 194).

MARKAL was also used to support a subtle change in government attitudes to what was at the time one of the most controversial of the technology options, nuclear power. The 2003 White Paper had concluded that 'its current economics make [nuclear] an unattractive option for new, carbon-free generating capacity' (DTI 2003a, p. 12), despite it making a significant contribution in many of the MARKAL scenarios developed as part of the supporting analysis. However, in the 2007 White Paper the technological results from MARKAL are given greater prominence, including sensitivity analyses of key parameters such as future fuel prices and innovation rates and runs to examine the impact of excluding certain technologies. These led to the conclusion that 'excluding nuclear is a more expensive route to achieving our carbon goal even though in our modelling, the costs of alternative technologies are assumed to fall over time as they mature' (DTI 2007a, p. 194).

This change in the government's stance on nuclear power was likely for a wide variety of reasons, including (but not limited to) the increased importance of security of supply, improvements in nuclear waste storage prospects and rising fossil fuel prices (DTI 2007a, pp. 180–216). However, the ability of MARKAL to clearly demonstrate the economic value of nuclear power appears to have been an important element in justifying nuclear as a low carbon option.

Use in Relation to the Climate Change Act

Following the 2007 Energy White Paper, the government published a draft Climate Change Bill, which became an Act of Parliament in 2008. This put in place a new legislative framework of five-year carbon budgets and established an independent Committee on Climate Change to advise government on the level of these budgets. As of mid-2013, the most recent use of MARKAL within this context has been in *The Carbon Plan*, published by the Department of Energy and Climate Change in 2011 (HMG 2011), which sets out proposals and policies for meeting the first four carbon budgets (covering the period to 2027). This report continued to rely substantially on quantitative modelling results to envisage how best to achieve the emission reduction targets (AEA 2011). The *Carbon Plan* states that: 'in line with our principle of seeking the most cost effective technology mix, our starting point for this has been to take the outputs of the "core" run of the cost-optimizing model, MARKAL' and that this core run 'illustrat[es] the technologies likely to contribute to reducing emissions, and the most cost effective timing for their deployment' (HMG 2011, p. 16). It should be noted that MARKAL is not the only model used to inform the *Carbon Plan*, which also draws on results from ESME (developed by the Energy Technologies Institute) and DECC's own Carbon Calculator. The *Carbon Plan* made use of MARKAL–'Elastic Demand', or MED, another variant on the standard version of the MARKAL model, in which the level of demand for energy services varies according to the costs of meeting them, based on a set of user-specified price elasticities. This is framed in the published reports as providing some insight into how changes in consumer behaviour (for example, lifestyle changes) could influence reductions in carbon emissions.

Use by the UK Committee on Climate Change

The Committee on Climate Change (CCC) has itself arisen as an institutional innovation from the changing energy-climate policy conception (other such innovations include the Low Carbon Innovation Co-ordination Group, which has also used results from MARKAL among other models). While the CCC shares the need of central government to analyse costs and technology pathways, it is not in the position of having to justify specific legislative proposals in the impact assessment format specified by the Treasury. While government departments have a strong need for tools that provide closure around specific options, the CCC is able to take a more reflective and advisory approach – including more explicit acknowledgement of the many uncertainties.

The Committee's first carbon budget report (CCC 2008) was the first policy venue to use the MARKAL–Elastic Demand (MED) model to examine the economic and technological implications for reducing carbon emissions by 80 or 90 per cent by 2050 (AEA 2008a; 2008b). The CCC appears to differ from other venues in the way in which it approaches assumptions and limitations of the modelling process. A frequently referenced limitation of the MARKAL model is its assumption of perfect foresight, meaning that the model is unable to capture the impact of uncertainty associated with factors such as technological innovation rates or fuel prices. While this limitation of modelling results is acknowledged and discussed in publications from government departments, modelling in support of the CCC's fourth carbon budget goes much further to overcome these limitations. Work for the CCC's fourth carbon budget (Usher and Strachan 2010), reported also in the fourth carbon budget report

(CCC 2011) deepens the focus on uncertainties by making use of the stochastic formulation of MARKAL.

Other Policy Venues

The Technology Innovation Needs Assessment (TINA) led by the Low Carbon Innovation Co-ordination Group (made up of government departments and other stakeholders) has used MARKAL and ESME outputs in identifying technology and innovation needs. Apart from its use within government departments and by the CCC, MARKAL has also been used in an NGO policy venue context, by the Institute for Public Policy Research in collaboration with the World Wildlife Fund (WWF) and Royal Society for the Protection of Birds in a report on reducing national carbon emission by 80 per cent by 2050 (IPPR et al. 2007). The goal of this work was to demonstrate how an 80 per cent target was within reach, both economically and technically, whilst excluding new nuclear build, placing limits on the use of both wind and biofuels and including emissions from international aviation in the analysis. In comparison with the 60 per cent target held in government policy at the time of publication, this study explores a far more ambitious future, 'effectively establish[ing] an upper bound on technological feasibility and costs' (IPPR et al. 2007, p. 6). The model used in the analysis is based largely on the MARKAL–MACRO model used in the 2007 Energy White Paper (Strachan et al. 2009). Although the report states that it uses the same underlying assumptions as the government and the Stern Review (IPPR et al. 2007, p. 4), the modification of just a few key parameters in MARKAL can have a substantial influence upon the results.

MARKAL AS A BOUNDARY OBJECT

In our view, a changing consensus on the policy image of the energy-climate policy nexus or problem has supported changing but sustained, if differentiated, use of MARKAL by several different but intersecting policy communities. From information flow and systems perspectives, Fong et al. (2007, pp. 16–17) observe that the value of a boundary object depends primarily on how well it can 'decontextualize knowledge on one side of a boundary and recontextualize it on the other side'. MARKAL is far from readily comprehensible by all, but we would suggest that its technological focus has made it valuable to a number of influential constituencies, particularly those with private or public interests in advancing the R&D required for energy system transformation.

The model also has further, interrelated attributes that lend themselves to playing a boundary object role. As an optimization model, MARKAL sets in the foreground the more knowable and more analytically tractable elements of a pathway to meeting targets, while putting in the background issues such as the politics and cultural and behavioural dimensions and (largely) the interaction with the macro-economy. As such, it facilitates the (perhaps tacit) belief that it is possible to 'plan' (more or less) an explicitly 'optimal' transition to a low-carbon energy system, in cost terms. Other modelling paradigms, such as a macroeconomic model with some form of endogenous technological change, could be considered just as valid an approach to thinking through some of the same issues. These would not, though, provide the policy image of a clear, technology-based roadmap, nor the sense of control over the structure and evolution of the energy system. Indeed, part of MARKAL's appeal is that it is not confined by historical relationships and hence allows users to envisage new energy systems; conversely, however, its recommendations risk being divorced from institutional and behavioural realities, often conceived of as 'barriers'. This capacity for facilitating new visions and new scenarios seems to help in gaining consensus across influential communities. One could even say that there is an affective role to scenario tools such as MARKAL, in that they give *hope* that different energy futures are possible. In a sense such tools are socially progressive, capable of supporting the imagining of radically different futures, freed from the constraints of some of the more difficult realities. Others, too, have commented on the role of technological imaginaries in aspects of UK energy policy (Levidow and Papaioannou 2013). To date, little has been said about the role of models in this regard, which we would suggest in the case of MARKAL has been highly influential.

Yet, the aspects of the future that MARKAL envisages are limited and largely technical. MARKAL enables one to examine radical change within the energy system but the model is not designed to capture directly those dimensions of change that are more emergent, uncertain, ungovernable and harder to quantify. These include aspects of political, social, corporate and other understandings of, and responses to, attempts to manage a transition. These in turn relate to, for example, perceptions of the distribution of costs and benefits to different parts of society; issues of market structure, vigorously debated during the Electricity Market Reform process in the UK; the institutional and policy arrangements required to enact change as rapidly as that depicted in MARKAL scenario results; and the culturally and socially embedded nature and determinants of consumer energy demand. In short, MARKAL is forced to meet particular targets but questions about their political feasibility, and the institutional arrangements and political strategies necessary to meet them, are unaddressed. Arguably, the reduction of these and other issues to indirect representation via demand elasticities (a feature also typical of other models), helps to connect elite communities by the act of elision: controversy is avoided or reduced by the reductionist shift to technical parameters.

In the use of MARKAL, we see mutually supportive connections between interests. Some aspects of the dispositional variant of the advocacy model referred to by Hoppe (2005) are evident, in which science and technology advisors and policy actors are seen as jointly shaping political discourse around a central story line (Hajer 1995), problem definition (van der Sluys 1997), or rhetorical style (Hood 1998), in a way that connects different epistemic and interest communities and government agencies, to form interlocking networks of knowledge and power or discourse coalitions (Wittrock 1991, p. 333). However, advocacy would be too strong a description of the actuality in this case, at least on the academic-consultancy side. Rather there is co-production of knowledge and understanding, and some degree of policy shaping by those within and outside formal government organizations. Moreover, as suggested above, the nature of MARKAL itself determines what can and cannot be modelled and further shapes policy through its own authority and the legitimacy given to its output, particularly through the privileging of techno-economic and numerical information.

In the latter, we see something of the potentially *exclusive* aspect of a boundary object: it binds communities with overlapping interests but this may also confer a certain political power and the ability to resist attack or critique by those with different agendas or views. MARKAL is unlikely to be replaced in its particular role until the policy image of the climate-energy problem changes once again, or until alternative models are perceived to perform the same role in a better or preferable way. In this respect, UK energy modelling has been described as in need of a broader range of analytical tools (Strachan 2011) and perhaps a likely scenario is that MARKAL becomes supplemented by a number of tools suited for related but different purposes: as and when the energy policy problem becomes perceived as more differentiated and multifaceted, so the opportunity for policy entry by additional and/or alternative tools will arise. If these are to succeed, it is important that they, too, are capable of delivering output capable of being rendered (translated) by and for multiple influential constituencies and, moreover, of supporting the interests of those communities.

Moreover, the mode of use of a policy-relevant tool is likely to vary by institutional context and MARKAL is no exception in this regard. Drawing on a large body of policy literature, Hertin et al. (2009) identify three main types of knowledge use: conceptual learning, when knowledge gradually allows new information, ideas and perspectives to enter the policy system; instrumental learning, when knowledge directly informs concrete decisions; and political use, when knowledge is used to attain political objectives, including justification of decisions already taken. Looking across policy venues, use of MARKAL would seem to fall into each of these categories, though definitive claims are generally difficult to make in these contexts.

CONCLUSIONS

In this chapter, we have described the way in which a particular model, namely the MARKAL least-cost energy system model and its variants, has achieved considerable influence in UK energy and climate policy, being deployed in several key policy venues and over a considerable period of time. We have accounted for this influence in terms of the various outputs of MARKAL being transferable across contexts, to support alternative, long-term technological visions in a timely and flexible manner. MARKAL's target-oriented capabilities and technological focus arguably reduce the opportunity for controversy and political friction, while serving the needs of private as well as public sector constituencies with an interest in the major research, innovation and deployment needs of energy system transformation. Despite the relative opacity of the MARKAL model and the limitations of numerical models in terms of capturing important qualitative aspects of energy system change, for the time being it continues to function as a successful boundary object, capable of being deployed in response to changing images of the climate-energy policy problem in the UK. Of course, it is thoroughly dependent on the existence of related policy priorities and it would certainly be instructive to compare the use of models in other national contexts, particularly where climate policy is afforded a lesser priority.

In terms of future research directions, a key issue is how the policy use of this particularly long-standing model (and its successor, the closely related TIMES model) will develop (a) in relation to other modelling tools suited to similar purposes and (b) in relation to the increasing understanding that energy system models typically have limited capacity to engage with the social factors that are critical in socio-technical transitions. In the context of climate change, despite social, institutional and policy innovation arguably being more urgent than technological innovation (Upham et al. 2013), the primary focus of innovation funding and discourse remains technological (ibid). Energy policy modelling remains likewise largely technology-focused. There are many reasons for this, not the least of which is that technology development has a broad, supportive constituency arising from its economic value to particular actors, whereas behavioural and social changes tend to have more diffused, social benefits (often relating to a reduction in various social costs rather than an increase in income) (ibid), tend to be more controversial, difficult to steer and anticipate and hence more difficult to model. If we were to take one key message from the social and behavioural change literature (Whitmarsh et al. 2011), it would be that most people view energy as thoroughly embedded in their daily lives, which of course it is. Yet this means that energy policy is de facto inseparable from other policy arenas and it means that when individual and organizational decision makers make energy-related choices, consciously or unconsciously, cost-based decision rules are unlikely to capture the range of possible or likely outcomes. Given this, it may well be that those macro energy policy modelling tools that are best able to make use of other types of data, be this gained through qualitative or quantitative techniques, will function as the most successful boundary spanners, bringing together the various constituencies of energy transitions.

Finally, it should be noted that there is an historical contingency to policy model use, even if this use may be relatively sustained. The period that we have documented has witnessed a political consensus emerge in the UK about the need for decarbonization. This consensus appears less secure at the time of this writing than it did in the late 2000s. As the image of the policy problem continues to shift, the alignment between policymaker focus and model paradigm may no longer hold, creating space for alternative tools – perhaps tools that engage better with affordability and equity, social innovation or smart grid systems – to compete with MARKAL.

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NOTE

1. While the wider case for action in this form was made through the Stern Review, MARKAL enables assessment of particular options for taking that action.

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