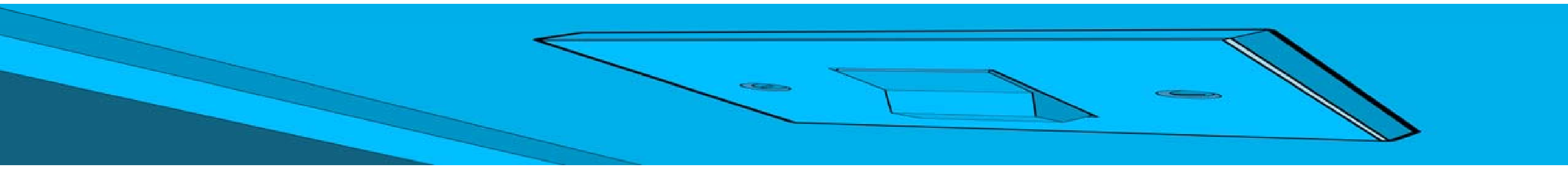

UKERC

WORKSHOP ON MODELLING FUTURE ENERGY TECHNOLOGY COST AND CHOICE

Meeting Report, 15th November 2005

Dr Neil Strachan and Dr Nazmiye Ozkan, UK Energy Research Centre

Event organised and sponsored by:

UKERC psi dti AEA TECHNOLOGY ENVIRONMENT

UK Energy Research Centre

THE UK ENERGY RESEARCH CENTRE

The UK Energy Research Centre is a publicly funded organisation charged with drawing together energy research in the UK while establishing itself as a centre of research excellence.

By taking a co-ordinated and collaborative approach to national and international energy research, and through our own interdisciplinary research activities, we will provide the knowledge needed to work towards a sustainable energy system and realise UK energy policy goals.

The Energy Systems and Modelling (ESMT) Theme of UKERC

The UKERC's ESMT research activities are being undertaken by the Policy Studies Institute (PSI) and the Cambridge Centre for Climate Change Mitigation Research (4CMR) at the University of Cambridge, with collaboration from Cambridge Econometrics.

Executive Summary

This workshop brought together researchers working within the International Energy Agency's ETSAP network of MARKAL model users, together with a broad range of practitioners from the UK energy modelling community.

This opportunity for the two modelling communities to learn from each other's work was enabled by the UK hosting the regular ETSAP semi-annual meeting which discussed modelling issues related to the MARKAL / TIMES family of energy models on subsequent days. One of the purposes of the UKERC Meeting Place is to develop networking and collaboration between UK energy researchers and also with the wider network of international energy practitioners.

The costs and characteristics of future energy technologies and how quickly they penetrate markets is a fundamental driver in the evolution of energy systems. Future technology cost is critical in assessing the costs of energy policies, ranging from economic competitiveness, environmental protection and emission mitigation, security of supply and equitable access to energy services. In response, a major ongoing effort by the energy modelling community has sought to better understand and incorporate this key driver of technological change into their energy models.

The scope of the workshop was to:

- highlight the approaches in a range of energy models to determining the future costs of existing technologies and the introduction of currently pre-commercial energy technologies;
- stimulate discussion on conflicting and complementary approaches to characterizing future energy technologies.

A very broad ranging and insightful day of presentations and discussion followed from an impressive array of over 50 modellers and energy policy analysts. Key themes emerging from the presentations and discussion focused on moving to best practices in modelling future energy technology costs and choice, and included:

- The trade-off between the more intellectually rigorous and power expression of endogenous technological change vs. the computationally simpler method of exogenous technological change with detailed sensitivity analysis;
- Small changes in input assumptions (including learning rates) can lead to large differences in technology costs and hence very different evolution paths of the energy sector;

- Whether to consider technology learning at a global or a national scale is important in how you define the ability of a country or region to impact the future costs of a technology and/or to benefit from being a first mover in investing in new energy technologies;
- If there is no deployment, there is no technology learning – this implies the need for public support of early diffusion to bring down the currently high cost of new energy technologies;
- Uncertainty is a pervading issue and needs to be made explicit in modelling runs and presentation of results;
- It is an open question as to whether uncertainty is greater or less in an endogenous vs. exogenous specification of technology learning;
- Further work in the theoretical and methodological underpinnings of technology learning and cost improvement needs to be undertaken; and
- One builds model for insights rather than answers – this point needs to be stressed to policy makers who may be seeking simple answers or technology winners – this is not what models are designed to give.

The meeting was organised by the UK Energy Research Centre's Meeting Place function in association with IEA ETSAP (International Energy Agency's Energy Technology Systems Analysis Programme), the Policy Studies Institute (PSI), AEA Technology (AEAT) and the Department of Trade and Industry (DTI). The Steering Committee comprised GianCarlo Tosato (ETSAP), Sarah Keay-Bright (UKERC), Peter Taylor (AEAT) and Neil Strachan (PSI).

Contents

Introduction

Modelling future technology cost and choice

What the costs and characteristics of future energy technologies will be, and how markets and individuals choose to use these technologies, is one of the principal and fundamental drivers in the evolution of energy systems. Future technology cost and choice is also critical in assessing the costs of energy policies, across a wide spectrum of public policy goals. These include price and non-price mechanisms, supply side policies to push technologies forward or demand side policies to pull technologies into the market. Future technology characteristics are instrumental in meeting key energy issues ranging from economic competitiveness, environmental protection and emission mitigation, security of supply and equitable access to energy services.

In response, a major ongoing effort by the energy modelling community has sought to better understand and incorporate this key driver of technological change into their energy models. This has included understanding the interacting process of technological change from basic R&D through innovation and market diffusion with multiple feedbacks between these stages.

Furthermore the underlying features of the systems context in which technologies develop and the pervading issue of uncertainty regarding technology characteristics needs to be addressed. In addition a range of observed features in technology innovation and diffusion need to be considered and explicitly modelled (if feasible) including learning by doing and learning by using, negative and positive spill-overs in the development and use of technologies, path dependency, clustering of interlinked technologies, non-economic barriers to use, and regulatory and infrastructure constraints to technology market penetration.

Technological change can be modelled autonomously or endogenously. Autonomous technological change is not explicitly driven by market conditions within the model and tends to be calibrated to past experience in technology improvements and uptake of efficiency measures. In practice such a route can yield interesting insights, especially in smaller energy markets where global assumptions can be made exogenously. With this approach, in the nearer term, care is taken to utilize[American spell-check?] the insights of the expert knowledge, recent trends and other bottom-up metrics of energy improvements.

In the longer term where technology costs are much more uncertain, scenario and sensitivity analysis can be run relatively easily to map out the possible range of technology futures and the resultant impacts on the energy system. However, for long run problems such as climate change where fundamental restructuring in energy systems and the development and use of completely novel energy technologies is required, treating technological change as endogenous to the modelled system is a significant advantage.

Thus technology costs can now be directly derived from increased research spending, penetration and resultant experience with technologies, and interlinked clustering of technologies. One drawback of such models is the significantly enhanced computation effort they require, hence making technology detail or sensitivity analysis harder to incorporate.

Scope of this workshop

This workshop brought together researchers working within the International Energy Agency's ETSAP network of MARKAL model users, together with a broad range of practitioners from the UK energy modelling community. This opportunity for the two modelling community to learn from each other's work was enabled by the UK hosting the regular ETSAP semi-annual meeting which discussed modelling issues related to the MARKAL / TIMES family of energy models on subsequent days. One of the purposes of the UKERC Meeting Place is to develop networking and collaboration between UK energy researchers and also with the wider network of international energy practitioners.

This workshop on modelling future technology costs and choice held the obvious benefits to the UK energy research community in general and modellers in particular, from interactions with a network of international experts, both within the main sessions and through bilateral discussions and informal networking. This included potential future collaborations on data collation, modelling support, and identification of joint research projects. The stated overall goals of the workshop were:

- to highlight the approaches in a range of energy models to determining the future costs of existing technologies and the introduction of currently pre-commercial energy technologies;
- to stimulate discussion on conflicting and complementary approaches to characterizing future energy technologies.

Presentations

NOTE: electronic versions of all presentations are freely available on the UKERC (www.ukerc.ac.uk) and ETSAP (www.etsap.org) websites.

Introductory Session

Introduction to UKERC and Goals of Workshop, Neil Strachan, Policy Studies Institute

Neil Strachan formally welcomed the workshop delegates, and briefly described the UK Energy Research Centre (UKERC) and its twin goals of original research and the development of UK energy research capacity. UKERC's energy systems modelling theme (ESMT) was highlighted, specifically its work developing the UK version of the MARKAL model in a collaborative venture with AEA Technology, top-down macro-econometric modelling with Cambridge Econometrics' MDM-E3 model, and integration of these twin modelling approaches. Before closing with an overview of the workshop, work to scope out the UKERC Energy Data Centre by Geoff Dutton of Rutherford Appleton Laboratory was outlined.

Overview of ETSAP, and MARKAL Family of Models, GianCarlo Tosato, ETSAP

GianCarlo Tosato, the Project Head of the ETSAP network, gave a broad overview of the ETSAP network, the MARKAL and TIMES energy modelling tools, and how these models have been utilized in energy policy analysis.

The ETSAP community has operated and collaborated for nearly 20 years, and has approximately 120 active institutions in around 60 countries. The MARKAL and TIMES models developed collaboratively over the past two decades are E4 models (economy, energy, engineering, environment) models of an entire energy system, and track commodity flows through the entire system together with the technologies that transform and utilize energy.

These are optimisation models that simultaneously consider supply and demand in a dynamic equilibrium. Model variants allow macro economic impacts, uncertainty, endogenous technological change, materials or near optimal solutions to be investigated in depth. Typical applications of the models include technological competitiveness under different market conditions and constraints, life cycle analysis, and emission reduction policies and instruments.

In the discussion that followed, special modelling treatment of nuclear was noted including different possible fuel cycles and reprocessing options . In addition how to incorporate the costs of dismantling and discount rates used are key for the future costs of nuclear technologies.

In addition it was noted that the UK and other energy systems are far from optimum, thus you may need to force policy options that meet economic equilibrium but will not be selected by the model. This can be done using tools such as technological specific discount rates, or conversely if a technology is forced in the model, this can tell you what this costs, or what the non-economic barrier is costing the system. Last, it was noted that MARKAL models can incorporate physical reality in energy service demands by incorporating information on degree days, square meter heating requirements, insulation requirements for old and new buildings, single / multiple family houses etc .

Session 1: Key issues in energy technology modelling

Innovation and Threshold Effects in Future Energy Technology Modelling, Dennis Anderson, Imperial College

Dennis Anderson explored the complex issues in modelling endogenous technological change and considering threshold effects. The former is a well known phenomena which tracks the improvements in costs reduction with cumulative production. Learning rates of 10- 20% for every doubling of capacity are commonly observed for a range of energy technologies. This has considerable implication for policy as public investments in the early diffusion of alternative energy technologies can yield considerable improvements in their future costs and characteristics.

Further, more threshold effects can be observed when the new technology becomes cost competitive with the incumbent technology and rapidly penetrates a mainstream market. Thus the marginal cost of an abatement strategy is no longer convex (or smoothly upward sloping). This has important implications for both policy makers, and also for energy modelling as results can drastically change with small changes in assumptions due to endogenous threshold effects.

In the discussion that followed it was noted that models with linear cost characterizations also give different results when there is small change in assumptions. In MARKAL, there are 2 ways to deal with this: stochastic optimisation for uncertainty, and modelling to systematically generate near-optimal alternatives. Monte Carlo simulations can then be used to see which solutions are robust.

It was noted that modelling endogenous technological change is computationally complex. However there are projects ongoing (e.g., Cascade Mints) that are focused on clustering effects of technologies, R&D and learning by doing and learning by searching, and stochasticity suggesting an ongoing move to modelling endogeneity. In addition other projects are integrating learning by doing using niche markets. And even if a range of technologies are defined exogenously, including endogenous structure and capturing externalities are important.

Energy Technology Paths and Technology Learning, Clas-Otto Wene; Wenergy AB

Clas Otto-Wene focused on the issues of moving away from globally optimal technology paths to explore local optima that may represent a very different mix of fuels and technologies and their use for only a small increment in cost. Investigating these alternate and path dependent technology scenarios is an important task for insights in energy policies and energy system evolution. In large part these potential structural shifts are due to learning effects and the resultant costs and characteristics of energy technologies. Thus the policy decision to support development and early diffusion costs of new technology options becomes critical, and energy models may need to focus on niche market analysis to provide information on overcoming initial myopic cost barriers with a ‘learning investment’.

The discussion that followed focused on the role of public vs. private market player in such learning investments, and how to impart to policy makers the result that many technology futures are realistically achievable at costs of similar magnitudes.

Technological Change in Environmental Modelling: Learning Curve Versus Technical Coefficients, Jonathan Köhler and Haoran Pan University of Cambridge

Jonathan Köhler proposed an alternate methodology to represent endogenous technological change by moving away from technology specific learning rates to changing input-output (I-O) technical coefficients. These I-O outputs are an attractive candidate to express changing technology as they are based on industrial and sectoral data, are embedded within the wider economic and energy system and often represent specific technologies. Using a simulation model, time steps can incorporate historically derived I-O metrics plus an increment attributable to induced technological change. Last it was noted that in very long-run problems such as global climate change, an endogenous treatment of technological change was particularly important.

In the discussion that followed a distinction was made between innovation at the national vs. global scale. This is important in terms of whether the model assumes perfect knowledge spill-overs from R&D on a global level, or whether first movers in a technology in particular regions can wield a comparative advantage.

For example in photovoltaics, Germany and Japan are the leading countries, and producers can generate extra economic rents as time is needed to use/produce that product.

It was also noted that in the very long run, costs to tend to converge whatever method of endogenous technical change is used.

Session 2: Further issues in future energy technology costs and choice

Issues on Future Technology Cost Estimation: An (Incomplete) Overview, Nazmiye Ozkan and Neil Strachan, Policy Studies Institute

Nazmiye Ozkan's presentation framed the key issues in modelling future energy technology costs and choice. This includes understanding the interacting process of technological change from basic R&D through innovation and market diffusion with multiple feedbacks between these stages. Furthermore the underlying features of the systems context in which technologies develop and the pervading issue of uncertainty is technology characteristics needs to be addressed. In addition a range of observed features in technology innovation and diffusion need to be considered including learning by doing and learning by using, negative and positive spill-overs in the development and use of technologies, path dependency, clustering of interlinked technologies, non-economic barriers to use, and regulatory and infrastructure constraints to technology market penetration.

Technological change can be modelled autonomously or endogenously. Autonomous technological change is not explicitly driven by market conditions within the model and tends to be calibrated to past experience in technology improvements and uptake of efficiency measures. In practice such a route can yield interesting insights, especially in smaller energy markets where global assumptions can be made exogenously. In this approach, in the nearer term care is taken to utilize the insights of expert knowledge, recent trends and other bottom-up metrics of energy improvements.

In the longer term where technology costs are much more uncertain, scenario and sensitivity analysis can be run relatively easily to map out the possible range of technology futures and the resultant impacts on the energy system. However for long run problems such as climate change where fundamental restructuring in energy systems and the development and use of completely novel forms of new energy technologies is required, treating technological change as endogenous to the modelled system is a significant advantage.

Thus technology costs can now be directly derived from increased research spending, penetration and resultant experience with technologies, and interlinked clustering of technologies. One drawback of such models is the significantly enhanced computation effort they require, hence making technology detail or sensitivity analysis harder to incorporate.

In the discussion that followed, a number of additional factors were raised in relation to future technology cost including social and political acceptability of technological options. It was noted that it is extremely difficult to mimic endogenous technological change through any exogenous function, except perhaps by back-casting from scenario endpoints. It was an open question as to whether uncertainties were greater of less in the endogenous or endogenous formulation. Once again the key question of treating technological change at a national or global level for policy decisions was raised.

Modelling Endogenous Technological Change in MARKAL and other Optimisation Models, Socrates Kyrepos, Paul Scherrer Institute and Gerard Martinus, ECN Netherlands

Socrates Kyrepos discussed how the MARKAL model has been developed to account for endogenous technological change. In modelling terms this has been based on a linearalisation of the non-linear non-convex characterization of technologies with experience learning in a mixed integer linear programming variant that works well but significantly adds to computational complexity. This approach can generate very different technological mixes if initially expensive technologies are used in an early stage and their costs are hence reduced. An extension is to identify clusters of technologies that share a common technological component and apply the same technology learning parameter to all of them. Current methodological work seeks to embody technological change in a non-linear formulation directly.

In the discussion that followed the question was again raised as to whether there is greater or less uncertainty in an endogenous framework. Monte Carlo simulation is one way to investigate the sensitivity of the learning rates but integrated energy models have a whole range of uncertain parameters (e.g., climate damages, economic growth etc). There is also an issue on the terminal point condition that the model uses and the lifetime of installed capital (and hence the number of repeated investments). If the majority of learning occurs early in the simulation this is less of a problem.

Overview of NEEDS Project: Scenario Dependent Evaluation of Technology Externalities, Denise Van Regemorter, Katholieke Universiteit Leuven

Denise Van Regemorter outlined the NEEDS project that seeks to evaluate the full costs and benefits of energy policies and energy systems in the EU member states and the region as a whole.

A key part of this challenge is to develop robust and defendable life cycle analysis for new energy technologies and to integrate this with the monetary valuation of externalities imposed by these energy technologies. One potential difficulty to be overcome is the issues in drawing boundaries for life cycle analysis. This project is utilizing and contributing to the ongoing development of the pan-European TIMES model.

Some discussion was paid to the difficulties in incorporating life cycle analysis and endogenous technological change. For example different technological paradigms may arise with radically different life cycle implications, notably in the derivement and use of secondary energy carriers such as electricity and hydrogen.

Stochastic integrated assessment modelling with induced technical change
Stephen Albreth, Cambridge University

Stephen Albreth presented work in progress that embodies endogenous technological change into the modelling field of integrated assessment that explicitly links cost and energy policies with the benefits of mitigating damage from climate change. Although this model representation categorized abatement steps rather than specific technologies, uncertain learning rates can be incorporated. Ongoing work is looking at characteristic learning with non-constant uncertainty attached (i.e. either the uncertainty in learning becomes resolved or gets worse) in an agent based modelling extension.

In a technical discussion that followed some practical modelling difficulties of this approach based on earlier attempts were outlined.

Insights from the Climate Change Policy Review and Implications for Energy Technology Modelling, Michael Grubb, Carbon Trust and Imperial College

Michael Grubb closed the second presentation session with some more encompassing thoughts on technological change and the economics of climate mitigation leading on from the UK climate change review which included a meta-study of modelling approaches: These included bottom up technology models where transaction costs in using new technologies is key, sectoral models where industry can capture scarcity rents from limiting emissions, and macro models where the treatment of revenue recycling is important. In all, different models answer different questions. One potential solution for important solving issues – such as whether there are low cost efficiency gains resulting from non-optimal current use of energy – is to undertake actual policy experiments.

Discussion Session: Best practices in modelling future energy technology costs and choice

Tim Foxon of Cambridge Econometrics opened the discussion by noting the importance of modelling as an heuristic tool, and hence what insights specific models can or cannot give. Furthermore, it was stressed uncertainty is a pervading issue and should be explicitly treated. And last, energy modellers were encouraged to look to other fields for tools and insights to apply to energy-specific problems (e.g., complex non-linear behaviours).

A lively and stimulating general discussion followed starting with the notion that one builds models to gain insights rather than find answers. In terms of learning it is clear that if no deployment takes place no learning will occur, raising the issue of public support of early technology diffusion. The empirical base for technology learning may need to be critically re-examined however. For example the causality of more deployment leading to lower costs could equally apply the other way round (as suggested by some economists).

Specific lessons include the scope for mature technologies to start relearning, often stemming from a change in market circumstances (e.g. improved performance and learning from wildcat oil drillers in the face of severe competition). A key issue appears to be whether to consider learning at the global or national level. For many national studies of small or mid-sized economies, the drivers of learning may be able to be derived exogenously as they depend on global uptake levels with key nations including the USA, China and India. Unless the UK has a strong comparative advantage or disadvantage in a particular technology it is fair to say that technology deployment mirrors average global deployment and hence learning.

In terms of explaining energy model results to policy makers there was a general feeling that end-use sectors offered most scope for efficiencies and altered investment patterns - an important message (e.g. in the long term CO_2 reduction planned for the UK). Many have limits on potential and/or market imperfections or barriers to overcome. A harder question is to convince policy makers on the issues of complexity and uncertainty and to help them think in terms of understanding the key drivers as opposed to simple answers, or picking winners. In addition there is the balance of a model to consider in that each component should have roughly the same level of detail and sophistication, and the recognition that a model cannot incorporate every relevant factor (for example an engineering based model like MARKAL does poorly in building in cultural factors).

Finally there remains a huge amount of important modelling work to be built upon the tool already developed. This includes better quantification of poorly defined costs and benefits of using or switching energy use, more relevant scenario and baseline specification and the incorporation of new insights including the explicit incorporation of the value of reducing uncertainty and the diffusion process of new energy technologies into fragmented and regulated markets.

Paul Ekins of the Policy Studies Institute closed the workshop by commending the speakers and participants for a full and stimulating day of discussions and thanked the organizing committee and support staff for such a well run event.

Workshop Programme

10.00 Arrival and Registration

Introductory Session: Chair – Peter Taylor, AEA Technology

10.30 Introduction to UKERC and Goals of Workshop
Neil Strachan, Policy Studies Institute

10.45 Overview of ETSAP, and MARKAL Family of Models
GianCarlo Tosato, ETSAP

Session 1: Chair – Peter Taylor, AEA Technology

11.10 Innovation and Threshold Effects in Future Energy Technology Modelling
Dennis Anderson, Imperial College

11.40 Energy Technology Paths and Technology Learning
Clas-Otto Wene; Wenergy AB

12.10 Technological Change in Environmental Modelling: Learning Curve Versus Technical Coefficients
Jonathan Köhler, University of Cambridge

12.40 LUNCH

Session 2: Chair – GianCarlo Tosato, ETSAP

1.40 Issues on Future Technology Cost Estimation: An Overview
Nazmiye Ozkan and Neil Strachan, Policy Studies Institute

2.10 Modelling Endogenous Technological Change in MARKAL and other Optimization Models
Socrates Kyrepos, Paul Scherrer Institute; and Gerard Martinus, ECN Netherlands

2.40 Overview of NEEDS Project: Scenario Dependent Evaluation of Technology Externalities

Denise Van Regemorter, Katholieke Universiteit Leuven

3.10 COFFEE/TEA

3.30 Stochastic integrated assessment modelling with induced technical change
Stephen Albreth, Cambridge University

4.00 Insights from the Climate Change Policy Review and Implications for Energy Technology Modelling
Michael Grubb, Carbon Trust and Imperial College

Session 3: Chair – Paul Ekins, Policy Studies Institute

4.40 Discussion – Best Practices in Modelling Future Energy Technology Costs and Choice
Discussant 1: Tim Foxon, Cambridge Econometrics

5.00 General discussions

5.40 Summing up
Paul Ekins, Policy Studies Institute

5.45 DRINKS RECEPTION

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