Greenhouse budgets

SIR—Hammond *et al.* suggest[1] that for political purposes the relative importance of greenhouse gas emissions from various countries should be based on the observed rate of increase of atmospheric concentration rather than on calculated contributions to future concentrations as suggested by the IPCC (refs 2–4). The advantages alleged by Hammond *et al.* are a lack of dependence on inaccessible models and the removal of arbitrary choices of the time horizon considered. But their choice of a one-year time horizon is itself arbitrary and the use of observed atmospheric increases to assess relative source contributions is equivalent to assuming an effectively constant airborne fraction. This assumption breaks down when increases depart from exponential growth, so in our view is inappropriate for planning possible reductions.

As an example, the currently observed increase in CH_4 reflects continually increasing sources. If emissions stabilized then the concentration would also soon stabilize. The approach of Hammond *et al.* would then treat CH_4 emissions as harmless even though present emissions would keep atmospheric CH_4 levels (and the consequent radiative forcing) at more than double the natural pre-industrial level.

If fairness is desired, then we can see no alternative to modelling relations between sources and concentrations. Even highly sophisticated models can be parameterized so that model calculations can be performed with personal computers, spreadsheets or by hand (see ref. 4). One change to the IPCC approach that we do suggest is the use of CH_4 rather than CO_2 as a reference case. CH_4 has the advantages of having a more linear relation between concentration and radiative forcing and a response that is well characterized by a single lifetime. Also, this lifetime is relatively short so that the integrated effect rapidly ceases to change as the time horizon is increased beyond a few decades. By ceasing to use CO_2 as a reference case, the special problems of CO_2 only appear when discussing CO_2 and are not factored into all other comparisons.

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SIR—The proposal of Hammond *et al.*[1] to account for contributions of greenhouse gases to the atmosphere has a major virtue that the authors have failed to claim in that it emphasizes the rate of warming. Although Hammond *et al.* did not mention this point, I believe that it is crucial. These authors suggest that each country's annual contribution to increases in the greenhouse effect can be determined by weighting that country's emission of each gas by the global atmospheric increase in that gas divided by the total anthropogenic source of that gas (the so-called airborne fraction), and then multiplying by the infrared heating effectiveness of that gas. I will refer to these as greenhouse forcing contributions (GFCs). Because a year is short compared to the lifetimes of most of the greenhouse gases, this is essentially an instantaneous measure of change of radiative forcing, as Hammond *et al.* note (though not a direct measure of warming).

It is the rate of climate change, rather than the eventual magnitude of the total anthropogenic change, that will be most troublesome. Warming the Earth by a few kelvin over the course of several millenia would change the planet's ecosystems, although probably not catastrophically. The evolution of human systems and civilization forced by anthropogenic climate change would then become small compared to most other developmental pressures, which is probably a reasonable goal.

Some policy makers and laypeople suggest that attempts to slow greenhouse climate change will cause great economic and social upheaval, and that if this delays climatic disaster by only a few decades, it is not worth the bother. The investment and development timescales for agricultural and energy systems are about 30 years. If we slow climate change down to the level that significant change occurs over at least two or three such periods, rather than one, I believe we will have done something useful. We will also have provided a small reprieve for the ecosystems.

Use of the scheme of Hammond *et al.* presents an issue that is not yet a problem, but may become one. Since there are feedbacks between climate change and both CH_4 and CO_2, there may eventually be a time when the increases in the atmospheric content of these gases exceed direct anthropogenic output. In fact, such feedbacks can lead to changes in the atmospheric concentration of greenhouse gases in the absence of any anthropogenic sources (and probably have in the past). This is distinct from the claim by Enting and Rodhe (left) that concentrations would soon stabilize if emissions stabilize. Some nations might strongly object to being credited with greater emissions than they actually release, especially as the initial cause of that atmospheric increase might be the result of warming from different greenhouse gases released by other nations in the distant past. The emission weighting coefficients should probably not be allowed to exceed one.

As another small amendment to the proposal of Hammond *et al.*, not only should scaling of emissions be updated each year, but so should the infrared heating effectiveness coefficients be updated. These will change due to increasing knowledge, the nonlinear dependence of absorption on concentration of some greenhouse gases, and the changing concentrations of other gases with overlapping absorption bands.

Global warming potentials (GWPs), such as those proposed by the IPCC[2], treat all greenhouse forcing, regardless of when it occurs, as if it were equal. Further, such potentials are scenario-dependent and require predictions of the future mix of greenhouse gases[5]. There is a fundamental error in using the proposed GWPs in that it masks responsibility for the rate of climate change. I believe that short-term (annual) GFCs, with attributed contributions limited to actual emissions, are a better choice for determining national responsibility for increasing greenhouse gases.

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HAMMOND *ET AL.* REPLY—Under the IPCC scheme, the impact of emitting a kilogram of a greenhouse gas is given by a GWP, which can be represented as $Ir_0 L(T)$, where Ir_0 is the current infrared heating efficiency and $L(T)$ is an effective lifetime, including the concentration-dependent variation of infrared heating efficiency, and is parameterized by a chosen integration period or time horizon T. A similar quantity, which following Handel we will call the GFC, is represented in our scheme by $Ir_0 A_t$, where A_t is the empirically determined airborne fraction.

By comparison, the airborne fraction can also be thought of as an effective lifetime, but one which is related to the current and past behaviour of the atmosphere rather than to its projected future behaviour. A GFC is not useful for predicting the future, but we believe that it is very useful for representing the relative impact of different gases in a manner suitable for diplomatic agreements.

We disagree with Enting and Rodhe that a one-year time horizon is arbitrary—