Modelling in Public Policy

Exploring Research Requirements to Support the Use of Modelling Evidence in Energy Policy Development

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Executive Summary

This document summarises discussions held at a workshop hosted by Ofgem on 15 May 2017, which explored the use of modelling analysis in public policy, and in particular identified research requirements to support this use of modelling. There was a wide range of attendees from academia, industry and government.

The workshop was split into two halves; the first focused on the perspective of technical modellers, the second on the perspective of policy-makers. Summaries of the presentations from both halves of the workshop, and the wide ranging discussions that followed, are given in this document. The following key themes emerged as priorities for R+D; strikingly, the discussion mainly emphasised general issues of modelling and policy practice, rather than specific technical improvements to particular system models:

- ***Communication***

  Effective communication between modellers and policymakers is critical, both in terms of modellers understanding policymakers' needs, and in terms of policymakers having a realistic understanding of the messages provided by modelling studies. Training for all relevant communities, and the involvement of specialists in translating modelling results to a widely accessible form, might play a key role. The ultimate goal is for policymakers, who might not have a technical background, to be able to use modelling evidence in decision process based on a more meaningful understanding of what the model says about the real world.

- ***Uncertainty***

  All models are simplifications of the real world and there can be uncertainty over both the parameters and inputs of the model, and over how the model structure relates to the real-world system under study. Both have an impact on the results of the model, and need to be accounted for if there is to be a logical basis to consequent decision making by policy makers. Uncertainty is often not communicated, even when it was considered in a modelling study, which can lead to misunderstandings. This can be a cultural issue in each of the policy and modelling communities' views of the role of the other, and it may also be a practical issue of how information on uncertainty is best communicated.

- ***Wider issues in the role of modelling within policy processes.***

  Further specific suggestions of areas for further work include:

  - Ex post analysis of modelling studies and the success (or otherwise) of consequent decisions, to assess fully the performance of modelling approaches and learn lessons for future studies

- Consideration of how modelling can best support policy decisions on different timelines, considering practical issues such as the analyst resource available to organisations.
- Systematic methods for understanding consequences of high-impact, low probability events.
- Understanding that using modelling for energy policy has an impact on other sectors, and also in the interaction between different energy carriers in an integrated system.
- Approaches to quality assurance and model curation.
- Identifying and disseminating best practice from current modelling studies within the energy sector and more widely.

Further information, and acknowledgments

For further information on this report and workshop, please contact Dr. Chris Dent (lead organizer) at chris.dent@ed.ac.uk.

The authors (Amy Wilson, Claire Copeland, Evelyn Tehrani and Chris Dent) wish to thank everyone who presented and contributed views to the workshop plus this report, and also the sponsors of the event: Supergen Hubnet as lead sponsor, Ofgem as event host, plus Durham Energy Institute, the Centre for Energy Systems Integration, and the Maxwell Institute for Mathematical Sciences (the joint Mathematics Schools of Edinburgh and Heriot-Watt Universities).

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0. Introduction

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The workshop was split into two halves; the first focused on the perspective of technical modellers, the second on the perspective of policy-makers. Summaries of the presentations from both halves of the workshop and the discussions that followed are given in this document. The workshop was held under Chatham House rules (meaning that what was said can be reported, but not who said it), with the exception of the keynote presentations.

Sections 1 and 2 of this report cover the presentations, breakout groups and plenary discussions in the two halves of the day. The intention is to report as accurately as possible the views presented at the workshop. Therefore the words used here are those of the authors of the report, and the content contains points made on the day and does not necessarily reflect the views of the authors.

Section 3 presents conclusions and a summary of directions for research emerging from the day. This content has been assembled by the report authors, and consists of prominent themes on which there was a strong degree of consensus, or which were particularly striking. The conclusions have also been informed by subsequent discussions with workshop attendees, and several researchers who were unable to attend the event.

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1. Technical modelling session

1.1 Using Modelling to Support Policy and Market Design Decisions

Prof Benjamin F. Hobbs, Johns Hopkins University

Professor Hobbs discussed the wide variety of roles that models can play in policy development and decision making. Different levels of model complexity can be used for particular policy purposes:

- Simple models can be used to gain insight and improve understanding as to the general behaviour of actors operating in a system containing the problem or issue.
- More complex models can then be used to derive quantitative results and confirm decisions and courses of action to take.
- Models can also be used to find out what the optimal solution to a policy problem is under specific conditions. Investigation can then be taken to determine which policy decisions will support this optimal solution and to estimate the benefit of implementing a particular policy.

Professor Hobbs gave several practical examples where modelling was used to support public policy, including both models that were used to provide insight (simple) and those which were used to make more concrete decisions (complex). One example of a simple model with just two types of generation was used to demonstrate the notion that spot market electricity prices should incentivise flexible generation. A much more complex model, designed to support multi-stage decision-making for transmission planning, was then described.

Finally, Professor Hobbs argued that better models were needed to support key issues in energy system policy. Examples included the need for better coordination of bulk and distributed investment, and for models investigating the impact of different support schemes for carbon reduction and renewable generation. Also highlighted was the need for optimisation methods that can be used on large-scale and non-convex problems, and the need for interdisciplinary research to tackle current problems in energy systems.

In the discussion that followed the need to remember that "models are always wrong and some are useful" was highlighted. In other words the need to acknowledge that the model and the real world are different things. It is also necessary to understand the uncertainty in statements made about the real world based on modelling evidence. Both the policy maker and the modeller need a realistic understanding of what the modelling results mean for the real world.

1.2 Uncertainty in Modelling for Complex Systems

Prof Michael Goldstein, Durham University

Professor Goldstein's presentation described the importance of considering uncertainty when using complex computer models to support policy. It is critical not to mistake the model for the real-world when it is being used to support policy decisions. All models are simplifications of reality, and an assessment of a model's weaknesses and differences from the real world must be made in order to link the model to the real-world decision making.

Professor Goldstein highlighted that the Bayesian statistical methodology for assessing uncertainty is well developed, and has been applied to a wide variety of different models in different applications. He summarised this methodology, with particular emphasis on approaches for assessing uncertainty when models are computationally expensive to run.

Uncertainty analysis typically involves performing multiple model runs, and it might be possible only to sample sparsely the relevant space of model inputs if either the model is computationally expensive, or the number of inputs is large. He demonstrated how statistical "emulators" of computer models, which quantify uncertainty in the model output at inputs for which it has not been evaluated, allow systematic uncertainty analysis even in these circumstances. These emulators can also be used for history-matching, i.e. to find reasonable values for unknown data inputs, or to identify the range of inputs that are consistent with observed outputs.

He also spoke of the need to investigate discrepancies between the model and the real-world both internal to the model (e.g. the degree of uncertainty in internal model parameters) and external (e.g. phenomena which are not included in the model structure). By quantifying modelling uncertainty and the degree of uncertainty with which the model predicts real world phenomena, it is possible systematically to link forecasts made using the model to the real world and avoid overconfidence in projections.

1.3 Break-out session

The workshop attendees were split into four groups. Each group was given one question to consider. At the end of the session, the groups reported their thoughts back to the workshop. A summary of the responses to each question is given here.

1.3.1 What are the biggest research challenges for the technical modelling community?

- **Uncertainty**

  Considering planning background uncertainty in policy is perhaps both the most important and the most difficult research challenge, particularly as there is a need to consider uncertainty on very long timescales (>20 years).

- **Dimensionality**

  The dimensionality (i.e. number of inputs to models) of energy system problems is increasing. Faster computers can go some way to mitigating this issue when computing results of existing models.

- **Model Complexity**

  Larger and more complicated models are increasingly being used to provide evidence in support of policy decisions. As per the previous point, there are technical challenges in building such models and in efficient computation. There is also the question of whether these more complicated models are actually adding to our understanding of the real-world system under study.

- **Communication**

  It is critical to communicate effectively the results of modelling studies and the assumptions underlying these studies.

- **Quality & Transparency**

  Quality assurance, i.e. ensuring that any data and assumptions being used are fully documented, is vital. Current procedures can sometimes result in policy-makers being asked to trust modelling output without such a full record of data and assumptions.

- **Societal Factors**

  There is a need to include consumer choice and behaviour in models.

- **Technology**

  The rate of change in technologies is rapid and considering this in model building and policy decision making is challenging.

- **Global economy**

  Greater global inter-connectivity adds complexity to energy system modelling.

1.3.2 How should uncertainty be dealt with when modelling for long term policy?

- **Communication**

  In addition to technical modelling issues, a key challenge when modelling uncertainty is communicating this uncertainty to stakeholders. Policy makers need to be made more aware of the need for quantification of uncertainty.

- **Uncertainty Analysis**

  It is important to plan for an uncertainty analysis at the start of any study, and design the system modelling and uncertainty analysis together. Decision makers commissioning a modelling study might not appreciate the value of a thorough uncertainty analysis, and also the resource required to carry this out. Methods for assessing in advance the value of doing an uncertainty analysis can be helpful here.

- **Higher Resolution Data**

  There is a particular need for methods for dealing with uncertainty when including spatial or temporal matters in models (i.e. geographical data or time series, or simplifications thereof).

1.3.3 What do technical modellers need to do to better communicate with policy makers?

- **Staggered or Staged Decision Making**

  Technical modellers need to communicate the benefit of regarding planning decisions under uncertainty as multi-stage problems, as uncertainty in planning background should reduce as real time approaches. An example is the capacity market, where it may be better to procure less capacity 4 years ahead, with the option of procuring in the 1 year ahead market. Use of decision or event trees in technical modelling may be helpful.

- **Uncertainties**

  Uncertainty in modelling results often could be communicated better, and frequently average values and point estimates are used rather than considering uncertainty at all. This can mislead decision makers into thinking that results are more precise than they actually are.

- **Data Visualisation**

  Graphical techniques can be used to help technical modellers communicate with policy-makers. An example of visual representation of uncertainty is the Bank of England fan charts[1].

- **Implementation Procedures**

  Procedures can inhibit communication between modellers and policy-makers, and development of improved methodology. For example, quality assessments of modelling studies might be completed when a final decision has already been taken, and thus cannot be used to support improvement in that particular study. Work needs to be done to identify where institutions have procedures that are working well, and share best practice.

[1] Bank of England's fan charts e.g. http://www.bankofengland.co.uk/publications/Documents/quarterlybulletin/qb050301.pdf

- **Importance**

  Technical modellers need to be aware that communication is an extremely important part of a modelling study.

- **Memory**

  There can be a lack of institutional memory. For instance forecasts over a 12 month period might not be evaluated for quality once the 12 month period is over, and thus lessons are not learned going from one forecasting period to another. Evaluating forecasts or projections used to support longer term planning studies is more challenging still.

1.3.4 Where has existing modelling research been inadequate in meeting the needs of policy makers?

- **Timescales**

  The time taken to carry out research may be longer than the time available in order to take a decision. Thought is thus required as to how appropriate modelling can be developed to support decisions in the short term, while also carrying out longer term R+D on how modelling can provide better decision support in the future.

- **Awareness**

  It is important that modelling research is communicated well. Policy makers may not be aware of all the models available. Modellers need to be able to build confidence in their models and assumptions so that policy makers feel comfortable using them. Stronger links between government and academia could help here, so that communication and interaction is dynamic between the two sectors.

- **Societal Factors**

  There is a need to incorporate social and behavioural modelling into traditional models and to study the societal distributional impacts of policies.

- **Keeping Pace with Developments**

  Modelling research can fail to address rapid changes in an energy system. Considering possibilities outside of those already observed can be critical when looking to the future. For instance; the possibility of completely new technologies might not naturally be incorporated in standard parametrised models.

- **Incentives**

  Different incentives can be a barrier to academics working with policy makers – for instance the former might principally be rewarded for publications in particular journals, rather than receiving reward for working directly for the benefit of society. There is also an issue with lack of access to good data in academia because of proprietary and paywall issues.

1.4 Panel discussion

Key points made were:

- There is greater data availability and tools now than there have been before. However, there is a need to reappraise existing methods as we look to major changes in the energy system over the coming years.
- Information on uncertainty should be provided to the policy maker, so that they can make an informed decision. The modeller thus needs to consider carefully the handling of uncertainty both in analysis and communication. The specific policy maker also needs to be identified, as this affects the remit and requirements for models and communication – possible clients could be government, National Grid etc.
- Uncertainty analysis needs to be conducted more carefully than is usually the case at present. It is often overlooked that model results, without quantification of uncertainty in their relationship with the real world, may not provide a sound logical basis on which to make decisions. While results without uncertainty quantification might appear simpler and more definitive, this is not a reason to omit this further necessary step.
- There is considerable value in ex post assessment of previous modelling studies. An assessment of what has been successful and what has not is helpful in supporting good decision making, to identify possible improvements in methodology and data handling. See for example the working paper published by UKERC in 2014 "Reflecting on Scenarios"[2]. There can be a mismatch between data availability and decision timescales for capital planning – being ready to take advantage of data in a timely way is key, but assembling data can be a very long term process.
- There appear to be differing views as to the knowledge needed to apply model results in the policy sector. It is important in the application of results to understand the limitations in the modelling study, both in terms of possible events that have not been considered, and in terms of the extent to which the model structure includes representations of relevant real world phenomena.
- One interesting example from the past: In 1982 J Edmonds Jay Riley projected what the CO_2 emissions would be for the year 2000. The number produced was lower than

[2] W. Dowell, E. Trutnevyte, J. Tomei & I. Keppo. 2014. UKERC Energy Systems Theme: Reflecting on Scenarios. Working Paper. http://www.ukerc.ac.uk/publications/ukerc-energy-systems-theme-reflecting-on-scenarios.html

others' projections but over time was shown to have been correct. However, while the projection was correct it was for the wrong reasons; there were cancelling errors in predictions. In 2008, analysis underpinning limiting CO_2 emissions by 2050 from different modelling groups provided very different answers, and the right lessons need to be learned from this range of projections and recommendations. It is further important to choose carefully an appropriate metric when assessing quality of projections.

- Uncertainty can be overestimated as well as underestimated, which also needs to be considered in modelling and decision analysis. Careful quantification of both modelling uncertainties and their consequences are required.
- The UK Government's "Aqua Book[3]", which gives guidance on model quality assurance in government, was recommended as a source of information on current best practice. This covers perspectives both of modellers and of the users of modelling results. In particular, it advises decision makers not to expect a single figure for model-based projections, where modelling uncertainty or planning background uncertainty is relevant.

2. Policy session

2.1 The Role of Modelling in Energy Regulation

Dr Andrew Wright, Ofgem

Dr Wright first outlined the roles and responsibilities for the statutory body Ofgem, and which aspects of policy making sit with government and which with Ofgem.

In making policy decisions Ofgem consults with a wide range of stakeholders, and assesses the evidence including conducting impact assessments in line with its mission of "*making a positive difference for energy consumers*".

Ofgem seek five outcomes for consumers in policy development:

1. Lower bills
2. Less environmental impact
3. Improved reliability and safety
4. Better quality of service
5. Better social outcomes

[3] UK Government Aqua Book: https://www.gov.uk/government/publications/the-aqua-book-guidance-on-producing-quality-analysis-for-government

Examples of regulatory stances taken by Ofgem are:

- Promoting effective competition to deliver for consumers
- Driving value in monopoly activities through competition and incentive regulation
- Supporting innovation in technologies, systems and business models
- Managing risk for efficient and sustainable energy
- Protecting the interests of consumers in vulnerable situations

Following on from this, broad issues where modelling is used to support decision making include:

- Trade-offs (cost-benefit analysis and beyond)
- Regulatory and market arrangements are by necessity pragmatic approximations.
- Markets do not always function well.
- Distributional effects are important.
- Complexity and uncertainty.

Dr. Wright then described specific questions on which Ofgem decisions have been strongly influenced by modelling:

- Interconnector "cap-and-floor".
- Strategic wider works (e.g. Caithness-Moray).
- Gas emergency cash-out reforms.
- Electricity balancing reforms.
- "TransmiT" – reform of locational TnUoS charges.
- Embedded benefits.

In addition some models are integrated into regulatory and market processes – for instance:

- Volume to procure in capacity auctions
- SO incentives (BSIS) – base-line modelling
- Cross-border market coupling

On these latter examples, improved model performance offers an immediate payback for consumers.

In summary, key issues for development proposed by Dr. Wright were:

- Dealing with uncertainty and risk
    - Short term
    - Longer term

  - Resilience
- Modelling real-word decision making
  - Ex-ante decisions under uncertainty
  - Behavioural biases
  - Institutional factors
- Dynamic effects of competition
- Communicating model outputs especially probabilistic concepts

2.2 Prof Gordon MacKerron, University of Sussex

The UKERC working paper “Reflecting on Scenarios” published under UKERC’s Energy Systems Theme in 2014 reviews the use of UK energy scenarios over the period from the late 1970s to 2013[2].

The most striking finding is that wide ranges of scenario/modelling exercises failed to capture what turned out to be actual historical events. This in part reflects the relative narrowness of the techniques used that were often versions of the MARKAL model. There has been perhaps too much emphasis on consistency of approach and a reluctance to embrace diversity. It is probably the case that over-emphasis on cost-optimisation leads to a relatively narrow set of future visions. Scenarios chosen tend to be dominated, perhaps unsurprisingly, by present concerns at the time of the study. Thus scenarios have successively concentrated on subjects like oil prices, nuclear power and now ambitious carbon emission reductions, or particular technological fashions.

Politics inevitably plays a role in scenario choices e.g. taking a benign view of security of supply. Official forecasts are also constrained to assume an optimistic future economic growth rate, which tends to lead to future energy demand assumptions at the upper end of any plausible range. Where scenarios are constructed independently of Government and have a strongly narrative content, less inflated expectations of future energy demand are more likely to be considered. When the Royal Commission on Environmental Pollution published its radical 22nd report in 2000 “Energy – The Changing Climate”, two of its four scenarios for 2050 had energy demand no higher than in 2002, and in one case below 2002 levels. The very large and wide-ranging stakeholder input to these scenarios appears to have been influential. A future low energy demand now seems more plausible than many believed possible back in 2000.

In more recent work, there is a strong tendency to develop scenarios that assume that carbon emission commitments will always be met. Historically, and in recent years, there has been a tendency to assume that nuclear power will be cheap and that renewables will remain relatively expensive.

In the nuclear case, this bias has been especially strong. In 2008 when the Department for Business Enterprise & Regulatory Reform (BERR) published its White Paper on nuclear power, it provided a range of future costs for nuclear power. The costs reflected the BERR belief that nuclear power would be an attractive proposition for private investors without state intervention. The highest imagined future cost provided by BERR was £1,625/kW (£2050/kW in 2017 prices). The current cost for Hinkley Point C is assessed to be £6,100/kW, an outcome that exceeds the anticipated 'maximum' level from under a decade ago by a factor of almost three.

There are also other 'fashions' that have a strong influence in the way that the future is portrayed. An example of this is that in the early 21st century it was widely expected that hydrogen and fuel cells, and carbon capture and storage technology, would be widely implemented in the period between 2020 and 2030. This is no longer so. At the present time, disillusionment with the costs of new large nuclear reactors is in part responsible for recent interest in some quarters that small modular reactors (SMRs) will become significant by 2030 or just beyond. However SMRs remain unproven on a commercial scale, and thus it remains to be seen whether present ambitions for the technology will be realised.

2.3 Break-out session

The format of this break-out session was the same as the morning session, except the questions were more focussed on policy.

2.3.1 What do policy makers need to do to better communicate with modellers?

The group identified three areas where communication could be improved:

- **Consequences**
  Policymakers need to understand better the consequences of decisions. Modellers can assist policymakers in interpreting the model results for policy purposes. Policymakers need to help modellers appreciate their priorities when considering the different potential outcomes of policy decisions.
- **Model Design**
  Communication between policymakers and modellers needs to occur in each stage of the model design and development. The questions that the model is to address will go through an iterative process, requiring input from both policymakers and modellers.
- **Motivation**
  The above can be improved through an understanding of the motivation(s) for both sides (policy makers and modellers). For instance, modellers may have a particular interest in academic publications, while the primary interest of policymakers may be to

obtain an answer to a particular question. This can lead to misunderstanding between the two.

2.3.2 What models would policy makers like to see developed for energy which either don't exist or are currently inadequate?

The group commented that all models were inadequate to some extent. It was stressed that the processes of designing and developing a model is as important as the resulting model and outputs. Openness and humility was called for, as was avoiding a situation where a particular policy outcome follows from the choice of model rather than underlying drivers.

Specific new models or features of modelling that the group would like to see:

- Data sharing and methodology development for modelling studies that cross boundaries between different systems.
- Large scale agent based models
- Greater spatial detail in modelling to allow multi-level policy decisions
- More uncertainty analysis

2.3.3 What do policy makers do when faced with modelling results that do not match policy requirements?

There were a number of courses of action that might be taken, depending on the particular policy organisation. The course of action can also depend on the stage of the policy making process at which the model results are being used.

Early in the policy process unexpected results can be used to inform and change the direction of the policy and in most extreme cases to change policy completely. There could also be requests made for more modelling and consideration given to wider political factors. The cost impacts on other sectors may be considered.

In the late stages of the policy making process the above actions may also be taken, although large changes of direction might be more difficult. There may be attempts made to understand why the modelling results do not match policy requirements[4], and in some cases the modelling results will be criticised.

[4] This links to points made earlier about the value of ex post analysis of quality of modelling studies.

2.3.4 What else is needed to improve policy making based on technical modelling in practice?

Communication was raised repeatedly in this group as a key issue. Specifically:

- Exchange between modellers and policy makers needs to be more frequent, better quality, and more pro-active
- Policy makers need to be integrated into the modelling process to ensure that models are designed to match the particular policy purpose
- There generally needs to be more interaction with a wider range of stakeholders in the modelling process

There were also suggestions as to how the modelling process itself could be improved to best meet policy makers' needs:

- Prior to the specification of detailed modelling approaches and tools there should be an initial challenge process to the research questions being addressed by the model and testing of the assumptions
- Systematic reviews of the evidence could be performed, perhaps adopting methodology from the medical sciences
- Approaches to handling uncertainty in decision support need to be improved
- Transparency and humility are needed on the part of modellers – it should be clear what a model does and how, and there should be a logical argument to back up any claims made about a model's capabilities.
- There is a need to recognise that model outputs reflect social and historical assumptions, and also judgments on what to include in the model, although a well-conducted modelling study will attempt to minimize consequences of this.

For the policy making process there were the following suggestions:

- Policy makers should access and consider a greater diversity of evidence and models in the policy process
- There should be expert analysis and review of decisions, so that lessons are learned over time
- Policy process needs to build in more interaction with modellers in scoping research modelling questions.

2.4 General Discussion

Suggestions from the general discussion that followed covered a range of issues:

a. Models' role in policy decision making

- Models while hugely valuable and informative are a simplification of the real world; this should not be forgotten. Policy makers need greater awareness about what can and cannot be modelled and the scalability of a particular model.
- Models should not be developed to provide a specific answer (on a specific date) but applied for an investigation around the problem or issue e.g. how do we transition in an efficient way? Cost optimisation is very powerful, and even though we do not live in a perfect world it is still helpful, but other considerations are also important e.g. societal issues and environmental issues more generally.
- Policy decisions have a huge influence on the energy sector, and interact with costs and the development of technology – this should be accounted for in the modelling process and investigation of different scenarios/pathways.
- It is necessary in many policy studies to consider the whole system and different energy vectors.

b. Policy Makers & Understanding

- Some models are very technical and difficult to understand. There is therefore a danger that modelling takes discourse away from particular stakeholders. Models are best developed when taking a wide range of opinions and perspectives, and therefore an inclusive approach is needed. A way needs to be found therefore to be able to relate/communicate complex models and approaches to the widest possible audience.
- Those that can understand the minds of both policy makers and modellers and act as intermediaries are gold dust!

c. Path Dependency & Complexity in Modelling

- Over time path dependency in modelling creates problems in verification and communication as models are developed to be ever bigger and more complex – there may be inertia in how certain approaches are used without ongoing critical reappraisal, or policy recommendations might become driven implicitly by the modelling approach chosen rather than by more fundamental issues.
- Computer technology development has made possible more complex models and stochastic analyses. It was pointed out that many people drive a car without understanding the engineering behind the car – perhaps there is a need for something similar with modelling? Or is there some required minimum degree of understanding to use models robustly?
- Models need to be balanced, objective and transparent.

d. Synthesising Evidence from Models

- The Committee on Climate Change have published good examples of synthesising evidence from models e.g. this 2016 report on *"UK land use projections and the implications for climate change mitigation and adaptation"*[5]. It was suggested that there is perhaps the need to model the modellers, due to their influence on future policy?
- In comparing energy models with climate models – it was observed that there is greater rigour in climate rather than energy modelling in particular in undertaking uncertainty analysis.
- There can also be complexity in interpreting competing messages from different models, and methods for considering this systematically are required – again, climate science may provide interesting case studies.

e. Degree of Uncertainty

- Timescale is a major factor here: the degree of uncertainty over system background is typically less on shorter lead times, which should be accounted for both in modelling and in the way decision processes are structured.

3. Conclusions & Recommendations

Many specific points were made in the presentations and discussion sessions, as described in the previous sections. This final conclusion section summarises the following key themes that ran through the workshop; communication, uncertainty, and research into policy processes. Strikingly, the discussion mainly emphasised issues of modelling and policy practice, rather than specific technical improvements to system models.

A. Communication

Effective communication between modellers and policymakers is critical. This is not only in understanding the model and its results, but also in terms of understanding each other's timescales and priorities. If there is improved understanding then policymakers are better placed to select the appropriate model for the task in hand rather than relying on incumbent approaches. Modellers are likewise better placed to deliver analysis that meets the policymakers' needs.

Training may be required both for policymakers to appreciate what models can and cannot do, and for modellers to appreciate the needs of policymakers. A key issue in communication is that the educational and career backgrounds of modellers and policy decision makers are typically very different. This means that very careful choice of language

[5] Committee on Climate Change 2016 UK land use projections and the implications for climate change mitigation and adaption. https://www.theccc.org.uk/wp-content/uploads/2016/08/ADAS-for-CCC-UK-land-use-projections-and-implications-for-mitigation-and-adaptation.pdf

and visualisations are required if policymakers are to take decisions based on a realistic understanding of modelling analysis. To facilitate increased collaboration between modellers and policymakers; a third party, that can understand the needs and communication styles of both sides, could be helpful.

The ultimate goal is for policymakers, who might not have a technical background, to be able to use modelling evidence in decision process based on a more meaningful understanding of what the model says about the real world.

B. Uncertainty

All models are simplifications of the real world and there can be uncertainty over both the parameters and inputs of the model, and over how the model structure relates to the real-world system under study. Both have an impact on the results of the model, and need to be accounted for if there is to be a logical basis to consequent decision making by policy makers. Uncertainty analysis needs to be undertaken so that there is greater understanding as to why the model gives the answers it does, and how this relates to the real world. Uncertainty analysis should also account for the fact that as one approaches real time (e.g. when the consequences of a particular investment decision will be realised), the uncertainty over system background reduces; this should be accounted for in both modelling analysis and the timing of real-world decisions.

The roles of different complexities of model were also discussed. Simple models are effective tools to gain insights into a problem, though it is important to have a logical basis indicating that these are insights into the real-world system (rather than the model itself). More complex models are developed to make quantitative projections to support policy decisions. The hope is that by adding further modelling detail this will result in greater learning about the world and better decision making. Careful uncertainty analysis is required though to link the modelling results to the real-world system.

Uncertainty is often not communicated, even when it was considered in a modelling study, which can lead to misunderstandings. This can be a cultural issue (e.g. policy makers not wanting to consider uncertainty, or at least modellers thinking that policy makers don't want it), but it may also be a practical issue of how information on uncertainty is best visualised and communicated.

C. Research into the Role of Modelling within Policy Processes

There is a need to undertake wide ranging research into the processes by which models are being used in policy making, and how this can be improved. Specific areas for further work include:

- How uncertainty analysis and a greater understanding of the model-world relationship can be integrated into the modelling/policy process, given the very different backgrounds of the analysts and decision makers involved.
- Ex post analysis of modelling studies and the success (or otherwise) of consequent decisions, to assess fully the performance of modelling approaches and learn lessons for future studies. This might need to be done some years after the initial study, to give time for consequences to be seen.
- Consideration of how modelling can best support policy decisions on different timelines, considering practical issues such as the analyst resource available to organisations. For instance, sometimes in major decisions there will be time available for substantial bespoke model development, and on other occasions there may be much less time for model development.
- Systematic methods for understanding consequences of high-impact, low probability events.
- Understanding using modelling impact of energy policy on other sectors, and interaction between different energy carriers in an integrated system.
- More generally, there is significant value in identifying and disseminating best practice from current modelling studies within the energy sector and more widely, both in technical modelling and in all aspects of communication.

Quality assurance and model curation is an area receiving a great deal of attention in government at present. There is need for research on this (or at least examination of good practice in other sectors) – the ultimate aim is for decision makers to be able to take decisions informed by the robust real-world messages which modelling studies provide. All providers of modelling based evidence should follow good practice on quality assurance and curation, including those in academia where such good practice is not deeply embedded. There is also considerable value in data, and information on model inputs, assumptions, structures (and ideally code), being publicly available, so that external parties can engage in debate in an informed manner based on the modelling results.

Particular issues arise when a specific modelling approach is used to support the development of policies over an extended period[6]. This can lead to a consistent behavioural bias when interpreting the model results in policy making, or a lack of ongoing critical assessment of the chosen approach. Consideration of a variety of modelling approaches can help avoid such systemic policy decision bias, along with robust quality assurance processes of modelling studies that provide the necessary critical assessment.

[6] . For example, Hall & Buckley (2016) demonstrate how the model MARKAL is predominate in some areas of UK policy. See for more details: L.M.H. Hall, A.R. Buckley. 2016. A review of energy systems models in the UK: Prevalent usage and categorization Applied Energy 169 (2016) 607–628

The Government Aqua Book ("guidance on producing quality analysis for government") provides an excellent guide to good modelling practice. However some aspects of implementing this (for instance sections on management of uncertainty) provide a serious technical challenge even to the most advanced methodological research groups in academia – there is thus a particular need for research on how scientifically valid approaches can be developed which are suitable for wide field application, and how analyst groups in government can develop their own scientifically valid approaches which fully meet Aqua book requirements.