Targets for Stabilization of Atmospheric CO_2

Christian Azar* and Henning Rodhe

The United Nations Framework Convention on Climate Change (*1*) calls for a "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." However, the required level is still unclear. There are two main reasons. First, the climatological, ecological, and social impacts associated with any given level of atmospheric CO_2 concentration are still uncertain; the equilibrium impact on global temperature of a doubling of the CO_2 concentration alone is estimated by the Intergovernmental Panel on Climate Change (IPCC) to have an uncertainty range of (at least) 1.5° to 4.5°C (*2*). Second, even if impacts were known with 100% certainty, the concept of dangerous interference is ultimately a question of value judgments that can only be settled in the political arena.

These two facts largely explain the widespread reluctance in the scientific community to discuss acceptable atmospheric stabilization levels. The IPCC has, for instance, published CO_2 emission trajectories leading to atmospheric stabilization in the range of 350 to 1000 parts per million by volume (ppmv) (*2*, *3*), but without endorsing any of these levels. This range of stabilization levels may be perceived as the range of acceptable levels, with the upper and lower ranges as extremes and a mid-value (550 or 650 ppmv) as a reasonable compromise; however, this perception of the range as a definition of what is acceptable is not what the IPCC intended.

Establishing acceptable atmospheric stabilization levels is inherently difficult, but avoiding this discussion leaves decision makers and social scientists, like economists, in an even more difficult position. The situation calls for greater participation from the scientific community in the debate over long-term stabilization levels.

Given the present scientific uncertainties, no firm conclusions can be drawn, but interesting insights can be obtained by comparing expected changes in equilibrium temperature obtained from a simple model with some measures of the natural variability in global temperature. In Fig. 1, we have reproduced IPCC's scenarios (S350 through S1000) leading to stabilization of atmospheric CO_2 in combination with the expected change in equilibrium temperature since the beginning of the Industrial Revolution for each of these stabilization levels. We assumed a linear relation between the change in global temperature and radiative forcing. The mid-point estimates correspond to a temperature sensitivity of 2.5°C per CO_2-equivalent doubling, and the uncertainty ranges correspond to the sensitivity range 1.5° to 4.5°C. Furthermore, we have assumed that the contribution from all other greenhouse gases and aerosols combined is 1 W/m^2 (*4*). Although not directly comparable, all of the IPCC IS 92 scenarios (*5*), except IS 92e (which includes very large SO_2 emissions), have a combined non-CO_2 forcing in the range 0.7 to 0.9 W/m^2 by the year 2100 in relation to pre-industrial times (*6*).

A more complete analysis would have to consider not only the absolute magnitude of the global average temperature changes but also regional changes and the associated socioeconomic impacts. It is also necessary to carefully analyze the transient phase, because the rate of climatic changes on both a global and a regional level is of critical importance (*7*).

In Fig. 1, we have also indicated an estimate of the natural fluctuation of the global average surface temperature change during the past millennium (*8*) and the estimate by the Stockholm Environment Institute of the "high-risk" temperature change (*9*). A further comparison can be made with the change in global mean temperature of about 5°C that is estimated to have occurred during the past glacial cycle (*10*).

If the climate system is sensitive to CO_2 increases in the IPCC's upper range, then a CO_2 concentration of only 550 ppmv will be sufficient to yield a change in average global temperature of a magnitude approaching that which occurs during the transition to an ice age. It appears that to keep the changes in global temperature within the range of natural fluctuations during the past millennium, the climate sensitivity has to be low and the atmospheric CO_2 concentration has to be stabilized at around 350 ppmv.

The burden of proof must lie on those who argue that it is safe and acceptable to cause changes in the global climate system that substantially exceed the natural fluctuations during the past millennium. Given that this fluctuation in global average surface temperature is around 1°C (or less), a temperature increase by 2°C may be seen as such a critical level. Until it has been proven that a temperature increase above 2°C is safe or that the climate sensitivity is lower than the central estimate, the projections shown in Fig. 1 suggest that the global community should initiate policies that make stabilization in the range 350 to 400 ppmv possible. This conclusion is, of course, not final. Further research and observations may imply that the stabilization target has to be revised.

On the basis of the IPCC estimates (*3*), we conclude that this target would require annual CO_2 emissions to be on average about 50% lower (within a wide range) than at present over the next century. In reality, the reduc-

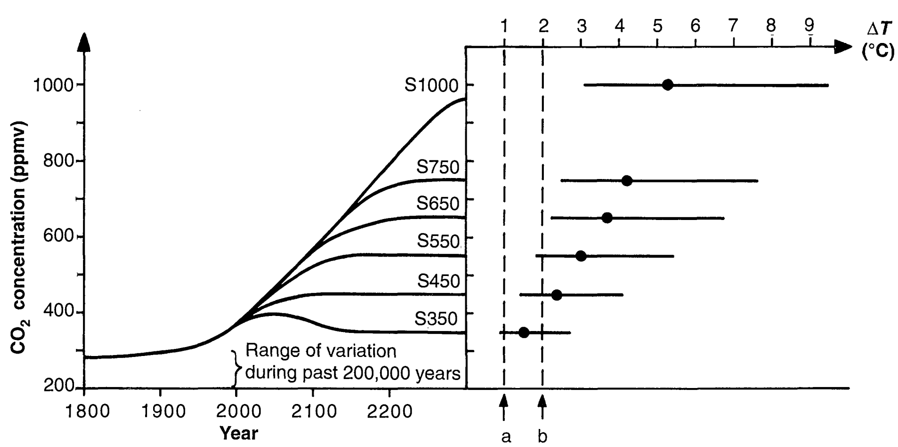

Fig. 1. (Left) IPCC stabilization scenarios for atmospheric CO_2 (S350 through S1000). (Right) Corresponding equilibrium changes in global mean temperature ΔT since pre-industrial times (central values plus uncertainty ranges) estimated by the IPCC (*2*). Other greenhouse gases and aerosols combined have been assumed to add 1 W/m^2. The dashed vertical lines denote (a) the estimated range of variability of the change in global mean temperature during the past 1000 years (*8*) and (b) the temperature change considered to be high risk by Stockholm Environment Institute (*9*).

C. Azar is at the Institute of Physical Resource Theory, Chalmers University of Technology–Göteborg University, 412 96 Göteborg, Sweden. H. Rodhe is in the Department of Meteorology, Stockholm University, 106 91 Stockholm, Sweden.

*To whom correspondence should be addressed.

tions would be less stringent in the near term and much larger over the later half of the next century. Wigley *et al.* (*11*) point out that stabilization in this range can be reached even if we follow the IPCC IS 92a "business-as-usual" emission trajectory for another decade or so (*12*). However, this does not imply that it is possible to wait and do nothing during this time and then decide to opt for a low stabilization target. To achieve the subsequent, rather rapid departure from business-as-usual emissions, the inertia of the energy system (that is, the long-lived character of energy technologies and the associated infrastructure) makes it necessary to adopt policies over the next decade that discourage investments in long-lived carbon-intensive technologies, stimulate research and development, and create market shares for energy technologies and systems that emit low levels of or no CO_2.

Policies will also be needed to constrain emissions of other greenhouse gases. For the low stabilization targets discussed here, the negative forcing from sulfate aerosols will be close to zero over the second half of the next century, and the contribution from non-CO_2 greenhouse gases may contribute more than 1 W/m^2. These effects would further constrain the allowable emission space for CO_2.

REFERENCES AND NOTES

1. *UN Framework Convention on Climate Change* (United Nations, Climate Change Secretariat, Palais des Nations, Geneva, 1992).
2. Intergovernmental Panel on Climate Change, *Climate Change 1995: The Science of Climate Change*, J. T. Houghton *et al.*, Eds. (Cambridge Univ. Press, Cambridge, 1996).
3. Intergovernmental Panel on Climate Change, *Climate Change 1994: Radiative Forcing of Climate Change and an Evaluation of the IPCC IS 92 Emission Scenarios*, J. T. Houghton *et al.*, Eds. (Cambridge Univ. Press, Cambridge, 1995).
4. Note, however, that because aerosols are not well-mixed in the atmosphere, it is wrong to think of these as merely offsetting the positive radiative forcing from well-mixed greenhouse gases (*3*).
5. The IPCC IS 92 scenarios should not be mixed with IPCC's stabilization scenarios (S350 through S1000). The former is a set of emission scenarios for greenhouse gases and aerosols (*3*).
6. T. M. L. Wigley, in *Climate Change and the Agenda for Research*, T. Hanisch, Ed. (Westview, Boulder, CO, 1994), pp. 193–222.
7. An interesting study along these lines was recently carried out by J. Alcamo and E. Kreilman [*Global Environ. Change* **6**, 305 (1996)].
8. T. J. Crowley and K.-Y. Kim, *Geophys. Res. Lett.* **22**, 933 (1995); see also (*2*), pp. 173–176.
9. R. J. Swart and P. Vellinga, *Clim. Change* **18**, vii (1991); F. R. Rijsberman and R. J. Swart, Eds., *Targets and Indicators of Climatic Change* (Stockholm Environment Institute, Stockholm, 1990).
10. J. Hansen, M. Sato, A. Lucis, R. Ruedy, *Philos. Trans. R. Soc. London Ser. B* **352**, 231 (1997).
11. T. M. L. Wigley, R. Richels, J. Edmonds, *Nature* **379**, 240 (1996).
12. Wigley *et al.* (*11*) also argue that reduction deferral is preferable from an economic point of view, although this conclusion is controversial. The main reason for the controversy is that the economic models used to support their conclusion are poor in capturing complex and critical factors such as technological change and the inertia of the energy system [see, for example, M. Grubb, *Energy Policy* **25**, 159 (1997)]. Grubb also stresses that the uncertainty about the stabilization target is critical for near-term policies.

13. C.A. acknowledges support from the Swedish Council for Planning and Co-ordination of Research.