Comparing apples with oranges

RICHARD BETTS

The drivers and impacts of climate change extend beyond greenhouse gas emissions and rising temperature, especially when deforestation enters the picture. In deciding how best to mitigate, we may need to favour direct calculations of cost over current means of measuring climate change.

Climate policymakers need to know the total level of atmospheric greenhouse gases that we should not exceed globally, and how one means of cutting emissions compares with another[1]. Both of these issues involve quantifying the effects of various greenhouse gases from different sources. In addition to carbon dioxide, the concentrations of other greenhouse gases such as methane, nitrous oxide, halocarbons and ozone, are also increased by human activity. Moreover, greenhouse gases are emitted from many different sources — for example, carbon dioxide is emitted by deforestation and cement production as well as by the burning of fossil fuels.

So how do we compare, say, methane emissions with those of carbon dioxide? And can we compare deforestation with the burning of fossil fuels? This question is particularly topical for the December 2007 United Nations Climate Change Conference in Bali, Indonesia, as attention is once again turning to forests, which have been given less prominence in the climate policy process in recent years.

JAMI DWYER

The effects of deforestation have been quantified by comparison with carbon dioxide emissions from burning fossil fuels, but this approach may be misleading.

COMMON COMPARISONS

Comparisons are routinely made by quantifying the 'carbon dioxide equivalent' of a greenhouse gas or emissions source. There are two forms of carbon dioxide equivalent in common use. The concentrations of greenhouse gases at a particular time are compared with the concentrations, for example, before the industrial revolution, and the contribution of each greenhouse gas to global warming is gauged in terms of 'radiative forcing'[2]. This is a measure of the change to the energy balance of the planet and is broadly representative of the impact on global mean surface temperature. In this context, the carbon dioxide equivalent of a particular concentration of a greenhouse gas is the concentration of carbon dioxide that would result in the same mean temperature change.

The concept can be extended to several other changes to the climate system. For instance, carbon dioxide equivalents can be calculated for changes in the concentration of atmospheric aerosols such as dust, soot and sulphate — a by-product of burning fossil fuels — which can heat or cool the climate, and for changes in surface albedo — the proportion of solar radiation reflected back to space — resulting from modified forest cover and from soot deposited on snow[3]

Another type of carbon dioxide equivalent focuses not on concentrations but on emissions[4]. The usual metric is the 'global warming potential'[2], which integrates the radiative forcing of an emitted quantity over a specified timescale and compares that with carbon dioxide (different greenhouse gases are naturally removed from the atmosphere over different timescales).

DIVERSE IMPACTS

Although there is now overwhelming evidence that human activity is the dominant cause of global warming, this does not mean that the overall impacts of each greenhouse gas from each individual source are in proportion to their relative contributions to global warming[5]. Global mean temperature change is, of course, a primary concern in assessing the impacts of climate change because of its direct relevance to sea-level rise via expansion of sea water as it warms and melting of ice caps and glaciers. But there is increasing concern over other influences on regional temperature and precipitation, such as changes in evaporation owing to land-cover change — and over various impacts, such as changes in water resources, agricultural yields and biodiversity[6], that are caused by warming but are also affected very strongly by other processes. For example, biological and chemical responses to carbon dioxide and ozone, and physical and biological effects of land-cover change, all modify the impacts of global warming[6].

The importance of the different emissions sources is perhaps best illustrated by considering what the current impacts of climate change would be if all of the observed warming had resulted from carbon dioxide emitted by burning fossil fuels — that is, if there had been no emissions of other greenhouse gases and no changes in forest cover. A wealth of scientific evidence — and, indeed, common sense — suggests that if that were the case, the impacts would be very different from those currently observed. Among other effects, we would have more acidic oceans[7], increased plant growth and carbon uptake[8], and potentially also reduced extraction of soil water by plants, leading to a higher global average river runoff[9]. Because of the lower surface albedo of intact forest cover, temperate regions might be 1 °C or more warmer[3], whereas deforested parts of the tropics could be approximately 1 °C cooler[10]. Fewer habitats would have been destroyed directly, and air quality would not have been affected by surface ozone increases, although changes in aerosol concentrations might have altered it in other ways.

Carbon dioxide from fossil fuels has caused only about half of the current anthropogenic greenhouse warming[2]. Thirty-seven percent is attributable to greenhouse gases other than carbon dioxide, and an estimated 15 percent has arisen from land-cover change by humans, primarily deforestation[2]. The relative contribution of fossil-fuel carbon dioxide emissions is increasing, but land-use change and other greenhouse gases still contribute approximately two-fifths of the total carbon dioxide equivalent emissions when they are defined in terms of global warming potential[4].

Appropriate determination of the relative value in cutting emissions of different gases from different sources therefore remains vital. If we are aiming to avoid greenhouse gas concentrations rising above, say, 550 parts per million of carbon dioxide equivalent, are the overall impacts the same whether most of this rise is carbon dioxide itself or whether carbon dioxide is limited to much lower levels at the expense of other greenhouse gas concentrations? Will avoiding deforestation that would have emitted a million tonnes of carbon dioxide have the same effect as reducing fossil fuel emissions by that amount? Are biofuels and nuclear power equivalent in terms of their contributions to avoided damages? In all of these cases, the evidence suggests not.

ALTERNATIVE APPROACH

So if the current concepts of carbon dioxide equivalent are incomplete, what is the alternative? Radiative forcing is neat because it allows comparison in terms of a well-defined quantity, but it does not permit comparison with other drivers of climate change quantified in different units, as illustrated above. The same problem arises in trying to compare effects on the climate system, such as changes in water and food resources. Because the ultimate aim of climate-change mitigation is to reduce the cost of human interference with the climate system, the most logical option is to compare various emissions sources in terms of their final impacts, such as human lives lost, species driven to extinction or economic damages[11].

At this stage, it is difficult to predict whether such ‘impact-based’ carbon dioxide equivalents of changes in non-carbon dioxide greenhouse gases would be greater or less than those indicated by estimates of radiative forcing. For example, although some effects of climate change caused by radiative forcing could be offset by carbon dioxide itself through fertilization and increased water-use efficiency in land ecosystems[8,12], carbon dioxide will exert further detrimental effects through ocean acidification[7].

However, when comparing the effects of deforestation with those of fossil fuel burning, there is good reason to believe that an end-to-end metric would give a greater relative weight to the overall impact of deforestation — especially tropical deforestation — than is given by current comparisons based on radiative forcing. Decreasing deforestation rates in the tropics would not only help mitigate climate change through reduced carbon dioxide emissions; it could also help to conserve biodiversity and ecosystem services and maintain relatively cooler, moister climates in these regions by preventing major changes to the regional water cycle. Thus, in decisions about the respective roles of deforestation and biofuels, several of the aims of stabilizing greenhouse gas concentrations would be served more effectively by a more complete consideration of ecosystem services.

The existing definitions of carbon dioxide equivalent are vital for the current policy process on climate-change mitigation and should not be discarded in haste. They are limited, however, in their ability to assess the real impacts of climate-change drivers, so comparisons of different greenhouse gases from different sources in terms of radiative forcing are still somewhat like the proverbial comparison of apples with oranges. In time, more far-reaching decisions will need to be taken in the context of conflicting priorities. Current carbon dioxide equivalents will then need to be supplemented with more holistic metrics.

Richard Betts is Head of Climate Impacts at the Met Office Hadley Centre, Fitzroy Road, Exeter, EX1 3PB, UK.
e-mail: richard.betts@metoffice.gov.uk

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