What is ‘dangerous’ climate change?

HUGH TURVEY/SPL

To combat global warming, we must first assess just how likely it is to occur.

Stephen H. Schneider

In the third assessment report of the Intergovernmental Panel on Climate Change (IPCC), the climate modellers of working group 1 (see Box 1 for glossary) dramatically revised upwards the top-range limit of their predictions of global warming from the previous value of 1–3.5 °C to 1.4–5.8 °C between now and 2100 (refs 1, 2). This sweeping revision depends on two factors[3] that were not the handiwork of the modellers: smaller projected emissions of climate-cooling aerosols; and a few predictions containing particularly large CO_2 emissions.

This big increase in the projection of severe climate change is certainly plausible, but an unanswered question lingers: “How likely is it that the world will get 6 °C hotter by 2100?” The answer depends on the likelihood of the assumptions underlying the projections, so the components of this projection deserve careful analysis.

The most famous ‘scenarios’ (see Box 1) used by working group 1 in the IPCC’s second assessment report[1] were six ‘business as usual’ projections, and one central scenario formed the basis of several calculations used by working group 2 (ref. 4). Because there is a lag of a few years between emissions predictions, climate models’ responses, and analysis of possible impacts, the IPCC decided to prepare a special report on emissions scenarios (SRES) to produce a family of updated projections in time for the writing and review cycle for the third assessment in 1999/2000 (see Box 2, overleaf). For this reason, preliminary scenarios were released, and several climate-modelling groups produced general circulation model (GCM) runs driven by six ‘illustrative scenarios’ of the 40 emissions projections in the special report. Unfortunately, the time lag persisted, and the impacts-assessment literature[5] still did not have enough time to incorporate the updated climate runs for the latest round of the IPCC.

The likelihood controversy

I attended a preliminary meeting of the SRES group, led by Nebojsa Nakicenovic, at the International Institute for Applied Systems Analysis near Vienna. I was impressed by the broad representation of the group: academic scientists, environmental organizations, industrial scientists, engineers, economists and systems analysts. Their task was to imagine plausible alternative future societies and technologies that would determine the emissions profiles and drive climate-change scenarios.

The approach — suggested by industrial participants — was to create ‘storylines’ about future worlds from which population, affluence and technology drivers could be

BOX 1: Glossary of terminology

Working groups. Writing teams of 100–200 lead authors, dozens of review editors and hundreds of peer reviewers from scores of countries who, as the Intergovernmental Panel on Climate Change (IPCC), produce assessments of the literature for about 100 governments. **Working group 1** deals primarily with the science of climate change, evaluating projections of alternative future climate changes and events. **Working group 2** assesses the potential impacts of such projections, prospects for adaptability and potential vulnerabilities. **Working group 3** assesses mitigation and other policy options for dealing with climate changes. There have been three cycles of assessment reports since 1990.

Special reports. Focused assessments of topics that governments decide need additional treatment. The special report on emission scenarios (SRES) is discussed in this article, but others have been prepared, for example on aviation impacts and carbon sinks.

Storylines. A framework from the SRES explicitly to recognize different demographic, social, economic, technological and environmental developments. Each scenario represents a specific quantitative interpretation of one of four storylines. All the scenarios based on the same storyline constitute a scenario ‘family’.

Scenarios. According to the SRES: “Scenarios are alternative images of how the future might unfold and are an appropriate tool with which to analyse how driving forces may influence future emission outcomes and to assess the associated uncertainties.”

General circulation models (GCMs). The most comprehensive three-dimensional, time-evolving simulation models available. They often couple submodels of the atmosphere to oceans, to ecological systems and to ice systems. Omission of explicit treatment of processes on a smaller scale than the ‘grain size’ of the models creates uncertainties in their outputs, especially for regionally specific projections.

Forcing. Any scenario of greenhouse-gas emissions or aerosols implies that the radiant energy transferred between the Earth’s surface and space by the atmosphere can be modified. So the scenarios are fed into biogeochemical cycle models to translate the emissions into concentrations of radiatively active constituents, which, in turn, ‘force’ the climate to change by perturbing the heat balance of the Earth–atmosphere system. Working group 1 has translated SRES emissions scenarios into radiative forcing to drive climate models that in turn produce projections used by working group 2 to assess potential impacts.

We are facing the worrying prospect of dozens of users selecting arbitrary scenarios and climate sensitivities.

inferred (see Box 2 for details). It was an impressive exercise, and gave rise to radically different families of emission profiles up to 2100 — from below current CO_2 emissions to five times current emissions. Because of the divergent views of participants about the likelihood of each storyline, the final report offered no assessment of the relative likelihoods, in an attempt to avoid endless disputes.

While acknowledging the logic of avoiding fruitless debate, I strongly argued at the time that policy analysts needed probability estimates to assess the seriousness of the implied impacts; otherwise they would be left to work out the implicit probability assignments for themselves (see ref. 6 for fuller discussion). I urged the expert group to provide a subjective probability assessment for less expert users, but I was not persuasive enough, and the SRES authors expressed "no preference" for each scenario (page 46, ref. 3).

The confusion I feared is already surfacing. The most typical assumption is a uniform probability distribution across storylines (scenarios). This might seem to imply a uniform probability distribution in the outcome that really matters to policymakers: the likelihood of a particular temperature rise by 2100. But this inference would be incorrect, because uncertainties compound through a series of modelling steps. Uncertainties in emissions scenarios feed into uncertainties in carbon-cycle modelling, which feed into uncertainties in climate modelling, which drive an even larger range of uncertain climate impacts. This 'cascade of uncertainties'[7] is compounded by the very wide range of emissions offered by the SRES authors.

Working group 1 transferred this broad range of emission projections into radiative forcings of the climate system (see Box 1 and Fig. 18 in the technical summary of ref. 2), producing a wide range of temperature projections by means of a simple model tuned to seven general circulation models (out of a possible 18 cited by working group 1 — Table 9.1 of ref. 2). These seven models represent a range of equilibrium climate sensitivities from 1.7 to 4.2 °C warming for a doubling of CO_2. The result of combining the climate-sensitivity estimates from the seven models with the six illustrative scenarios from the special report (Box 2) is the dramatic revision upwards in the IPCC's third assessment which has attracted so much attention, as global warming of more than 3.5 °C would have severe effects[5].

If all scenarios and sensitivity projections are given equal likelihood, we might intuitively expect that any combination from these two sets would also be uniformly likely, so 1.4 °C would be as probable as 5.8 °C warming. But this is not the case. Instead, the resultant combined probability distribution for global surface warming in 2100 would have a peak at the centre — just like a typical bell curve[8]. If all 18 GCM sensitivities are combined with all six illustrative scenarios (108 possible combinations), then indeed a peaked bell curve results (see Fig. 1 for an example). As a limiting case and for illustration, if only the outlier emissions scenarios are combined with the 18 climate sensitivities (36 possible combinations), then the probability distribution for 2100 warming would not be as peaked as a bell curve, but would have a much flatter distribution.

For illustrative purposes, I have chosen arbitrarily a temperature increase of 3.5 °C as a 'threshold' beyond which many believe substantial climate damage would occur. In Fig. 1, the blue bars show that the resultant bell curve for all 18 GCMs and all six illustrative scenarios implies that 23% of the 108 values obtained for a possible temperature increase in 2100 are greater than 3.5 °C. For the truncated case in which only the highest and lowest emissions scenarios are used (yellow bars), 39% of these 36 possibilities are for a warming of 3.5 °C or greater. With the relative lack of middle-value scenarios, the probability distribution is much flatter than before.

Clearly, a policymaker concerned with "avoiding dangerous anthropogenic interference in the climate system"[9] would propose stronger policies and measures if there was a 39% chance of exceeding the 3.5 °C warming 'threshold' than if the figure was 23%. But what do these figures actually represent? Unless probabilities are assigned to individual scenarios and GCM climate sensitivities (for example, as in ref. 10), their joint distribution (in this example the likelihood of some temperature rise in 2100) will depend on the particular selection of scenarios and models, as Fig. 1 clearly demonstrates. To assess the likelihood of future temperature increase, we can either estimate more consistently the subjective likelihood for each scenario and climate sensitivity, or estimate the joint distribution (2100 temperatures) explicitly. Early attempts at this estimation have been made (T. Wigley and S. Raper, personal communication; M. Webster *et al.*, see http://mit.edu/globalchange/www/reports.html).

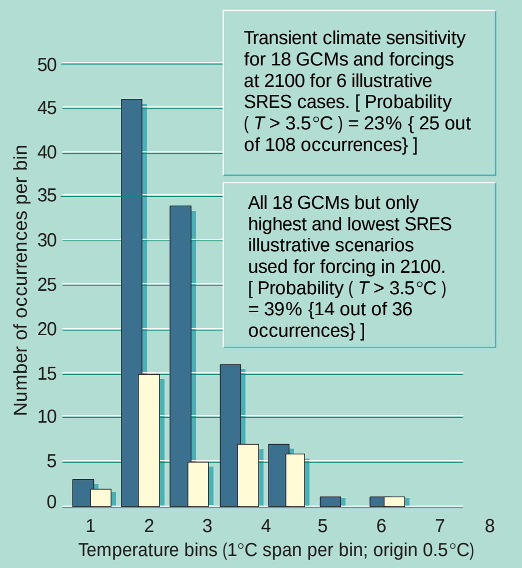

Figure 1 **'Frequency' of 'severe' climate impacts in 2100. The difference between the yellow and blue bars shows how selection of scenarios can lead to arbitrary results. The histograms are the number of occurrences of temperature increases around 2100 in seven bins, each 1 °C wide and beginning at 0.5 °C (for example bin 3 represents the number of occurrences of temperature increases (*T*) between 2.5 °C and 3.5 °C at 2100). The blue bars represent the distribution that results from the product of all 18 GCM transient climate sensitivities (in °C warming for a transient climate forcing at the time of an equivalent doubling of CO_2; from Table 9.1 of ref. 2); and all six radiative forcings at the year 2100 from the six illustrative emissions scenarios (from Fig. 18 of the technical summary of ref. 2). Of the 108 numbers represented by the joint inclusion of 18 climate sensitivities and six forcings, 25 occur in bins representing temperature increases greater than a threshold value of 3.5 °C — a rise that many would consider could cause extensive and significant climate damage. The yellow bars represent a case in which all 18 GCM sensitivities are used, but only two emission scenario forcings (the highest, A1FI, and the lowest, B1). Fourteen out of 36 outcomes are greater than the threshold of 3.5 °C warming in 2100, representing a much larger likelihood (39%) of severe climate damage than for the other case. The likelihood of crossing some threshold is thus sensitive to the particular selection of scenarios and climate sensitivities used. Arbitrary selections will produce distributions that could easily be misinterpreted as containing subjective probabilistic analysis when they do not — until judgements are formally made about the likelihood of each scenario or sensitivity. For this reason the word 'frequency' appears above in quotation marks. It is not a justifiable probability distribution as the subcomponents are chosen without a "traceable account"[6] of the logic of the selection process.**

KEVIN LEE/NEWSMAKERS

Emissions, impacts and the implications of policy responses all depend on how society is structured over time.

Social conditions and emissions

One of the most important points of the SRES storylines approach is that the socio-economic conditions driving emissions would also help to form the adaptive and mitigative capacity of various countries or regions[11]. Emissions, impacts and the implications of various policy responses are all mutually dependent on how society is structured over time. This insight is one of the most positive developments of the approach, and will occupy integrated assessments of climate change for the foreseeable future. It is essential that the storyline approach should continue and expand, but, as I have shown here, future work should attempt to deal more forthrightly with the difficult issue of the relative likelihood of each scenario, and to provide more guidance as to the independence of each storyline.

What next?

The special report leadership was not wrong, of course, about how difficult it would be to assign subjective probabilities to radically different visions of the future. But in the probability vacuum that followed its assertion that all scenarios were "equally sound", we are facing the even more worrying prospect of dozens of users selecting arbitrary scenarios and climate sensitivities to construct frequency charts that, like the histogram of Fig. 1, are built on implicit assumptions. In the risk-management dilemma that constitutes climate-change policymaking, I would definitely put more trust in the probability estimates of the SRES team — however subjective — than those of the myriad special interests that have been encouraged to make their own selection.

Meanwhile, as we wait for the IPCC to decide whether to reassemble the team for this controversial labour, climate policy-makers will have to be vigilant, asking all advisers to justify the threshold they choose for predicting 'dangerous' climate change, as well as to provide a "traceable account"[6] of how they selected their emissions scenarios and model sensitivities, as these jointly determine the probability of future risks. ■

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Box 2: Summary of special report's findings

The most compelling conclusions of the special report on emissions scenarios are:

(1) Alternative combinations of main scenario driving forces can lead to similar levels of greenhouse-gas emissions by the end of this century. Scenarios with different underlying assumptions can result in very similar climate changes.

(2) Technology is at least as important a driving force of greenhouse-gas emissions as are population and economic development across the set of 40 scenarios.

The 40 scenarios, consisting of four main 'families' and various subgroups, each have a distinct narrative storyline containing different assumptions on population, economic and technological growth; orientation towards a global economy and community; and attitudes towards economic, social and environmental goals.

The scenarios cover the full range of greenhouse-gas and SO_2 emissions that SRES authors could imagine as plausible.

One prominent scenario group is the A1 series. This is distinguished by its technological emphasis on coal (A1C), oil and gas (A1G), non-fossil energy sources (A1T) or a balance across all sources (A1B). In the working group 1 summary for policymakers, A1C and A1G groups are combined into one fossil-intensive group, A1FI. All scenario families are said to be 'equally sound'.

The scenarios are also grouped into four categories of cumulative CO_2 emissions, which indicate that scenarios with different driving forces can lead to similar cumulative emissions, and those with similar driving forces can branch out into different categories of cumulative emissions.

Four scenarios are designated as 'markers'. Together with two scenarios from the A1 family, the six 'illustrative' scenarios form the backbone of the range reported by working group 1.

The report's authors recommend that any evaluation should include at least the six illustrative scenarios.

All scenarios describe futures that are generally more affluent than today. Many envisage a more rapid convergence in per capita income ratios in the world than do the 'business as usual' scenarios, despite having divergent greenhouse gas and SO_2 emissions (compare A1 and B1 scenario families).

Many greenhouse-gas emissions described in the special report are lower than the central 'business as usual' level in the second assessment report, especially towards the end of the twenty-first century. Emissions of SO_2, which have a cooling effect on the atmosphere, are significantly lower than in the second report.