COMMENTARY

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Dangerous assumptions

How big is the energy challenge of climate change? The technological advances needed to stabilize carbon-dioxide emissions may be greater than we think, argue **Roger Pielke Jr**, **Tom Wigley** and **Christopher Green**.

The United Nations Climate Conference in Bali in 2007 set the world on a two-year path to negotiate a successor to the 1997 Kyoto Protocol. Yet not even the most rosy-eyed delegate could fail to recognize that stabilizing atmospheric carbon-dioxide concentrations is an enormous undertaking. Here we address the magnitude of the technological changes required to meet that challenge. We argue that the size of this technology challenge has been seriously underestimated by the Intergovernmental Panel on Climate Change (IPCC), diverting attention from policies that could directly stimulate technological innovation.

The IPCC uses 'reference' scenarios of future emissions that assume no policy interventions directed towards reducing greenhouse-gas emissions (notably carbon dioxide) to determine the magnitude of additional emissions reductions ('mitigation') needed to stabilize atmospheric carbon-dioxide concentrations at various levels. It is on these additional reductions that policy-makers have focused most attention.

Here we show that two-thirds or more of all the energy efficiency improvements and decarbonization of energy supply required to stabilize greenhouse gases is already built into the IPCC reference scenarios. This is because the scenarios assume a certain amount of spontaneous technological change and related decarbonization. Thus, the IPCC implicitly assumes that the bulk of the challenge of reducing future emissions will occur in the absence of climate policies. We believe that these assumptions are optimistic at best and unachievable at worst, potentially seriously underestimating the scale of the technological challenge associated with stabilizing greenhouse-gas concentrations.

The reference scenarios used by the IPCC's fourth assessment report (AR4) were described in a 2000 Special Report on Emission Scenarios[1] (SRES). In 2003, the IPCC decided not to develop comprehensive, new scenarios for AR4, so they used the SRES scenarios and related pre- and post-SRES scenarios[2,3] based on similar socioeconomic assumptions.

Climate scientists have argued that the outdatedness of the SRES scenarios is not that important when running them through climate models, because the scenarios cover a wide range of possible future emissions. But for IPCC Working Group III, which is concerned with mitigation of climate change, the details of emissions scenarios matter a great deal for considering policy options.

To assess the full challenge of reducing future emissions in line with particular stabilization targets, we begin with a 'frozen technology' baseline[4–6], which assumes that future energy needs are met with the technologies available in some baseline year (the technologies are 'frozen' in time). This approach differs from the SRES scenarios, which include various rates of spontaneous decarbonization[4,7].

"The technological challenge has been seriously underestimated by the IPCC."

The IPCC Working Group III links carbon-dioxide emissions to four specific 'drivers': population[1]; economic activity (gross domestic product or GDP) per capita; energy intensity (primary energy consumption per unit of GDP); and carbon intensity (carbon-dioxide emissions per unit of energy). These four elements are the building blocks for all emissions scenarios, and are widely used in climate-change assessments including efforts to estimate the costs of mitigation.

Decarbonization of the global energy system depends mainly on reductions in energy intensity and carbon intensity. These result from technological changes that improve energy efficency and/or replace carbon-emitting systems with ones that have lower (or no) net emissions.

The true baseline

We also use the emissions-scenario building blocks in our analysis, but adopt a frozen-technology baseline to reveal the full challenge of decarbonization. Using this baseline also reveals the huge amount of emissions-reducing technological change built into the SRES and similar scenarios. Built-in emissions reductions were discussed briefly in AR4 by Working Group III (ref. 4), but are not reflected in its Summary for Policymakers or elsewhere. The significance of starting with a frozen-technology baseline is not yet widely appreciated.

Figure 1 (overleaf) shows the assumptions in the IPCC AR4 report for future emissions reductions during the twenty-first century, consistent with a carbon-dioxide stabilization target of about 500 parts per million. In the Working Group III report, the IPCC observes that "there is a significant technological change and diffusion of new and advanced technologies already assumed in the baselines"[4].

But how much is "significant"? The median of the reference scenarios considered by the IPCC AR4 (righthand bar, Fig. 1), requires 2,011 gigatonnes of carbon in cumulative emissions reductions to stabilize atmospheric carbon-dioxide concentrations at around 500 parts per million (the blue and red portions of the AR4 bar). This scenario also assumes that 77% of this reduction (the blue portion) occurs spontaneously, whereas the remaining 23% (the red portion) would require explicit policies focused on decarbonization.

These assumptions are robust across the scenarios used by the IPCC. Figure 1 also

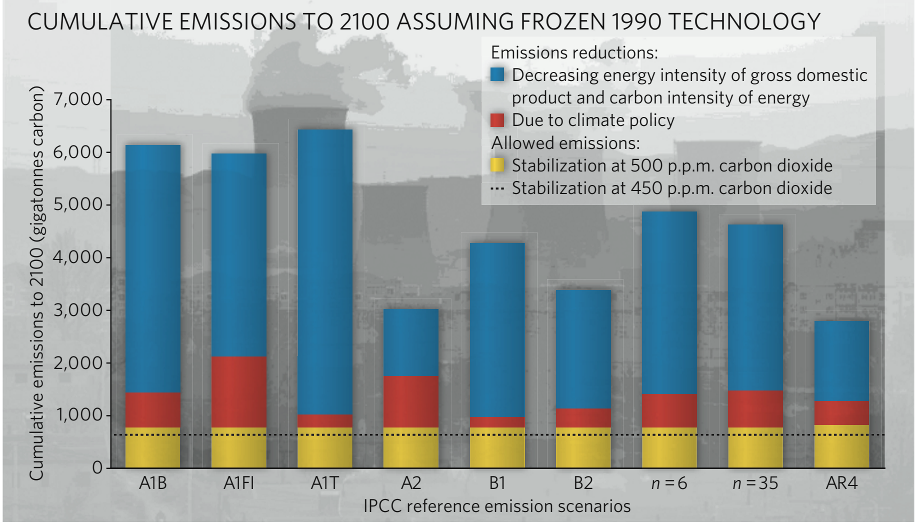

Figure 1 | Cumulative emissions. **A range of 'built-in' emissions reductions (blue) in the scenarios used by the Intergovernmental Panel on Climate Change (IPCC). Total cumulative emissions to 2100 associated with a frozen-technology baseline are shown for: six individual scenarios, the means of these scenarios (n=6), and for all 35 IPCC scenarios, and the median of the scenario set (AR4). Additional reductions will have to be achieved by climate policy (red), assuming carbon-dioxide stabilization at about 500 parts per million (p.p.m.), leaving allowed emissions for this stabilization target (yellow).**

shows the same breakdown in the 6 'illustrative' SRES scenarios[1] (plus the mean of these 6 and of the 35 complete SRES scenarios considered by the IPCC). In all cases, the IPCC assumes that most of the challenge (between 57% and 96%) of achieving stabilization at around 500 parts per million will occur automatically, leaving a much smaller emissions-reduction target for explicit climate policies.

Unpredictable future

The IPCC scenarios include a wide range of possibilities for the future evolution of energy and carbon intensities. Many of the scenarios are arguably unrealistic and some are likely to be unachievable. For instance, the IPCC assumptions for decarbonization in the short term (2000–2010) are already inconsistent with the recent evolution of the global economy (Fig. 2). All scenarios predict decreases in energy intensity, and in most cases carbon intensity, during 2000 to 2010. But in recent years, both global energy intensity and carbon intensity have risen, reversing the trend of previous decades.

Most SRES scenarios also predict a rapid decline in energy intensity (exceeding 1.0% per year), which may be neither realistic nor achievable. To achieve a century-long 1.0% annual rate of energy intensity decline requires very large increases in energy efficiency[8]. Even with a substantial policy effort this would be very difficult to achieve. Only about 20% (± 10%) of global energy intensity decline can be expected from sectoral shifts in economic activity, such as from manufacturing to services[8]. The rest must come from improved efficiencies in individual energy-using sectors, requiring either technology changes or new technologies.

One reason for the current rise in global energy and carbon intensities is the economic transformation taking place in the developing world, especially in China and India. As development proceeds, rural populations move to high-rise buildings that consume energy and energy-intensive materials. This process is likely to continue, not only in these countries, but all over populous south Asia, and eventually Africa, until well beyond 2050. An analysis of China's carbon-dioxide emissions estimated them to be rising at a rate of between 11% and 13% per year[9] for the period 2000–2010, which is far higher than that assumed by the SRES scenarios for Asian emissions (2.6–4.8% per year).

Because of these dramatic changes in the global economy it is likely that we have only just begun to experience the surge in global energy use associated with ongoing rapid development. Such trends are in stark contrast to the optimism of the near-future IPCC projections and seem unlikely to alter course soon. The world is on a development and energy path that will bring with it a surge in carbon-dioxide emissions — a surge that can only end with a transformation of global energy systems. We believe such technological transformation will take many decades to complete, even if we start taking far more aggressive action on energy technology innovation today.

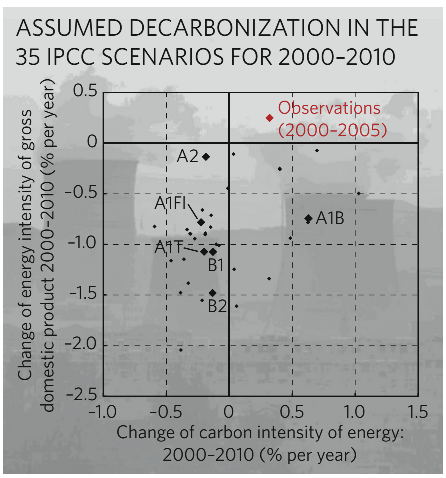

Figure 2 | Decarbonization discrepancies. **Implied rates of carbon- and energy-intensity decline from the 2000 Special Report on Emission Scenarios, showing six illustrative scenarios. The red marker indicates actual observations (2000–2005) based on global economic growth calculated using market exchange rates.**

Enormous advances in energy technology will be needed to stabilize atmospheric carbon-dioxide concentrations at acceptable levels. If much of these advances occur spontaneously, as suggested by the scenarios used by the IPCC, then the challenge of stabilization might be less complicated and costly. However, if most decarbonization does not occur automatically, then the challenge to stabilization could in fact be much larger than presented by the IPCC[10,11].

The IPCC plans to update the SRES for its next report (due in 2013 or later), but in the meantime climate policy would be better informed by having a clear view of the size of the technological challenge.

There is no question about whether technological innovation is necessary — it is. The question is, to what degree should policy focus directly on motivating such innovation? The IPCC plays a risky game in assuming that spontaneous advances in technological innovation will carry most of the burden of achieving future emissions reductions, rather than focusing on creating the conditions for such innovations to occur. ■

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1. *Special Report on Emissions Scenarios* (eds Nakicenovic, N. & Swart, R.) (Cambridge Univ. Press, Cambridge, UK, 2000).
2. Hanaoka, T. *et al. Greenhouse Gas Emissions Scenarios Database and Regional Mitigation Analysis* GCER Report (Natl Inst. Environ. Stud., Tsukuba, Japan, 2006).
3. Nakicenovic, N., Kolp, P., Riahi, K., Kainuma, M. & Hanaoka, T. *Environ. Econ. Pol. Stud.* **7,** 137–173 (2006).
4. Fisher, B. S. *et al.* in *Climate Change 2007: Mitigation, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds Metz, B., Davidson, O. R., Bosch, P. R., Dave, R. & Meyer, L. A.) Ch. 3, 218–220 (Cambridge Univ. Press, Cambridge, UK, 2007).
5. Edmonds, J. A., Wilson, T. & Rosensweig, R. *A Global Energy Technology Strategy Project Addressing Climate Change: Initial Findings from an International Public–Private Collaboration* (Joint Global Change Research Inst., College Park, Maryland, 2001).
6. Edmonds, J. A. & Smith, S. J. in *Avoiding Dangerous Climate Change* (eds Schellnhuber, H. J. *et al.*) 385–292 (Cambridge Univ. Press, Cambridge, UK, 2006).
7. Green, C. & Lightfoot, H. D. *Making climate stabilization easier than it will be: The report of IPCC WG III,* 6–13 (McGill University, C^{2}GCR Quarterly, 2002-1, 2002).
8. Baksi, S. & Green, C. *Energy Pol.* **35,** 6457–6466 (2007).
9. Auffhammer, M. & Carson, R. T. *J. Environ. Econ. Manag.* (in the press)
10. Hoffert, M. I. *et al. Nature* **395,** 881–884 (1998).
11. Hoffert, M. I. *et al. Science* **298,** 981–987 (2002).

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