CAN THE IPCC SRES BE IMPROVED?*

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1. THE IPCC SRES PROJECTION APPROACH

The IPCC was established by the World Meteorological Organization (WMO) and the United Nations Environmental Program (UNEP) to "assess the scientific, technical and socio-economic information relevant for the understanding of human-induced climate change" (IPCC, 2000). The Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) (2000) developed a range of emission scenarios that were designed to provide "input for evaluating climatic and environmental consequences of future greenhouse gas emissions and for assessing alternative mitigation adaptation strategies" (IPCC, 2000).

The report covers four regions: OECD90 (all countries that belonged to the Organization of Economic Development (OECD) as of 1990), REF (countries undergoing economic reform – East European countries and the Newly Independent States of the former Soviet Union), ASIA (all developing countries in Asia) and ALM (developing countries in Africa, Latin America and the Middle East). OECD90 corresponds to UNFCC (1992) Annex II countries. REF includes non Annex II, Annex I countries. OECD90 and REF are categorised as industrialised regions (IND) and ASIA and ALM are categorised as developing (DEV).

The SRES highlights the interdependency between what they regard as the major driving forces of future emissions. According to the SRES, the main driving forces of

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future greenhouse gas trajectories are "demographic change, social and economic development, and the rate and direction of technological change" (2000, p5).

To represent a range of driving forces and resultant emissions the SRES considers four "qualitative storylines" called "families": A1, A2, B1, and B2. From these four families, 40 alternative scenarios are developed in 6 scenario groups.

The SRES scenarios were designed to "cover a wide spectrum of alterative futures to reflect relevant uncertainties and knowledge gaps" (2000, p24) and to "cover as much as possible of the range of major underlying 'driving forces' of emissions scenarios" (2000, p24).

The **A1 storyline** includes "very rapid economic growth, global population that peaks in the mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies" (SRES, 2000, p4). Economic convergence among regions is a major underlying theme of the scenario family. The three scenario groups in the A1 family are differentiated by their technological emphasis: fossil fuel intensive (A1F1), non-fossil energy sources (A1T), or a balance across sources (A1B).

The **A2 storyline** describes "regionally orientated" economic development and relatively slow economic growth per capita and technological change (compared with the other storylines). "The underlying theme is self-reliance and preservation of local identities" (SRES, 2000, p5).
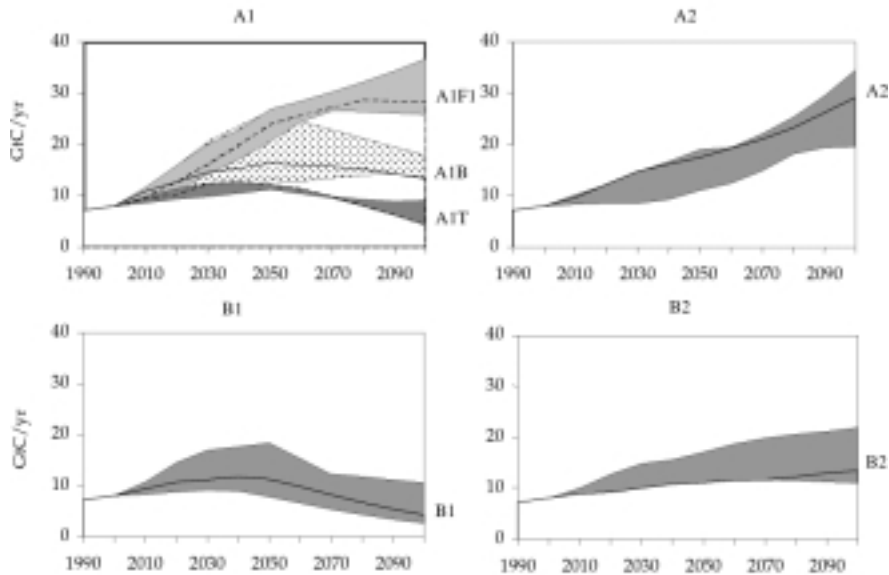

Figure 1. Total global annual CO_2 emissions

Source: IPCC (2000) Appendix VII. Marker scenarios shown as solid lines

The **B1 storyline** describes "a convergent world" ("efforts to achieve equitable income distribution are effective" (SRES, 2000, p182)) with a population structure as in the A1 storyline, "but with rapid changes in economic structures towards a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies" (SRES, 2000, p5). There is an emphasis on "global solutions" and "improved equity".

The **B2 storyline** emphases "local solutions", continuously increasing population (at a rate lower than in the A2 storyline), "intermediate" levels of economic growth and "less rapid and more diverse technological change than in the B1 and A1 storylines" (SRES, 2000, p5).

Figures 1 and 2 demonstrate the range of global annual CO_2 emissions and cumulative CO_2 emissions for each of the SRES storylines. It is important to recognise that although the emission projections documented in the SRES include environmental policies, they do not include "explicit policies to limit greenhouse gas emissions or to adapt to the expected global climate change" (2000, p172). They therefore represent outcomes in the absence of direct climate change policies.
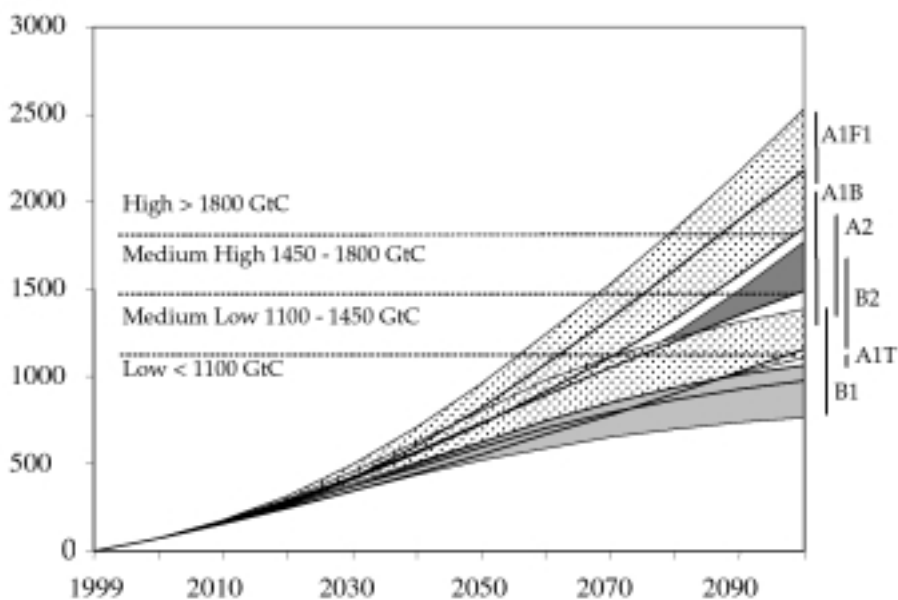

Figure 2. Cumulative SRES carbon emissions range from 800 GtC (gigatonnes of carbon) to over 2500 GtC with a median of about 1500 GtC

Source: IPCC (2000) Appendix VII. Marker scenarios shown as solid lines

The SRES highlights the finding that scenarios with different driving forces can exhibit similar emissions and scenarios with similar driving forces can exhibit different emissions. The SRES were designed to "be transparent" and "reproducible" (2000 p25). However, the relationship between alternative driving force assumptions and projected emissions is far from clear. The SRES recognises that there is a need for the "main driving forces, and underlying assumptions" to "be made widely available" (p47). Until this is completed it is difficult to critically assess the usefulness of the SRES emission projections.

Figures 3 and 4 contain PPP adjusted data sourced from Maddison (2003) and exchange rate adjusted data from the SRES. Maddison's GDP PPPs are calculated using the GK method of aggregation. These estimates are used because Maddison's data are quoted within the SRES (and are therefore well-known to the SRES authors) and because they provide the comprehensive country coverage needed to undertake comparisons with the SRES regions.

Figure 3 compares the historic income per capita growth rates presented in the SRES with growth rates calculated on a PPP basis. The historical growth rates used in the SRES are considerably different to Maddison's estimates for the REF and ASIA regions.

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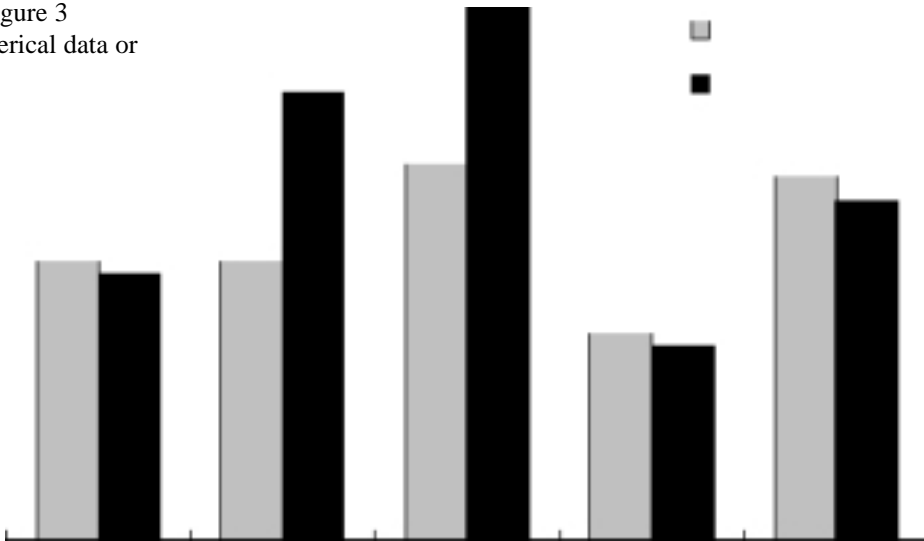no numerical data or
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Figure 3

Figure 4 compares the regional income per capita ratios used in the SRES with estimates based on Maddison's data set. Income per capita in each of the three regions is compared to the income per capita level in the OECD90 region in 1990. The SRES data indicates significantly higher inequality than suggested by Maddison.

These comparisons are important because they illustrate the magnitude of the difference between PPP based and MER based estimates of output and economic growth. As is set out in the UN's *System of National Accounts* (the professional standard for national accounting) when the objective is to compare the volume of goods and services produced between countries, PPP conversions and not market exchange rates should be used.

a. Convergence and Economic Growth in the SRES

The SRES represents, in part, the IPCC's response to the evaluation of its previous scenario exercise undertaken in 1992, the IPCC IS92 Emissions Scenarios. The evaluation recommended changes to a number of the key assumptions regarding the driving forces of future emissions. In particular, it was suggested that the impact of convergence in income levels between developed and developing countries be

Figure 4: Income per Capita, Ratio of OECD90 to Other Countries 1990
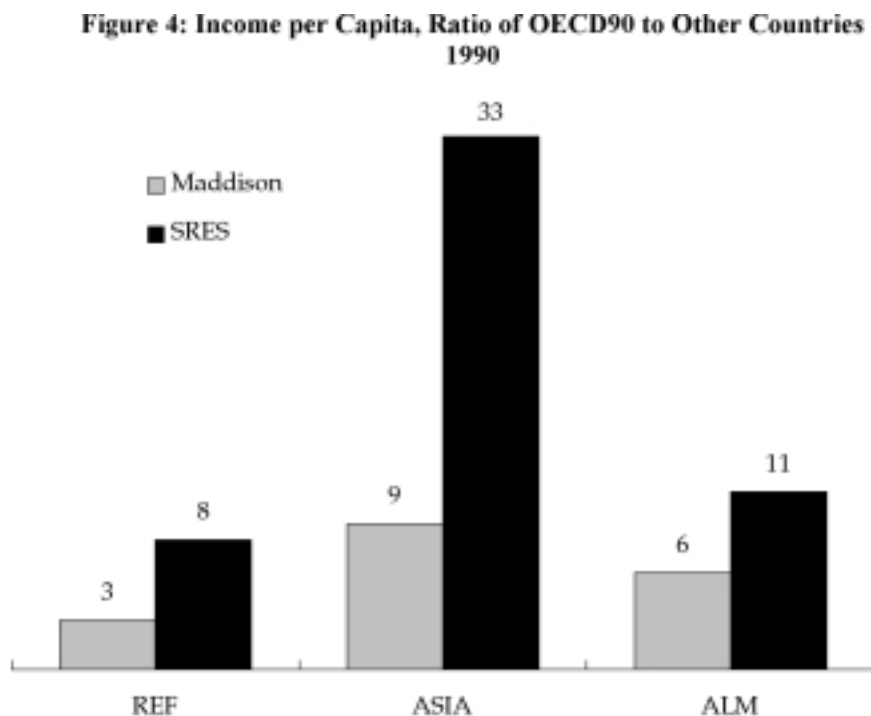
Source: SRES Table 4-6 (the midpoint of the range is used), Maddison (2003)

Figure 4

considered. As a consequence, convergence in income per capita levels represents one of the driving forces in the SRES and is a major theme of the SRES scenario analysis.

As outlined in the previous section explicit convergence assumptions characterise the SRES A1 and B1 scenario families. For this reason we focus on these scenarios and, in particular, the marker scenarios from these families.

Whilst convergence in income per capita is a central theme of the A1 and B1 scenario families, the convergence assumptions that characterise the SRES scenarios do not appear to be limited to income per capita. The SRES report uses the terms "economic convergence" and "convergent world" in describing the A1 and B1 storylines and the B1 family includes technology convergence, economic structure convergence, and education convergence assumptions. SRES assumes a negative relationship between income per capita and final energy intensities and, as with income per capita, energy intensities are assumed to converge in the A1 and B1 scenarios.

The SRES does not provide an explicit description of the convergence models used in the A1 and B1 scenarios, making it hard to provide a critique. The only way to examine the convergence assumptions is to analyse the historical and projected growth rates that appear in the report. Table 1 summarises the historic economic and income per capita growth rates used in the SRES and the projected growth rates for the A1 and B1 marker scenarios. Table 2 contains historical and projected income per capita ratios across the SRES regions for the A1 and B1 marker scenarios.

The information in Table 2 illustrates the convergence assumptions that characterise the A1 and B1 families. The ratio of the poorest region in 1990 (ASIA) to the richest region (OECD90) is projected to increase from 0.02–0.03 to 0.66 in the A1 marker scenario and to 0.45 in the B1 market scenario over the period 1990 to 2100. In the A1 marker scenario the catch-up is a byproduct of "rapid economic development and fast demographic transition" (2000, p197). In the B1 marker scenario, the reduction in income inequalities is due to "constant domestic and international efforts" (2000, p200).

The SRES appears to consider a situation in which steady states across countries are converging so that the distinction between conditional and unconditional convergence disappears. Whilst there is a large body of literature in support of the existence of various forms of conditional convergence there is little evidence of unconditional aggregate convergence. Even if steady state characteristics across countries were to converge, the empirical literature suggests that the rate of convergence in income per capita would be very slow. The SRES authors acknowledge that "it may well take a century (given all other factors set favourably) for a poor country to catch-up to levels that prevail in the industrial countries today, never mind the levels that might prevail in affluent countries 100 years in the future" (p 123).

2. PPP VERSUS MER IN G-CUBED: AN ILLUSTRATION

Castles and Henderson (2003a, 2003b) suggest that if PPP adjusted data were used in the SRES, the projected economic growth rates would be lower and so would the projections of emission levels. We now examine the magnitude of the consequences of

the Castles and Henderson critique of the SRES by generating a baseline projection from the G-Cubed model outlined in McKibbin and Wilcoxen (1998) based on our usual growth convergence assumptions using a PPP measure of initial gaps between countries. We solve the G-Cubed model under our conventional assumptions of the gaps in productivity growth being related to the overall PPP gaps. We then regenerate the productivity projection by changing the initial gaps for China and LDCs in the model to be based on MER measures of GDP per capita. This implies that we move

Table 1. SRES Growth Rates

	1950–1990	1990–2050		1990–2100	
		A1	B1	A1	B1
Economic Growth Rates (% per year)					
OECD90	3.9	2.0	1.8	1.8	1.5
REF	4.8	4.1	3.1	3.1	2.7
IND	3.9	2.2	1.9	2.0	1.6
ASIA	6.4	6.2	5.5	4.5	3.9
ALM	4.0	5.5	5.0	4.1	3.7
DEV	4.8	5.9	5.2	4.3	3.8
WORLD	4.0	3.6	3.1	2.9	2.5
Income Per Capita Growth Rates (% per year)					
OECD90	2.8	1.6	1.5	1.6	1.2
REF	3.7	4.0	3.0	3.3	2.8
IND	2.9	2.0	1.7	1.9	1.5
ASIA	4.4	5.5	4.8	4.4	3.9
ALM	1.6	4.0	3.5	3.3	3.0
DEV	2.7	4.9	4.2	4.0	3.5
WORLD	2.2	2.8	2.3	2.7	2.2

Source: SRES Tables 4–5, 4–7

Table 2. SRES Income Per Capita Ratios (Ratio to OECD90)

	1990	2050		2100	
		A1	B1	A1	B1
OECD90	1.00	1.00	1.00	1.00	1.00
REF	0.11–0.15	0.58	0.29	0.92	0.65
ASIA	0.02–0.03	0.30	0.18	0.66	0.45
ALM	0.06–0.12	0.35	0.27	0.56	0.56
DEV/IND	0.05–0.08	0.36	0.28	0.62	0.55

Source: SRES Table 4–6

China's gap from 0.2 of the United States to 0.1 of the United States and the gap for developing economies from 0.4 of the United States to 0.13 of the Unites States. That is, for China, the gap relative to the US doubles under the MER approach and for developing economies, the gap more than triples.

The results for the difference in emissions in the MER case versus the PPP case are shown in Figure 5. By 2050 we find that the G-Cubed model using growth rates based on MER initial conditions produces 21% more emissions than the same model using PPP based initial conditions. By 2100 this is 40% higher emissions. The impacts on cumulative emissions would be less than this and on temperatures (which depend on cumulative emissions) even less. Nonetheless this is more than 3 times the overestimate found by Manne and Richels (2003). The higher emissions are due to higher emissions in LDCs and China due to higher growth but are also due to higher emissions in industrial economies. Stronger growth and a higher marginal product of capital implies that industrial countries sell more to developing countries as well as receiving a higher return on capital invested in these economies. Both of these effects raise emissions and levels of income in non developing economies.

Based on these estimates from the G-Cubed model it seems that the assumptions about the initial levels of income based on MER versus PPP measures are very important for estimates of future carbon emissions. This is a consequence of the particular assumptions we adopt with regards to the convergence model.

Although the results we find are significant, they cannot be directly applied to the SRES approach. Firstly, it is not clear that the SRES actually based any or all of the
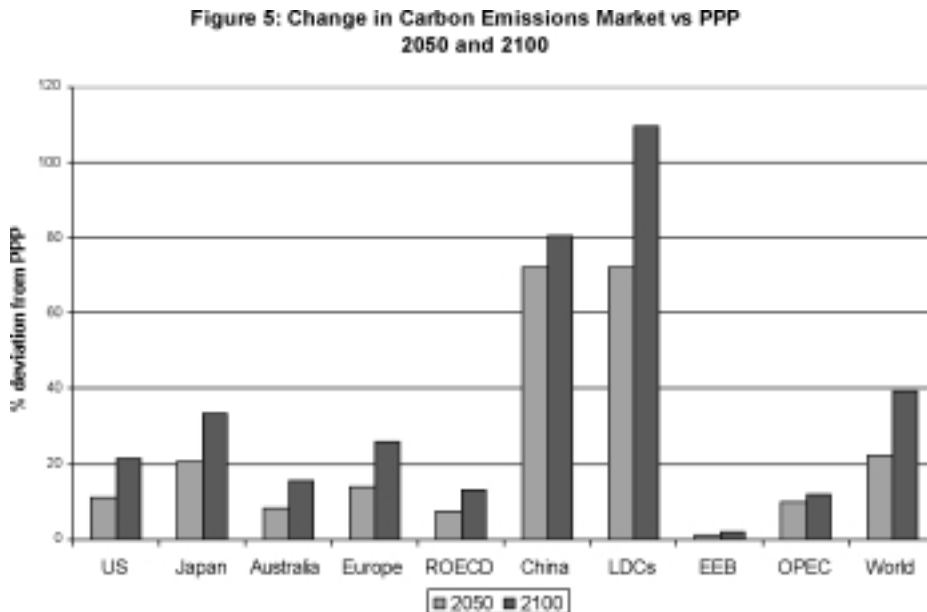

Figure 5

projections in the study on a standard growth convergence model, despite spending considerable space summarizing that literature. In many of the models used in the SRES the entire economy is summarized by the exogenous path for GDP growth and emissions growth is driven by technology. GDP plays a minor role except as the scale variable. Indeed it is likely that the projections of emissions in the SRES were undertaken by the modellers before the chapter on economic growth was even written, because the economics of growth doesn't really play an important role given the underlying methodology of the models used.

If the modellers in the SRES used market exchange rate GDP differentials but the rate of convergence from the PPP convergence models then there is a problem as argued by Castles and Henderson (2003a) and as we illustrate in this paper. If the SRES models used an MER based convergence model by adjusting the rate of convergence to be consistent with the MER approach then there is still a problem because there is no evidence of convergence of GDP per capita in MER terms. This is why the growth convergence literature that has been published since the development of PPP GDP data and does not use market exchange rates. Secondly there is also no evidence of convergence between MER and PPP exchange rates so in our opinion there is no way to go from a PPP convergence model to a MER convergence model.

However, it may just be that the models did something completely different to what is suggested in the SRES report. One alternative that likely underlies some of the projections is that the concept of convergence is implemented by specifying a gap between $US incomes per capita at the start of the projection period and an arbitrary gap between $US incomes per capita at the end of the projection period. The problem with this approach is that it relies on the evolution of the real exchange rate between countries to be able to say anything about the underlying drivers of growth at the sectoral level within a country. Many of the models used do not have the real exchange rate modelled and therefore cannot back out the underlying drivers of growth within a country for driving real economic growth. Even this approach would suffer from the same critique that income gaps measured in $US at different points in time cannot be used to derive underlying economic growth.

While it is possible that some of the SRES scenarios contain growth rates that are higher than would be case if PPP had been used in comparing base GDP, it does not follow in these scenarios that lower GDP growth would translate to lower emissions. We illustrate in the full version of this paper that the relationship between emissions and GDP depends on the relative importance of various sources of growth as well as the production structure and the nature of technological change. It is possible to have a model with growth drivers and parameters setting that result in GDP and emissions moving in opposite directions.

3. STORYLINES VERSUS PROBABILITIES

As noted above, the SRES develops a number of different storylines for its analysis, but does not make any judgement about the likelihood of any of these storylines. An important alternative to this approach is to try to develop explicit probability distributions for the key outcomes (such as emissions) from the projections exercise. Such an approach would attach an explicit probability distribution to key model input

variables and then use a range of techniques (Monte Carlo analysis, for example) to propagate this uncertainty throughout the model. The result would be a probability distribution for key output variables.

Grubler and Nakicenovic (2001) reject this sort of approach because in their view 'probability in the natural sciences is a statistical approach relying on repeated experiments and frequencies of measured outcomes....Scenarios describing possible future developments in society, economy, technology, policy and so on are radically different' (p.15).

But as Pittock, Jones and Mitchell (2001) point out 'this frequentist basis for probabilities in predictions of an unknown future is not possible in the earth sciences either, since there will be only one real outcome which cannot be measured now' (p 249).

Rather, uncertainty analysis in economics and earth sciences requires not a frequentist but a Bayesian approach in which prior assessments of the probability of key input variables are put into an appropriate modelling framework (see the discussion in Malakoff, 1999).

There are a number of possible sources for these prior probability distributions. In terms of key model parameters, they could come from the statistical estimations of the parameters themselves. Alternatively, they could be constructed so as to reflect expert judgements of a particular issue. (This sort of analysis has been used to excellent effect by Nordhaus, 1994, and the various techniques used are described in detail in Morgan and Henrion, 1990).

Whatever the source, uncertainty analysis within a particular modelling framework gives powerful insights into the sources of uncertainty in the model and the drivers of particular modelling results. This insight is unfortunately lacking in the SRES results as presented. It is impossible to tell from the SRES what a small change in assumptions means for the results.

Importantly, probability distributions for emissions could be used as an input into subsequent climate analysis (as undertaken, for example, by Wigley and Raper 2001) to ultimately derive a probability distribution for temperature changes. Such a distribution would be extremely valuable for policy makers, and would assist in planning and policy development. The work by Webster et al. (2003) is an excellent example of how uncertainty analysis can be used in a combined economic and earth systems model. By explicitly modelling uncertainty in emissions as well as other climate factors, they derive an explicit probability distribution for temperature change.

While the probability distributions developed in this way may be imperfect in many regards, it has the advantage of being explicitly derived, with known assumptions that can be tested and challenged. The problem with the current SRES results is that policy makers inevitably overlay their own implicit distributions, which may well be based on political rather than scientific considerations.

4. CONCLUSION

Projecting the world economy over long time horizons is challenging. One only has to consider the problems that would have been encountered in 1900 in projecting carbon emissions in the year 2000. Indeed it would have been difficult in 1970 to do well in

predicting 2000, given the important structural break in many economic and energy variables resulting from the OPEC oil price shocks. Nonetheless it is important to use the best methodology available to attempt to gain some idea about where carbon emissions might be heading. The mistake would be to rely on the accuracy of these projections for the efficacy of the policy responses that might follow from the predictions. Given the enormous uncertainties in this type of prediction exercise, the policy responses should deal with the uncertainties and the need for flexible responses rather than fixed targets based on projected outcomes[1].

A key issue facing policy makers is how to interpret the projections of the SRES in the light of the various critiques that it has faced. On the basis of our methodological discussion in this paper, we offer the following observations.

First, it is crucial to understand the drivers of emissions projections and their sensitivity to changes in key assumptions. While this understanding cannot be gleaned from the SRES in its current form, there is no reason why the various SRES models could not be explored to further understand these sensitivities.

Second, as we have argued, a broad range of projections without any sense of likelihood is of limited use to policy makers. Indeed, it is potentially misleading as it can lead to researchers applying the upper bound as the most likely scenario. Currently there is no basis for such a choice and work is needed to further understand the likelihood of different projections.

It should be possible to increase understanding of both these issues even if the underlying SRES scenarios remain unchanged.

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1 See McKibbin and Wilcoxen (2002) for a long discussion of the range of uncertainties in climate change.

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