1 Climate change

Introducing some of the issues

The central concern in this chapter is to provide a broad background picture of the scientific, political and economic issues relating to the enhanced Greenhouse Effect. This initiates the exploration of links between different disciplinary perspectives and some common problems they share. As the structure of the book shows, understanding complex environmental problems requires moving from scientific knowledge of physical relationships and impacts to socio-economic variables in order to comprehend the range of moral dilemmas faced and the limits to human understanding. This will then give insight into the different perspectives and languages being brought to bear on the issue, while allowing the substantive arguments to be identified.

The following pages explore the development of climate change as an international policy concern. Natural science has been at the fore of the debate, but as regulation of various emissions has moved onto the political agenda so economists have entered the debate. Here I begin to identify and describe how human-induced environmental change is linked to economic analysis and introduce themes which are explored in more detail by other chapters. As will be seen, seriously addressing the enhanced Greenhouse Effect challenges the approach to resource allocation of mainstream economics. A range of subjects arise which are relevant to all environmental policy issues: the objectivity of scientific information, asymmetry of costs and benefits over space (regional impacts) and time (intergenerational impacts); risk, uncertainty and ignorance; institutional power over information and policy; and the role of ethical judgement. Each of these areas is a major topic requiring research and posing serious challenges to the current conceptualisation of pollution as a technical problem which requires an engineered solution. Yet, as will be shown in this chapter, similar problems have been and continue to be posed by other pollution externalities. The difference in the case of the enhanced Greenhouse Effect is how the issues confront the analyst simultaneously, are non-separable and on a global scale.

This chapter sketches out some of the issues to be pursued later in the book and gives some context to the enhanced Greenhouse Effect in terms of economic and scientific approaches to pollution. In the next section the connections between developed industrial economies and pollution are drawn out. This is followed by a short introduction to the economic approach to pollution as an externality and critiques of this characterisation. Then the role of scientific knowledge and scientists is given a similar overview. The influence of science in society is a key concern which recurs throughout the book, and particularly the desire for scientific knowledge to be regarded as value free and separable from the political process. How the science of climate change has developed is then introduced in an historical briefing with key information summarised in several tables. A short precursor to some of the ethical concerns which will be raised later is provided before drawing concluding remarks. This introduction aims to provide the context within which the issues concerning the enhanced Greenhouse Effect fall.

Air pollution and the modern economy

The origins of this book lie in the early 1980s when I was working on the impacts of various forms of air pollution on the environment: primarily sulphur dioxide and nitrous oxides, as causes of acidic deposition in Europe and North America, and tropospheric ozone smogs resulting from car emissions. These problems provided lessons as to how pollution, and the environment in general, has been treated by business, politicians, academics and the public. They also raised serious questions about the (lack of) interactions between economics and natural science in policy formation. Natural science and socio-economic disciplinary fields largely avoided each other throughout the twentieth century. They also both have a tendency to ignore the political discourse in which they are entwined, wishing to be regarded as offering objective facts free from value judgements, e.g. the desire of the more recent reports of the Intergovernmental Panel on Climate Change (IPCC) to avoid discussing the meaning of 'dangerous anthropogenic impacts on climate change' because this is seen as a value judgement and part of the political process.

Perhaps this facade of political immunity is responsible for the dominant approach to pollution problems. For decades this has been to reduce the physical and political presence of pollution without addressing the underlying causes in the way economic and technological systems are being driven. Solutions have been offered and accepted without adequately reflecting upon their own eventual consequences. The environmental engineering and management approach could be summarised as 'dilution is the solution to pollution', a philosophy which is still prevalent in many quarters. Thus, pollution and environmental impacts have been transferred back and forth from one medium to another (air, land, oceans) and pushed across jurisdictional and ecosystem boundaries. Readily observable pollution incidents with immediate local damages (e.g. deaths) have been transformed into unobserved, long-term impacts spread internationally. Environmental threats have been transformed from high-frequency low-impact events to low-frequency high-impact events. This historical trend seems set to continue with new forms of 'pollution' which have the same economic and political causes but which redefine our understanding of the concept. Thus, the enhanced Greenhouse Effect and genetic bio-engineering can be seen as representing the latest (but undoubtedly far from the last) phases in this progress towards rapid globalisation of human-induced environmental change.

The last century of coal combustion in the UK provides an example. Coal burning for household heating and cooking was responsible for the infamous London smogs through which Sherlock Holmes struggled to find clues, and into which Jack the Ripper disappeared. These 'pea soup' smogs were finally brought to an end due to the high number of hospital admissions and deaths being recorded by the newly founded National Health Service in the early 1950s. In particular, during the London smogs of 1952–3, the death toll rose above 4,000, especially affecting the old and those with cardiac and respiratory disorders (Holdgate, 1980: 79). The Clean Air Acts of 1954 and 1962 restricted the zones where coal could be burnt while electricity produced by large coal-fired power stations was increasingly used for heating and cooking. Coal smogs were largely removed, although exceedance of World Health Organisation standards continued to occur in certain areas.

One result of the new power stations was to inject sulphur dioxide and nitrous oxides high into the atmosphere, where they were out of sight and out of mind. That was until the 1970s when Scandinavian scientists began to publicise the link between the changes in their forests and water ecosystems due to acidic deposition. A decade of dispute and research led to the more general acceptance that the long-range transportation of air pollutants from the UK and Germany to Scandinavia was possible, but there was no action by the major emitters. Emissions were given more serious attention by the German government as their own forests began to die and environmentalists began to successfully move into mainstream politics. The main impact on emissions in the UK was due to the changing political and economic fortunes of the coal industry with Conservative administrations determined to break the power of the mining unions. The availability of cheaper natural gas and a move away from heavy industry aided this political agenda. Thus, political and structural change was affecting emissions rather than any concern for environmental damages inflicted on others.

Acidic deposition remains a serious problem which has destroyed and is destroying ecosystems across Europe. In the late 1990s the Scandinavians were forced to issue health warnings against pregnant women eating fish due to the heavy metals released into the water by acidic deposition, which then accumulates in the body of the fish. The developing human foetus is particularly vulnerable to the toxic effects of these heavy metals. Of course decades of acidic deposition have also contaminated water supplies, in a similar fashion, and Scandinavian households in remote areas dependent upon ground water are at risk. The Norwegian and Swedish programmes for liming vast areas on a regular basis merely maintain a life line for ecosystems (similar to the geo-engineering options offered to counter climate change), which can only stand a chance of recovery if acidic deposition from burning fossil fuels in the United Kingdom and Germany are strictly curtailed. In the meantime ecosystems are degraded, biodiversity lost and once vibrant communities disappear as fish die and ecosystems degrade. However, attention has moved away from that ongoing environmental disaster and many seem to believe the problem has gone away because the media rarely seems to report on it anymore.

Tropospheric ozone is more frequently discussed because urban smogs are an international and seasonal phenomenon occurring in Athens, Los Angeles, London, Mexico City, Tokyo and Vancouver, to mention a few places. The brown nitrous oxide pollution hanging over a city turns to a blue ozone haze when stimulated by sunlight. When gases are trapped by the right weather conditions (e.g. an inversion in a mountain valley area) they can build up to high concentrations over several days. Ozone smogs often have a visible and directly observable presence. Health impacts can be serious for the young and old, and for others burning eyes and respiratory problems will result from high concentrations. While a focus on human health can often raise a more immediate reaction from the public this is only part of the picture. Wider damage also occurs to materials and ecosystems. Ozone affects plant growth and can contribute to loss of agricultural crops and forest decline (as has been notable and publicised in Germany).

Attempts to control the precursor emissions, coming largely from cars, have had limited impact. Many economists have tended to regard this as a failure by government to take into account economic incentives. The approach favoured by government administrations has been to adopt pollution standards, justified on scientific grounds, because these are meant to provide absolute protection (i.e. there is believed to be a threshold beyond which pollution impacts start to occur and below which damages are insignificant). However, regulation to meet scientifically pronounced thresholds is deemed economically inefficient because no account is given to the expected costs of pollution control in comparison to the expected benefits of avoiding damages. A controversial debate erupted on exactly these issues during the second international assessment of climate change (i.e. under IPCC Working Group III, to be discussed later).

In addition, direct regulation is also criticised by economists as ineffective because humans are regarded as acting primarily out of self-interest and therefore deemed to require financial incentives to change their behaviour (i.e. taxes or subsidies). The need for government intervention to adjust prices sits uncomfortably with the thrust of mainstream economics which favours a *laissez faire* approach. Ironically, the mechanisms of the market are meant to correct the failures of the market. These ideas seem to have moved to centre stage in negotiations on climate change regulation where the US has held sway and the idea of trading emissions is becoming enshrined under the Kyoto Protocol of the Framework Convention on Climate Change.

Economic understanding of pollution

Pollution is often seen as an activity involving a limited number of actors or agents and so a readily identifiable source and target. In economics the case of a smoky factory being sited near a laundry or a firm polluting a stream used by a farmer are typical examples. Thus, pollution is described as an activity by one agent which imposes negative consequences on another agent who has no control over the activity harming them, termed an externality. The aim of environmental economics is then to make all agents take account of the damages they impose on others, termed the need to internalise the externalities. Under a 'polluter pays principle', the factory should be charged for emitting smoke and the firm for putting waste in the stream. This charge should reflect the monetary amount of damages caused to the laundry or farmer per unit of pollution. This effectively places a price upon the environmental damages and so encourages polluters to reduce their use of the environment as a waste sink, which in turn means damages should be reduced. The avoidance of environmental damages is then described as the benefit of pollution control for society.

This particular economic approach appears in various IPCC reports. For example, while the report on regional impacts mentions legal and institutional strengthening, public participation and education, great emphasis is given to 'removing pre-existing market distortions (e.g. subsidies), correcting market failures (e.g. failure to reflect environmental damage or resource depletion in prices or inadequate economic valuation of biodiversity)' (Watson *et al.*, 1997: 6). However, the enhanced Greenhouse Effect challenges this model because rather than a few actors the entire population is liable to be affected. As is described in chapter 2, the responsible gases arise from numerous sources many of which are an integral part of modern industrial society. The focus of attention has been upon carbon dioxide caused by burning of fossil fuels: oil, coal and gas. However, other activities such as using artificial fertilisers, fridges, growing rice and raising cattle release nitrous oxides (N_2Os), chlorofluorocarbons (CFCs) and methane respectively. The idea that these are simple external effects which can be internalised by calculating an appropriate tax begins to lose credibility. In fact this characterisation had been questioned before the concern over the enhanced Greenhouse Effect took hold.

Kapp (1950) had criticised the concept of the externality as failing to recognise how economic systems operate. That is, given that firms are meant to maximise profits and individuals seek their own best interest, the pushing of damages onto others and avoiding the associated costs is to be expected as a normal and prevalent activity of the successful economic agent. This means terming pollution an externality is to engage in double-speak of Orwellian proportions. Pollution is internal to the economy and economic activity, and especially so if the system is as self-serving as mainstream economics assumes and describes. Profits are maximised by making use of all the 'free gifts of Nature' that are available, passing along costs to other agents (especially competitors) and avoiding as many waste disposal costs as possible. Similarly, the self-centred hedonistic consumer seeking to maximise their own welfare is directed to make use of all that is provided freely by others (whether wittingly or otherwise), avoid considering how their lifestyle may impact upon others (unless this gives them pleasure) and in fact actively get others to pay. Consumption and production at least cost for the individual agent can be achieved by avoiding as many costs as possible including pollution control costs.

Another theoretical argument against the simple story of externality theory was provided by work on incorporating the laws of thermodynamics into economics in the late 1960s, which lead to the concept of materials balance theory (Kneese, Ayres and d'Arge, 1970). The first law explains that matter like energy can neither be created nor destroyed. This means all material and energy production in an economy must produce an equal amount of waste material and energy, although in a qualitatively different form. Quantitative economic growth leads to qualitative degradation of the environment and hence a range of damages are self-imposed upon society due to additional consumption. Economic growth is then seen as a social process in which quality of life is eroded across a range of activities while the promise of more growth is meant to compensate for any social or environmental harm.

Thus taxes or tradable pollution rights to allow market transactions will fail to address the pervasive problem being conceptualised as 'externalities'. The inherently social character of consumption and production activities combines with the physical laws to portray a rather different picture of pollution than that found in mainstream economics. As Hunt and d'Arge (1973) explain, the individual agent is pushed by an 'Invisible Foot' to promote unintended harm and social misery. The activities of the Invisible Foot seem particularly strong in the consumer society of modern economies where consumption is a competitive activity driven by the desire to keep ahead of the 'Joneses'. This form of 'progress' is evident at both household and national government levels.

The scientific problem

The standard response of natural science to pollution problems is to construct models of expected outcomes and try to test them empirically. Such empiricism has been used effectively to support standards recommended to environmental agencies and legislators and is the key concern of ecotoxicologists. In essence the approach relies upon repeatedly doing the same action under controlled conditions to see if the same outcome results.

Thus, a given concentration or dose of a pollutant will be given to a subject or target and the response predicted from models based upon repeatedly doing so. For example, the health impacts of ozone smogs is predicted from exposing healthy young adults to low concentrations while monitoring how performance is affected during exercise. Models are used to extrapolate results to higher concentration, less healthy individuals, children and the aged. Alternatively, animal experimentation may be employed and the results transferred to humans on the basis of models.

The results from the dose-response approach are surrounded by a range of probable errors and uncertainties (Dickie, 2001). For example, the response of different individuals can vary widely for numerous unexplained and uncontrolled reasons, long-term impacts from low concentration exposure are neglected, actual concentration exposure (length, levels, frequency, mixture, time of day) can be difficult to reproduce but is known to be critical to response. Research extending the dose-response approach to the impacts of ozone smogs and acidic deposition on agricultural crops, and carbon dioxide (CO_2) on forests, have shown similar problems (Spash, 1997). For example, in trying to estimate the damage from ozone exposure to, say, potatoes the variety being exposed determines the response so no general dose-response function can be applied to all potatoes. Research budgeting has meant choosing a selection of varieties for study. The practices of farmers in growing their crops also changes the impact. In experiments all growing conditions are perfect to produce a healthy plant and then deviations from this ideal, due to exposure to a single pollutant, are analysed. In practice crops are grown under a range of environmental stresses (e.g. drought, pest invasion, lack of nutrients) and farmers have an impact on how crops respond (via irrigation, pesticides, insecticides and fertilisers). In addition, crops are exposed to multiple pollutants rather than one in isolation so response in the field can bear no relationship to the experimentally derived dose-response functions.

In terms of global climate change scientists use the experimental approach at different levels. Dose-response work is used directly to try and assess the impacts of temperature, water shortage and increased gas concentrations on plants and animals. More generally, modelling and empirical observation are employed to support theories about the impacts of emissions on global climate. In this latter case deviations in climate from that expected without human gas emissions are being predicted and evidence sought from global monitoring and historical records (discussed further in chapter 4).

The scientific approach also tries to predict the probability of making an error about the relevance of a functional relationship. This can be due to accepting an hypothesis (e.g. a dose-response model) as true when it is in fact false (a false positive), or rejecting the hypothesis as false when it is in fact true (a false negative). The way in which experimentation is conducted can accentuate the type of error. Thus, field experimentation, for example to test the hypothesis that genetically modified crops never transfer genes to other species, may be conducted to test that the hypothesis can (under some specified conditions) hold. Experimentation is conducted and evidence compiled to show how crops may be grown without gene transfer occurring rather than trying to achieve such transfer but then failing to do so. The risk of a false positive remains high and genes may be transferable, but the evidence was being compiled to show safety not danger. The body conducting an experiment becomes important because of the variety of ways in which experiments can be conducted, i.e. the type and range of relationships which are being investigated. This is an obvious reason why self-regulation and scientific evidence from vested interest groups is highly questionable. For example, large numbers of experiments have been conducted on genetically modified crops and this has been used to claim they are 'safe' in terms of gene transference, but the aim of those experiments was largely to investigate productivity improvements not gene transference.

The same empirical approach is being applied to the enhanced Greenhouse Effect. The models being employed are called general circulation models (GCMs) and were developed by atmospheric scientists to improve their understanding of how the atmosphere operates. That is, these models were not originally intended to predict global, and extrapolate regional, climate. Five GCMs have in the past tended to dominate the literature, each known by its associated research group: one from the UK produced by the Meteorological Office (UKMO), and four from the National Aeronautical and Space Administration (NASA) in the USA produced by the Goddard Institute for Space Studies (GISS), the National Center for Atmospheric Research (NCAR), the Geophysical Fluid Dynamics Laboratory (GFDL), and Oregon State University (OSU). One problem for these models has been their lack of detail on land formations and initial absence of any interactions with the oceans. As noted the models were aimed at studying the circulation of the atmosphere, but the application to global climate change has meant their former approach of ignoring two-thirds of the planet surface (the oceans) and regarding the rest as uniform blocks (no geographic description), on the scale of a country the size of France, was untenable. However, computing and modelling capacity is limited so a choice is still required as to the detail given to land, sea or air.

In the face of such potential for variability the scientific community has attempted to provide a consensus on the scientific understanding of the enhanced Greenhouse Effect, which is explored in chapter 2. As explained later in this chapter, international conferences, organisations and bodies of the United Nations (UN) have created a synthesis of information. Several large volumes have been produced over the past 30 years which attempt to cover the science in an objective way while trying to avoid the political implications of this work. Yet part of the scientific approach to pollution has been to determine thresholds and suggest emissions reductions. The result has been to describe various 'scenarios' while trying to avoid statements on the reductions required to avoid human-induced climatic change.

From a purely institutional perspective the international scientific bodies working on climate change are political bodies working within a political process, commanding power and authority, and elevating participants in terms of their international profiles and status. Various internal review procedures might be used to produce final documents and reports with varying results in terms of content and emphasis. The Intergovernmental Panel on Climate Change has become the most important body and employed the following process for its 1995 Second Assessment Reports (SAR), published in 1996. Government nominated experts were selected by government representatives to form the writing teams under three IPCC Working Groups: (I) science; (II) impacts, adaptation and mitigation; (III) economics and social dimensions. The texts these groups produce were then sent for comment by a peer community and hundreds of responses returned to the writing teams for consideration. The chapters of the full SAR were attributed to the authors, while a policymakers summary for each IPCC Working Group was meant to draw out key points. A 'Synthesis Report' was produced at a plenary meeting. As Grubb *et al.* (1999: 5) note: 'Since this represents a statement of what governments officially accept as a balanced account of the state of knowledge and reasoned judgement, its precise wording is subject to intensive negotiation between governmental delegations'. At the same time the IPCC has been precluded from making policy recommendations and is meant merely to be a source of internationally accepted knowledge.

The difficulties this raises can be seen in the artificial separation of socio-economics across working groups. Social factors such as population and energy use affect scientific predictions of Working Group I which therefore must rely upon assumptions concerning future political economy. The impacts reports of Working Group II, which were initially seen as listing physical consequences, have had to include more socio-economic research and this was compounded by the SAR remit expansion to adaptation and mitigation. The distinction between Working Groups II and III has been unclear. Indeed literature and topics which appeared under Working Group III in the SAR appear under Working Group II under the third assessment where the distinction between socio-economic and physical science seems less clear. Indeed there is some discernible tension within this institutional structure as to the meaning of 'objective' natural and social science versus relevant socio-economic analysis. More generally, the IPCC is embedded within an international debate covering a range of socio-eonomic (e.g. trade, globalisation, poverty, land ownership) and environmental (e.g. biodiversity loss, ozone depletion, urban air quality) issues.

In fact the institutional role of the IPCC has itself been given some attention by international political scientists (see Paterson, 1996). The IPCC grew from an international scientific community of climate change researchers dominated by geophysicists and meteorologists. Key figures have maintained a dominant role throughout all international assessments of climate change since the 1970s. Such influence must impact the direction of research and the areas seen as most useful to fund. At the same time the direction of international negotiations clearly influences the IPCC reports. For example, since the Kyoto Protocol raised the language of sustainable development this has begun to appear within the IPCC and has affected the Third Assessment Reports (TAR). The IPCC is therefore best viewed within the context of a series of historical events concerning climatic change research which are described later in this chapter.

A point to which I return in chapters 4 and 5 is the perception that information on complex environmental problems can conform to the scientific model of neutral information about objective facts. For example, combining hundreds of divergent opinions on a contentious international economic and political issue is far removed from 'objective' experimental science. As Paterson (1996: 154) has noted, the development of climatic research seems to show that: 'knowledge is something which is strenuously fought over, rather than something which acts in the background as a precursor to political action'. He goes on to argue that the success of GCM models, to the exclusion of other relevant climate models, data and related disciplines, has been due to their compatibility with broader political developments.

Questions must also be raised over the idea that there is a clear division of scientific fact from policy recommendation. The range of uncertainty relevant to environmental problems has in the past raised questions over the relevance of thresholds. Pollutants may be harmful for certain individuals even at low doses, they can bio-accumulate, they may cause impacts on the next generation rather than the individual being exposed, they can cause changes within the balance and structure of ecosystems. That is, the idea of a totally benign positive emissions level is often erroneous so that the actual decision is about the extent to which damages are acceptable rather than identifying an objective threshold at which the environment converts all chemicals and waste products to harmless substances.

Similarly, the debate over emissions reductions under the enhanced Greenhouse Effect concerns accepting that science is part of a discourse on policy. Climate scientists have been shown to hold specific policy beliefs on the need for action (Bray and von Storch, 1999). Hence there should be little surprise that the scientific community of the IPCC can clearly be seen as holding the normative belief that emissions must be reduced substantively. Calls for cuts have been made in the press by the IPCC Chair for its first decade, Bert Bolin, and Working Group I Chair, John Houghton, as well as other lead authors of IPCC reports, e.g. the petition to Kyoto by 11 European climate scientists for 20 per cent reductions. The absence of such statements from the IPCC SAR is due to its explicit politicisation and inclusion as a pre-negotiating document within a political process. In the first assessment a clear statement appeared on the level of CO_2 emissions reductions required to prevent atmospheric concentrations from continuing to increase (Watson *et al.*, 1990: 5): 'In order to stabilize concentrations at present day levels, an immediate reduction in global anthropogenic emissions by 60–80 per cent would be necessary'.

No such clear statement on CO_2 emissions reductions appeared in the SAR. In the meantime the language of stabilisation became associated in international negotiations with emissions levels rather than the more crucial atmospheric concentrations (which require emissions reductions). The drafting of the third assessment report involved strenuous attempts to avoid stating that any of the predicted events were dangerous because this was regarded as political territory which might imply the IPCC had an opinion about emissions reductions and was overstepping the scientific remit.[1] In contrast to the statement above calling for immediate action, the TAR policymakers summary states that in order to stabilise atmospheric concentrations (at whatever level): 'Eventually CO_2 emissions would need to decline to a very small fraction of current emissions' (IPCC Working Group I, 2001: 12). Of course the longer the delay the higher the atmospheric concentration and the greater the climate forcing so that average global sea level and atmospheric temperature will rise further.

A brief historical overview of developing awareness of the enhanced Greenhouse Effect

The potential of the enhanced Greenhouse Effect to add to the list of human-induced environmental problems became of increasing scientific and then public concern in the late 1980s and early 1990s. The enhanced Greenhouse Effect, like acidic deposition, concerns the long-range movement of chemicals through natural systems induced by the modern evolution of human activity. For those who had studied some atmospheric science and worked on air pollution control, the potential for significant environmental damage to persist unchecked could quickly be recognised as a real and present danger posed by the scale of economic activity. Perturbation of the Greenhouse Effect is easily understandable as one logical outcome of releasing a cocktail of chemicals into the upper atmosphere (the ozone hole being another). As discussed in more detail in chapter 2 and summarised in table 1.1, the science behind the Greenhouse Effect was established over a century ago. The main question has been the extent to which human impacts on the functioning of the atmosphere will have adverse consequences.

The importance of research and modelling of climate and the role of human interactions with climate only developed in the second half of the twentieth century (for more details on this historical development see chapter 2 of Paterson, 1996). In general, the opinion in the limited earlier literature was that CO_2 emissions would lead to global warming, with regional and seasonal variations, and this would benefit humans by delaying the next glaciation and improving agricultural production. In fact, during the technocentric optimism of the 1950s and early 1960s a common belief was that humans would be able to overcome the vagaries of Nature such as weather. As Patterson (1996: 24) notes, for example, President Kennedy addressed the UN General Assembly in 1961 proposing further international co-operation to eventually achieve 'weather control'.[2]

Such remarks were encouraged by the success of the World Meteorological Organisation (WMO) with data collection and co-ordination in order to understand and predict weather. A key event in this international co-operation and research was the International Geophysical Year which initiated experimentation and research worldwide. Data collection also aided the rejection of the hypothesis that human greenhouse gas (GHG) emissions were disappearing benignly into the oceans. Notably, the establishment of CO_2 monitoring at Mauna Loa in Hawaii produced conclusive evidence of an ever growing problem as concentrations were seen to rise year on

Table 1.1 Some events in the development of scientific understanding of weather and climate

	Year	*Comments*
Fourier article	1827	Theory of the 'hothouse effect' of climate regulation establishing the atmosphere as a key determinant of global temperature
Tyndall article	1861	CO_2 and water recognised as radiative absorbers affecting climate
First International Meteorological Congress, Vienna	1873	Build-up to establishing International Meteorological Organisation
International Meteorological Organisation	1878	Formally established
Arrhenius article	1896	Double CO_2 leads to 5–6°C temperature increase; seen as positive consequence in his 1908 book
Callendar article	1938	Support for Arrhenius; empirical evidence linking increased CO_2 and global warming; seen as positive consequence
World Meteorological Convention	1947	Established World Meteorological Organisation under new United Nations
World Meteorological Organisation (WMO)	1951	Began operation replacing International Meteorological Organisation
International Geophysical Year	1957	Sponsored by WMO and International Council for Scientific Unions (ICSU)

year (see report of the data in chapter 2). This led to a meeting of the Conservation Foundation on the subject in 1963 which concluded that a 3.8°C average temperature increase would occur under a doubling of CO_2, and the first official government acknowledgement occurred in the 1965 Report of the President's Scientific Advisory Committee. Research into climate, especially in the US, was also stimulated by Cold War concerns over the impacts of nuclear weapons and how their detonation might initiate a never-ending 'nuclear winter'.

Only a limited understanding of natural systems is required to realise that reactions to large-scale human pollution can be unexpected and far removed in time or space from the original releases. Yet social scientists were slow to explore the consequences of such pervasive activities as fossil fuel combustion. Instead, during the 1970s and early 1980s, those showing concern for the impacts of rising CO_2 levels were primarily natural scientists. During this period the damage from human industrial and mass consumption activities became readily apparent, although economic analysis of these issues remained a minority pursuit (Spash, 1999). In the area of climate change research, until the late 1980s, the only economist showing any consistent concern and attempting some analysis was Ralph d'Arge, who also presented the only economic paper at the 1979 World Climate Conference.

In the 1970s, the United Nations through the WMO began to provide a focus for international efforts to co-ordinate environmental research on climate. In addition the UN organised several conferences following the major 1972 Stockholm meeting (which also raised the profile of acidic deposition problems). These explored the relationship between and fragility of human and natural systems with a particular emphasis on climate, see table 1.2. The culmination and synthesis of information from these meetings occurred in 1979 with the aforementioned first World Climate Conference where approximately 400 delegates from 50 countries were in attendance. The conference declaration emphasised the role of CO_2 in climate formation and the need for action to prevent adverse climatic changes. In the same year the US National Academy of Sciences was able to report on the state of climate modelling and confirm confidence in the prediction of a 1.5–4.5°C temperature increase from a doubling of pre-industrial CO_2 concentrations in the atmosphere, expected sometime during the twenty-first century. However, the political and economic response took another decade and a series of extreme weather events (e.g. cyclones), droughts (especially that hitting the US in 1988) and high temperature years, which by the end of the 1980s made that decade the warmest on record.

General acceptance of human ability to enhance the Greenhouse Effect with adverse consequences has proven more difficult than might be expected. The scientific predictions changed little during the 1980s while the complexity of the models became greater and the role of other greenhouse gases besides CO_2 was recognised as equally important. More scientists, although far from all, did agree on global warming as the inevitable consequence of continued GHG emissions, and this group grew dramatically by the end of the decade. The Villach Conference of 1985 is credited with achieving a scientific consensus and its declarations on expected changes were widely quoted. The first report of the Intergovernmental Panel on Climate Change (IPCC) in 1990 was essentially the same (which is hardly surprising as it was compiled within a year). Towards the end of the 1980s sizeable reductions in emissions were being called for both by the scientific and policy communities (see table 1.3). For example, the 1988 Toronto Conference wanted 20 per cent reductions from then current levels at the time as a starting point.

By 1990 several nations were proposing unilateral reductions in CO_2 emissions and all European Community (EC) countries, except the UK, agreed on stabilisation of aggregate EC emissions. This informal EC agreement would have allowed Spain, Greece and Portugal to increase emissions. The US under the Bush administration remained opposed to emissions controls, while the Soviet Union was opposed to controls 'at the current time'. Divisions were clear between those proposing substantial reductions, up to 50 per cent, those proposing stabilisation of emissions (not atmospheric concentrations) at various levels, and those opposing any action. The positions being taken by various countries by the end of 1990 are reported in table 1.4.

Table 1.2 Events changing scientific perception of human–climate interactions

	Date	*Comments*
Revelle and Suess article	1957	Anthropogenic CO_2 going into the atmosphere not the oceans
Start of monitoring of CO_2 at Mauna Loa, Hawaii	1957	Keeling under supervision of Revelle as part of International Geophysical Year
US Meeting on consequences of CO_2 increases	1963	Conservation Foundation, double CO_2 lead to 3.8°C average temperature rise
Report of President's Scientific Advisory Committee	1965	Acknowledge possibility of anthropogenic climate change
Global Atmospheric Research Programme (GARP) and World Weather Watch	1967 1968	Established to improve scientific understanding and distribute data on weather; venture of WMO and ICSU
Study of Critical Environmental Problems	1970	One-month workshop in Massachusetts; Kellogg Chair Climate Effects group
Study of Man's Impact on Climate	1971	Conference at Wijk, Sweden; warming or cooling could result from CO_2 increase
UN Conference on the Human Environment	1972	Led to the establishment of United Nations Environment Programme (UNEP)
Physical Basis of Climate and Climate Modelling	1974	GARP Conference
UN World Food Conference	1974	
US Climatic Impact Assessment Program, six-volume report	1975	Project initiated 1973, assessing impact of supersonic aircraft on climate; first attempt at economic and social measures, 40 social scientists, General Chair Ralph d'Arge
Symposium on Long-term Climate Fluctuations	1975	International meeting organised by WMO, held at Norwich, UK
Panel of Experts on Climate Change	1975	Established by WMO
UN Water Conference	1976	
Workshop on comprehensive modelling of the atmosphere	1976	WMO backed, held at US National Oceanic and Atmospheric Administration
UN Desertification Conference	1977	
First World Climate Conference, Geneva	1979	Sponsors UN, WMO, ICSU; global warming predicted and seen as a negative consequence; d'Arge economic impacts
World Climate Programme	1979	Established by WMO to co-ordinate international research on climate
US National Academy of Science Report	1979	Double CO_2 lead to 1.5–4.5°C temperature increase

Table 1.3 Events leading to a political agenda for the enhanced Greenhouse Effect

	Date	*Comments*
Villach Conference	1985	Organised by WCP; inclusion of other GHGs in models; first international scientific consensus; double CO_2 or equivalent lead to 1.5–4.5°C temperature increase; call for economic and policy research and a Convention to regulate emissions
Villach and Bellagio Workshops on developing policies for responding to climatic change	1987	Organised by WCP; call for limitation and adaptation strategies
Montreal Protocol	1987	Initial regulation of CFCs to prevent stratospheric ozone depletion
US drought	1988	Half the states in US registered as drought stricken
Hansen, chief NASA climate scientist, statement to US Senate, Energy and Natural Resources Committee	1988	High degree of confidence in cause–effect relationship implicating human GHG emissions in climatic warming
Toronto Conference on the Changing Atmosphere: Implications for Global Security	1988	First major political treatment of the issue. CO_2 reduction by 20 per cent from 1988 levels by 2005
World Congress on Climate and Development	1988	Held in Hamburg; call for 30 per cent reduction by 2000 and 50 per cent by 2015; some dissenters
Intergovernmental Panel on Climate Change (IPCC)	1988	Established by WMO and UNEP; remit included assessing socio-economic consequences; Bolin chair
New Delhi Conference	1989	First conference on developing country perspective
Ministerial Conference on Atmospheric Pollution and Climatic Change	1989	Signatories to stabilise CO_2 by 2000 at levels set by the IPCC; Noordwijk Declaration, The Netherlands
Meeting of Small Island States	1989	Met in Maldives and produced Male Declaration

A movement was now underway for the development of a Convention to address the issue, but this also meant greater legal and political consideration. In December 1990 the UN established a negotiating committee for the Framework Convention on Climate Change (UNFCCC), following on from the Second World Climate Conference in November. This was the start of international negotiations which after seven years produced the Kyoto Protocol. Representation of national interests in negotiations would mean defensive diplomacy and a shift in the international debate. Governments generally withdrew from the level of emissions reductions initially proposed and began to produce measures well below those called for prior to the start of international negotiations. In fact reduction was replaced in many

Table 1.4 Emissions controls proposed in 1990

	Target		*Proportion of 1990 world CO_2 emissions (%)*
Emissions reduction proposals	%	*Date*	
Germany	25	2005	3.2
Italy	20	2005	1.8
Australia	20	2005	1.1
Netherlands	3–5	2000	0.6
Denmark	20	2000	0.3
	50	2030	
New Zealand	20	2000	0.1
Emissions stabilisation proposals	*Level*	*Date*	
Japan	1990	2000	4.4
UK	1990	2005	2.8
Canada	1990	2000	2.0
Italy	1990	2000	1.8
Belgium	1988	2000	0.5
Austria	1990	2000	0.3
Finland	1990	2000	0.3
Sweden	1988	2000	0.2
Norway	1990	2000	0.2
Switzerland	1990	2000	0.2
Ireland	1990	2000	0.1
No controls proposed			
USA			22.0
USSR			18.4

Source: *The Independent* newspaper, Monday 29 October 1990, cited by Harrison (1991).

quarters by 'stabilisation', which required only maintaining 'current' emissions rather than allowing them to grow exponentially. Similarly, 'prevention' of climate change was changed to 'mitigation' of impacts.

At the same time industrially developing countries became involved in the debate. These countries have been concerned that they should be compensated for emissions reductions and that the industrially developed nations accept responsibility for having degraded the global environment, putting their livelihoods at risk. The low-lying island states are particularly susceptible to sea level rise and have organised themselves into an association, the Alliance of Small Island States (AOSIS), which has lobbied for substantive emissions reductions, i.e. 20 per cent by 2005 for industrialised economies.

The last phase in the development of international events surrounding the enhanced Greenhouse Effect was to establish an international treaty, the UNFCCC (adopted May 1992, came into force March 1994), and mechanisms for its operation, the Kyoto Protocol (adopted December 1997, yet to come into force due to lack of

Table 1.5 Events concerning the convention and protocol on climate change

	Date	*Comments*
IPCC Working Groups established	1989	WG I: Science; WG II: Impacts; WG III: Responses
Second World Climate Conference	1990	IPCC First Assessment Report
IPCC WG I Report	1990	Most important, least original; claimed inclusive and consensus of leading scientists; certain that GHGs enhance Greenhouse Effect; 60–80 per cent emissions reduction needed to stabilise atmospheric CO_2
Alliance of Small Island States (AOSIS)	1990	Established at Second World Climate Conference
UN Resolution 45/212, Protection of global climate for present and future generations	1990	Established the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change
IPCC Supplementary Science Report	1992	
UN Conference on Environment and Development	1992	25,000 attendees in Rio; Framework Convention on Climate Change initial signatories
IPCC Emissions Scenario Report	1995	
First Conference of the Parties	1995	Berlin
IPCC Second Assessment Reports	1996	WG I: Science; WG II: Impacts, Adaptation, Mitigation; WG III Economics and Social Dimensions
Third Conference of the Parties, Kyoto Protocol	1997	10,000 attendees in Kyoto; Protocol gives structure for addressing GHG emissions. 5 per cent reductions over 1990 levels. Requires ratification
Sixth Conference of the Parties	2000	The battle for ratification continues
USA withdrawal from Kyoto	2000	Initiative of incoming President Bush
IPCC Third Assessment Reports	2001	WG I: Science; WG II: Impacts, Adaptation, Vulnerability; WG III Mitigation

ratifying countries) (see table 1.5). In many ways the UNFCCC was a disappointment as momentum had been building for an agreement on actual reductions in GHG emissions. Instead the Convention merely expressed concern, proposed data gathering and delayed future action. The defining objective is given under Article 2:

> The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally

> to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

The Framework Convention was watered down by US opposition coming via the Bush (senior) administration. The US position had been clearly against quantified targets since 1991. Their then proposed 'comprehensive reduction strategy' actually meant allowing an increase of US emissions of CO_2 by 15 per cent because CFCs were already being phased out under the Montreal Protocol (Paterson, 1996: 54). A similar problem persists with the Kyoto Protocol, where, if gas emissions have fallen in some countries due to structural change (e.g. Eastern Europe), overall targets or even increased emissions can occur while maintaining an aggregate level of stabilisation. In effect no positive action or ethical responsibility for emissions reduction is then deemed necessary.

Under such an approach the sudden 'conversion' of Margaret Thatcher, in 1988, to an environmentally concerned politician demanding action on climate change, is more easily understandable. UK Conservative administration policy to close coal mines and remove the power base of the unions had already unintentionally lowered CO_2 emissions. Note, environmentalism was not then on the agenda, and, for example, funding for research into clean coal technologies was withdrawn in the administrations' first term. The Green credentials of the government could be easily boosted by employing the US argument on CFCs (the Montreal Protocol was hot on the agenda with a London new signatories session in March 1989). Under judicious choice of a base year for emissions reduction no further action or actual pollution control would be required.

The stated aim of the Kyoto Protocol is for an aggregate reduction of 5 per cent in CO_2 equivalent emissions over 1990 levels by Annex I countries (i.e. industrialised countries undertaking the commitment) at sometime between 2008 and 2012. While the Kyoto Protocol has been described as 'the most profound and important agreement of the late twentieth century' (Grubb, Vrolijk and Brack, 1999: xxxiii) the same authors note that:

> Given extensive flexibilities in the agreement, the specific commitments of the Protocol are modest in terms of both environmental and economic impacts: implementing the commitments themselves will neither halt global emissions growth, nor have a discernible impact on economic growth.

In addition, the Protocol will be unsustainable without US participation between 2000–4 (Grubb, Vrolijk and Brack, 1999: 276), and this is far from certain given business opposition, internal political divisions (e.g. Senate vs White House), and Presidential elections. In the latter regard the election of Bush (junior) immediately led to the US administration boycotting the Protocol, although the international response was perhaps more negative than they had expected. Even achieving the modest Kyoto commitments will be difficult for many countries because of the lack of positive action being planned. As the Director of long-term co-operation and policy analysis for the International Energy Agency has stated (Bourdaire, 1999: 37): 'Our projection indicates that unless substantial new policies to promote climate-friendly technologies are adopted to reduce CO_2 emissions, the Kyoto commitments will not be met by OECD countries in the period 2008 to 2012'.

Only during this decade of negotiation did the economics profession begin to pay serious attention to the enhanced Greenhouse Effect. Within that time frame global climate change has moved from being discussed by a handful of economic articles and half a dozen authors to being the focus of special issues in mainstream journals, the topic of hundreds of articles and books, and being discussed by thousands of economists (from Nobel laureates to humble undergraduates). Yet, the relevance of much of this work is highly questionable. As will be shown, there remain serious problems with assessing the monetary value of expected control cost and impacts (most controversially loss of life), and political debate has been caused over the economics in the SAR report of Working Group III. Under the TAR, Working Group III had a changed role and mainly covered mitigation measures which had previously been the remit of Working Group II. The debated issues under SAR Working Group III were then downplayed, qualified and merged into a broader discussion of impacts under Working Group II. The role of socio-economic analysis remains problematic. That is, the idea of physical impacts being objectively definable as separate from socio-economics has apparently failed. However, a similar step with regard to scientific prediction has yet to be taken despite the obvious reliance of scientific projections upon socio-economic scenarios (e.g. the IPCC itself uses such scenarios to inform Working Group I; Nakicenovic *et al.*, 2000). Despite the reshuffling of Working Group tasks, there still appears to be a belief among leading scientists of the IPCC that objective science leads to physical prediction and that socio-economic analysis is then conducted as a final stage (e.g. see Watson, 2001), although this has already broken down as a model.

In several other respects economic analysis also proves problematic. The approach taken to uncertainty is narrow and fails to adequately address surprise events and catastrophes, and the use of discounting to reduce distant values asymptotically to zero appears morally vacuous. Modelling of efficient regulatory approaches, such a tradable permits, persist in using unrealistic market models and ignoring institutional and political factors. Models attempting to investigate economic growth impacts fail to be related to the latest (if any) scientific knowledge and are too abstract for the policy purposes for which they are unfortunately being employed. Those policy purposes include arguing that only a small percentage of economic activity will be affected by a doubling of CO_2 and that adjustment costs for any substantive control of GHGs are lower the longer they are delayed. These arguments have aided those negotiating a delay in any action and wishing to avoid binding constraints.

Values and ethical concerns

Economics over the past century has managed to develop away from explicit consideration of politics, ethics and social relations. This has been part of the scientific project to define the subject as providing objective information. However, the project is exposed as misguided once simple models are applied to complex environmental issues. As will be discussed, the objective empirical approach is difficult to apply to the natural sciences, let alone those dealing with social relations such as economics.

In particular, the philosophical basis upon which modern economics is founded becomes questionable. The essence of the economic argument is that the best action is determined by comparing consequences. Emissions control of X per cent is estimated to cost $C and will prevent so much harm or damages which are measured in terms of $B benefits of that control. Harm is equated to good and compared. If current humans value the creation of future harm below an associated value of present benefits then they should proceed with the harm. That is, a harmful action is justified by creating enough good to compensate. Alternatively, if preventing harm requires too much in terms of lost good then the harm should be allowed to continue ($B – $C < 0). Harm and good are tradable items in a market economy.

In order to make such an approach operational all the consequences of emitting GHGs need to be taken into account in monetary terms. This means trying to define uncertain future events in great detail and then attributing exchange prices to those events. Controversy then arises over the values placed on the loss of human life, the distress of human migration and species loss. While these are difficult enough to consider another range of consequences are expected but fall beyond economic assessment, e.g. the diminishing scope for systems to operate independent of human management, and forced adaptation of cultures and societies. There is in addition a misunderstanding of the content and meaning of economic assessments. The range of values typically being assessed has been expanded from direct use of environmental attributes to indirect or passive use which includes being willing to pay for possible future use (option value) and the continued presence of an attribute regardless of any intended use (existence value). These indirect use values have been confused in the literature with valuing Nature or environmental entities on grounds that they are intrinsically valuable, i.e. valued separately from how much somebody is prepared to pay. That human life is deemed intrinsically valuable is perhaps why there are such strong rejections of studies by some economists which attempt to place values on preventing the loss of life. Intrinsic value in Nature is more controversial but that controversy emphasises the limited scope within which economic assessments fall. As some environmental philosophers have been at pains to explain (regardless of the role of intrinsic values) some values are constituted by their non-tradability and incommensurability (O'Neill, 1993).

Another area of major concern is how humans discriminate across space and time. The former relates to a lack of action to aid other humans currently alive who already suffer a range of problems which climate change will make worse. Economics has tended to distance itself from issues relating to any inequity in the distribution of resources which is assumed to be a political question. The latter concerns the regard for future generations and any obligations the current generations has towards the future. Economics has used discounting procedures to turn such issues into a technical debate, but as chapter 8 explains this is flawed both theoretically and ethically. The impacts of deliberately inducing global climate change across both space and time raise questions of compensation which again economists have tried to avoid.

The arguments to be explored in chapters 9 and 10 concern these issues, the inseparability of science, economics and politics and the importance of ethics in all these areas. The discourse of science and economics tries to avoid this debate although it is at the heart of concerns about controlling the enhanced Greenhouse Effect. The negotiating language of the high per capita material consumption economies is about losing the perceived associated good from material throughput, that of developing industrial economies about achieving such throughput which is seen as good, and that of environmentalists about the harm to the poor unable to adapt to change, future humans forced to adapt, extinction of non-human species and loss of ecosystems' resilience, stability and functioning. In all this, the way in which the debate is dominated by a purely consequentialist rhetoric has been perpetuated through international negotiations and has resulted in the form of the Kyoto Protocol. That this is rhetorical can be seen in the continued neglect of energy efficiency which has consistently shown large benefits in terms of reduced resource consumption and environmental improvement. Apparently much of the economic discourse is merely being used to reinforce 'business as usual' while neglecting the moral discourse in which it implicitly participates. Yet this is symptomatic of a scientific discourse which predicts dramatic impacts on human and natural systems but refuses to directly discuss what is dangerous or harmful.

Conclusions

In recognising this latest air pollution problem the characterisation of pollution itself has become challenged along with the role of science and economics. The calls for better knowledge before action and assessing the costs and benefits of pollution control must been seen in context. Science persists in the rhetoric of a belief that there is an objective answer to such issues, that the public are ill informed and experts who have access to the 'truth' must help make decisions. Mainstream economics generally ignores the environment and characterises pollution as a minor aberration to an otherwise perfect system.

The enhanced Greenhouse Effect, like acidic deposition before it, has belatedly forced economists to pay attention to the environment, for a short time at least. Those in the mainstream sub-discipline of environmental economics struggle with fitting square pegs into round holes as they try to reduce environmental complexity to fit their models, and relegate the inherently social and ethical aspects of consumption and production. Effective communication between disciplines has been sorely lacking and despite on-going attempts to address the problem, such as the development of ecological economics, the divide persists.

The failure to communicate between IPCC Working Group Reports has been significant, although there has been some attempted redress under TAR through greater attention to the development of a variety of socio-economic scenarios meant to inform all reports (Nakicenovic *et al.*, 2000). Initial dominance of the IPCC by meteorologists and geophysicists served to reinforce the separation between natural and social science approaches. Partially this divide has been due to a lack of interdisciplinary training and the belief that mono-disciplinary research can meaningfully address environmental issues. Thus, science is seen as providing objective facts upon which to act, while economics is meant to determine optimally efficient actions from human preferences (reflected in market prices). The unfortunate result is that neither has managed to communicate effectively with the general public on environmental (or other) issues. Both are apparently easily used within a political context to reinforce and negotiate pre-existing positions. However, there is little reason to dismiss all the information being supplied as without content or meaning; rather, that information must be understood within the context of its production.

As the IPCC enters the second decade of its existence there are some notable changes taking place. The reporting context is moving from natural science to socio-economics by giving greater emphasis to the provision of goods and services essential for sustainable economic development. This raises issues as to the commodification of the environment (e.g. see Vatn, 2000) and the meaning of sustainability and development. A more regional approach begins to move away from GCMs and raises questions as to socio-economic differences affecting the realisation and adjustment to impacts. The interaction with other environmental problems (such as biodiversity loss or land degradation) raises the pervasive character of human interaction with the environment and the social causes of damages. The need to address social trends, if predictions are to have any validity, means addressing future population structure and distribution, the path and type of economies expected and desired, and issues such as whether alternative technologies are going to be seriously placed on the agenda. The inclusion of more experts from industrially developing economies brings into the process different perspectives on all these issues and should raise equity and justice as concerns. The struggle to define vulnerability raises questions of the definition of damage or harm and reveals the impossibility of avoiding ethical judgements.

A key aim of this book is to provide an interdisciplinary perspective which pulls together science, economics and ethics. This might then give some insight into how human society in general and economics in particular has come to the point of discussing the optimal extinction of species and the extent to which current humans prefer more global climatic experimentation to reducing their rate of material consumption. The 'older' air pollution problems, mentioned in this chapter, show that failures in pollution control and policy go far beyond blaming an environmental agency or current government administration for ineffectiveness. The more serious questions concern how science operates and interacts with policy and business; how economic policy is studied, designed and justified; what role is played by the media in providing, controlling and ignoring information; whether and how the voice of the least powerful in society is allowed to enter the debate; and to what extent individuals should be expected to take responsibility for their actions and the values constituting the society in which they and their descendants live. The following chapters probe some of these questions more than others.

Notes

1 As this chapter underwent final writing the third assessment report of the IPCC was in production. Information indicated a similar approach to the SAR in terms of production of the reports. There was some indication of the beginnings of a change in direction with regard to several socio-economic subjects or at least greater awareness of alternatives. Policymakers summaries for each Working Group under the TAR had been approved and were available at the time of final work on this chapter and are cited where appropriate and relevant information has changed. Greater analysis of TAR therefore occurs in the final chapters of this book.

2 Such desires for total human management of climate still persist with technological optimists pushing for global 'engineering', also termed geo-engineering. Ideas include chemical seeding of the oceans to increase carbon uptake and spreading various substances in the upper atmosphere to increase backscatter of incoming radiation. This is put forward as the least-cost option to prevent global climate change despite the potential and unknown consequences of such deliberate attempts to manipulate the functioning of global systems.

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