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ENVIRONMENTAL CHANGE UNIT

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FULL FUEL CYCLE STUDY:

EVALUATION OF THE GLOBAL WARMING EXTERNALITY FOR FOSSIL FUEL CYLES WITH AND WITHOUT CO_2 ABATEMENT AND FOR TWO REFERENCE SCENARIOS

Report to the

International Energy Agency

Greenhouse Gas R&D Programme

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2. Evaluating Mitigation Benefits

Most assessments of climate change damages[1] have assumed an instantaneous, equilibrium change. That is, climate change is assumed to happen to the present economy, or a future economy that is the same as the present one. The economy is not allowed to gradually change its resource use in conjunction with the threat of climate change. In contrast, this study, like the previous IEA GHG work, has calculated the cost of climate change against a future world that is substantially different from the present world, and including the pathway between the present and 2100. Figure 1 shows this approach, using the IS92a projection of Gross World Product (GWP) as an indicator of the reference scenario (IS92A). The effect of climate change is the cumulative departure between 1990 and 2100 between the reference projection (IS92A) and the reference projection as modified by climate change (IS92A*). In the diagramme, the IS92A* is below the IS92A, indicating that the aggregate impact of climate change is negative. For some sectors, such as heating demand, the impact of climate change is positive and IS92A* would be above IS92A.

Since the economic valuation of climate change depends on the difference between a reference scenario and the reference with climate change, alternative reference scenarios of the future need to be evaluated. Two such scenarios are considered in this report:

- IS92a: Non-intervention projection or "business-as-usual" – medium population and economic growth leads to higher personal incomes. Standards of living improve, but large populations are still poor and resource use is still sensitive to climatic fluctuations, although less so than at present.
- IS92d: Sustainable or "resilient development" – low population growth, high personal incomes, and high energy efficiency reduce sensitivity to climatic fluctuations, even more so than in the IS92a world. More equitable standards of living enable countries to be resilience to resource limitations.

We suggest that the contrast between the IS92a "non-intervention" and the IS92d "resilient development" scenarios highlights diverse views of the future. In both futures, conditions improve as gauged by economic growth and environmental concerns reflected in GHG abatement. Thus, the potential for regional collapse, as might be possible with water scarcity and famine in some semi-arid areas, is less likely than at present. To capture the extreme cases of resource scarcity and conflict, a different reference scenario would be required (see Section 14).

Analysis of these two scenarios for fuel cycles with and without GHG capture has implications for calculating the externality costs of fuel cycles (Table 1). This report looks at the economic implications of four situations. Average conditions are represented by the upper left and lower right boxes:

- Fuel cycles without greenhouse gas capture against a reference world of low GHG abatement (the upper left box in the table) is typical of the present fuel cycles. If these fuel cycles continued and GHG abatement was not widespread, the fuel cycle externality should approach the average externality for energy production from fossil fuels.

[1] Following convention in economics, we generally use the term damages and costs to denote net damages and costs. In such cases, benefits would be negative damages or negative costs. The issue of aggregating costs and benefits from disparate sectors and regions is discussed in Section 15.

- The analogous situation for advanced fuel cycles with greenhouse gas capture is against a reference case of (relatively) high GHG abatement (the lower right box in the table). Again the fuel cycle externality approaches an average for energy production. The first IEA GHG report analysed only this situation.

The other two boxes represent transitional or anomalous situations:

- Advanced fuel cycles with abatement in a world of relatively little control of GHG emissions (the upper right box) would contribute relatively less to global warming than the average fuel cycle. This illustrates the case of the pioneering power station developed as part of a strategy to reduce emissions from the present technology to a more efficient future.
- Fuel cycles without abatement operating in a world of high GHG abatement (the lower left box) might arise if present technology persists in a world that has largely adopted advanced controls. Such fuel cyucles might be considered obsolete (*ie*, they are older stations that have not been replaced) or are free-riders, taking advantage of cheaper technology.

For the first time in the published literature, this report to the IEA GHG covers the four situations shown in Table 1.

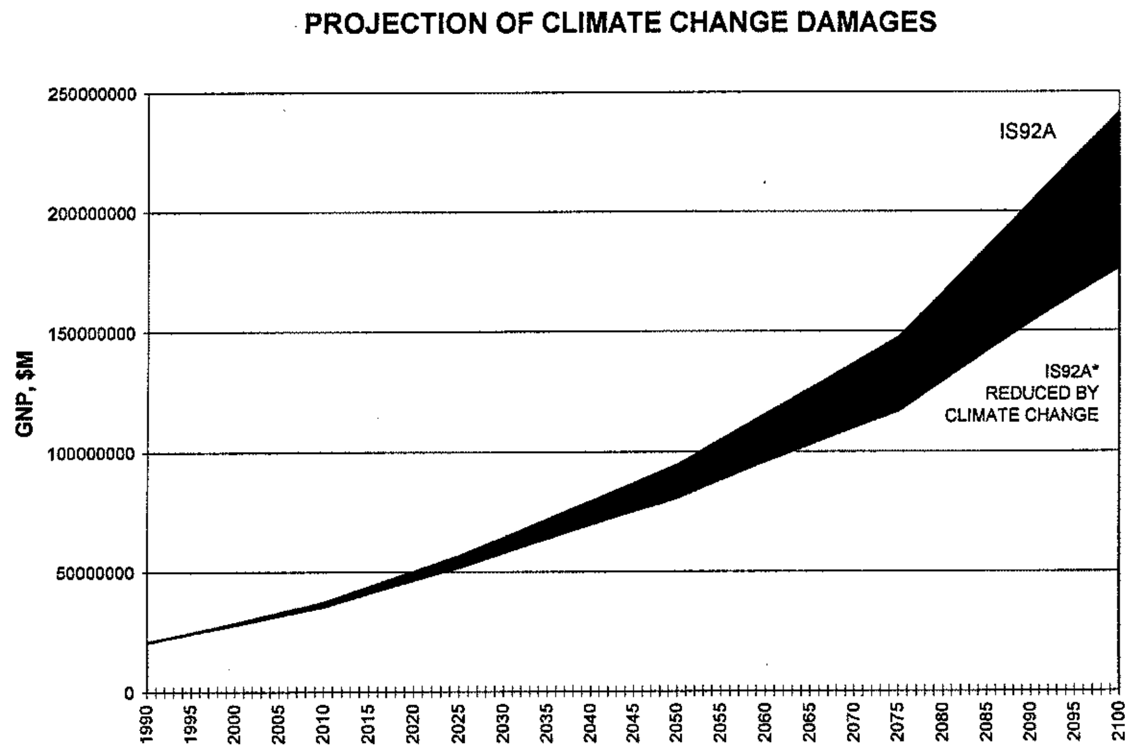

Figure 1. Projection of climate change damages. IS92A represents Gross World Product projected according to the IS92A scenario, without climate change. IS92A* shows the marginal effect of (adverse) climate change, based on the IS92a high estimate (see below), although the timing of the change is estimated.

Table 1. Comparison of World Reference Scenario and Individual Fuel Cycle GHG Abatement

World Scenario		**Fuel Cycle GHG Abatement**	
Projection	**GHG Abatement**	**Low**	**High**
Non-interventionist IS92A	Low	***Present Fossil Fuel Cycles***	***Transition or Pioneer***
Resilient Development IS92D	High	***Obsolete or Free-rider***	***Future Fuel Cycles with CO_2 Capture***

3. Methodology and Reference Assumptions

3.1. Overview of methodology

The methodology follows the approach used in the earlier IEA GHG study (Figure 2; see Appendix 1 for details). The steps involved, and enhancements in this report, are:

- Specify reference scenarios from 1990 to 2100 without climate change. Two reference scenarios were used, as explained above.
- Calculate global-average temperature change and sea level rise. An updated version of MAGICC (for 1995) was used that allows emission scenarios to be input into the model at an annual time step. This resolves some of the difficulty for fuel cycles that start and end between the five-year time steps used previously. The 1995 version of MAGICC results in slightly lower warming than the earlier version used in the IEA GHG study. However, the marginal effect of each fuel cycle is similar.
- Add fuel cycle GHG emissions to the global GHG emissions. See below and Appendix 2 for a summary of the fuel cycles evaluated in this report.
- Calculate the incremental effect of the fuel cycles on global-average temperature and sea level using MAGICC.
- Create spatial scenarios of climate change using results from a General Circulation Model. As in the earlier study, the GISS (Hansen *et al.* 1988) model was used.
- Calculate first-order impact models for the current climate and for the scenarios of climate change. An updated baseline climatology was used.
- Summarise the impacts by country, for example the total heating degree days.
- Calculate country-level economic impacts.
- Sum the country-level direct costs to a global total and add global contingent value sectors. Regional results are included, although they are more indicative of the geographic spread of impacts, rather than being reliable estimates of costs in each country.
- Calculate proportion of costs attributable to the design fuel cycles.
- Calculate net present values (NPVs).

Major changes in valuation reflect both more appropriate techniques and more reliable estimates of effects. For all of the sectoral impacts, the economic models were updated to include the comparison between the IS92a and IS92d scenarios. Energy and water now reflect market mechanisms, with water surplus/scarcity used to estimate both demand and supply. Values in all sectors reflect projections in wealth, such as Gross National Product (GNP). Valuation of wetlands and drylands is based on capital costs rather than annual costs. Calculation of the global cost of disasters was included. Scalars were introduced to incorporate other, indirect costs. The discussion of impacts on energy demand and biodiversity has been expanded, although model improvements were not warranted.

The relationships between changes in temperature, precipitation and sea level rise and the selected impact sectors are shown in Figure 3. The direct cost sectors are energy, agriculture, water resources, coastal protection, and loss of wetlands and drylands due to sea level rise. These costs are estimated based on direct methods of market prices, supply and demand.

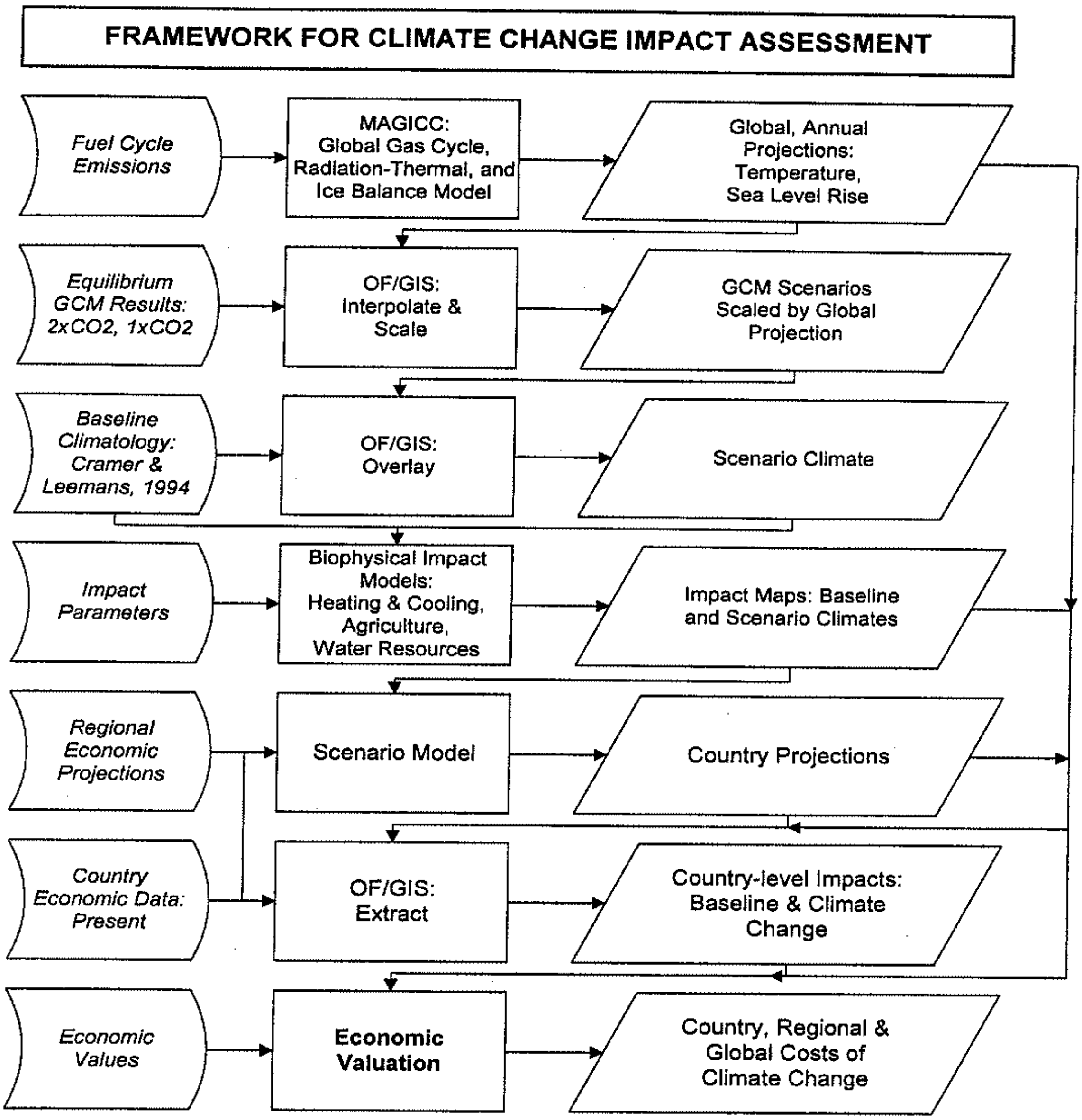

Figure 2. Framework for Climate Change Impact Assessment. The sequence of analyses for calculating the global cost of climate change proceeds from projections of global emissions to climate scenarios, biophysical modelling, country projections, and economic valuation.

Much of the total cost of climate change in previous studies (and this one is no exception) is derived from changes in welfare. These costs are typically quantified by means of contingent valuation that are subjective and sensitive to assumptions about future values or value systems. In this study we distinguish between sectors that are quantified by direct means of valuation, based on the cost of using specific resources, and sectors that can only be valued indirectly, for example by assigning a (subjective) value to the existence of species or to a person's life. The latter sectors are described in this section. The assumptions and numbers presented here for the two reference scenarios are still fairly conservative. This is, we have discounted the likelihood of large ecosystem collapses and assumed somewhat modest differences between the two scenarios. As an exercise in methodological development, we have focused more on the direct costs sectors.

The indirect costs sectors – biodiversity and disasters – include more subjective estimates of contingent valuation and the value of a statistical life. Health and welfare effects and other sectors (value of ecosystem function, for example) are valued simply as a scalar of other costs, to provide comparable numbers as commonly reported in the literature. For the present project, it was not deemed worthwhile to further develop these cost estimates. Existing approaches provide a wide range of values and are contentious when applied across countries. It is unlikely that further effort in the next several years will provide more robust estimates.

The assessment of uncertainty is built into the analytical framework. In this report, low, medium and high estimates are reported. These correspond to the low, best guess, and high estimate of global climate change from MAGICC and subjective estimates of the range of likely economic values of impacts, for example depending on the statistical value of life or the price of electricity. Uncertainty is further discussed in Section 12.

3.2. Advanced fuel cycles with greenhouse gas abatement

The analytical methodology tests the incremental effect of individual fuel cycles on global warming and its economic cost. Four types of fuel cycles are compared, each with against two reference scenarios. Thus, the comparison in Table 1 is realised as in Table 2. Including GHG capture to a fuel cycles is not necessarily a simple addition of specific processes. The most efficient systems will be highly integrated. For example, the IGCC and PF+FGD fuel cycles are both based on coal, but represent different engineering designs. The IGCC enables carbon dioxide to be captured more efficiently. An equivalent comparison of advanced and present technology for gas fuel cycles was not developed in the earlier IEA GHG report. For this report, a rough estimate of emissions if CO_2 were not captured was derived from the NGCC fuel cycle, labelled below as the NGCCx case. The fuel cycle designs and GHG emissions were calculated by collaborating institutions.

Construction of the power stations is assumed to begin in 2002, begin operation in 2005, and be decommissioned in 2035 (Table 1). The design capacity is 500MW, with load factors (availability) of 82-88 per cent. Carbon dioxide emissions are greatest for fuel cycles without GHG capture (Table 4). As noted above, the fuel cycles are scaled up in order to perturb the global climate model, MAGICC. In this analysis, the scalar was 1000.

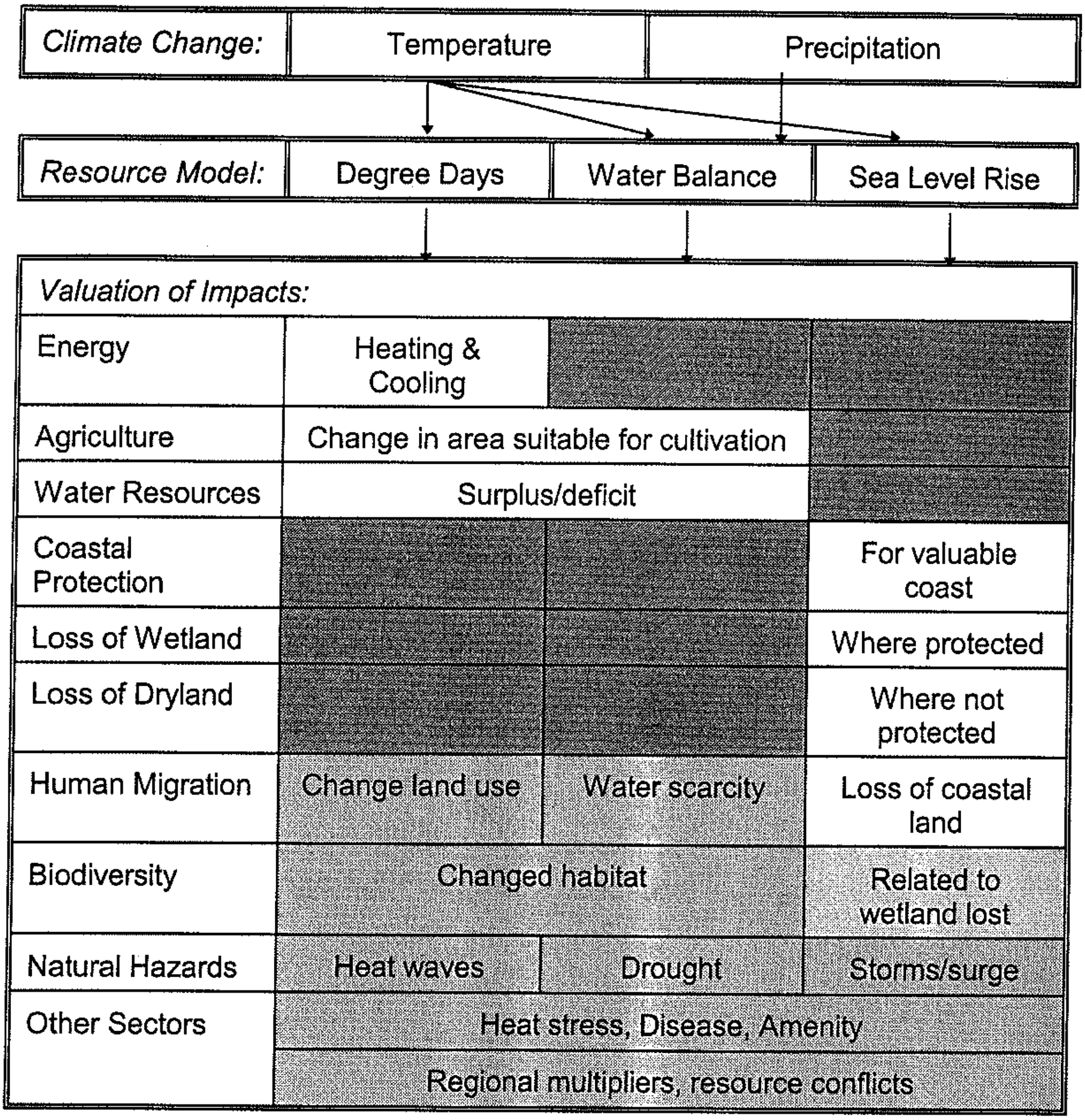

Figure 3. Impact Models and Sectors. Clear cells are direct impacts with quantitative estimates of damages. Light shade indicates impacts that are evaluated by indirect means including the value of statistical life and contingent valuation. Other Sectors represents all other costs of climate change, derived from a scalar applied to sectors with net costs. Heavy shade indicates combinations of causes and impacts that are not estimated and are likely small or not relevant.

Table 26. Comparison of Externality Costs of Coal Fuel Cycles, medium estimate.

World Scenario		Fuel Cycle GHG Abatement	
Projection	**GHG Abatement**	**Low**	**High**
Non-interventionist IS92A	Low	**PF + FGD** ***1.36 c/kWh***	**IGCC** ***0.25 c/kWh***
Resilient Development IS92D	High	**PF + FGD** ***0.49 c/kWh***	**IGCC** ***0.09 c/kWh***

Table 27. Comparison of Externality Costs of Natural Gas Fuel Cycles, medium estimate.

World Scenario		Fuel Cycle GHG Abatement	
Projection	**GHG Abatement**	**Low**	**High**
Non-interventionist IS92A	Low	**NGCCx** ***0.81 c/Kwh***	**NGCC** ***0.14 c/kWh***
Resilient Development IS92D	High	**NGCCx** ***0.29 c/kWh***	**NGCC** ***0.05 c/kWh***

17. Conclusion and Further Research

In summary, the global cost of climate change is likely to be significant, whether for the IS92a or IS92d worlds. At the high end, it could reach almost half of Gross World Product. The more likely, medium estimate is a potential cost of $20-75,000,000M, or 0.2-0.7% of GWP. The fraction of global costs that can be attributed to individual fuel cycles varies according to their emissions and the reference global warming. A coal fuel cycles without GHG capture may be responsible for an externality of over 1 c/kWh. In contrast, an advanced fuel cycle in a world with GHG capture, would have an externality an order of a magnitude lower, less than 0.1 c/kWh.

The methodological conclusions from the past two years of research on a linked-model/spatial pathway approach to the economic evaluation of climate change appear to be:

- A transient analysis explicitly evaluates the magnitude and timing of the impacts of future climate change against a explicit reference scenario of the world without climate change. This provides a more dynamic assessment than a static-equilibirum evaluation, and requires the analyst to disentangle the cost of climate change from changes in the economy that adapt to climate change without significant costs.

- The use of a reference scenario limits the analysis by discounting the extreme cases of regional environmental, economic and social collapse. That is, if climate change is not a marginal change in resource use, current economic approaches are inappropriate.

- The total cost of climate change is sensitive to the assumptions about the reference comparison. In a "resilient development" scenario (the IS92d), a world that is relatively less populated (the UN low estimate) and comparatively wealthy would suffer less extreme damage from climate change than a "non-intervention" or "business-as-usual" scenario.

- At least half of the total cost is attributed to changes in welfare, calculated by methods of contingent valuation that are subjective and sensitive to assumptions about future values.

- A large range of uncertainty results from relatively modest changes in assumptions, even within the context of the reference scenario.

- Assuming climate change impacts are marginal to a reference scenario, the relative contribution of different fuel cycles can be estimated by evaluating their time-dependent profiles of emissions and subsequent effects on global warming.

- Since the largest costs are subjective, the full cost of climate change may be unknowable: measuring subjective contingent valuation is not feasible at the global level and cannot be carried out for future generations. An option worthy of greater investigation is the present willingness to pay a risk premium to avoid future damages from climate change, rather than directly estimating future costs and benefits.

The present assessment is far from complete. The remaining uncertainties warrant further research. Alternative scenarios of climate change (for example the U.K. Meteorological Office transient run) would reveal the extent of the spatial bias inherent in the GISS GCM. The assessments of agriculture and water could be improved with crop- and landscape-specific models, although the information requirements for a global assessment are prohibitive. The direct costs estimated for agriculture could be compared with results from world trade models, such as reported by Reilly *et al* (1994) and Fischer *et al.* (1994). The energy demand estimates could be refined based on population distribution rather than country-aggregates. Other direct-cost sectors could be introduced, for example effects on tourism (Rotmans, *et al*, 1994), pests and disease are often cited. While such refinements can be undertaken for the direct cost sectors, they are unlikely to make a significant contribution toward reducing the range of estimates of total costs.

Country-level dynamic impact modelling is required to address many of the uncertainties. For example, evaluation at the country level of human settlement and its relationship to sea level rise, net coastal erosion and loss of drylands due to desertification would improve the spatial specificity of estimates of migration costs and potential regional conflicts over resources. At present, it is impossible to give an accurate assessment of the magnitude of winners and losers between countries.