INFORMATION FOR MEMBERS

From the

Parliamentary Office of Science and Technology

Briefing Note

16

July 1990

GLOBAL WARMING

An unprecedented international scientific effort is underway to understand the effects of man's activities on global climate, in preparation for the world climate conference in November. The UK is playing an important role through the Inter-Governmental Panel on Climate Change (IPCC) which is assessing relevant scientific knowledge, possible impacts of climate change, and response strategies.

This briefing note summarises current knowledge on global warming, and examines some remaining uncertainties which are relevant to decision-makers.

THE GREENHOUSE EFFECT

Although the term 'greenhouse effect' has crept into daily use, it is worth recalling that the effect is fact, not hypothesis. The natural effect (largely due to water vapour and carbon dioxide naturally present in the atmosphere) makes the Earth 33°C warmer than it would otherwise be, and makes life possible. The same effect on Venus (where the atmosphere is mainly carbon dioxide) makes that planet hot enough to melt lead.

The greenhouse effect is caused by trace gases in the atmosphere trapping heat radiated back from the Earth to space, just as glass traps heat in a greenhouse. Human activity has increased the amounts of some of the gases naturally present. We have also developed and released new greenhouse gases not present in nature. The result is that more heat is trapped, the heat balance of the earth is affected, and the average temperature of the Earth will rise with consequent effects on climate and sea-level. Most public discussion of the greenhouse effect thus relates to the potential global warming resulting from the increase in the natural greenhouse effect arising from man's activities.

THE GREENHOUSE GASES

The gases producing the greenhouse effect are well known -the most important are carbon dioxide (CO_2), methane, and nitrous oxide (which have natural as well as man-made sources), and chloro-fluorocarbons (CFCs)[1] which are man-made. Table 1 shows the main anthropogenic sources of these gases, and the current rate of growth in their atmospheric concentrations. The global warming potential (GWP) of each gas depends both on its efficiency at absorbing radiation and its lifetime in the atmosphere -Table 1 shows that, over 100 years, methane traps 21 times as much radiation as CO_2, while CFCs can trap up to 10,000 times as much. Of course, the overall effect on global warming depends not only on the GWP but also on the amounts of gas released into the atmosphere. This is taken into account in Figure 1, which shows that CO_2 was responsible for about half of the total contribution to global warming from 1980 to 1990, followed by CFCs, methane and nitrous oxide.

Table 1 THE GREENHOUSE GASES

GAS	GWP*	Increase each year	Major man-made sources
Carbon dioxide	1	0.5%	Fossil fuel-based energy, Deforestation
Methane	21	0.9%	Rice paddies, Natural gas, Cattle
CFCs	1-10,000	4%	Fridges, Air-conditioners, etc.
Nitrous Oxide	290	0.25%	Agriculture, Fossil fuels

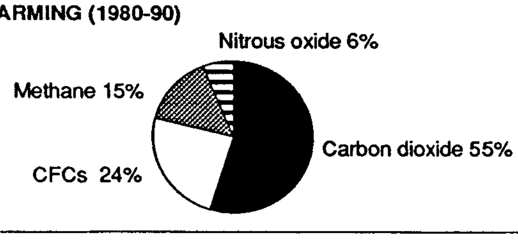
*Global warming potential over 100 years

EFFECTS OF GREENHOUSE GASES

Temperature Increase. While the amount of extra heat trapped by greenhouse gases can be calculated, the consequent rise in global temperature will depend on the influence of clouds, ocean mixing, sea-ice etc. Predictions therefore require the use of complex mathematical models of the climate system (atmosphere-ocean-ice-land), known as General Circulation Models (GCMs). These have been used to calculate the 'climate sensitivity' -the eventual temperature rise resulting from a doubling of carbon dioxide concentration relative to pre-industrial levels. IPCC predicts this to be between 1.5 and 4.5°C, with a best estimate of 2.5°C. The historical relationship between global temperature and CO_2 concentrations during previous ice ages and warm inter-glacial periods also lends support to a climate sensitivity of 2-4°C.

If these estimates are correct, 0.5-1.1°C of warming

Figure 1: CONTRIBUTION OF DIFFERENT GASES TO GLOBAL WARMING (1980-90)



1. Ozone in the lower atmosphere also contributes to global warming, but cannot be quantified at present.

should already have occurred over the last century. In fact, global temperature has risen by 0.3-0.6°C since 1890, but the natural variability of climate is of a similar magnitude, making it impossible to draw firm conclusions on the amount of global warming that has occurred. Nevertheless, one analysis (by the USA's Marshall Institute) claims that the temperature rise can be accounted for by variations in solar radiation, implying that the effects of greenhouse gases over the same period must be small. Their underlying assumption (that the sun's radiation - as measured by sunspot numbers - can vary sufficiently to account for the observed changes in global temperature) is, however, contradicted by satellite data available since 1978. It is also possible that natural variations in climate have operated in the opposite direction to that assumed by the Marshall Institute, in which case they would have masked a still larger man-made greenhouse effect.

Rate of Temperature rise. Calculating the temperature rise by a given date involves further assumptions - the most important being on the role of the oceans and the amounts of greenhouse gases emitted in the future. The latter depend on the growth rates of population and economies, sources of energy, agricultural practices etc., and are as uncertain as any other assumptions about the future. Nevertheless, assumptions made under a 'business as usual' scenario within the IPCC, suggest increases in greenhouse gases equivalent to a doubling of the CO_2 concentrations will occur by 2025, leading to a mean global temperature rise of 2°C (range 1.3-2.8°C) above pre-industrial levels by 2030[2] and of 3.3°C (range 2.2-4.8°C) by 2070. Relative to today, these correspond to further rises of 1.1°C (2030) and 2.4°C (2070). These figures are not, of course, equilibrium ones, and rises would continue until (and for some time after) greenhouse gas concentrations stabilised or fell.

Sea-level. As the world warms, the oceans expand, raising sea-level. To this is added water from melted ice on land from retreating glaciers. Compensating effects could arise if snowfall over Antarctica or Greenland increased. IPCC estimate that (on the same 'business as usual' scenario used to calculate temperature changes above), sea level will rise 20cm (range 10-30cm) by 2030 and 45cm (range 33-75cm) by 2070, relative to today's levels. The response of sea level to warming is however, very slow due to the thermal inertia of the oceans and the slow response of ice masses. The effects of a change in global temperature would thus take hundreds if not thousands of years to realise fully.

The Impact on Climate. Although still in their early stages, GCMs do simulate the general features of current and past climates, and scientists have some confidence in their ability to predict the general consequences of global temperature rises. These include:

- the northern hemisphere will warm more rapidly than the southern;
- temperature rises will be greater over land masses, particularly away from large oceans (e.g. in southern Europe and central North America);
- average precipitation will increase slightly (up 7% by 2070), but large areas will encounter reduced soil moisture, due to the higher temperatures.

Effects in the UK. Reliable detailed regional climate predictions are still beyond the abilities of existing climate models. Nevertheless, some general predictions have been reported for whole regions, including the UK/Europe; these are summarised below:

FORECASTS FOR EUROPE (INCLUDING UK)
eventual impact of doubling CO_2 concentrations

Winters become 2.5 - 4°C warmer, and wetter
Summers become 2 - 2.5°C warmer, soils drier
Main vegetation zones move hundreds of km north, irreversible decline possible in natural and commercial forests
Agriculture expands in north, reduced in south (net reduction likely)
Increased vulnerability to flooding of coastal population and industry

A more detailed assessment of potential impacts in the UK is underway by the Climate Change Impact Review Group of the Dept. of the Environment. A particular problem in predicting effects in the UK arises from the influence of the Gulf stream and the tracks of the North Atlantic storms on our climate. Only minor changes in these could have major influences on us that would not be shared by most other parts of the world. Climate models allow no prediction of these local factors at present, though models of ocean circulation are under development and may yield information soon.

Effects on Agriculture. Higher concentrations of CO_2 increase the efficiency of plant growth for some species, and can stimulate yields, other conditions being equal. Climate changes may therefore lead to some areas where agricultural yields improve. On the other hand, reductions in soil moisture and/or increased heat stress may lower yields in other areas, or cause some zones to become barren. On the basis of current models, IPCC concluded that world food production could probably be maintained, but the cost of achieving this is unclear. An analysis of the effects of predicted rates of global warming on US agriculture has suggested that overall crop yields could be maintained to 2030, though at increased costs due to greater reliance on irrigation.

In Europe, agriculture near the northern limit of current crops might expand (e.g. USSR and Scandinavia), though this potential may be limited by soils and terrain. In the Southern half (mid-France southwards), potential agricultural yield may fall 10-30% due to reduced summer soil moisture. The same trends are expected to occur in N Africa, increasing desertification both north and south of the Sahara.

Effects on Ecosystems. Natural ecosystems reflect the climate and environment within which they are lo-

2. An increase of 2°C would make the earth warmer than at any time during the last 120,000 years.

cated, and have changed markedly as a result of previous climatic shifts. However, the predicted rate of warming (0.3°C per decade) is much faster than any previously-encountered natural change and is likely to be beyond the capacity of some species to adapt, threatening their survival. Many adaptation mechanisms (seeding, migration) also require uninterrupted natural environments. Many of our more natural ecosystems (in, for instance, National Parks, SSSI's) are protected islands adjoining agricultural or urban lands. Some less mobile species could thus find themselves stranded in increasingly unsuitable environments. Those which could migrate swiftly (e.g. birds) could leave the reserve devoid of species it was designed to protect.

ISSUES

Dealing with Uncertainty

Political responses to the threat of global warming have fallen into two broad camps - those who call for more scientific understanding before considering controls on emissions, and those who call for early action to be taken on the basis of evidence so far gathered[3].

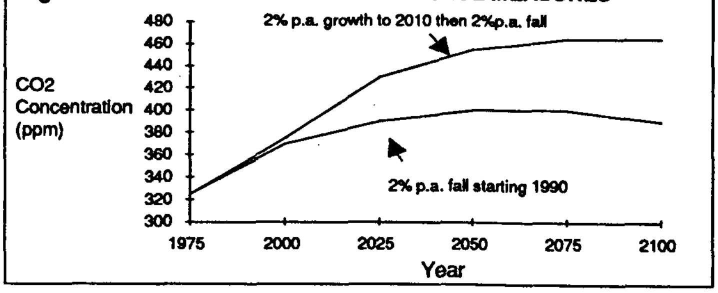
An important facet of the greenhouse effect is that there is considerable delay between cause and effect. Thus the full effects of doubling CO_2 concentrations by the year 2030 would not be felt on sea levels for centuries. Equally, similar delays would be encountered between controls on greenhouse gases and realising any benefits thereof. Additionally, some changes appear likely to be irreversible, e.g. loss of tropical forests leads to a hotter and drier local climate, making recovery difficult.

This inertia arises from a number of factors. One is the great capacity of the oceans to slow the initial temperature rise. Another is the lifetime of different gases in the atmosphere, during which they contribute to global warming. CO_2, CFCs and nitrous oxide have very long lifetimes; hence, following a change in emissions, their atmospheric concentrations respond slowly and do not reach a new equilibrium for centuries. Continuation of present-day emissions thus commits us to increased gas concentrations and warming over long periods. This is illustrated in Figure 2 which shows that the additional amounts of CO_2 in the atmosphere as a result of a 20 year delay in applying a 2% p.a. cut in emissions, are still increasing after 2100.

In order to reduce uncertainties, research is underway to improve knowledge of clouds, oceans, the biological/chemical/geological fate of greenhouse gases, polar ice sheets and other aspects required for better predictions of man's impact on climate. International coordi-

3. National policies range from commitments to reduce CO_2 emissions by 2000 (e.g. Germany, Netherlands) to a refusal to make a commitment to future emission reductions (e.g. USA). In the UK, the Prime Minister has announced *inter alia* the Government's intention to return CO_2 emissions to their 1990 level by 2005, as part of an international effort.

Figure 2: EFFECTS OF DELAY IN CONTROL MEASURES



nation is via the World Climate Research Programme and the International Geosphere-BiosphereProgramme. Nationally, the Met Office, NERC institutes, government departments and several universities are involved. Even so, unequivocal evidence of the causes of global warming and an ability to make reliable and detailed predictions of local consequences may require a further 10-15 years. If controls were delayed for this period and the rate of global warming turned out to be within the range currently forecast by IPCC, considerable additional warming would by then be in the pipeline.

Those opposing early controls thus assume that the advantages of avoiding costs now outweigh the risk of having to introduce more extreme measures later (or suffer the environmental consequences). Those in favour of reducing emissions see such measures as all the more effective the earlier they are taken (Figure 2).

Control or Adapt?

IPCC calculate that stabilising emissions at current levels would only delay the date of CO_2 doubling from 2025 (business-as-usual) to 2050. In order to stabilise greenhouse gas concentrations at today's levels (i.e. to restrict climatic changes to those already in the pipeline as a result of past actions), cuts of between 50 and 80% in current man-made emissions of most greenhouse gases are needed. This is against a backdrop of considerable pressure for continued increases. For instance, annual increases in CO_2 emissions over the last 35 years have averaged 3.1%, while population has grown at 1.9%. The UN's recent predictions for world population growth foresees the eventual world population reaching 11-14 billion before it stabilises. Thus, even if per capita emissions of CO_2 were prevented from rising further, population growth alone could still lead to a doubling or tripling of emissions.

In the face of such figures, many have considered the option of adapting to a 'greenhouse world'. Many of Society's infrastructures are renewed on timescales of 50-100 years and it is has been argued that we could adapt by starting to include in the planning process, forecasts of the future trends in climate, sea level etc. While this approach may be possible in the initial phases of global warming, the large increases in emissions envisaged in the 'business-as-usual' scenario ultimately entail sea level rises and other changes which are outside the range of adaptability for many nations. Most threatened by sea-level rises are island communities, and estuaries, river deltas and coastal areas, many of which have high population densities.

A combination of adaptation and control is likely to be needed. Assessing the optimum course will require substantially better information on the detailed climatic changes likely to result from global warming and their resulting economic and social impacts.

Possible Targets for Control

The relative importance of various sectors contributing to global warming is shown in Figure 3. Fossil fuels used for energy, transport etc. are most important, followed by CFCs, deforestation and agriculture. Increasing attention is being given to identifying the most cost-effective options for reducing greenhouse gas emissions. For instance, both the Commons Energy Committee and the Lords Science and Technology Committee supported 'no-regrets' measures which are justified in their own right, yet would reduce greenhouse gas emissions -e.g. by promoting more efficient production and use of energy and energy conservation (POST Briefing 11). Replacing destruction of tropical forests by proper management could also reduce emissions, as could applying the general principle of sustainable development and moderating world population growth. In addition, non-fossil fuel sources of energy (wind, solar, tidal, nuclear) contribute little to global warming. There is also scope for improved recovery of methane from landfill sites (POST Briefing 3).

At the recent London Conference of parties to the Montreal protocol on substances that damage the ozone layer, it was agreed to phase out CFCs by 2000. This will reduce the contribution of these substances to global warming in the long term, but preventing short term increases will require better recovery[4] of CFCs in current use -e.g. from refrigeration equipment. In addition, some replacements for CFCs (the HCFCs) are also greenhouse gases, though with lower GWPs than the gases they replace. Many thus support further research to identify chemical or engineering alternatives to CFCs which avoid the use of greenhouse gases altogether.

Supporters of such 'no regrets' policies argue that they should be introduced now. As and when more detailed and reliable forecasts of climate change are available, more specific and potentially costly measures could be considered if current forecasts hold.

National Differences

In view of the current moves towards discussion of an international convention on climate change, it is relevant to consider how different countries contribute to and may be affected by global warming.

4. Adequate recycling capacity by CFC manufacturers now exists, but the amounts recovered are limited by the effectiveness of collection by retailers, commercial and industrial users, and by local authorities.

Figure 3: CURRENT CONTRIBUTIONS OF VARIOUS ACTIVITIES TO GLOBAL WARMING

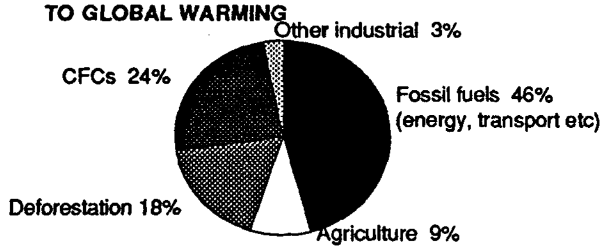
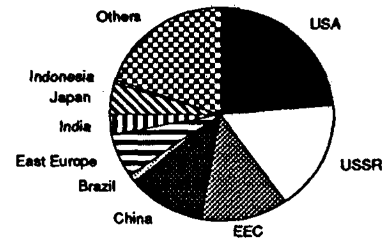


Figure 4: WORLD FOSSIL CARBON EMISSIONS (1989)



Per Capita CO_2 emissions tonnes carbon per year	
USA	5.7
Neths	3.8
USSR	3.5
Germany	2.7
UK	2.6
Japan	2.3
France	1.9
India	0.2

It is inevitable that there will be considerable variations in the potential impact of climate changes on different countries. Low-lying regions would be uniquely threatened by sea-level rises. In terms of terrestrial effects, some areas are expected to experience a worsening of already marginal agriculture (e.g. North Africa/Sahel). However, some northern countries (Northern Europe, Canada, USSR) where agriculture is limited by late frosts, may see their agricultural potential increase. As more reliable climate predictions become available therefore, countries may see themselves as 'winners' or 'losers' in the initial phases of global warming.

With regard to emissions, Figure 4 shows the relative importance of emissions of CO_2 from a number of countries (as well as per capita emissions from some of them), and demonstrates the current dominance of the industrial nations. However, IPCC forecasts suggest that by 2025, emissions from OECD nations will have fallen from 50 to 33% of the total, those of the past and present Warsaw Pact economies from 25 to 22%, and the rest of the world will have increased from 25 to 44%. These trends illustrate the increasingly global nature of greenhouse gas sources, and hence the need for global cooperation if they are to be controlled.

FURTHER READING

Additional details and background information are available from POST, 2 Little Smith St., Westminster, London SW1P 3DL, tel:(071)-222-2688.

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