WHITE PAPER MODELLING - USE OF THE MARKAL ENERGY MODEL

1. The White Paper is underpinned by a wide range of analytical work. Annex A lists the reports that are already available or will be available on the DTI website on the day the White paper is published. The analysis included:

- work commissioned from Future Energy Solutions using the MARKAL energy model to consider the options and costs of achieving long-term reductions in CO_2 emissions;

- consideration of the system costs attached to increasing levels of electricity generation from renewables from 10% to 20 or 30%[1] ;

- a review of the evidence in relation to the type and scale of ancillary effects (such as impacts on air quality) that may accompany reduction in greenhouse gas emissions[2]**;**

- consideration of issues attached to security of gas and electricity markets, of the barriers to the operation of competitive markets that might lead to inadequate or costly provision of security, and the scale of such potential impacts[3] ;

2. The focus of this technical note is on the work using the MARKAL energy model to examine the costs to the UK energy system of reducing CO_2 emissions.

What is the MARKAL energy model?

3. MARKAL is a bottom-up technology model of the energy system. It was initially developed by the International Energy Agency (IEA). We have used a UK version of the model. But MARKAL has been adapted for use in many countries, including the US, the Netherlands, Sweden, Australia and Germany. The IEA is currently developing a multi-region version of the model, precisely to consider the kinds of issues – technology choices under a CO_2 constraint – that we have examined for the UK. Technologies are assumed to be developed globally and to benefit from advances in design, engineering and production stemming from such broad involvement, although the implications of more limited innovation have been explored.

4. As a bottom-up model, MARKAL consists of a menu of energy technologies characterising the production, transmission and use of energy, with associated information on the costs of these technologies. Different tranches of the same basic technology can be made available in the model at different assumed costs (e.g. the second GW of onshore wind generation – at the best sites – at lower cost than the first

[1] www.dti.gov.uk/energy/developep/080scar_report_v2_0.pdf

[2] www.defra.gov.uk/environment/economics/index.htm

[3] www.dti.gov.uk/energy/whitepaper/

GW and so on), or at costs which vary over time (e.g. further technological development allows new build of a particular technology to be lower cost in 2020 than in 2010).

5. Having specified assumed levels of energy demands to be met, the model can be used to determine the combination of technologies which will meet those needs at least overall cost. Further constraints can then be added. In particular the model specification includes estimates of the level of CO_2 emissions attached to the fuels used by each technology. This enables the model to be used to meet the same energy demands while constrained to limit CO_2 emissions to a specified maximum level. A different set of technologies is likely to be chosen to meet the constraint at least cost. Comparison of the overall costs with and without the constraint gives us information on the costs of meeting the constraint.

6. Further information on the model is contained in the consultants' reports of the modelling work[4] (references below).

Modelling work commissioned

7. Work using MARKAL was originally commissioned by DTI and other departments to inform the work of the Inter-departmental Analysts Group (IAG)[5], and was fed into the PIU Energy Review. In particular, this work has examined the cost of achieving, as recommended by the Royal Commission on Environmental Pollution (RCEP), a 60% reduction in CO_2 emissions by 2050. The initial work was published in February 2002[6].

8. One of the main conclusions was that the costs of achieving such a substantial reduction in CO_2 emissions might be around 0.5-1% of GDP in 2050. This would be broadly equivalent to a reduction in the assumed GDP growth rate of 2.25% a year of perhaps 0.01 percentage points a year.

9. To inform consideration for the White Paper we commissioned further work from Future Energy Solutions to clarify what was driving the results. In particular, the work has conducted a wide range of sensitivity analyses, mainly aimed at considering the circumstances in which costs of moving to a low carbon economy would rise.

10. Amongst the sensitivities examined in this further work have been the following:

- what happens to overall costs if energy efficiency fails to deliver greater carbon savings or if it only delivers at increased cost;
- what happens to overall costs if the level of innovation in low carbon technologies is constrained – i.e. the costs and efficiency of new and existing low carbon technologies do not improve further after 2010;

[4] www.dti.gov.uk/energy/whitepaper/

[5] www.dti.gov.uk/energy/greenhousegas/index.shtml

[6] www.etsu.com/en_env/html/climate_change.html

- what happens if the amount of gas used could not increase above its level in 2000;

- what happens if taxes on transport fuels are varied so as to encourage the entry into the market of hydrogen and other low carbon fuels;

- what happens if costs for new nuclear generation vary both upwards and downwards;

- what happens if nuclear power and sequestration are excluded;

- what happens if the commercial discount rates used to model investment choices in generation technologies are varied;

- in addition, model runs were undertaken to reflect a range of possible post-Kyoto commitments as well as the RCEP target.

Key results

11. In terms of impact on GDP, key results from the modelling work, including the various sensitivity runs, suggest that:

  - the cost to GDP in 2050 is of the order of 0.5-2% or between £10-50bn, compared with a forecast level of GDP in 2050 of around £2500bn.;

  - this equates to a reduction of between 0.01 and 0.02 percentage points in the average GDP growth rate over the period between 2000 and 2050 (i.e. from an assumed 2.25% a year under our baseline scenario to perhaps 2.23% to 2.24% a year);

  - higher energy prices will impact on the competitiveness of a number of industrial sectors and regions and countries of the UK. Sectors particularly affected may be chemicals, man-made fibres, paper, iron and steel and non-ferrous metals. Wales, the North East, Yorkshire and the Humber and the North West are the areas with the highest concentration of these industries in the UK;

  - energy costs as a share of GDP decline over the period to 2050, notwithstanding the costs of low carbon measures.

12. Further key messages are that:

- on the cost assumptions made, a range of technology options become available to reduce CO_2 emissions;

- innovation is important in reducing costs. The model runs showing the highest costs were those in which either the level of innovation in new and existing low carbon technologies was limited or where nuclear and carbon capture and storage were completely excluded combined with limits on improvements in energy efficiency. Costs in 2050 on these runs were around 2-3 times those of the baseline runs;

- under most scenarios the share of renewables in electricity generation increases to between 25% and 40% by 2050. If new nuclear build and carbon sequestration are excluded as options more is required of renewables in order to meet the carbon dioxide constraint;

- energy efficiency improvements are required to provide a substantial contribution to meeting reduction targets at low cost;

- options to reduce CO_2 in the transport sector are relatively high cost. In the absence of future carbon constraints, fossil fuel use continues to dominate. In the constrained CO_2 runs, the transport sector moves significantly into hydrogen fuel cells after 2030 or in some cases after 2040.

- in general, the costs of many of the lower carbon technologies are fairly close. As a result relatively small changes in assumed cost for a particular technology can mean it either plays a large role in the future technology mix, or very little at all. Combined with the substantial uncertainty attached to these assumptions of future costs, this suggests that there is likely to be value now in using policy tools, wherever practicable, that leave the market to find the lowest cost routes to emission reduction. It also suggests that technological changes and the costs of options should be reviewed regularly.

What confidence can we have in the MARKAL results?

13. MARKAL is purely a modelling tool. In interpreting the results it is important to be aware of limitations in its approach. In particular:

- MARKAL is only as good as the assumptions – on future energy demands, availability and costs of technologies – that are fed into it. Expert views have contributed to those assumptions. Modelling is a useful tool for gaining an insight into the energy system but there is great uncertainty about the forecasts which it provides. Modelling does not factor behaviour;

- there are no feedbacks within the model from either (i) the costs of technologies deployed, which will impact on energy prices, to levels of energy demand; or from (ii) the level of assumed CO_2 constraint to the costs of technologies. We could expect, for example, that in a world committed to substantial CO_2 reduction low carbon innovation might be more successful, with costs falling faster;

- the choice of technologies is driven by a cost minimisation assumption. At the extreme, marginal differences in assumed cost as between two technologies can lead the model to "choose" all of one technology and none of the other. In the real world, there is likely to be a greater continuum in the costs of each technology, such that in practice the costs overlap and both technologies are deployed (and there is also likely to be value in diversity).

14. The answer to these points is that we must be careful in the way we use MARKAL and in the conclusions we draw from it. In our work we have been trying to test out various visions of the future – not to predict a single picture for 2050, or the path towards it. We have explored different assumptions for the level of energy demands, for the technologies that might be available, and for their costs. On the basis of that wide range of analyses we are then looking for general conclusions that seem to be robust across the model runs, or for what the sensitivities can tell us about what matters most in leading to either relatively low or high costs of moving to a low carbon economy. Used in this way the approach can give useful insights.

Comparison of MARKAL results with other studies of overall cost impacts

15. As a further check on the MARKAL results, in particular on overall cost impacts, it is also worth looking at costs of CO_2 reduction as estimated in other studies.

16. More generally, we might identify broadly three types of modelling approach that have been used to consider costs of emission reduction. The three types of model are:

i. **Macroeconomic**. These models are generally very country specific. They may allow for supply and demand to be out of balance (for markets not to clear). Hence, they are probably best suited to consideration of the dynamics of transition towards lower carbon futures and for applications in the short to medium term. Results, in terms of GDP response, show considerable variation across models – they can be very model-dependent, according to the particular assumptions employed.

ii. **General equilibrium**. These models assume that markets clear. They cannot address transitional costs, but are better suited to long run estimates, on the basis that in the long-run resources are re-deployed and the economy reverts towards long-run trends.

iii. **Bottom-up**. These models will tend to represent technology and energy efficiency from a detailed set of choices. The model will choose the technologies to deploy depending, in particular, on their costs and the costs of energy inputs. Depending on the particular model it may be possible to constrain the choices in some way. But in general, like general equilibrium models, this type of approach is better suited to consideration of long-run impacts than transitional costs. The MARKAL model we have used is one version of a bottom-up model.

17. In general, it tends to be considered that models of types i and ii, may overestimate costs. They start from a position that deployment of resources in the base case is optimal. Such an approach is criticized for underestimating the potential for low cost efficiency improvement and ignoring gains that may be tapped by non-price policy change. Worst case results come from models using macro-economic

models, with lump sum recycling of revenues, no emission trading and no non-carbon backstop technology.

18. Bottom up models of type iii, on the other hand, assume that there is a lot of low or nil cost technology or energy efficiency potential. Estimates from such models can be criticized for under-estimating costs on the basis that they ignore various hidden costs, transaction costs or other constraints that in practice limit the take-up of what are, otherwise, cost-effective technologies.

19. Some studies suggest that GDP costs in 2020 and beyond can be significantly lower than in the Kyoto period (2010). This is mainly a reflection that in the longer-term substitution possibilities may be greater, and resources will tend to be redeployed. Hence, we see that general equilibrium models (more suited to the longer-term) tend to estimate lower costs than macroeconomic models (better suited to the short-term).

20. But the result is also confirmed in some of the macroeconomic models which present results for costs to GDP over time. Thus:

- a 1998 study by the US Energy Information Administration[7], looking at the costs of Kyoto (in its higher cost assessment) indicates that in 2010, a 4.2% loss of GDP losses was split 3.4% to adjustment costs and 0.8% to long-run impact. By 2020, the estimated GDP loss is 0.8%, comprising 0.2% adjustment cost and 0.6% longer-run impact.

- even a (very pessimistic) study by the International Council for Capital Formation[8] suggests than the GDP cost of Kyoto, for the UK, is substantially reduced by 2020 (1%) as against 2010 (4½%). Even if the UK continued, beyond Kyoto, on a straight line path to a 60% cut 2050, the GDP cost in 2020 (2%) would be less than the cost of Kyoto in 2010 (4½%).

21. This is not the place for a review of other specific studies, although our background work examined a large number of such studies. Nevertheless, it is clear that one of the factors leading some models to predict relatively high costs is that they aim to reduce carbon by substantial amounts over relatively short periods – in the extreme cases, over 3-5 years. The shorter the period of adjustment, the greater the costs are likely to be:

- the substitution possibilities are less;
- low carbon technology options have less time to develop and fall in cost;
- investment decisions cannot be timed to coincide with the natural end of life of existing assets, leading to greater costs with premature retirement.

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[7] http://tonto.eia.doe.gov/FTPROOT/service/oiaf9803.pdf

[8] http://www.iccfglobal.org/

How does MARKAL fit within the range of cost estimates?

22. MARKAL is a bottom-up model which assumes a rich database of potential energy-efficiency and low carbon technology choices. The database also allows for continued learning, on a global scale, which leads to significant cost reduction for some options. The basic structure of the model, therefore, is that it might be expected to produce fairly low estimates of costs to GDP.

i. because it is looking to the long-term it is not concerned with adjustment costs associated with markets being out of balance;
ii. because it contains no information about hidden costs or other barriers that may constrain the take-up of otherwise cost-effective options.

23. However, as explained above, in our use of MARKAL we have examined a wide range of sensitivities. Some of those sensitivities have been explicitly concerned with addressing properties of the model that could – if it were left to run in an unconstrained way – lead it to understate costs. In particular, we have examined sensitivities to:

- the costs of low carbon technologies not falling as fast or as far as in a base case;
- the non-availability of certain low carbon technologies (nuclear and CO_2 capture and storage);
- restricted availability of energy efficiency options.

It is important, therefore, to consider the range of modelling results from MARKAL. That range suggests a cost to GDP in 2050 of perhaps 0.5-2%.

24. In a review of a wide range of studies the Intergovernmental Panel on Climate Change has concluded[9] that, in respect of Kyoto, the majority of studies indicate costs to GDP in 2010 of between 0.2% and 1% of GDP. These costs were halved with full allowance for emissions trading. In respect of stabilization of emissions at 550ppm – broadly similar to the 60% reduction in CO_2 we have considered in MARKAL - the average of estimated impacts on GDP was a loss of around 1% in 2020, rising to 1.5% in 2050, before declining to 1.3% in 2100. Although some studies found bigger impacts, most were below 3%. The average impact on annual GDP growth rate amounted to –0.003 percentage points, though estimates ranged up to –0.06 percentage points.

25. The MARKAL results look to be very much in the range of the results from that wider review.

26. In addition to long-term costs, there are related and very important issues of transitional and sectoral costs (including effects on income distribution and the competitive position of individual industries). MARKAL cannot fully address these. But wider modelling results from the substantial literature, aided by the insight of

[9] http://www.ipcc.ch/pub/pub.htm

macroeconomic models, indicate that there can be circumstances where transitional costs may be significant. However, such costs will be lower:

- the longer the period over which emission cuts can be phased;
- the more that policy can be pre-announced, and market players convinced of the direction of that policy – so that this can be factored into decisions;
- if policy addresses market failures or other barriers that mean the economy can move towards its productive potential frontier. A number of studies suggest that 20-30% carbon reduction can be achieved at low to nil cost if barriers to uptake can be tackled. Overcoming these barriers without regulation may be difficult.

It is these kinds of insights, together with those from the range of MARKAL runs, which have helped inform development of the White Paper.

ANNEX A

References

Author/lead department	**Date**	**Description**	**Web link**
DEFRA	2003	Ancillary Effects of Greenhouse Gas Mitigation Policies	http://defraweb/environment/economics/index.htm
DTI	2003	Annexes to the Energy White Paper “Our Energy Future – Creating a Low Carbon Economy	www.dti.gov.uk/energy/whitepaper/index.shtml
DTI	2002	Long-Term Reduction in Greenhouse Gas Emissions in the UK	http://www.dti.gov.uk/energy/greenhousegas/index.shtml
Future Energy Solutions	2002	Options for a low carbon future	http://www.etsu.com/en_env/html/climate_change.html
Future Energy Solutions	2003	Options for a low carbon future - phase 2	www.dti.gov.uk/energy/whitepaper/index.shtml
Ilex	2002	Quantifying the system costs of additional renewables in 2020	www.dti.gov.uk/energy/developep/080scar_report_v2_0.pdf
NERA	2002	Security in Gas and Electricity Markets	www.dti.gov.uk/energy/whitepaper/index.shtml