Modelling the UK energy system: practical insights for technology development and policy making

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Abstract / Summary

The Energy Technologies Institute (ETI) has developed an internationally peer-reviewed model of the UK's national energy system extending across power, heat transport and infrastructure. The Energy System Modelling Environment (ESME) is a policy neutral system-wide optimisation model. It models the key technology and engineering choices, taking account of cost, engineering, spatial and temporal factors.

Key points:

- A system-wide perspective, informed by modelling, is highly relevant because complex energy systems are made more inter-dependent by emissions reduction objectives
- Efforts to cut emissions are substitutable across a national energy system encompassing power, heat, transport and infrastructure.
- Energy systems are subject to key decision points and it is important to make the right choices in major long lived investments
- Policy makers should place policy in a system-wide context.

The ETI's current ESME-based analysis of the UK energy system shows that

- Decarbonisation can be achieved affordably (at around 0.6% of GDP), provided that the most cost-effective technologies and strategies to reduce emissions are deployed
- A broad portfolio of technologies is needed to deliver emissions reductions, with bio-energy and carbon capture and storage of particular system-wide importance

Policy makers can use energy system modelling to inform market and policy design, increase understanding of pathways (including the impacts of 'real world' constraints and inertia in deploying technology), and identify key 'contender' technologies with particular system-wide value.

Keywords: Energy system modelling, energy policy, decarbonisation, pathways, technology choice, system-wide value

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1 Introduction

The ETI was set up five years ago to accelerate the development of new energy technologies for the UK's transition to a low carbon economy. A key early initiative for the ETI was to build an energy system model to guide priorities for a portfolio of technology development programmes. ETI's Energy System Modelling Environment (or 'ESME', as it has become known) was originally conceived for ETI's own purposes in identifying and designing investments in technology programmes that provide the greatest strategic added value to its objectives.

Over time ESME has developed into one of the most powerful energy system models for the UK. ESME is available to the ETI's public and private sector members who have increasingly recognised its capacity to generate insights with relevance for wider national decarbonisation policy and strategy. It has been used to support work by the Climate Change Committee (CCC) on carbon budgets and its renewable energy review, and by the Department for Energy & Climate Change (DECC), for example, in informing its recent heat and bioenergy strategies. Increasingly the use of ESME outputs and insights has expanded into more strategic policy contexts.

This paper will explore the nature and potential use of the strategic insights that ESME can provide in helping to understand the UK's pathway to a low carbon economy.

Section two briefly summarises the status and use of energy system modelling in the UK, and considers the reasons why system modelling may provide novel insights and the case for using such insights in policy making.

Section three discusses the results from the latest version of ESME including the key implications around major technology choices, uncertainties and inter-dependencies.

Section four assesses how energy system modelling can be used practically to support policy design, including brief consideration of the implications of recent pathway modelling in ESME for technology investments and policy decisions.

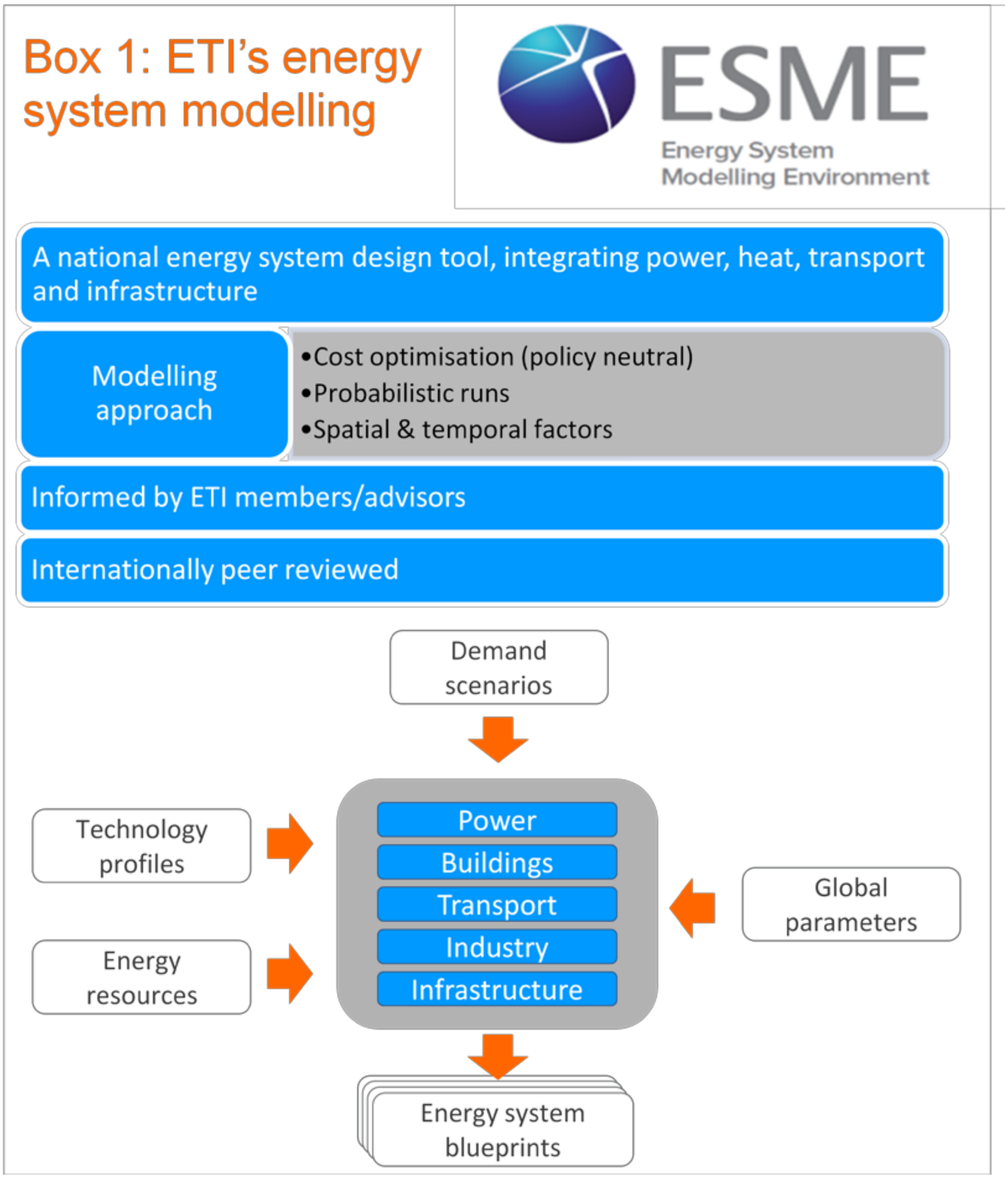
Finally the conclusion draws together arising implications, challenges for UK policy development, and areas for further improving and extending ETI's use of energy system modelling to inform technology development and policy.

2 Energy system modelling in the UK

Energy system modelling has an extensive pedigree, based to a large extent on the development of 'Markal' derived models, originally developed under the auspices of the International Energy Agency (IEA). Markal has been in use since the early 1980s (Seebregts, Goldstein and Smekens, 2001), and has been adapted for use in over 37 countries around the world.

In the UK, energy system modelling appears to have gained traction in recent years. Strachan, Pye and Kannan (2009) outline how modelling was used to informed energy policy reviews in 2003 and 2007. The adoption of carbon budgets and the creation of the CCC has also added momentum. The CCC has used energy system modelling, principally Markal-based, to support its work on carbon budgets and pathways to

2050. The Department for Energy and Climate Change (DECC) is also making use of both Markal and ESME, as well as other tailored models, to inform its decisions on carbon budgets and the UK carbon plan, as well as its carbon capture and storage (CCS) roadmap and strategies on heat and bioenergy.



ESME was originally designed for analysing energy technology choices rather than for policy analysis. In view of the close relationship between energy sector policy and technology choices, this paper considers how an energy system model such as ESME can be used to inform policy.

Markets and the future path of technology development are inherently uncertain. So it is reasonable to ask what can energy system modelling actually tell us that is relevant to real world decision making? How can we use energy system models like ESME to support sound policy making and investment strategies?

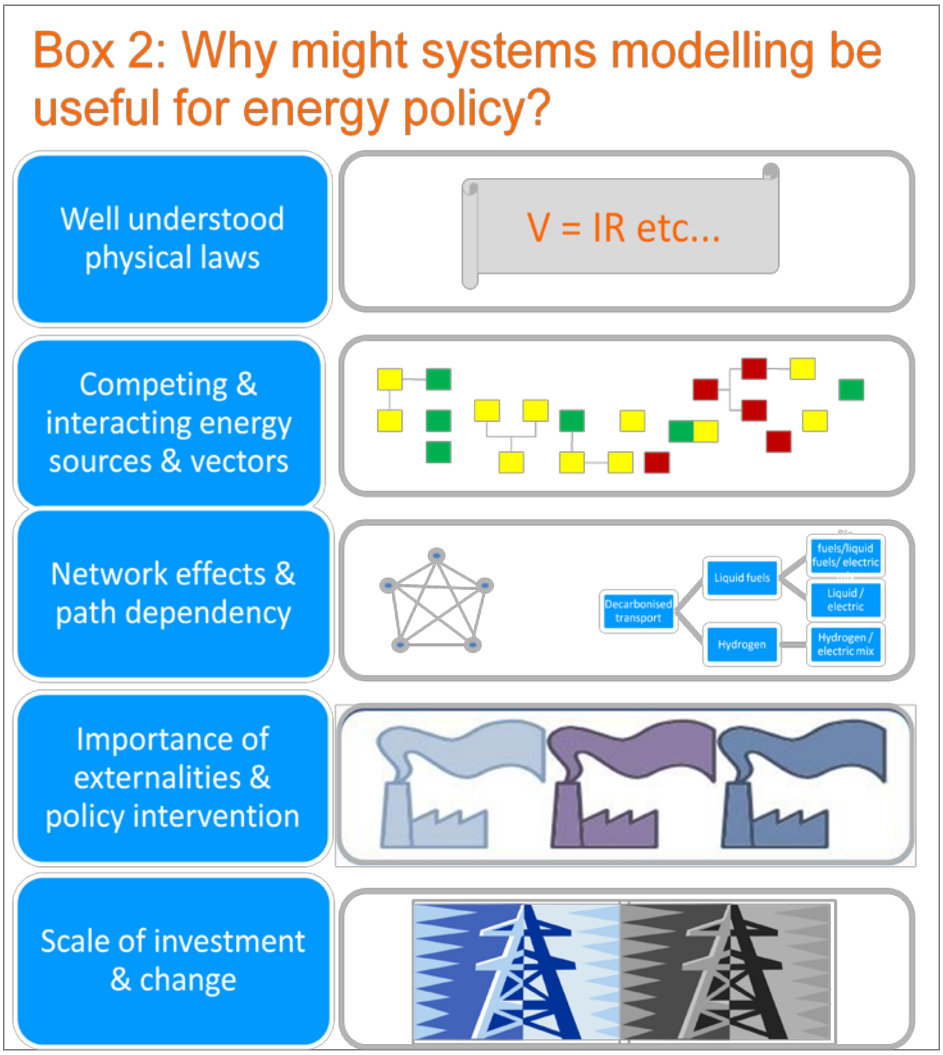
From a policy perspective, why not simply price in externalities and let markets decide? Players in the market may want to use modelling to guide commercial judgements about investments in technology development or market strategy, but for policy makers energy system modelling can seem uncomfortably close to a kind of algorithmic winner picking, within a utopia of technological determinism. Those who espouse the power of free markets might argue that attempts to forecast or model the future are likely to be futile, almost by definition, incapable of spotting disruptive 'black swans'.

There is something in this kind of reaction to energy systems modelling. We should indeed be cautious about the limits of our present day knowledge, let alone our computational ability to accurately represent either complex real time technical interactions, or the even more unfathomable motivations and behaviours of human decision makers within markets of the future. In the real world decisions have to be based on imperfect available knowledge, in contrast to the implicit assumption of perfect foresight in much system modelling. Modelling can only simplify and approximate real world complexities, political constraints, and imperfect knowledge, so its use in informing policy and investment choices must be tempered with caution and judgement.

However, there are a number of characteristics of energy systems that arguably make a systems modelling approach capable of generating novel and useful insights relevant for policy making.

- **Energy systems are complex but governed by well-understood physical laws** – this means that quantitative modelling is capable of representing system interactions and capturing dynamics that would otherwise not be understood. The overlay of decarbonisation policy objectives enhances the rationale for modelling national energy systems. Component systems and networks become more strongly integrated in an economic sense because emissions (or reductions in emissions) of greenhouse gases now become substitutable across a national carbon system. Physical and engineering based modelling of energy systems enables us to understand these interactions and to identify gaps and barriers in current economic and market structures.
- **Energy systems are characterised by competing and interacting sources of energy and vectors for transmission and distribution** (e.g. electricity & gas networks, fuel distribution systems) each with varying cost and performance characteristics, alongside inter-modal co-ordination and competition. A systems modelling approach in this context offers particular value, because it builds understanding of the combination of networks and inter-modal interactions capable of delivering energy service needs to users and consumers. In this sense energy systems come to have economic properties similar to transport systems (where a combination of asset-rich networks interact through both co-ordination and competitive mechanisms) to enable consumers needs (for mobility, or for comfort, light and power) to be met.
- **Network effects and path dependency** – energy systems are characterised by network effects (where the value or attractiveness of a good or service depends on the extent of its adoption) and depend to a significant degree on dedicated infrastructure networks with monopoly characteristics. These characteristics of energy systems mean that their development is likely to be, to some extent, path dependent. Many potential new energy technologies appear likely to be subject to network effects in their adoption, in part because they will need to be supported by compatible energy vectors and distribution networks. A potential example might be the introduction of new transport fuels and technologies (e.g. electric or hydrogen vehicles), where uptake may depend on a critical mass of users and outlets being reached. Building an 'early lead' may be key to achieving

widespread uptake and eventual dominance. In energy markets, this may work through early policy choices around incentives for new technologies. Systems modelling allows us to examine the implications of path dependency, and to identify the key choices which are likely to have the greatest impact on the long term costs of decarbonisation.



- **Energy markets are characterised by externalities and policy intervention.** Energy markets are characterised by extensive policy interventions and regulation, for a variety of reasons, including policy concerns around externalities (carbon emissions, planning), market power in monopoly networks and the political economy of energy security and affordability. The nature of energy services requires intervention and agreement to establish appropriate market institutions and conventions to facilitate trading and co-ordination within integrated systems. Markets are shaped by policy to an unusual degree. Energy system modelling provides a vehicle for examining underlying cost and engineering challenges of meeting consumer needs, in a policy-neutral context. It seems likely that a systems modelling approach will generate insights that no individual market participant would have an incentive to explore and expose. Energy systems modelling, and the insights it exposes, allows policy makers to understand and analyse how policies, markets and incentives could be aligned to deliver energy systems in future.

- **The scale of investment and change means that the returns to improving policy and investment choices are likely to be high.** Figures for the UK's investment requirements in moving to a low carbon economy run into the hundreds of billions. Many of the investments needed are in long life assets, so the need to take a view far into the future is unavoidable. Right sizing new assets, designing new networks well and making the right choices in renewing assets – or perhaps avoiding major errors - will reduce the costs of later retro-fitting and extend asset lives. The benefits of marginal improvements to investment and policy choices could dwarf figures typically quoted in impact assessments for many policy or regulatory decisions.

At the same time, users of energy systems models need to be aware of the limitations of analysis, and the particular features of individual models. For example, ESME uses simplified representations of cost structures, particularly for technologies which depend on economies of scale or which require lumpy investment in supporting infrastructures, such as treating hydrogen infrastructure as an overhead for hydrogen vehicles.

More difficult limitations relate to the difficulty of representing issues like technology risk which, in the real world, have a direct impact on costs through insurance, transactions costs and the cost and difficulties of financing. Issues around bankability and the development of credible new business models are, in practice, vital in the deployment of new technologies, but are not represented in modelling. Arguably these kinds of factors are reflected in the approach taken to discounting, but there still appear to be unresolved issues in this area. In addition, system modelling arguably still has a long way to go in understanding and calibrating the treatment of changes in consumer surplus associated with technology performance and consumers' experience.

3. A low carbon UK energy system

Colleagues at the ETI, together with our consultants Redpoint and Marakon, have worked to build, populate and improve ESME over the past 3 years, with help from a strategic advisory group drawn from ETI members and energy system modelling experts. This work progressed from an initial 'proof of concept' design through extensive testing and successive version improvements. By 2011 version 2 of ESME was beginning to be used to support wider strategic thinking in government and the CCC.

During 2012 ETI has worked on a number of improvements to ESME responding to the outcome from an external peer review. The enhancements focus on improving the ability to represent peak energy demands through more granular timeslicing and better representation of technology and system performance within these crucial 'peak' timeslices. This was achieved by increasing the number of diurnal timeslices the model solves for, improving the modelling of peak electricity demands and the representation of transmission, storage and security of supply constraints, improving the representation of peak day heat constraints and the association of heat technologies to buildings.

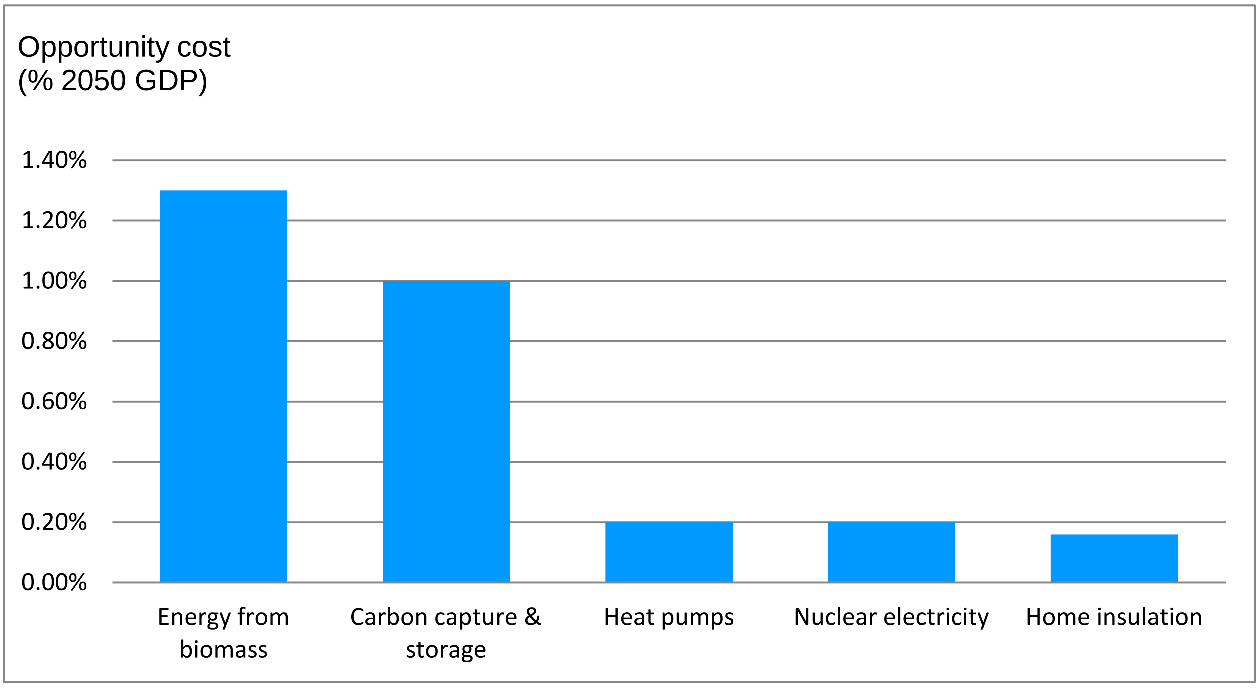
ETI is now using ESME version 3 to inform its vision of a low carbon UK energy system. By running ESME in probabilistic mode we are able to look at the robustness of technology choices to future uncertainties. ESME produces a wealth of data, so it's important to concentrate on the key insights. A tentative top ten are pulled out here:

1. **Decarbonisation appears affordable:** ESME suggests that the incremental cost of decarbonising the UK energy system by 2050 is affordable at around 0.6% of GDP (by comparison with a system

without carbon constraints). This compares with similar current items of spending child benefit (around 0.75% of GDP), international development aid (0.48%), nuclear decommissioning (0.43%). Orders of magnitude are the key thing here, and comparable with the Stern review's much quoted 1% of global GDP. Good decision making - that is focusing efforts on the most cost effective targets for emissions reductions - and investment in technology development are vital to achieving decarbonisation at this kind of cost.

2. **Few carbon abatement technologies are irreplaceable – most are substitutable within a broader portfolio:** Decarbonising the UK energy system is, unsurprisingly, likely to rely on deploying a portfolio of technologies to generate, distribute and convert energy into heat or power, or to reduce our demands, and cut emissions. But interestingly there appear to be only a handful of technologies which are difficult or expensive to replace with alternatives. System modelling suggests that most of the technologies can be substituted by some combination of alternatives within a realigned energy system. We have a wide range of options, and ESME points to the high value in maintaining a balanced and broad portfolio. Only a small number of technologies appear highly valuable, in the sense of being costly to replace with alternatives. Figure 1 shows the opportunity cost for the groups of technology which are most expensive to replace. In this context opportunity cost represents the incremental change in the annual costs of a carbon target compliant UK energy system in 2050 caused by exclusion of the technology.

Figure 1: Opportunity costs of key carbon abatement technologies



3. **Bioenergy could be central in containing UK decarbonisation costs and shaping the distribution of effort across sectors:** The results from version 3 of ESME suggest that, while biomass may only provide around 10% of primary energy resource, exploiting it as a source of energy could be central to an efficient decarbonisation strategy. The modelling deploys biomass from the 2030s, much of it in combination with CCS. Biomass is used to provide power and heat directly within industries such as refining, and in gasification applications to produce hydrogen, synthetic natural gas and electric

power in some combination. But the high value of biomass derives in large part from its unique ability when applied with CCS, to remove carbon from the atmosphere. These negative emissions in turn enable continued use of fossil fuels in applications which are particularly difficult to decarbonise, notably in transport, potentially avoiding significant cost and expense to the UK economy.

4. **Successful deployment of CCS could deliver major system-wide value:** Carbon capture and storage is the next most valuable group of technologies. ESME modelling suggests that failing to develop and deploy CCS could more than double the cost burden of decarbonisation. Again a significant proportion of this value (around £14bn per annum) derives from its combination with biomass. It can also be deployed in the power sector enabling continued use of both gas and coal as part of the portfolio of energy sources out to 2050. This is important because CCS acts as a baseload hedge in case of difficulties in deploying nuclear energy. Figure 2 illustrates intuitively how CCS is valuable.

5. **Nuclear or CCS is likely to be needed for low carbon baseload:** ESME modelling currently points clearly to a dominant role for nuclear electricity as baseload, with current scenarios showing nuclear generating around 75% of 2050 power and making up around 40% of installed generation capacity. ESME assumes a top limit of 40 GW of nuclear capacity in the UK based on likely site availability constraints. The nearest replacement for baseload nuclear electricity is combined cycle gas turbine (CCGT) generation with CCS, and in practice much depends on the relative global prices of gas and uranium, and other cost uncertainties. If nuclear electricity proves not to be deployable, fossil fuel based electricity with CCS appears a close competitor. Renewables are not able to substitute if new nuclear cannot be deployed at these levels due to cost, intermittency and site availability issues. While electrification is a key enabler of low carbon energy, on average ESME assumes overall electricity demand grows by only around 15% (with most simulations falling within a range from -5% to +25%). This compares with a range of 30 to 60% growth quoted in the government's 2011 Carbon Plan. This reflects ESME's more limited electrification of space heating and transport, alongside continuing deployment of a significant tranche of gas in space heating and gas and liquid fuels in transport. This, in turn, is enabled by bio-energy and CCS applications elsewhere providing either enabling carbon credits or low carbon gas and liquid fuels within a broader mix.

6. **Unabated gas could still be important for peak energy and as responsive capacity:** A notable feature of the modelled generation fleet for 2050, following the upgrade of ESME's peak energy features, is the significant tranche of around 12 GW of responsive open-cycle gas turbine capacity (compared with around 8 GW today) deployed to respond to short-term changes in renewable generation and peaks in demand. This capacity is expected to provide only around 0.5% of overall demand, but its deployment provides an insurance policy from a peak point of view, enabling the use of other less responsive low carbon forms of generation, particularly nuclear, to generate the bulk of electricity outside peak scenarios. This reinforces the salience of current debates around policy and market structures to reward flexible capacity that is required but hardly used.

7. **Uncertainty around current expectations of wind energy, particularly offshore:** Modelling using ESME version 3 is notable in deploying significantly less wind generation capacity than forecast in many scenarios (and, implicitly, in the momentum of current deployment trends). The 2011 Carbon Plan suggests that renewable electricity could account for 35 to 50 GW by 2030. ESME modelling tilts significantly more towards nuclear, CCS and unabated gas. No further offshore wind is deployed

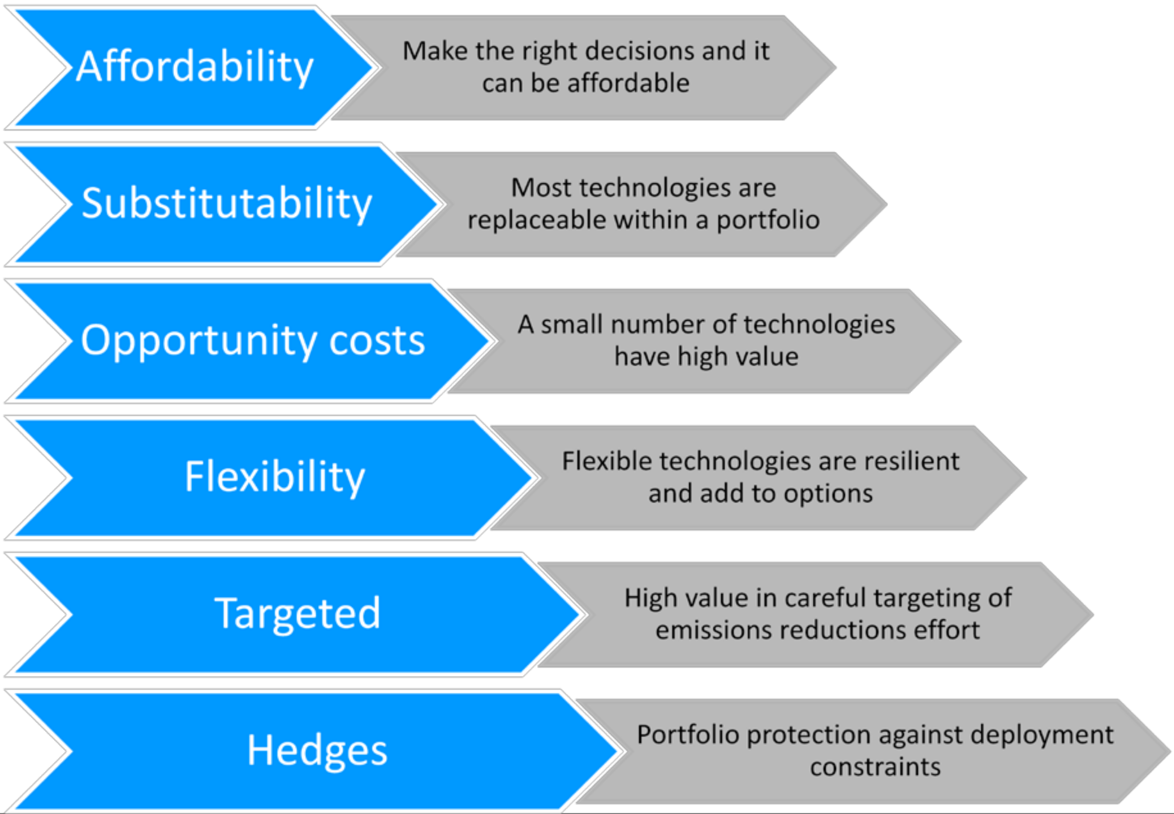
in many ESME scenarios reflecting current expectations about cost and the impact of intermittency on system-wide costs, although it remains the key hedging option. In effect ESME assumes that the big challenges around large scale nuclear and CCS deployment prove surmountable, at costs which render offshore wind uncompetitive. These are big assumptions, so the effort to improve the competitiveness of offshore wind costs remains a key part of the UK's option portfolio. ESME's smaller deployment of wind energy is also dominated by onshore wind. This can be seen as an artefact of simplified assumptions about the acceptability and planning challenges for onshore wind projects, or alternatively as an illustration of the potential value in exploring policy options to overcome them.

8. **Heat pumps deliver a major share of space heating, but 'traditional' gas boilers retain an important role**: By 2050 we could see heat pumps, mainly air source, supplying around 35% of the UK's space heating, but with gas boilers still supplying around 45% of space heating demand. This reflects the continuing peakiness of space heating demand, and the difficulty and expense of upgrading the energy efficiency of Britain's housing stock given that the majority of the 2050 housing stock has already been built. Right sized heat pumps running off baseload are more economic in energy efficient properties, with gas boilers remaining important in meeting peak demand in older less energy efficient buildings.

9. **Major changes to road transport, but liquid fuels may remain part of the mix for decades:** Transport is the most expensive sector to decarbonise and ESME consistently selects decarbonisation options in other sectors first. By 2050, however, ESME points to major changes in road transport, with major improvements in efficiency, an increasing role for gas in heavy goods vehicles, and a mix of liquid fuels and electricity for cars. But there are key uncertainties, particularly in the form of inter-dependencies with the success of bioenergy technologies. Successful deployment of CCS with biomass electricity generation would create substantial 'negative emissions', opening headroom for continued significant use of fossil fuels for cars. Alternatively bio-fuels could meet liquid fuel needs for cars by 2050, as part of a mix of options including efficient engines and plug-in hybrid electric vehicles. This is significant because it suggests that required emissions cuts could be achieved in transport without the need to create a risky and expensive new hydrogen distribution infrastructure.

10. **Building insulation activity is important, and so is focusing on properties where the gains are greatest**: ESME version 3 modelling points to the importance of domestic insulation options. But ESME chooses on average to deploy further insulation retro-fit measures in only around a quarter of existing homes. This looks somewhat lower than, for example, the 2011 Carbon Plan. It suggests that improving practical understanding of how to focus on properties where gains can be most economically achieved will be worthwhile. ESME characterises insulation options in simplified terms as packages in three levels ranging from basic insulation measures (e.g. cavity wall or loft insulation) through to more costly and sophisticated measures.

Box 3: Low carbon 2050 – what is ETI's modelling telling us?



System modelling and policy making

No model can fully reflect the complex physical reality of a national energy system, let alone the consistent fickleness of consumers' changing behaviour and norms over long time periods. In seeking to model efficient future energy system designs, ESME uses simplified forecasts of how technologies' cost and performance functions could develop over time. But technologies and markets evolve unpredictably, disruptive new technologies emerge and consumers' preferences interact and develop in new ways. Fables about the failures of central planning are commonplace. Central planning approaches, even with support from the most sophisticated systems modelling, are vulnerable to major policy mistakes and inflexibility. But at the same time, markets are not spontaneous and are themselves examples of planning and co-ordination.

So, with suitable circumspection about using energy system modelling to 'pick winners', what are the practical ways that policy makers can use models such as ESME? And what are the key policy implications from ESME as it currently stands?

Informing market and policy design with 'system engineering' insights for policy makers

The advent of carbon targets means that policy makers need increasingly to think in terms of a broader energy system. The need for policy makers to understand engineering and the physics of energy systems is not new. For example, Kirchoff's law and the broad parameters of electricity network engineering have shaped policy makers' potential options for reforming electricity policies and markets. But the carbon imperatives now mean that policy design needs both to address a much wider 'national energy system' scope encompassing all energy sources, vectors and demands, and to deliver a more fundamental transformation of current technologies. This multiplies the complexity of the physical interactions and system engineering problems that policy needs to address.

In this context it makes sense to think in terms of a universe of potential emissions reduction measures competing and integrating within a complex inter-dependent national energy system. Policy concerns around affordability mean that we need to incentivise emissions reductions where they are most cost-effective. Policy need to create frameworks and enabling policies, so that markets can be harnessed to reveal the best solutions over time.

Energy systems models reveal the non-obvious underlying interactions between major components of a national energy system. This then enables policy makers to understand how technologies can compete with and complement each other, in turn informing policy and market design.

For example ESME points up the size of the swing in heat demand as a key UK energy system challenge and provides insights into the nature of the competing low carbon alternatives. How can we move from our current reliance on gas boilers to a lower carbon mix of technologies which can deliver the heat services we need with much lower emissions? Policy needs to create market frameworks and conditions that enable alternatives (whether demand or supply options) to compete on a level playing field to deliver a low carbon solution.

The ETI's emerging work on sustainable future energy for car transportation provides a good example of how ESME modelling informs analysis at a more granular level of realism. At national energy system level ESME points to the importance of a strategic trade-off in the decades ahead between reducing use of liquid fuels for transport, and the success or otherwise of bio-energy either in combination with CCS or in bio-fuel production. A future electric / liquid fuels mix looks a plausible solution under a fairly broad range of scenarios, compared with more revolutionary and risky hydrogen-based options which require major new hydrogen infrastructure investments. This leads into a series of policy questions around the transition in both the vehicle fleet and supporting infrastructure, and the potential options to accommodate transport demands reliably within electricity systems. The ETI is currently planning further work on how to construct markets and incentivise the development of new technologies – whether in vehicles, pricing & business models, storage or infrastructure options – to most effectively integrate light transport powered by a mix of electricity and liquid fuels.

Informing understanding of policies and pathways

The ETI's use of ESME to understand technology pathways towards a low carbon economy is still at an early stage and thinking is still developing. But, as discussed in Section 2, the relevance of network effects, path dependency and externalities in the energy sector suggest that systems modelling may provide valuable insights around the transformation pathway and the sequencing of policy decisions and investments. Table 1 sets out some broad insights from pathway modelling in ESME version 3, and tentatively identifies policy challenges and choices which arise.

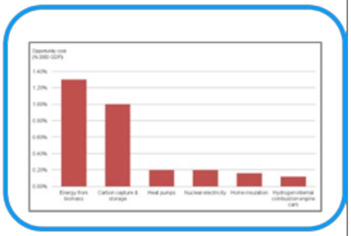
In interpreting the dimensions of modelled pathways set out in table 1 it's important to emphasise that this is a mean view, using an optimisation based on current cost and performance assumptions. A range of real world constraints are not fully represented. Systems models cannot produce ‘the answer’, and ESME also demonstrates that a range of alternative futures are also plausible.

In this context we can use ESME to build understanding of the implications of the current direction of travel in terms of policies and uptake of technologies. By constraining near term options to mimic current real world policies, inertias and markets, we can assess the nature of actions needed to take us closer to an ‘optimal’ pathway, and understand the likely costs of delays to addressing key barriers to the adoption of low cost carbon abatement options. The ETI is now beginning to explore the construction and use of such scenarios to produce policy-relevant insights.

Box 4: Using modelling to support policy making

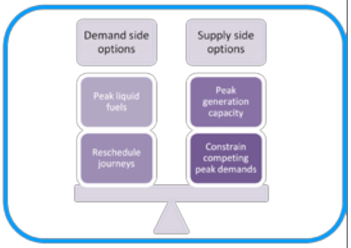
Identifying contenders

- Focus on enabling policies for technology options with highest system-wide value



System insights for market & policy design

- Technologies compete and complement in non-obvious ways
- Remove barriers and create level playing fields



Pathways insights

- Cautionary tales – how much will inertia cost?
- What do we need to do now?

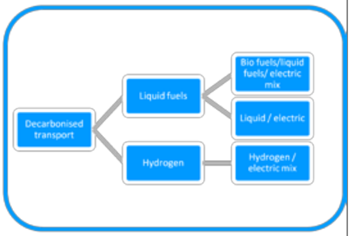


Table 1: ESME pathway modelling and policy challenges

Sector	Modelled pathway	Policy challenges
Power	**Interconnectors**: 6 GW deployed before 2020	Early work to build frameworks and agreement for these investments.
	Wind: deploys significant onshore capacity (11 GW by 2020, rising to 20 GW in 2030), but limited offshore capacity	May reflect modelling simplification of planning challenges. But suggests value of work to explore scope to improve acceptability of onshore wind (e.g. community benefit sharing)
	Gas: continued role, with CCS retrofitting to CCGTs up to 2030 and 10 GW expansion of OCGTs in 2020s. From 2030s CCGT CCS begins to be replaced by hydrogen turbines (hydrogen mainly from biomass with CCS).	Policy support for development of CCS is key to a future role for gas. This trajectory will require CCS development at scale from the early 2020s. Policy on support for biomass CCS applications needs clarification.
	Coal: coal capacity falls rapidly to 3 GW by 2030, with only limited application of CCS to coal (3 GW compared to 19 GW for gas), although coal retains a role in hydrogen production.	In view of limited resources for CCS development, policy needs to clarify a coherent strategic direction of travel for fossil fuel CCS.
	Nuclear: a major programme of new build for low carbon baseload (2020s - 1 GW per annum rising to 2 GW per annum during 2030s)	Policy focus on getting new nuclear underway, with the need to resolve strategic direction of travel for baseload in the early/mid 2020s. CCS is most likely competitor and has itself significant lead times.
	Biomass: little electricity generation from direct biomass firing. IGCC biomass with CCS could be significant from the 2020s	Policy clarity around bio energy CCS applications would improve the signal for investment in technology development.
Heat	**Space heating**: Significant deployment of ground and (especially) air source heat pumps during 2020s, reaching around 35% of the market by 2030.	Policy questions around how best to shape the market and improve understanding of consumer acceptability / market deployment of heat pumps.
Transport	Hydrocarbon use reduces rapidly only after 2030. Major strategic uncertainties remain around energy for cars, with optimal options highly interdependent with development of bio energy technologies.	Major policy questions focus on creating market structures that incentivise a flexible portfolio of technologies, and addressing complex transitions in vehicle fleet and infrastructure.

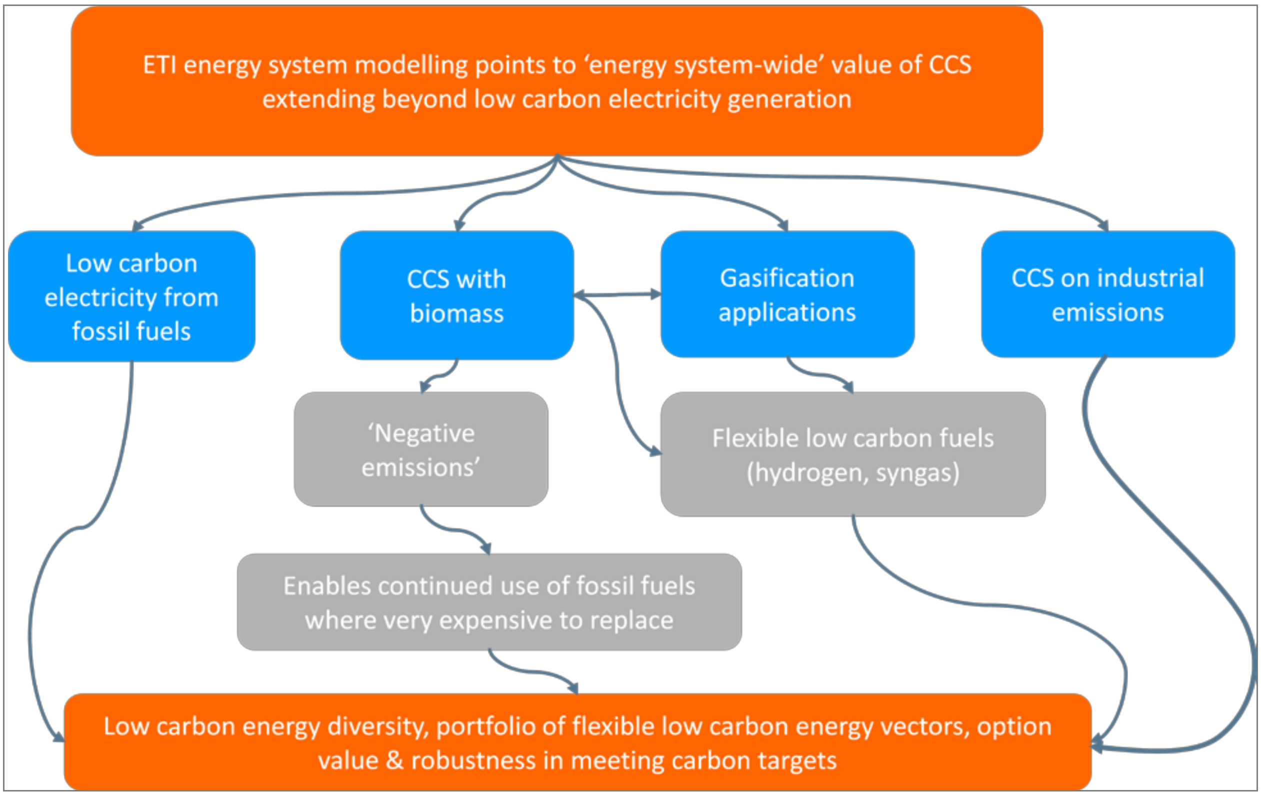
Identifying 'contender' technologies

Picking winners may be anathema. But a glance at DECC's website reveals policy makers' explicit interest in identifying 'contenders', or in other words, how to enable and support new technologies to reach the market.

Here the value of energy systems modelling seems intuitively clear in supporting identification of a portfolio of the most potentially valuable 'contender' technologies. Modelling can form part of a process of filtering 'contenders' for further support and incentives through policy, before, ultimately sinking or swimming in competitive markets.

ESME points clearly to CCS as a key 'contender' technology for the UK energy system. At this stage CCS has not been deployed at commercial scale within the UK, but ESME modelling is robust in pointing to a high potential system wide value for CCS in the long term. The scale and robustness of this potential value within modelling scenarios reflects the very specific modelled interactions of CCS across the energy system.

Figure 2: Energy system value of carbon capture and storage



Current policy discourse around CCS appears not to fully internalise this potential for long term energy system wide value (see Figure 2). For example the focus is on the cost competitiveness of CCS in terms of £/MWh of electricity by the mid 2020s which fails to take account of the potential future option value of developing CCS in the power sector as a means of opening up future applications with industry, with biomass to create negative emissions, and in producing flexible low carbon energy vectors (hydrogen, syngas).

Within ESME modelling CCS delivers major benefits, is robust to alternative scenarios and is important in determining the overall architecture of the national energy system. Policy makers might reasonably ask modellers to look at questions around unforeseen costs or performance issues, or breakthroughs in technical substitutes. The idea would be to understand what would need to happen to displace this technology from a future system, perhaps by modelling 'hypothetical breakthrough technologies' or assessing how wrong forecasts of cost and performance would need to be to erase future value.

Policy makers can then judge plausibility to inform judgements about the extent of investment or the scale and firmness of support to key technologies. CCS is a good example of this because it entails major investments in a complex novel value chain where long term public policy support is critical both to investors and the development of the supply chain.

In terms of 'contender' technologies, energy system modelling can also inform targeting of supporting focused modelling & analysis, which in turn can feed back into improving calibration and representation in system-wide modelling. ETI's work on more granular modelling of bioenergy, smart systems and heat (where ETI is investing in a major programme to build detailed understanding of consumer needs and behaviour and demonstration of solutions) and in road transport are examples of this.

5 Conclusions

Achieving a low carbon economy demands major investments in a number of new technologies within a complex, inter-dependent system. So there are a priori reasons to suppose that systems modelling will generate valuable insights. But, it will not provide a blueprint. Modelling insights need to be interpreted with expertise and caution, and supplemented with more granular analysis of particular technologies and challenges. Ultimately markets, for all their imperfections in the energy sector, should be harnessed in identifying the solutions that best meet our needs.

In the UK we are only at the start of using systems modelling to inform pragmatic policy making. At this stage experience with ESME supports some broad observations about systems modelling and its practical application in UK energy policy making.

First, ESME modelling highlights the importance of inter-dependencies across the energy system, so a systems wide approach to policy is likely to be valuable. Policy makers need to guard against the risks of policy silos, and explicitly place major policies such as electricity market reform within a system-wide context.

Second current ESME modelling suggests a number of strategic areas where policy and incentives need to be reviewed. These include consideration of:

- approaches to facilitating investment in major discrete power projects (CCS or nuclear) which appear to be particularly exposed to policy risk within current frameworks.
- incentivising the development of bio-energy with CCS, given its importance to choices across the energy system, and current expectations about the carbon price trajectory

- further action to create a level playing field between competing low carbon energy vectors (i.e. electricity, hydrogen, low carbon syngas) given the policy support under EMR for low carbon electricity generation
- shaping market frameworks to incentivise and enable transition from current reliance on fossil liquid fuels for transportation to a future portfolio mix of electricity, fuels and distribution networks.

Third, there are a number of areas of focus to enhance the real world decision relevance of ESME. We are beginning to explore how to create scenarios that model the likely outcome of constraints based on current policies and the existing direction of travel. This could increase understanding of 'cautionary tales' – how much we stand to lose by delaying change or failing to address real world barriers. We also want to look at how systems modelling can better represent how investment and policy choices are made under uncertain conditions, and what insights that generates for resilient policy pathways.

Finally ETI plans include building understanding of how to integrate focused supporting modelling work on key technology choices in areas such as transport, smart systems and heat and CCS deployment. This should add to the richness of the modelling of future energy systems, and enhance insights for both technology development and policy design.

Box 5: Summary

Energy systems modelling capable of generating novel insights with practical application

System wide perspective is key

- Identify best parts of system to decarbonise
- Level playing fields for emissions reductions across the energy system

Informing policy in terms of 'contenders', market design and the costs of inertia

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