WRITTEN EVIDENCE
TO THE STERN REVIEW ON THE ECONOMICS OF CLIMATE CHANGE
from

PROFESSOR PAUL EKINS
Head, Environment Group, Policy Studies Institute
Professor of Sustainable Development, University of Westminster
Co-Director, UK Energy Research Centre (UKERC)
(with responsibility for UKERC's Energy Systems and Modelling theme)

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1. INTRODUCTION

This evidence is concerned with the assessment of the costs of reducing carbon emissions with the objective of mitigating climate change[1]. This is directly relevant to the third set of issues being investigated by the Review: "The costs and benefits of actions to reduce the net global balance of greenhouse gas emissions from energy use … taking into account the potential impact of technological advances on future costs;", and will hopefully contribute to the Review's intention to provide "An assessment of the economics of moving to a low-carbon global economy". The evidence addresses the issue of these costs as they have been estimated for the UK, estimates which are likely to be relevant for industrial countries more generally. The starting point of this analysis is the robustness of the economic analysis carried out by the UK Government in the preparation of the 2003 Energy White Paper. This is obviously relevant at this time of another UK Energy Review, because further analysis of these issues is being undertaken in this context, with a significant contribution being made by the UKERC's Energy Systems and Modelling theme.

2. MODELLING ENERGY SYSTEM COSTS OF DECARBONISATION

Analysis and estimates of the costs of decarbonisation make an important input into UK energy policy, and were an important input into the UK Energy White Paper, which was published in February 2003. This analysis concluded that "the cost of reducing CO_2 emissions by 60% by 2050 was in the range of £200-£300 per tonne of carbon. GDP in 2050 was reduced by 0.5-2.0%, equivalent to an average annual reduction of between 0.01 and 0.02 percentage points from a business as usual GDP growth rate of 2.25% per annum." (DTI 2003a, p.28) This evidence first seeks to make a brief assessment of the reasonableness of this estimate.

An important part of the analysis for the White Paper (described in detail in DTI 2003b), and that part which generated the costs numbers cited above, was carried out using the MARKAL energy model. MARKAL is a bottom-up model of the energy system that was originally developed by the International Energy Agency (IEA) and has been used, and is still used, in many countries round the world, by governments, academic and other research institutions, and consultancies. It is an established and much-used model with a well understood structure and limitations. It was, therefore, a reasonable choice for the analysis that was carried out.

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[1] This is a revision of evidence that was submitted in 2005 to the House of Lords Economic Affairs Committee for their inquiry into 'Aspects of the Economics of Climate Change'. It has been brought up to date in the context of the new UK Energy Review.

The UK MARKAL model, which was operated for the White Paper analysis by the consultancy Future Energy Solutions (FES) for the DTI, contains a variety of cost and performance data about different technologies within a structure of the energy system. Model runs seek to meet given energy demands (and any imposed constraints, such as on carbon emissions) at least cost. Clearly the results that emerge from such model runs are very dependent on the input assumptions about costs and performance that have been made for the different technologies.

Before looking at the input assumptions, it is worth asking whether the output from MARKAL, in particular the cost result that the GDP costs of a 60% carbon reduction by 2050 would be in the range 0.5-2.0%, is out of line with results from other models. In fact, there is evidence from a meta-analysis of the costs of carbon reduction from a wide range of models (Barker et al. 2002) that the majority of GDP cost estimates from these models fall within the same range as those from this use of MARKAL. Some of the cost estimates are higher, and some are lower, but this is very much the central range of the estimates. While this says nothing about the quality of MARKAL as a model, the fact that these results fall within the interval estimated by a very large number of other international and national studies means that they are not in themselves implausible. However, they still need to be assessed in detail in terms of the input assumptions that generated them.

3. THE INPUT ASSUMPTIONS TO MARKAL

Two of the most important sets of input assumptions are those related to the costs of two major ways of reducing carbon emissions: the development and implementation of more efficient ways of using energy, and the development and deployment of ways of capturing renewable energy sources. It is therefore worth examining whether the assumptions used in these areas for the White Paper analysis were reasonable.

3.1 Energy Efficiency

The input assumptions to the MARKAL model on energy efficiency included an assumption that there was some availability of currently cost-effective energy efficiency measures, which are not yet implemented. Whether there are in fact opportunities for cost-effective energy efficiency measures that are not taken up, and to what extent, is still a controversial issue among economists. Many economists believe that if such opportunities existed, people and firms would take them up of their own accord. As evidence of this, it might be thought that the existence of a number of subsidy programmes in the UK to promote energy efficiency shows that the White Paper underestimated the costs of energy efficiency.

However, it is possible that these subsidies are necessary to overcome a number of *non-financial* barriers to the take up of energy efficiency measures (ranging from landlord-tenant problems, to a lack of interest in and information about the products and measures, to capital constraints, to a dislike of disruption to the home). In recent years there has been a substantial accumulation of evidence in the UK, from analyses of the early home energy efficiency programmes by the National Audit Office (NAO 1998), to the data contained in reports from the Performance and Innovation Unit, the Energy Saving Trust and the Carbon Trust (PIU 2002, EST 2002, Carbon Trust 2004), to the significant over-achievement under the Climate Change Agreements (CCAs, AEAT 2003a,b, DEFRA 2003, Ekins 2005 forthcoming), that suggests both that opportunities for cost-effective energy efficiency measures exist, and that the policy measures that have been implemented to realise them have indeed saved the relevant parties both energy and money.

Of course this evidence is not entirely conclusive, and doubtless debate about the extent of unimplemented cost-effective opportunities for energy efficiency will continue. However, having been someone who, as an economist, was sceptical of the claims about cost-effective energy efficiency opportunities, I now believe that the balance of evidence (both in terms of research showing the existence of 'barriers' to energy efficiency (see, for example, Sorrell et al. 2004), and in terms of actual policy-driven implementation of cost-effective energy efficiency measures) is now clearly showing that these opportunities exist. While it may be possible to characterise some of the barriers to the implementation of cost-effective energy efficiency measures (such as household disruption) as 'costs', the fact remains that, if they are overcome, in financial terms (and therefore in GDP terms in aggregate) the economy will be better off.

Of course, to say that cost-effective energy efficiency opportunities exist does not mean that they are easy for policy to realise in practice (and the model used a 25% discount rate on the demand side to define cost-effectiveness conservatively in terms of a four-year payback). But it does mean that if people can be subsidised or coerced into realising these opportunities, then they will save money and, other things being equal, carbon emissions will be reduced at negative net financial cost, which is what the energy efficiency inputs (up to some level) to the MARKAL model assumed. I consider that such an assumption now represents the evidence-based position.

3.2 Renewables

In the MARKAL modelling for the White Paper the cost estimates for a wide range of low or no carbon electricity generation technologies were in the range shown in Table 1. It can be seen that, between 2000 and 2040 they range from about 2.5-4.5p/kWh (compared with a current average wholesale price of electricity of 2-2.5p/Kwh).

Such cost estimates are extremely uncertain, especially for technologies such as renewables which are still in their infancy, and especially in respect of time horizons as far out as 2040. It is especially difficult to incorporate such elements as the network and grid costs for these technologies (such as the back up required for the intermittency of some renewables, and the reconfiguration of the distribution network which would be required for extensive distributed generation), because the precise nature of what is required is still not clear. It is also not easy to include some of the benefits of new technologies (for example, distributed generation can reduce transmission losses, and the availability of wind energy is higher in winter when demand, and peak demand which is the most expensive to service, is higher). The modelling in MARKAL sought to capture the cost of back-up associated with intermittent generation, by only allowing a proportion of intermittent (for example, wind) capacity to count towards firm capacity at times of peak demand.

Table 1: Estimated Costs for Selected Low-Carbon Technologies

Core assumptions	Year available	Capital Cost £/kW	Fixed op. Cost £/kW	Efficiency %	Load Factor %	Plant Life yrs	Electricity cost p/kWh
Existing GTCC	2000		12.0	40 %	90 %		2.2
New GTCC/CO2 CCS	2040	450	17	66 %	90 %	25	3.1
Existing Nuclear	2000		80		75 %	40	1.2
New Nuclear	2020	1100	60		85 %	40	3.0
Energy Crops	2030	700	30	50 %	85 %	25	2.6
Wind On-shore	2000	530-570	17-20		28-50 %	20	2.5-4.3
Wind On-shore	2040	330-360	15		28-50 %	20	1.6-2.8
Wind Off-shore	2040	450-510	16-21		29-43 %	20	2.8-3.7

Source: DTI 2003b, Annex C, pp.116 ff.

One estimate of the costs of generating 20% of UK electricity in 2020 from wind has put them at 3.3p/kWh, including generation, variable and network costs, compared to fossil fuel (CCGT) generation costs, calculated on the same basis, of 2.98p/kWh (Dale et al. 2004, p.1954). For comparison, as shown in Table 1, the range of wind costs used as input into the MARKAL model were 2.5-4.3p/kWh for on-shore wind in 2000, 1.6-2.8p/kWh for onshore wind in 2040, and 2.8-3.7p/kWh for offshore wind in 2040. Clearly this too is contested ground, and likely to remain so for some time, but this evidence suggests that the inputs in this area used for the MARKAL modelling are in the centre of the range of cost estimates for wind.

Even so, with the current costs of gas-fired generation well below those of renewables (except perhaps onshore wind at the best sites), renewables would at present not be deployed without subsidy, and it may be that in order to reach Government targets for renewables (10% electricity generation by 2010, 20% by 2020), the subsidies will need to be significantly larger. This does not mean that the MARKAL-estimated GDP costs of carbon reduction for 2050 (0.5-2.0% GDP, as noted above) are necessarily too low, for at least two reasons.

Firstly, the level of subsidy for wind (and other renewables) now (or even up to 2020) says absolutely nothing about the GDP costs *in 2050* of having introduced substantial renewable generation by then, which is what the MARKAL model is estimating. This depends on a whole range of other factors, of which probably the most important are the extent to which it is assumed that innovation brings down the cost of renewables, and the level of fossil fuel prices. Clearly such factors are also uncertain, but there is no evidence that the rate of innovation or the fossil fuel prices assumed in the MARKAL modelling were too high (too high oil prices would reduce the net cost of implementing more expensive non-fossil alternatives). In fact the highest assumed oil price in 2050 in the various scenarios that were modelled was $35 per barrel [DTI 2003b, p.68], well below the price that has persisted since 2004). These issues are far more important to the 2050 GDP costs of decarbonisation than the current level of renewables subsidies.

Secondly, it is not straightforward to go from the direct costs of renewables (as expressed through the level of subsidy that needs to be paid for them) to the GDP costs of their introduction. The standard MARKAL model (that used for the analysis) is a partial equilibrium model, not a general equilibrium model or macromodel (which incorporate feedbacks between the energy and economic systems, which the standard MARKAL does not). However, this is likely to *exaggerate* the GDP costs of introducing renewables, rather than the reverse. This is because the MARKAL modelling for the White Paper does not take account of the way in which a real economy would adjust to reduce the macro-costs of introducing renewables. If such introduction raised the price of energy, then consumers and firms would use less of it, new energy efficiency technologies would be developed and introduced, the renewables industries themselves would employ people and generate incomes and, perhaps, exports (as the Danish wind industry has done). All these linkages would tend to reduce the direct costs of introducing renewables, which is what MARKAL calculates. It is therefore possible to argue on these grounds that the MARKAL GDP-cost estimates of carbon reduction are too high, rather than too low.

4. SENSITIVITY ANALYSIS

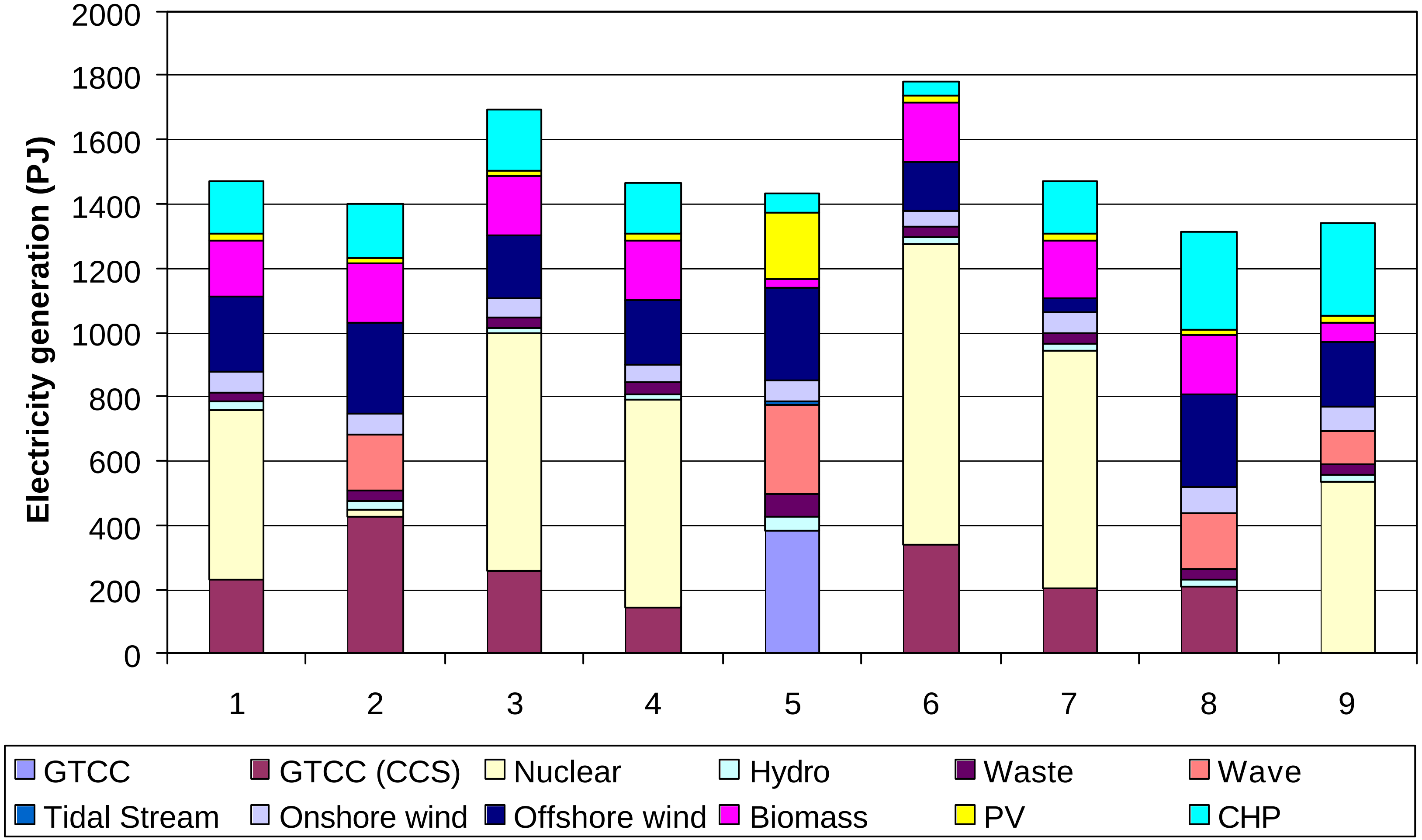
Because of the uncertainties (noted above) in many of the key modelling variables in the modelling exercise carried out for the Energy White Paper, sensitivity analysis (changing the variables to see how they affect the outcomes) is critical. As noted above, this analysis generated a range of GDP cost estimates which differed by a factor of 4 (0.5-2% GDP). The final question that is addressed here is whether the range of assumptions employed in the sensitivity analysis actually matches the range of reasonable uncertainty about some of the parameters.

The range of costs for wind used in the modelling are given in Table 1. It is interesting that all the low-carbon technologies considered in the modelling (which included nuclear, hydro, waste, wave, tidal stream, onshore wind, offshore wind, biomass, PV and CHP) had estimated costs in 2040 for at least some of their output in the range 1.6-4.0p/kWh[2]. This means that if any one, or even a few, of these technologies fails to deliver the cost reductions over 45 years which are assumed in the model, then low-carbon generation can be supplied by a mix of the others.

There were nine different possible generation mixes which were calculated as part of the sensitivity analysis (see Figure 1).

[2] In the modelling many of the technologies had different cost tranches representing slightly different applications or locations of the same technology. In 2040 some of the most expensive tranches for domestic PV, tidal stream and large-scale wave had costs greater than 4p/kWh (but less than 6p/kWh) - while cheaper tranches of the same technologies were less than 4 p/kWh at this time.

Figure 1: The Results of MARKAL Sensitivity Analysis: Nine Different Possible Generation Mixes for 2050
(Source: Taylor 2004)



All the nine possible generation mixes resulted in generation that contributed to a 60% overall reduction in carbon emissions by 2050, vary enormously in the technologies that are used. It is only if the costs of all, or the great majority of, the low-carbon technologies fail to reduce substantially with increasing deployment that the costs of low-carbon generation, and thence of carbon abatement, would be significantly above those estimated[3]. Past experience with the costs of new technologies would suggest that, while possible, this is unlikely.

On energy efficiency the investment costs were estimated to range from £0-50/GJ in the household sector, and £0-35/GJ in industry and services. Some energy efficiency improvements were achieved at negative net cost once fuel savings were taken into account. The maximum uptake of energy efficiency in the model yielded improvements of 55% for households and 35% for industry and services. The rates of improvement were varied in the sensitivity analyses from the maximum improvement delivered by the model to the historical average improvement of the last 30 years (medium improvement) to the historical average improvement of the last 10 years (low improvement). It was the latter assumption that generated the highest costs of carbon abatement, but still below 2% of GDP by 2050.

As with the costs of electricity generation, these assumptions do not seem unreasonable. As noted above, there is substantial evidence that opportunities for negative-cost energy efficiency improvements are widespread, while the assumption that the rate of energy efficiency improvement remains the same as that of the last ten years, despite new government policies, is positively pessimistic.

In addition to considering reduced energy efficiency and different sets of technology costs and exclusion of technologies, the sensitivity analyses also took into account possible limits on natural gas, reduced innovation, infrastructure issues, and the issue of wind intermittency. With the worst-case assumptions, the costs of a 60% reduction in carbon emissions by 2050 still came to less than 2% of GDP. I come to the conclusion from this brief examination of the issue that the range of sensitivity analysis assumptions employed in the MARKAL modelling for the White Paper do not seem unreasonable.

5. FUTURE MARKAL MODELLING IN SUPPORT OF UK ENERGY POLICY

In the context of the current Energy Review, DTI and DEFRA have commissioned the Policy Studies Institute (PSI) and, through PSI, Future Energy Solutions, to build a new MARKAL model further to explore UK energy system options and costs. The new model will be MARKAL MACRO, incorporating a simple CGE (computable general equilibrium) model (which was not the case for the White Paper modelling work), in order to provide a better estimation of the GDP costs of different policy and options and scenarios. The first results from this model will be available in summer

[3] When technology cost and performance were frozen at 2010 levels for the whole period, and a 70 % emissions reduction was applied, the GDP loss in 2050 was 3.6 %, but even with these extreme assumptions the GDP loss was below 2% for an emissions reduction of 60%. (personal communication with Peter Taylor, Future Energy Solutions, November 2004)

2006. If DTI and DEFRA agree, the modelling team would be pleased to interact with the Stern Review during the modelling process, and to share the early results, so that they can inform the conclusions of the Stern Review when it reports in autumn 2006. I would be pleased to discuss arrangements for this with the Stern Review if it wishes.

6. CONCLUSIONS

Estimates of costs in 2050 of deploying a wide range of new technologies are bound to be uncertain. Within the bounds of this uncertainty, however, the analysis above suggests that:

- MARKAL is a reasonable model to use for calculations such as were carried out, provided that (as with all models), its characteristics and limitations are borne in mind and input assumptions are carefully chosen and justified;
- The cost estimates used as inputs to the MARKAL model were both reasonable in themselves, and in accordance with both evidence and mainstream calculations of such costs;
- Sensitivity analysis varied these input cost estimates so that they represented fairly pessimistic assumptions about the likely development of these costs; and
- The MARKAL output cost estimates (the 0.5-2.0% of GDP) were very much in line with the majority of other estimates of these costs, derived from a wide variety of different models.

These conclusions about the analysis of the estimates of carbon reduction carried out by the Government for the Energy White Paper suggest a number of conclusions for the Stern Review:

1. Many people might regard the estimated costs as a relatively low price (a maximum of one year's increment to a national economy that is growing at 2% p.a.) to pay for a cut in carbon emissions which, if matched globally by other industrial countries, would be likely to do much to avoid the worst effects of climate change.
2. The estimated cost of carbon reduction in 2050 suggests that effective policies to reduce emissions are not incompatible with continuing economic growth and prosperity.
3. However, this relatively low cost in 2050 says nothing about the policy and political difficulties of actually achieving the cuts in emissions that are required. Much political skill will be required to make acceptable the costs of such policies as the Renewables Obligation or the EU Emissions Trading Scheme, and such changes in behaviour as foregoing an explosion of cheap foreign air travel, both of which are needed if carbon emissions are to be reduced by the extent envisaged.
4. The analysis commissioned by the UK Government of the policies outlined in its White Paper made a significant contribution to understanding of the broad economic implications of reducing carbon emissions by 60% over 60 years.

PAUL EKINS
Policy Studies Institute
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