SPECIAL REPORT

The costs of global warming

Efforts to forecast how Earth's future climate will affect us must consider the economic growth of both rich and poor nations. But there are doubts over the theories being used, as **Quirin Schiermeier** explains.

Discussions of climate change tend to involve uncertainties, and most climate researchers have come to accept the inherent unknowns of their business. After all, the climate models they use to project the course of global warming are generally seen as the best that science can offer. But there is a growing feeling that the economic assumptions on which their work is based are outdated and unreliable. And this could have serious implications for assessments of climate change.

The Intergovernmental Panel on Climate Change (IPCC), which coordinates efforts to predict the effects of global warming, is currently finalizing its fourth assessment report. It has asked 15 climate groups to run their models using output from a range of different 'scenarios', representing various assumptions about energy use, economic development and population increase up to 2100.

For the different models to be compared, all groups will run two of the 40 available scenarios — A1B, which describes a world with large economic growth and a balance between fossil and renewable energy sources, and B1, which assumes less economic growth and a large shift towards renewable energy. Each group will also run a selection of other scenarios. The results will be fed into the report of the IPCC's Working Group I, which projects how temperatures may rise over the next century.

Working Group II will translate this into likely effects on society, income, food security and disease, and Working Group III will assess the options for limiting greenhouse-gas emissions and mitigating climate change.

The scenarios were described in the IPCC's "Special Report on Emissions Scenarios" (SRES) for the panel's 2001 third assessment report. In June 2003, the IPCC decided that there was no time to develop new scenarios for its fourth assessment report, so the same ones are being used again.

But many economists are vehemently questioning the assumptions on which the SRES scenarios are based. They say the scenarios rely on outdated economic theories and fail to reflect how lifestyle and energy demand in both rich and poor countries are likely to change.

Climate researchers are familiar with the problem. "Some emissions scenarios are perhaps already demonstrably wrong," says Erich Roeckner, a climate modeller at the Max Planck Institute for Meteorology in Hamburg, Germany, who has modelled three of them for the IPCC (see "Early results"). "It is possible that all of them are wrong." But most feel that economics is a field they are not qualified to assess.

Ridiculous assumption?

One key criticism is the assumption that the economies of poor countries will quickly catch up with those of rich nations. "It is ridiculous to assume, as the IPCC does, that rich and poor countries will economically converge as rapidly as the European Union has done over the past 40 years," says Richard Tol, an economist at Princeton University in New Jersey.

A particular worry about convergence was first raised by David Henderson, former head of economics at the Organisation for Economic Co-operation and Development, and Ian Castles, former head of Australia's bureau of statistics, after the IPCC's third assessment report. They pointed out that the IPCC used market exchange rates to compare the wealth of different countries, instead of what a certain amount of money will buy in each place. This exaggerates the differences between countries, they argue, and overestimates how much poor countries will develop in coming decades, and how much their carbon emissions will increase.

Tol says that even if certain economic assumptions are wrong, the predictions of global warming itself may not be far off. The errors may even cancel each other out: if economic development is slower than thought, countries may also switch to renewable energy more slowly.

Susan Solomon, who chairs the IPCC's Working Group I, emphasizes this point. "Existing scenarios cover a very wide range of emissions trajectories," she says. "They are perfectly suited to physical tests of how the climate responds to fixed concentrations of greenhouse gas. In the simplified view of science it does not matter how the gas gets into the atmosphere, only how much of it is there."

Translating temperature changes into impacts on society is beset with unknowns.

But Tol argues that when it comes to translating those temperature predictions into impacts on society, how the carbon got there matters very much indeed. Many problems relating to climate change, such as the distribution of malaria and water-borne diseases, are highly sensitive to development and wealth, says Tol. "You can't use flawed economic scenarios for any meaningful analysis of the impacts of climate change."

In terms of human welfare, some even assert that the difference between the economic effects of the various scenarios is more significant than the predicted effects of climate change. For example, changes in malaria incidence that result from people becoming rich enough to have mosquito nets outweigh any changes in the geographical spread of malaria caused by global warming.

Development of the SRES scenarios was overseen by Nebojsa Nakicenovic, an energy economist at Vienna Technical University in Austria. He says he is aware of the criticisms, but argues that the scenarios were designed to

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cover a range of possibilities, and include one group that assumes little convergence.

Martin Parry, co-chair of Working Group II, which met in Merida, Mexico, last week to consider an early draft of the fourth assessment report, adds that he and his colleagues also take other projections into account, for example those from the World Bank or the Millennium Ecosystem Assessment. But which ones are likely to be right isn't for them to judge, says Parry. "The IPCC summarizes current knowledge — it does not have a view."

But economists such as Tol say that instead of considering an ever wider range of possibilities, the IPCC needs to rethink its scenarios and come up with a selection of likely options based on more up-to-date economic theory.

Tol believes that the composition of the SRES teams was too narrow, and that future efforts should have a wide range of experts. As well as convergence, they will need to consider how future societies will operate, how fast the population will grow, and how technological progress will change things. "All these questions are at the heart of economics," agrees Ottmar Edenhofer, an economist at the Potsdam Institute for Climate Impact Research in Germany.

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Edenhofer says that economists must also routinely check their ideas against historical data, and test their predictions against those of other teams, as climate scientists do. The way natural scientists compare their models "is a totally new thing in economics", says Edenhofer. "We can learn a lot from climate modellers."

The aim is to develop flexible theories, in which variables such as gross domestic product and technical progress influence one another, to test the effects of policy interventions — emissions caps or trading, for example — and work out the cost of different policies.

A few attempts have already been completed. In 2003, economists Michael Grubb of Imperial College London and Carlo Carraro of the University of Venice, along with John Schellnhuber, research director at the Tyndall Centre for Climate Change Research in Norwich, UK, launched a project to investigate how technological progress affects emissions strategies and mitigation costs.

Their comparison of models incorporating data on the economy, energy use and the environment suggests that climate policies such as the Kyoto Protocol will trigger technological change. They estimate that the cost of stabilizing emissions at 450 parts per million — a value it is hoped will be sufficient to avoid dangerous climate change — would be just 0.4% of the world's present gross product (O. Edenhofer *et al. Energy J.*, in the press).

And this week, William Nordhaus, an economist at Yale University in New Haven, Connecticut, published results from a model that combines data on historical climate, economic activity and country-specific temperature predictions to estimate the economic impact of a temperature rise of 3 °C. He concludes that such a rise would cause a 1–3% decline in global income — significantly larger than previous estimates (W. D. Nordhaus *Proc. Natl Acad. Sci. USA* doi:10.1073/pnas.0509842103; 2006).

The IPCC is starting to consider economists' concerns. In September 2005 it set up a group to look at scenario development led by Bert Metz, a chemist at the Netherlands Environmental Assessment Agency and co-chair of Working Group III. Metz says he will recommend the development of completely new emissions scenarios, including a more sophisticated treatment of convergence and technology. The IPCC will decide on whether to go ahead with Metz's plan at a meeting in April on Mauritius. But even if work starts now, the scenarios won't be ready for use until the IPCC's fifth assessment report, due in 2013 or later.

For critics such as Tol and Edenhofer, that's not a moment too soon. "Economists must learn to bring their knowledge to bear in the discussion, and climate scientists need to realize the significance of economics," says Edenhofer. Rather than arguing about temperature predictions, "the future battle will be about cost and damages". ■

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Early results

Global temperatures are likely to rise by 2.5–4 °C by 2100, according to the latest calculations by scientists at the Max Planck Institute for Meteorology in Hamburg, Germany.

The institute is one of 15 asked by the Intergovernmental Panel on Climate Change to run extended climate simulations for its fourth assessment report. The researchers ran six parallel experiments, requiring 400,000 computing hours, using their atmospheric general circulation model ECHAM5.

They looked at three emissions scenarios, representing carbon dioxide concentrations of 550, 700 and 800 parts per million (p.p.m.) by 2100 (see graph). Even under the most optimistic assumptions, the model suggests that the Arctic will become ice-free during summer by 2090, says Erich Roeckner, who heads the group. The global sea level will rise by up to 30 centimetres as water warms and expands, and by an additional 10 centimetres as part of Greenland's ice sheet melts. The scientists also expect a weakening — but not a shut-down — of the Atlantic ocean circulation. There will be more rain and snow at high latitudes and in the tropics, and less rainfall in Mediterranean and subtropical regions. Extreme precipitation and extreme drought are likely to increase worldwide. **Q.S.**