INFORMATION FOR MEMBERS

From the

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Briefing Note **33**

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GLOBAL WARMING
- *Update* -

The World Conference on Environment and Development (June 1992) will decide on a global climate convention; the outcome will depend on nations' assessment of the current science and its remaining uncertainties. The UK is active not only in original scientific research but also in the assessment of current knowledge by the Inter-Governmental Panel on Climate Change (IPCC).

This briefing examines recent scientific findings and how they may influence policies on global warming.

BACKGROUND

The question of how far human activity has started to warm the planet and affect the climate has been under intensive study for the last decade[1]. A major review of the state of the science was conducted in 1990 by the IPCC, in preparation for the World Climate Conference in November 1990. Since then, many of the underlying processes of the greenhouse effect have been confirmed but there have also been significant new findings on a number of important aspects.

The main gases which were thought to contribute to global warming are listed in **Table 1**, together with the rate at which their atmospheric concentrations are increasing and the latest information on the main sources. The amount of carbon dioxide (CO_2) in the atmosphere continues to grow roughly in line with earlier forecasts. With methane, revised estimates of the amount released from rice paddies and cattle farming suggest a lower growth rate than previously thought. In the case of chloro-fluorocarbons (CFCs), the amounts produced and consumed have fallen by 40% since 1986, and will fall further under the 1990 London amendments to the Montreal Protocol on protecting the Ozone Layer. But release of amounts already in use will cause atmospheric concentrations to continue rising for some years.

Each greenhouse gas traps a different amount of heat after entering the atmosphere, and the concept of global warming potential (GWP) was introduced to indicate the importance of each gas relative to CO_2. Calculating the GWP is complicated by the fact that gases also take part in secondary reactions in the atmosphere, which has led to the revisions in GWP in Table 1. The most significant change arises from the ability of CFCs to destroy stratospheric ozone. Since ozone is also a greenhouse gas, its depletion more or less balances out the global warming effect of the CFCs. This new knowledge has the effect of making carbon dioxide the most important greenhouse gas by far, responsible for over 70% of the anthropogenic greenhouse effect (**Figure 1**).

Table 1 THE MAJOR GREENHOUSE GASES (1992 data)

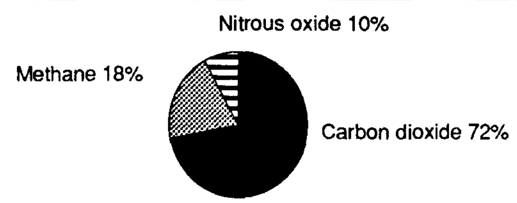
GAS	Increase each year	Major man-made sources	Global warming Potential :1990(&1992)
Carbon dioxide	0.5%	Fossil fuel-based energy, Deforestation	1(1)
Methane	0.5%	Rice paddies, Natural gas, Cattle, Landfills, Extraction of fossil fuels	21 (11)
CFCs	4%	Fridges, Air-conditioners, etc.	>1000 (0)
Nitrous oxide	0.25%	Agriculture, Fossil fuels, Nylon production.	290 (260)

THE EFFECTS OF GREENHOUSE GASES

The extent to which global warming occurs as a result of increased concentrations of greenhouse gases depends on the **climate sensitivity** - generally expressed as the temperature rise resulting from a doubling of carbon dioxide concentrations relative to pre-industrial levels. Climate sensitivity is estimated using general circulation models (GCMs), which simulate on a computer the real behaviour of the world's climate system. These models have to mimic all the complex interactions of the real system (atmosphere, land and ocean) and require the fastest supercomputers to carry out the necessary calculations. The last 18 months have seen improvements both in computer speed and in the detail of the models, particularly in their treatment of the oceans. This has not changed the IPCC consensus view that the climate sensitivity is between 1.5 and 4.5°C, with a best estimate of 2.5°C.

The speed with which the world might be warming also depends on the rate at which greenhouse gas concentrations increase, and it is here that there has been a significant shift in view. The 1990 assessment predicted that under a 'business as usual' scenario, the CO_2

Figure 1: CONTRIBUTION OF THE MAIN GREENHOUSE GASES TO GLOBAL WARMING (1992)



1. A description of the greenhouse effect and the underlying science was given in Briefing Note 16 (July 1990).

Table 2 AREAS OF POTENTIAL IMPACT CONSIDERED BY THE UK'S CLIMATE CHANGE IMPACTS REVIEW GROUP (DOE, 1991)

Soils	Flora, Fauna and Landscape, Agriculture,
Coastal Regions	Horticulture, Aquaculture and Forestry
Water Industry	Energy
Manufacturing	Minerals Extraction
Construction	Financial Sector
Recreation &Tourism	

Table 3 RESEARCH COUNCIL FUNDING INTO GLOBAL WARMING

	£m (1991/2)	
SERC	8.9	Satellite observation, atmospheric measurements and chemistry, clean technologies, coastal protection
AFRC	7.0	Biological responses to climate change in plants, animals etc, adaptation strategies for plants
NERC	21.5	Climate processes and modelling
	7.1	Impacts on sea-level, water resources
ESRC	0.19	Environmental change and public policy
	0.17	Social and economic effects

doubling milepost could be reached as early as 2025. The latest IPCC review presents a number of possible 'scenarios' of future emissions, taking into account revised estimates of population, industrialisation, deforestation etc. While some factors are likely to increase emissions of greenhouse gases (higher world population growth and deforestation), the new assessment of the role of CFCs will delay the date when greenhouse gas concentrations are equivalent to a doubling of CO_2. The more recent forecasts now predict that this will be delayed to 2050 or beyond.

Some recent events have also had an effect in the shorter term. The Kuwait oil fires released around 240 million tonnes of carbon dioxide (1% of a year's worldwide emissions). More than off-setting this, the eruption of Mt. Pinatubo in the Philippines ejected 3-5 cubic km of magma and 20 million tonnes of sulphur into the atmosphere. Most of the dust settled out rapidly, but small sulphate particles (aerosols) remain in the atmosphere and reflect incoming sunlight. Simple climate models predict this will cool the world by up to 0.5°C over the next year or so.

Sulphate aerosols are also put into the atmosphere by man's activities -primarily from fossil fuels, mostly in the Northern Hemisphere. These aerosols reflect back sunlight and also affect the amount and reflectivity of clouds. Recent research suggests that, in the Northern Hemisphere, their cooling effect may be off-setting from half to all the warming from the greenhouse gases released to date. This cooling effect is, however, likely to decline as sulphur emissions are reduced under EC and other international agreements to reduce acid rain[2], since sulphate aerosols stay in the atmosphere for a relatively short time (in contrast to the main greenhouse gases which stay in the atmosphere for decades).

THE EFFECTS OF TEMPERATURE RISE

Earlier analyses suggested that the effects of a warmer world on the oceans (primarily because water expands and takes up more space when it is warmer) would cause a rise in sea-level of between 10 and 30 cms by 2030, and between 33 and 75 cms by 2070, relative to today's levels. The more recent estimates suggest that the rate of increase from thermal expansion alone will be 2-4 cm per decade, to which would have to be added any contribution from melting glaciers. At the moment, sea level is rising at 1.5 cm per decade.

Little progress has been made in the last 18 months in our ability to predict more detailed effects of global warming on climate; these are limited to the general predictions listed in briefing note 16, i.e. for Europe:

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

Implications for the UK were considered by the Climate Change Impact Review Group (see **Table 2**). The potential impacts of sea-level rise are the easiest to evaluate in detail, and MAFF and the National Rivers Authority (NRA) have supported work to look at the vulnerability of parts of the south coast and East Anglia. The East Anglian study estimated the costs and benefits of anticipating sea-level rises by maintaining or improving sea defences, and concluded that maintaining the current defences up to 2050 against a 20cm rise would cost £150m and produce a net benefit of £963m; improving sea defences could save more (£1,021m). In addition, the Science and Engineering Research Council has just announced a 5-year research programme costing £4m into how and where the sea threatens the UK coast. MAFF and the NRA have agreed what rates of sea level rise should be assumed in various coastal areas as a basis for planning future sea defence works.

Other effects, including the important area of agriculture, are no nearer quantification than they were 18 months ago, although some research is underway (see **Table 3**). Initial consideration is also being given by DoE to the planning implications of future projections of global warming.

ISSUES

Has Global Warming Started?

The revised predictions reflect a consensus amongst a large number of scientists from the many countries in the IPCC. But IPCC emphasise that there are still many uncertainties in predictions of timing, magnitude and regional patterns of climate change, arising from an

2. The EC Large Combustion Plants Directive will cut SO_2 emissions to 42% of their 1980 level throughout the Community by 2003. The UN's Long Range Transboundary Air Pollution Convention's Helsinki Protocol, signed by 19 countries, pledges 30% cuts by 1993 on a 1980 baseline.

incomplete understanding of the sources and sinks of greenhouse gases, and of the influence of clouds, oceans, polar ice sheets and land surfaces.

In view of such uncertainties, there is universal interest in detecting any **actual** warming which can be reliably attributed to man's activities, rather than to the natural fluctuations of the climate. Much attention has been paid to the rise in mean global temperature of between 0.3 and 0.6 °C since 1890, and the particularly warm sequence of years during the 80's and through to 1991. IPCC calculations suggest that these increases are consistent with the climate sensitivity predicted by the models, with the off-setting effect of sulphate aerosols superimposed. However, some claim that the temperature variations can be accounted for by variations in solar radiation, which would imply that any effects of greenhouse gases over the same period must be small.

Points of dispute arise both over the reliability of the temperature records themselves and, if accepted, over whether they can be explained by natural variations in solar intensity. Ground temperatures are undoubtedly influenced by urbanisation, local heat sources and land-use changes, but considerable effort has gone into making allowances for these factors. Solar variability has been studied over a long period as far as sunspot numbers are concerned, but direct measurements of solar output by satellite have only been possible since 1978. Some scientists have pointed to apparent close correlations between the temperature record and certain indicators of solar activity (e.g. sunspot numbers or length of the solar cycle) as suggesting a strong influence on global temperature. However, the actual **measured** variations in the output of the sun since 1978 are insufficient to account for the observed changes in global temperature. This suggests either that the warming is, at least in part, due to greenhouse gases or there are variations in the sun's output over longer periods of which we are, as yet, unaware.

Other records are consistent with the warming trend of recent years although, because of natural variability, the changes cannot be reliably attributed to global warming induced by man's activities. Bleaching of tropical coral reefs has increased due to exceptionally warm seas. Snow and ice cover has decreased by 8% in the Northern Hemisphere since detailed records were started in 1973. Arctic sea ice cover has also decreased by around 2% over the last 9 years. The fate of Antarctic ice is the most important factor in determining future sea levels. At the time of the 1990 IPCC review, it was unclear whether Antarctic ice was growing or shrinking. However, the Wordie ice shelf in Antarctica has disintegrated and reduced in area by 1300 sq km since 1966, and detailed estimates by UK and US scientists indicate that the Antarctic Ice Sheet is **shrinking** by 470,000 million tonnes each year. If this came predominantly from ice shelves or icebergs, then sea level would not be affected, but if the grounded ice sheet proved to be the dominant source, sea level could be rising by up to 1.3 mm each year from Antarctic melt alone. There is disagreement over whether the Greenland Ice-sheet would grow or shrink in a warmer world.

At the time of the last IPCC review, unequivocal evidence of the rate and causes of global warming was thought to require at least a further 10 years' measurement and research. In the light of the latest predictions of a slightly slower rate of increase of greenhouse gases and in the offsetting effect of sulphate emissions, the date where there is incontrovertible evidence of the scale of global warming may be further delayed.

Extremes of Prediction

Although the direct effects of greenhouse gases in the atmosphere are relatively uncontroversial, part of the consequences for climate arise from the secondary effects ('feedbacks') of rising temperature - e.g. on evaporation from the sea, cloud formation, plant metabolism, and the mechanisms whereby greenhouse gases are removed from the atmosphere. Some scientists (including the USA's Marshall Institute) argue that these feedbacks have not been correctly estimated and that the climate sensitivity may turn out to be less than current models predict; in this case, global warming would be a much more distant problem than IPCC forecasts. Other scientists believe that warming could trigger 'runaway' positive feedbacks, making the situation much worse.

There has been some progress on resolving these uncertainties for the most important feedback mechanism, which is the effect of warmer temperatures on atmospheric moisture (water vapour acts as a greenhouse gas and amplifies any original effect). Current models assume that atmospheric moisture will rise in a warmer world, but this was challenged by a small number of scientists who postulated that increased convection in the air could **dry** the middle atmosphere, counteracting the greenhouse effect. Recent satellite observations suggest this is unlikely and that GCMs have correctly allowed for the amplifying effect of water vapour.

In other areas, disagreement remains. Some point out that if the Arctic permafrost were to thaw, then methane and carbon dioxide could be released in sufficient quantity to add substantially to global warming. The increased ultraviolet radiation which is penetrating the thinning ozone layer could also amplify global warming if it interfered with the ocean's plankton, which currently remove a large proportion of the CO_2 emitted by man's activities. For each of these positive feedbacks, however, there are possible negative feedbacks. Tree growth may be encouraged sufficiently in a warmer carbon dioxide-rich atmosphere to slow or limit the extent of warming, and there is evidence that cloud behaviour, at least in the tropics, might place an upper limit on the amount of warming that could take place. The resolution of these uncertainties will have to await the outcome of research underway.

Targets for Control

Earlier analyses had indicated that reducing emissions of CFCs could be important, not only because of their effect on stratospheric ozone but also because they were thought to contribute to global warming. This no longer appears to be the case. This supports the policy choices taken within the European Community, which have focused on commitments to restrain or reduce carbon dioxide emissions[3]. In contrast, US policy has been to focus any negotiations on emissions of all greenhouse gases (including CFCs) which would have allowed considerable credit for the reductions already underway on CFC use. This no longer appears sustainable on scientific grounds.

Concentrating on carbon dioxide will mean that any restraint will have to be achieved via the main activities shown in **Figure 2.** The key areas are the energy and transport sectors of industrialised countries, and population growth, increases in *per capita* energy use and land use changes (particularly deforestation) in developing countries (DCs). Negotiations include plans to slow deforestation, but DCs point to the high *per capita* emissions in developed countries (**Figure 3**) as indicating that industrialised nations should not only take the lead in reducing damage to the environment, but should also assist DCs to deal with the problems facing them.

Targets for a Climate Convention could also be based on ecological criteria - e.g. the EC has proposed that the Convention have the general objective of stabilising greenhouse gases at levels which 'prevent dangerous anthropogenic interference with climate and which would allow ecosystems to adapt naturally'. The implications of this could be to limit overall rates of warming to 0.1°C per decade and the maximum warming to 1°C.

The 1980s were on average about 0.2°C warmer than the 1970s, although not necessarily due to man's activities. IPCC's 1990 report anticipated a warming of 0.3°C per decade, but this is likely to be an overestimate due to the factors discussed earlier. Some conclude that, over the next decade, the rate of warming may well remain within the EC criterion, giving more time for scientific results to inform more detailed policy formulation. Others, including environmental groups, point to the steps already underway to cut SO_2 emissions to control acid rain, and to the temporary nature of Mt. Pinatubo's effect, and argue that steps to contain carbon dioxide emissions are still required urgently.

3. The EC has proposed that carbon dioxide emissions be stabilised at their 1990 levels by the year 2000. Denmark, the Netherlands, Belgium and Germany have announced lower targets by 2000; the UK has adopted the year 2005 as the deadline for emissions to return to their 1990 levels.

Figure 2 CURRENT CONTRIBUTIONS OF VARIOUS ACTIVITIES TO GLOBAL WARMING

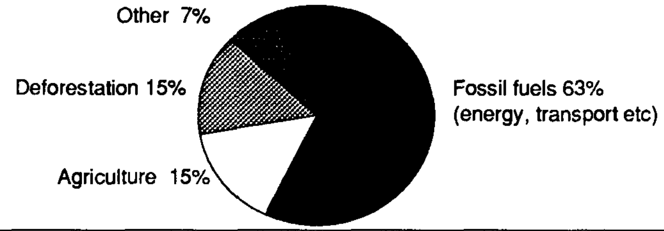
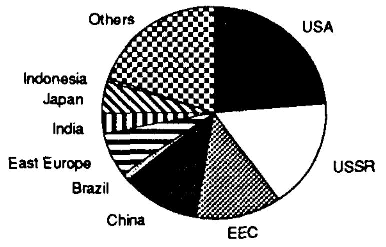


Figure 3 WORLD FOSSIL CARBON EMISSIONS (1989)



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

Notwithstanding current US policy, some US agencies have completed detailed reviews of how different carbon dioxide limiting or reduction policies might be applied. The US Office of Technology Assessment developed two scenarios based on actions in the fields of energy conservation, energy supply and forest management which would limit increases by 2015 to 15% ('moderate') over 1987 levels, or deliver a 20% reduction ('tough'). The 'moderate' scenario would be achieved with net savings to the economy, while the costs of the 'tough' scenario could range from a small saving to a cost of 1.8% GNP. Although not as detailed, UK studies suggest that CO_2 emissions could be reduced to 88% of their 1987 levels at no net cost, primarily through energy efficiency measures.

In addition to emissions control or adaptive strategies, a number of ideas for mitigation have been put forward. These range from proposals which are technically and economically feasible (e.g. increased afforestation), through CO_2 removal technologies (technically feasible but very inefficient with considerable difficulty in disposing of the CO_2 extracted), to planetary engineering. The latter has included ideas to put mirrors in space to reflect the sun, injecting dust or soot particles into the upper atmosphere using guns, rockets or even dirty aircraft engines, and fertilising the southern oceans with huge quantities of iron in the hope that marine algae would grow quickly and soak up excess CO_2. None of these is currently suggested to be workable, nor can their effectiveness or possible secondary effects on the complex climate system be predicted at present.

FURTHER READING

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

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