14 Climate change: science and the precautionary principle

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The first scientifically credible early warning about the possible dangers of climate change due to carbon dioxide (CO_2) emissions from burning fossil fuels came in 1897. While the basic physical principles of global warming are simple, however, the more detailed science of climate change is exceedingly complicated. Even now, more than a hundred years since the first early warning, many important details of climate change cannot be predicted with certainty. It is therefore unsurprising that the science of climate change and questions about the true value of burning fossil fuels have fostered sustained scientific and political controversy.

When the first volume of *Late lessons from early warnings* was drafted there appeared to be too much legitimate controversy about climate change for the issue to be included. A case study could have led to arguments that distracted attention from the valuable and robust lessons from more established issues such as asbestos, polychlorinated biphenyls (PCBs), chlorofluorocarbons (CFCs) and the ozone-hole, X-rays and acid rain. This decision was taken despite the then widespread acceptance that 'the balance of evidence suggests a discernible human influence on global climate' (IPCC, 1995a).

Over a decade later and after two more reviews by the Intergovernmental Panel on Climate Change (IPCC) of a much greater volume of climate change science it seemed appropriate to include climate change in this volume, despite some continuing controversy. The evidence that human activities are having a dangerous impact on the climate has strengthened since 1995. By 2007, the IPCC was able to conclude with 'very high confidence that the global net effect of human activities since 1750 has been one of warming' (IPCC, 2007a). Given the size and irreversibility (on human time scales) of many of the harmful effects of human-induced climate change, there is an urgent need for action to reduce CO_2 emissions and other greenhouse gases. Some contrarian views persist, however, as the authors illustrate.

This chapter summarises the history of growing knowledge about human-induced climate change and of the main actions, or inactions that accompanied it. Like many other chapters, it reflects the lifelong commitment of both authors to trying to understand and mitigate the effects of human-induced climate change. It concludes with some lessons and insights that are relevant to many other environmental and health issues.

Also included is a panel text describing how the IPCC's approach to assessing uncertainty evolved between its first to its fifth assessment reports.

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14.1 Introduction

The climate provides the background for the development of human civilisation. Historically, it has been a decisive factor determining where and how people live, what they eat, how they clothe themselves, how they structure their activities, where and why they travel, what hazards they face, and how they organise their response to those hazards. In fact, almost every aspect of human and social life is closely linked to climatic factors.

At the same time, the goal of becoming less dependent on the climate's vagaries has been an important driver for the development of human civilisation. Humans have learned how to construct shelters to protect themselves and their belongings from cold and rain, how to build irrigation systems that allow food production despite erratic rainfall, how to conserve and store food to prevent starvation at times when there are few natural food sources available, and so on.

Growing use of fossil fuels since the industrial revolution has arguably been the key factor enabling humankind to separate decisions about where and how to live from the local climatic conditions. Today, fossil fuels allow a significant fraction of humankind to heat or cool a building at the press of a button, to pump water over long distances and even between watersheds, to transport food across continents, often in artificially cooled environments, and to fly to holiday destinations with particularly attractive climates.

During recent decades, a rapidly increasing body of scientific knowledge has identified unexpectedly close links between these two major driving forces of social and economic development: the climate and burning fossil fuels. We now know that the use of fossil fuels, which has allowed the wealthy part of humankind to become less dependent on climate factors, is substantially changing the radiative properties of the atmosphere. It is thereby causing changes to the global climate system that are unprecedented at least since the end of the last ice age.

Ironically, or tragically, the societies that have contributed most to the problem of anthropogenic (i.e. man-made) climate change are generally least affected by its impacts, and vice versa. The massive use of fossil fuels — and the economic wealth that typically goes with it — allow fossil fuel-intensive societies to largely protect themselves from the vagaries of climate variability and weather extremes. In contrast, poor people who use little fossil fuels and who have contributed least to the problem have limited resources to cope with the hazards brought about by anthropogenic climate change. Worse still, they often live in regions with an already marginal climate.

It is not surprising that the strong links between these two fundamental drivers of human societies and their evolution have brought about an unprecedented level of interest, debate and conflict in the public, the media and at all political levels. Climate change policy has become a key item on the agenda of many high-level international meetings. In fact, the fifteenth session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP15) in Copenhagen in December 2009 was the second largest assembly of Heads of State and Heads of Government ever to occur outside the New York Headquarters of the United Nations (after the Earth Summit in Rio de Janeiro in 1992).

Anthropogenic climate change is in many ways a unique problem. First, the anticipated (and increasingly observed) effects of climate change and of climate protection policies are very large and widespread. Second, the expected 'winners' and 'losers' from climate change and from climate policies are very unequally distributed across the world and across time, which raises difficult questions of international and intergenerational equity. Third, the science of climate change and its interactions with other social and economic developments is extremely complex, which prevents clear-cut answers on many questions of particular relevance for decision-makers (e.g. on specific local and regional impacts of climate change).

Against the backdrop of an increasingly charged public and political environment, the science of climate change is continuously developing, producing robust results and identifying key uncertainties. In parallel to the evolution of science, unique institutions have been created to facilitate the transfer of scientific knowledge to decision-makers. Other forces have developed to obstruct this knowledge transfer by creating unfounded confusion even around robust scientific findings. As a consequence, climate scientists find themselves in an increasingly politicised environment.

Climate change is, of course, not the only global problem undermining the planet's ecosystems and economies. The loss of biodiversity, increasing water scarcity, dispersion of toxic chemicals, loss of productive land due to erosion and overgrazing, and the depletion of natural resources are, like climate change, the result of human societies' unsustainable practices. A global response was formulated at the UN Conference on Environment and Development (the Earth Summit) in Rio de Janeiro in 1992, with the adoption of Agenda 21 for sustainable development (UN, 1992). The subsequently adopted Millennium Development Goals (UN, 2000) establish a clear link between eradicating widespread poverty (Goal 1) and ensuring environmental sustainability (Goal 7). This development dimension is fundamental to dealing effectively with climate change, although in practice much of the scientific and policy discussion on climate change has been narrowly focused.

This chapter attempts to shed light on the co-evolution of climate change science and international climate policy by presenting key events, important actors and institutions, and the main conflicts. The focus is on the science-policy interface, the role of the precautionary principle in helping to deal with scientific and social uncertainties of long-term climate change, the link with the broader sustainable development agenda and the lessons that can be drawn so far.

14.2 Early development of the scientific knowledge base on human-induced climate change until the 1970s

First hints of the greenhouse gas effect

The greenhouse effect, as currently understood, is described in Box 14.1. The first hint of its existence dates back to the 1800s. Based on observations by Saussure from the late 18th and early 19th century, the Frenchman Joseph Baptiste Fourier correctly understood the observed atmospheric vertical temperature gradient (i.e. the observation that upper layers of the atmosphere are colder than lower layers) to be similar to the observed strong heating caused by a glass plate on an insulated box (Fourier, 1824). Up until that time, the absorption properties of atmospheric gases had been completely unknown.

Absorption of heat radiation by atmospheric trace gases

Nearly 40 years later, in 1863, John Tyndall, an Irishman working in Great Britain, published a remarkably precise description of the atmospheric greenhouse effect, which comes close to modern definitions:

> 'The solar heat possesses the power of crossing an atmosphere, but, when the heat is absorbed by the planet, it is so changed in quality that the rays emanating from the planet cannot get with the same freedom back into space. Thus the atmosphere admits the entrance of the solar heat but checks its exit, and the result is a tendency to accumulate heat at the surface of the planet' (Tyndall, 1863a).

Tyndall based his definition on his own observations of the absorption characteristics of atmospheric trace gases, including the key absorption bands of water vapour and carbon dioxide, which account for about 80 % of the total atmospheric greenhouse effect according to current knowledge.

The first scientist identifying fossil fuel use as a potential reason for climate change

In 1896, the Swede Svante Arrhenius used the knowledge of carbon dioxide absorption bands published by American scientist Samuel Langley to

Box 14.1 The greenhouse effect (IPCC definition)

Greenhouse gases effectively absorb thermal infrared radiation, emitted by the Earth's surface, by the atmosphere itself due to the same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus greenhouse gases trap heat within the surface-troposphere system. This is called the *greenhouse effect*. Thermal infrared radiation in the troposphere is strongly coupled to the temperature of the atmosphere at the altitude at which it is emitted. In the troposphere, the temperature generally decreases with height. Effectively, infrared radiation emitted to space originates from an altitude with a temperature of, on average, − 19 °C, in balance with the net incoming solar radiation, whereas the Earth's surface is kept at a much higher temperature of, on average, + 14 °C. An increase in the concentration of greenhouse gases leads to an increased infrared opacity of the atmosphere, and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing that leads to an enhancement of the greenhouse effect, the so-called *enhanced greenhouse effect*.

Source: IPCC, 2007d.

argue that increased combustion of coal — at that time mainly in Great Britain — could lead to higher surface temperatures. He stated:

> 'if the quantity of carbonic acid [i.e. carbon dioxide] increases in geometric progression, the augmentation of the temperature will increase nearly in arithmetic progression' (Arrhenius, 1896).

The modern formulation of this still valid relationship is that 'the temperature increase is proportional to the logarithm of the carbon dioxide increase'. Arrhenius's estimate that the global surface temperature would rise by 3–5 °C if atmospheric carbon dioxide concentrations doubled is close to present day knowledge. For example, the Intergovernmental Panel on Climate Change (IPCC, 2007a) has projected a 2.0–4.5 °C increase.

Arrhenius was not alarmed about the warming due to an enhanced atmospheric greenhouse effect, since his initial concern was the negative consequences for Scandinavia if cooling were to occur.

Early anthropogenic climate change debates until 1940

The issue of anthropogenic climate change was raised in the late 19th century by Eduard Brückner, although his interest was not the greenhouse effect. Instead his focus was the effects of deforestation and cultivation of land on the reflectivity of the land surface and its evaporation, given the huge changes people have made to vegetative cycles (Penck and Brückner, 1901–1909). Arrhenius, as already described, was the first to consider anthropogenic emissions and the greenhouse effect but the lack of accurate measurements of trace gas concentrations prevented a continuing debate except for a few follow-up papers by Arrhenius (e.g. in 1899). Even some decades later Callendar (1938) was only able to give a range of 274 to 292 parts per million volume (ppmv) for the atmospheric CO_2 concentration at the turn of the century.

Guy Stewart Callendar's 1938 paper published in the Quarterly Journal of the Royal Meteorological Society marked a milestone in the history of understanding anthropogenic climate change. He was the first to establish the full link from trace gas concentration change, observed only for carbon dioxide, via changed radiation fluxes from the atmosphere to the surface, to observed global mean warming for the period from 1900 to 1938. The following year he went further, stating:

> 'As man is now changing the composition of the atmosphere at a rate which must be very exceptional on the geological time scale, it is natural to seek for the probable effects of such a change. From the best laboratory observations it appears that the principal result of increasing carbon dioxide […] would be a gradual increase in the mean temperature of the colder regions of the Earth' (Callendar, 1939).

Callendar's paper failed to raise a major scientific debate even though the first (albeit rather inaccurate) measurements of CO_2 concentration changes were available, a major global mean warming episode had occurred between 1900 and 1940, and spectroscopy of trace gases had advanced. One reason why Callendar did not succeed in spreading his message, even among the scientific community, was because his meteorological colleagues did not believe the CO_2 concentration changes he claimed to have been observed ([2]). A second reason was the poor knowledge that most meteorologists then had of radiative transfer of heat radiation (also called terrestrial, or thermal infrared, or long-wave radiation) through the atmosphere.

From theoretical considerations on the transfer of energy in the global atmosphere to quantification in computer models

While the mechanisms underlying the transfer of energy around the global atmosphere are simple to understand in principle, quantifying this in a computer model remains far from easy. Accurate radiative transfer calculations in a spherical atmosphere require sophisticated numerical codes, as the basic equation fully established by Chandrasekhar (1950) is a so-called integro-differential equation that can only be solved numerically, demanding high performance computing facilities. Even today a comparably large amount of computing time is devoted to the 'brute force' calculation of a still very simplified radiative transfer in a climate model.

([2]) For accurate trace gas measurements, groups of laboratories have to measure concentrations of gases in samples given to them within an international comparison in order to eliminate larger systematic errors. Reliable change estimates for CO_2 were not available until the 1960s and data for the other two naturally occurring long-lived trace gases, N_2O and CH_4, were not available until the late-1980s.

Chandrasekhar's work allowed a more accurate calculation (at first only in atmospheres without clouds) of the increased downward thermal radiation and hence the global mean warming estimates, following any increase in greenhouse gases. In the second half of the 1950s and early 1960s such estimates for a doubling of CO_2 concentrations evolved steadily from original estimates without cloud influence reaching 2.5 °C (Plass, 1956). Adding the influence of clouds reduced this to less than 2 °C (Kaplan, 1960) but attempts to account for water vapour influence, via fixed relative humidity led to very high temperature increases (Möller, 1963). These were strongly disputed because the positive water vapour effect amplified the estimated impact of a doubling of CO_2 concentrations to nearly 10 °C warming.

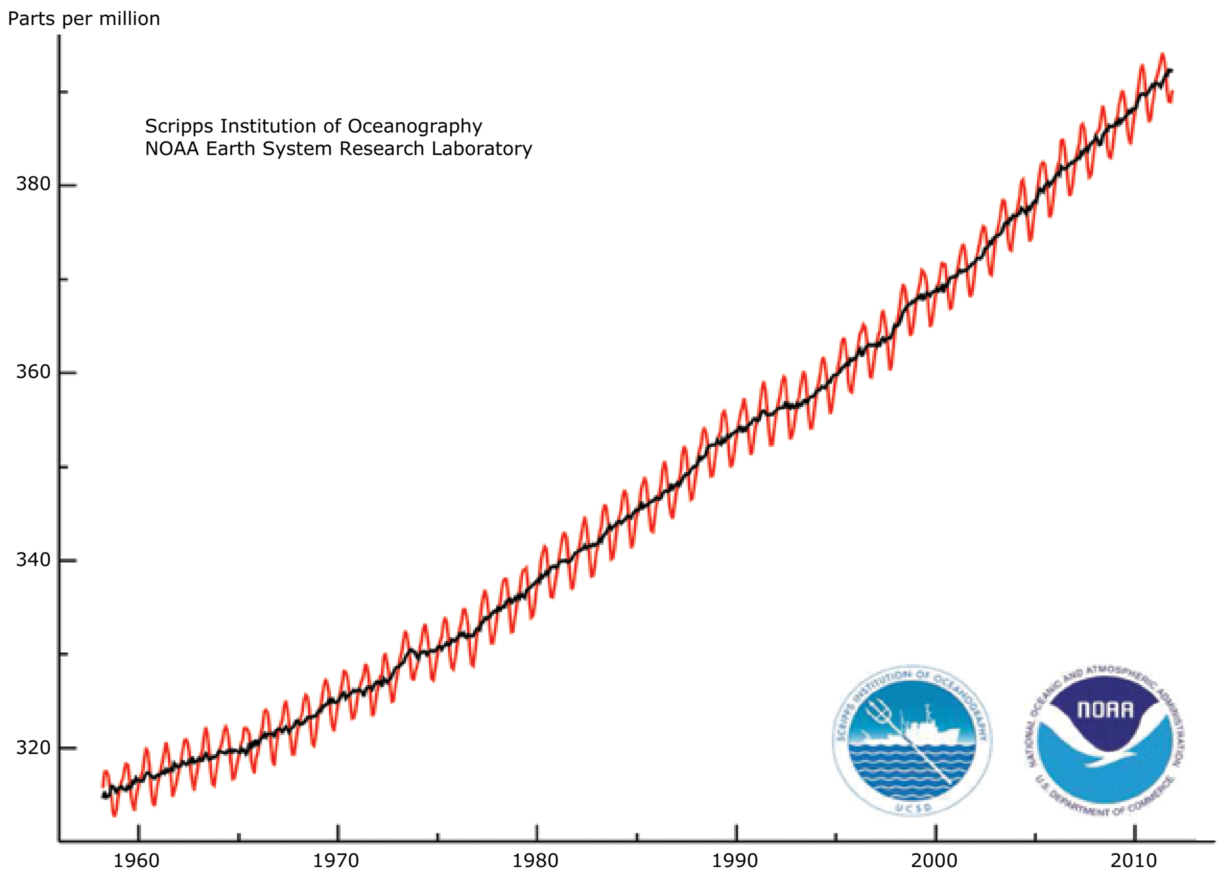
Establishment of long-term time series of greenhouse gas measurements

The International Geophysical Year from 1957 to 1958 marked the start of long-term monitoring of the most important anthropogenic greenhouse gas, carbon dioxide (CO_2). The US scientist David Keeling established two monitoring stations in very remote locations — Mauna Loa on Hawaii (Figure 14.1) and Antarctica — to measure the background concentration of CO_2 without the influence of nearby anthropogenic sources. These time series soon revealed the annual seasonal 'breathing' of the northern hemisphere (caused by the growth of biomass during the warm months and its decay during cold months). This annual cycle is weak at the South Pole, at the point furthest from the seasonal influence. It was this time series which, by 1970, had demonstrated a clear rising trend in global CO_2 concentration of some 0.4 % per year. The full trend curve can be found in NOAA (2011).

First calculations with global circulation models

Computers have had a huge impact on our ability to understand the atmospheric greenhouse gas effect. The advent of the first global three-dimensional atmospheric general circulation

Figure 14.1 Carbon dioxide (CO_2) mixing ratio at the Mauna Loa station on Hawaii



Note: The yearly averages and the annual cycle rise continually in the 50 year period. The annual cycle is caused by biomass growth during the Northern Hemisphere summer and the decay of biomass in the winter.

Source: NOAA, 2011.

models (AGCMs) for weather forecasting came with the first electronic computers in the late 1950s. By the early 1960s, an AGCM roughly representing the present day climate had also been run with doubled or quadrupled atmospheric CO_2 concentration.

These AGCMs rapidly reached a new higher equilibrium for surface temperature because the effect of the ocean, represented merely as a rather thin boundary of several 10s of metres in the model, was a poor representation of reality. Oceanic circulation — particularly vertical mixing — has a major impact, delaying the rise in global mean warming by at least several decades under present CO_2 concentration increases. Climate system sensitivity — the change in temperature resulting from a net change in incoming and outgoing energy at the top of the atmosphere ([3]) — has been investigated ever since such the first AGCM efforts of the mid-1960s.

The role of clouds

Simulations by AGCMs consistently indicated a surface temperature increase of around 1 °C for a net increase in energy flux of one watt per square metre at the top of the atmosphere, if the effect of clouds were trivial. Clouds cover more than 60 % of the Earth's surface, however, and their effect is far from trivial. They can reflect up to 80 % of solar radiation and they decouple thermal infrared emission from the surface into space. High clouds very often add to the greenhouse effect but low clouds lower it. Schneider (1972) was the first to realise that increasing cloud top height by 600 m is equivalent to a temperature increase of 2 °C. Reducing cloud cover by 8 % has a similar effect. Clouds are also influenced by air pollution, leading to higher reflectivity for geometrically thin water clouds and lower reflectivity for geometrically and optically thick water clouds, if they contain some black carbon.

It rapidly became evident that understanding cloud properties and the consequences of any changes in these, was a crucial element in predicting greenhouse gas effects. However, it proved very difficult to quantify what the net effect of these various changes would be.

Air pollution and climate change

The absence of obvious atmospheric warming from the late 1940s until the 1970s, despite the increase in greenhouse gases, revealed yet another facet of the anthropogenic climate change 'puzzle': that surface cooling could occur as a result of increased atmospheric turbidity, both in clear and cloudy atmospheres. This is because turbidity arising from anthropogenic air pollution affects the radiative transfer of energy in the following, sometimes unexpected, ways:

- it increases local planetary albedo (reflectivity) over dark surfaces like the ocean but decreases local planetary albedo over bright surfaces like sand dunes and snow (Yamamoto, 1972; Eschelbach, 1973);
- it strongly reduces solar irradiance at the Earth's surface — also called 'global dimming';
- it enhances cloud reflectivity for water clouds, especially for weakly absorbing minute, so-called 'aerosol' particles — the Twomey effect (Twomey, 1972 and 1974) — and reduces cloud reflectivity for optically thick water clouds, if black carbon or soot particles are part of the aerosol particles (Grassl, 1975).

As stated in IPCC's fourth assessment report (IPCC, 2007a), the latter two effects have remained a key uncertainty within the anthropogenic climate change debate, and are now estimated to mask the enhanced greenhouse effect by about one third.

Summary

By the end of the 1970s, it was known that the CO_2 concentration in the atmosphere was increasing by about 0.4 % per year; that a doubling of CO_2 concentration in climate models would lead to a mean global warming of several degrees centigrade; and that the water cycle contains two positive feedbacks (increasing the key greenhouse gas, water vapour, and lowering the reflectivity of earlier ice and snow surfaces), which act as an amplifier.

With that, most of the main elements of our current technical understanding of the issues were in place. It was not known, however, whether systematic

([3]) Radiative forcing is the rate of energy change per unit area of the globe as measured at the top of the atmosphere or at the tropopause level (the latter has been adopted by IPCC), if a certain radiatively active constituent of the atmosphere is altered and others remain fixed. It is measured in watts per square metre (Wm^{-2}), and positive values lead to surface warming. According to the IPCC, 'The radiative forcing of the surface-troposphere system due to the perturbation in or the introduction of an agent (say, a change in greenhouse gas concentrations) is the change in net (down minus up) irradiance (solar plus long-wave; in Wm^{-2}) at the tropopause AFTER allowing for stratospheric temperatures to readjust to radiative equilibrium, but with surface and tropospheric temperatures and state held fixed at the unperturbed values.'

changes of methane (CH_4) and nitrous oxide (N_2O) concentrations were taking place. Nor could CO_2 concentrations before industrialisation be determined.

14.3 Scientific breakthroughs regarding human-induced climate change during the 1980s

The 1980s brought scientific breakthroughs with respect to a number of the remaining uncertainties. As outlined below, these included historical greenhouse gas concentrations derived from air bubbles in ice cores, the emergence of coupled three-dimensional ocean-atmosphere-land models, and the clear signal of observed global mean warming in near-surface temperatures. These breakthroughs were largely the result of global change research coordination, as discussed in Section 14.4.

Trace gas history from air bubbles in ice cores
The air inside a snow pack in areas without summer melt, i.e. in the large inner parts of the two major ice sheets in Greenland and Antarctica, is trapped in small air bubbles within older snow that becomes progressively compacted. These tiny bubbles still exist in deep layers of an ice shield after several hundred thousand years.

During the 1980s, Swiss and French scientists (Neftel et al., 1985; Jouzel et al., 1987) were the first to determine the CO_2 concentration in these air bubbles of ice cores with enough precision to reconstruct the long-term history of greenhouse gases (CH_4 and N_2O concentrations could also be determined later). These findings established the strong correlation between CO_2 concentrations and the temperature at precipitation formation. However, the processes causing this correlation are still debated today. Greenhouse gases were clearly a global player in glacial cycles but the lower and upper limits of CO_2 concentration at about 190 to 200 ppmv for glacial maxima and about 280 ppmv during interglacials are still unexplained today.

It also became clear that the start and end of 'glacial' periods were initiated by the insolation changes in the Northern Hemisphere caused by long-term changes in the Earth's orbit around the sun. The consequences of these changes in the Northern Hemisphere climate are then amplified and made global by changing levels of greenhouse gases and by the ice-albedo feedback (Hansen, 2010).

Emergence of coupled atmosphere-ocean models
At the end of the 1980s, the first coupled atmosphere-ocean models emerged. These models included a three-dimensional representation of the ocean, which for the first time allowed simulations of the dynamic interactions between atmosphere and ocean under increasing greenhouse gas concentrations. The models, based on natural laws, are the only way for a look into the future, based on assumptions about human behaviour with respect to population changes, energy supply systems, land use change and global economic development.

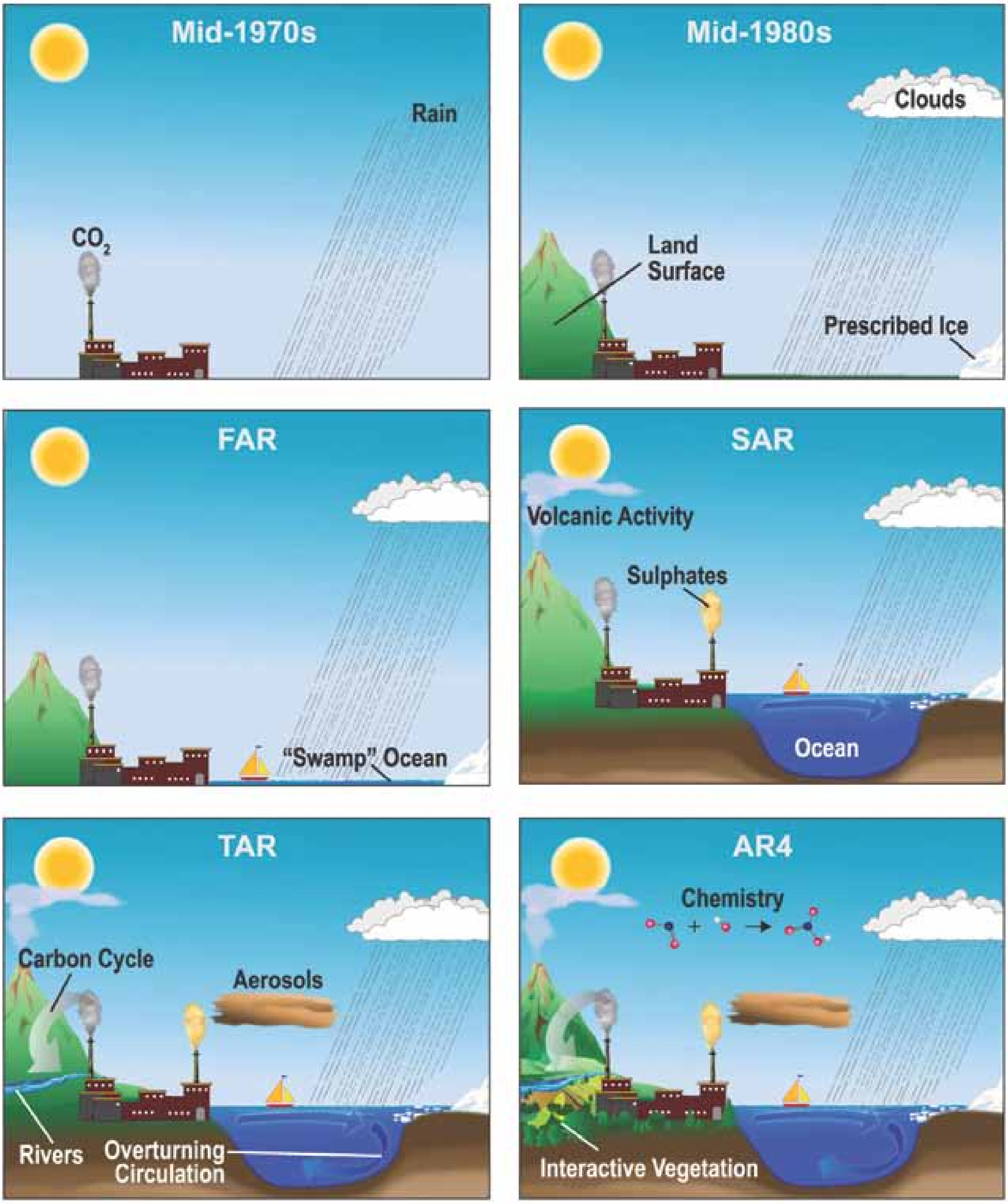
These first coupled models were, however, in need of 'flux corrections'. Flux corrections imply deliberately changing the energy and momentum fluxes at the air-ocean interface to prevent climate drift, i.e. a change in climate, in a constant greenhouse gas concentration scenario. It was not until the IPCC's third assessment report in 2001 that these flux corrections were no longer needed by some more advanced climate models.

One robust and anticipated result of these early coupled models was the delay of the full climate change signal by many decades compared to AGCMs due to the high heat capacity of the ocean. The models predicted that in a period with strong greenhouse gas concentration increase, such as now, less than two thirds of the mean warming that is inevitable due to the past concentration increase can be seen. Another important implication of the considerable inertia in the global climate systems is that the effects of policy measures taken now can only be detected after several decades. The progress in climate modelling during recent decades is depicted in Figure 14.2.

Detection of increased global mean air temperature
A further major development during the 1980s concerned temperature trends. While various regional air temperature trends had been published over the years, the first global trend analyses covering a full century only emerged during the 1980s (Groisman et al., 1987; Hansen et al., 1988). They were still rather uncertain, partly because there were gaps in the 'quality assurance' of observations from thousands of stations. Temperature time series can be inhomogeneous for many reasons, including changes in instrumentation, changed vegetation or buildings in the neighbourhood of the station, changed observers and infrequent calibration.

Other developments
Also in the mid-1980s, the 14th Ozone Report (WMO, 1984) provided the first more or less comprehensive list of the many artificial substances found in the atmosphere, subsequently known as the 'greenhouse gang', that apparently were very

Figure 14.2 Evolution of global climate change models



Note: The complexity of climate models has increased over the last few decades. The additional physical, chemical and biological processes incorporated in the models are shown pictorially by the different features of the modelled world.

Source: IPCC, 2007a.

strong greenhouse gases. Amongst them were the chlorofluorocarbons (CFCs), which were later found to be responsible for the hole in the ozone layer over Antarctica. That phenomenon became widely known only in 1985, although it had started several years earlier. That 14th Ozone Report could not, however, quantify the increase of methane and nitrous oxide concentration because the monitoring time series were too short given the accuracy of concentration measurements at that time.

14.4 Start of global coordination or climate change research and dissemination of findings on human-induced climate change

During the 1980s the climate change issue 'broke out' from being a largely scientific issue to a matter of concern for environmental policymakers. That is not to say that governments had totally ignored the issue previously. Much of the research on climate change had, in fact, been funded by governments. However, the warnings of global anthropogenic climate change by groups of leading scientists, speaking as an increasingly coordinated and unified voice, often reinforced and broadcasted by environmental non-governmental organisations such as the Climate Action Network, played a crucial role in raising the issues prominence. This knowledge transfer from science to policy became formalised with the establishment of a then unique, remarkable and authoritative scientific global climate change assessment body — the IPCC — in November 1988.

14.4.1 World Climate Research Programme

The first World Climate Conference in 1979, organised by the World Meteorological Organization (WMO), a specialised UN agency, agreed a World Climate Programme (WCP). Its research component, the World Climate Research Programme (WCRP), started in 1980 based on an agreement between WMO and the International Council for Scientific Unions (now named the International Council for Science) to organise and co-finance the first global change research programme.

The International Geosphere Biosphere Programme (IGBP), established in 1986, together with WCRP, now provides the main global organising and coordinating framework underpinning the bulk of scientific progress in understanding the functioning of the global system. A large part of the research assessed today by the Intergovernmental Panel on Climate Change (IPCC), was initiated in 1980 under the WCRP, which, for example, had by 1997 completed the first global survey of the physical status of the world oceans via its World Ocean Circulation Experiment (WOCE). The observations from this survey in turn allowed it to determine that the oceans absorb about 2 billion tonnes of carbon from anthropogenic carbon dioxide emissions per year, as presented in the IPCC's third assessment report (IPCC, 2001a, 2001b and 2001c).

14.4.2 Villach Conferences in 1980 and 1985

After two scientific conferences in the Austrian town of Villach in the early and mid-1980s, groups of high-ranking scientists issued initial warnings of the potential consequences of anthropogenic climate change. The scientists had been invited to Villach by the United Nations Environment Programme (UNEP), the World Meteorological Organization (WMO) and the International Council for Scientific Unions. In October 1985, these warnings culminated in the observation that:

> 'Many important economic and social decisions are being made today on long-term projects [...], all based on the assumption that past climatic data, without modification, are a reliable guide for the future. This is no longer a good assumption since the increasing concentrations of greenhouse gases are expected to cause a significant warming of the global climate in the next century. It is a matter of urgency to refine estimates of future climate conditions to improve these decisions' (WMO, 1986).

This paragraph captured one of the key threats of global climate change, namely that important features of our society, such as key infrastructure, may no longer be well adapted to prevailing climate conditions. Scientists, such as Scientific Committee on Problems of the Environment (SCOPE 29, 1988) highlighted that anthropogenic climate change could affect not only average conditions but also climate variability and weather extremes. Many extreme weather events might become more frequent and even new, more devastating extremes might occur as a result of changes in the distribution of climate parameters.

Box 14.2 Why do most policymakers accept IPCC statements as the most authoritative voice on climate change?

In all areas of science, reviews by authoritative groups of established scientists have for a long time been the preferred method of informing the scientific community and the public at large about the current state of knowledge. In the case of the IPCC, however, such assessments were lifted to a level never reached before in any field of science. The reasons primarily structural but also related to individuals, most notably the first IPCC chairman, Bert Bolin.

The structural advantages of the IPCC include the following:

- it is sponsored by well accepted institutions of the United Nations: the World Meteorological Organization (WMO), a technical agency in charge of climate matters, and the United Nations Environment Programme (UNEP);
- it is intergovernmental, i.e. government representatives are members of the national IPCC delegations;
- scientists and governments select the groups of authors for each chapter drawing from lists given by countries and accepting contributions by other experts in a certain subsector of climate research;
- the reviewing process is elaborate and involves the scientific community first and government-named experts in a second round, with all critical remarks and proposals for improvement judged by established scientists who are not authors of the chapters themselves.

A further essential part is the approval of the summary for policymakers 'sentence by sentence'.

14.4.3 Establishment of the Intergovernmental Panel on Climate Change

The IPCC originated from proposals of presidents of national meteorological services, put forward at the Tenth Congress of the World Meteorological Organization (WMO) in Geneva in May 1987. That Congress established an intergovernmental mechanism charged to deliver an authoritative assessment of knowledge about anthropogenic climate change, without which government attention was unlikely.

The Executive Council of WMO proceeded jointly with the United Nations Environment Programme (UNEP) towards establishing an intergovernmental panel of experts. This led, in November 1988, to the first meeting of the IPCC at the Geneva Congress Centre. Three working groups were formed. Working Group I assesses the physical scientific aspects of the climate system and climate change. Working Group II assesses the vulnerability of society and nature to climate change, and means of adaptation, while Working Group III examines mitigation measures for limiting or preventing the effects of greenhouse gases.

More specifically the IPCC's tasks are:

- to identify human induced influences on the climate and to compare these with other external influences and natural variability.

- to address, through process studies and observations, effects on the climate system of important feedbacks, both positive (enhancing change) and negative (reducing change), for instance those due to water-vapour, clouds and ocean circulation.

- to combine these influences and effects by means of numerical computer models simulating past and present climates and projecting future climate.

- to compare model simulations from different modelling groups with observations related to past and present climates, and so estimate the contributions to climate change from natural and human induced influences, together with their associated uncertainties. These computer models provide the only means of adding together all the non-linear processes involved in the evolution of climate.

- to describe the likely future impact on human communities and ecosystems.

All chapters of IPCC reports are reviewed, first by a limited number of expert scientists, then by the international community of climate scientists and others with an interest in reviewing, and finally by governments.

When the working groups meet in plenary, they consist of government representatives, generally both scientists and policymakers, which is a remarkable development in itself. However, the actual assessment work is done by selected scientists only. The overall IPCC structure has been judged successful and has been retained (see Bolin, 2008) although in 2010–2011 several changes were implemented to address criticism (see Section 14.6.4).

The creation of the IPCC represented a decisive turning point in recognition of the scale of the climate change problem, at least amongst technical and policy experts. The IPCC was immediately under pressure to publish its first full assessment of knowledge on (anthropogenic) climate change in time for the Second World Climate Conference (SWCC), scheduled for October 1990.

The IPCC first assessment report, 1990

The IPCC finished its first assessment report in June 1990. The report stated that:

- there is a natural greenhouse effect of the atmosphere which already keeps the Earth warmer than it would otherwise be;
- there is a strong increase of concentrations of all three long-lived naturally occurring greenhouse gases (CO_2, CH_4, N_2O), which is due to anthropogenic activities;
- global mean near-surface air temperature has risen by 0.3 to 0.6 °C during the 20th century;
- in the past there has been a strong correlation between greenhouse gas concentrations and the global mean temperature, as shown by concentrations of greenhouse gases in air bubbles from the last 160 000 years contained in ice cores in Antarctica.

In addition, the IPCC report also pointed to other observed changes in the climate system, including a rise in the mean sea level, the retreat of mountain glaciers in most regions, changes in the regional redistribution of precipitation, and other significant changes in climate parameters. On the basis of the evidence before them, however, and the level of proof that is required to conclude that observed climate change is significantly beyond the level of natural variability, the IPCC could not yet state that observed climate change has a man-made origin.

The IPCC Response Strategies Working Group concluded in 1989 that the potentially serious consequences of climate change justified the immediate adoption of response strategies, such as limiting emissions and preparing adaptation measures. The Working Group suggested that the United Nations agree on a framework convention that later could be supplemented with specific protocols, following the approach taken with the Vienna Convention on Protecting the Ozone layer and its Montreal Protocol. It also suggested setting goals for reducing emission levels in an equitable manner and listed many specific options for doing so across economic sectors.

The IPCC second assessment report, 1995

In 1995, the IPCC published its second assessment report. The Working Group I volume (IPCC, 1995a), agreed in November 1995, stated that 'The balance of evidence suggests a discernible human influence on global climate.' This was the first time that scientific evidence enabled the human-induced change signal to be perceived against the background of natural climate variability. This conclusion strengthened the urgency of calls to address climate change.

Box 14.3 Evidence of anthropogenic climate change

In March 1995, a pre-print of a peer-reviewed scientific paper (Hegerl et al., 1997) claiming that anthropogenic climate change had been detected was announced at a press conference in Hamburg, Germany. The founding director of the Max Planck Institute for Meteorology, Klaus Hasselmann, presented the work of his research group, which was based on four types of evidence: time series of long-lived greenhouse gas concentrations, observed geographical patterns of temperature anomaly time series, transient runs of a coupled atmosphere-ocean-land model, and the so-called fingerprint method (Hasselmann, 1997) searching for anomaly patterns attributable to distinct processes. The wide media coverage of this very unusual event emphasised the significance of the findings.

The Working Group II volume, covering impacts, adaptation and mitigation of climate change (IPCC, 1995b), presented a wealth of information. It indicated that impacts of anthropogenic climate change were already occurring and would pose serious risks in the future.

The Working Group III report, covering the economic and social dimensions of climate change, showed that there were many options available, both in terms of low-emitting technologies and available policy instruments to reduce GHG emissions significantly in all countries and economic sectors. The report also pointed to the importance of early mitigation efforts to improve flexibility in stabilising atmospheric greenhouse gas concentrations as a risk management approach.

The IPCC third assessment report, 2001

The IPCC published its third assessment report in 2001 (IPCC, 2001a, 2001b and 2001c). The role of human activity in causing climate change was further clarified: 'There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.' Evidence of climate change impacts around the world had strongly increased and projections of climate change impacts in the future were much more serious than in the past. The potential for strong reductions in global GHG emissions was clearly demonstrated and the costs of these reductions were shown to be modest compared to the projected increase in wealth. Insights into effective climate policies had grown significantly.

The IPCC fourth assessment report, 2007

On 2 February 2007 Working Group I of IPCC (2007a) stoked the political debate by clearly pointing out humankind's responsibility for the observed mean global warming:

> 'The understanding of anthropogenic warming and cooling influences on climate has improved since the third assessment report, leading to very high confidence that the global net effect of human activities since 1750 has been one of warming, with a radiative forcing of 1.6 Wm^{-2} (uncertainty range 0.6 to 2.4 Wm^{-2})'.

This statement strengthened the claim that an anthropogenic climate signal had been detected in the second and third assessments. The IPCC's Working Group II report in April 2007 (IPCC, 2007b) concluded that the extent of climate impacts on natural systems had further increased and that risks of future impacts were considered higher than in previous assessments, including an onset of negative impacts at lower temperature changes (see also Smith et al., 2009) than previously assumed. It included for instance the observation that:

> 'Approximately 20–30 % of plant and animal species assessed so far are likely to be at increased risk of extinction if increases in global average temperature exceed 1.5–2.5 °C.'

In May 2007 Working Group III on mitigation of climate change (IPCC, 2007c) made it clear that global emissions need to peak not later than 2015 to have a 50 % chance of keeping long-term temperature increase below 2 °C above pre-industrial levels. If peaking were delayed to 2025 the world would be committed to at least 3 °C warming in the long term. The report confirmed that ample options for reducing GHG emissions are available at modest costs. The report also suggested that the costs and benefits of mitigation are broadly comparable, even for the most stringent stabilisation of GHG concentrations studied (i.e. 450 ppm CO_2-eq.).

The *Stern review on the economics of climate change* (Stern, 2007) published at about the same time was more unequivocal. It stated that the costs of aggressive mitigation action are substantially lower than the costs of climate impacts and adaptation measures. It should be noted that the benefits of avoided climate change are notoriously difficult to estimate, since many impacts cannot easily be translated into monetary terms. In addition, co-benefits of reducing emissions, such as health benefits due to reduced air pollution from coal or increased energy security due to lower imports of fossil fuels, are not included in these calculations.

The outcomes of the Stern review were influenced by the choice of discount rates, which determine the weighting of future benefits and costs in decision-making. The Stern review employed very low discount rates and argued why that was the right choice. Not all economists agree with the approach used (e.g. Nordhaus, 2007).

One of the reasons for the stark messages about the urgency of reducing emissions was the higher estimate for so-called 'climate sensitivity', compared to previous reports. Working Group I stated that the 'best estimate' for a doubling of the CO_2 concentration compared to pre-industrial levels is a 3 °C increase in the mean global temperature, with a lower bound of + 2 °C and an upper bound of + 4.5 °C at two standard deviations. More recent studies confirmed this range (Rummukainen et al., 2010). The third assessment report had estimated climate sensitivity as 2.5 °C (without providing upper and lower bounds). As a consequence, GHG concentration levels for avoiding a particular temperature increase have to be lower than previously indicated. In particular, the European Union had originally estimated that a CO_2 concentration of 550 ppmv would be compatible with its goal of limiting the increase in global mean temperature to 2 °C above preindustrial levels. According to the new assessment, staying within this temperature limit requires greenhouse gas concentrations to remain below about 450 ppm CO_2-eq., which in turn implies a maximum concentration for CO_2 alone of about 400 ppm (compared to measured 380 ppm in 2007). To achieve that, CO_2 emissions would have to be reduced by 50–85 % from 2000 to 2050 globally, and by 80–95 % in industrialised countries.

Such a goal may appear Herculean. Nevertheless, many scenarios have been developed that achieve such a low carbon future using different portfolios of measures. Some scenarios still allow for relatively high shares of fossil fuels (coal and gas) for electricity production but require power plants to be equipped with CO_2 capture and storage. Other scenarios rely on a large share of nuclear power and yet others bring emissions to very low levels by moving to producing 80–100 % of electricity from renewable sources (e.g. WBGU, 2003; Greenpeace/EREC, 2007; van Vuuren, 2007; IEA, 2009 and 2010; IPCC, 2011).

IPCC special report on renewable energy sources and climate change mitigation

The Working Group III special report, *Renewable energy sources and climate change mitigation* (IPCC, 2011), is an assessment of the literature on the scientific, technological, environmental, economic and social aspects of the contribution of six renewable energy sources to mitigating climate change, published in 2011. Some of the main messages are:

- 'A significant increase in the deployment of renewable energy by 2030, 2050 and beyond is indicated in the majority of the 164 scenarios reviewed in this special report';

- In 2008, total renewable energy production was roughly 64 EJ/year (12.9 % of total primary energy supply) with more than 30 EJ/year of this being traditional biomass. The global primary energy supply share of renewable energy differs substantially among the scenarios. More than half of the scenarios show a contribution from renewable energy in excess of a 17 % share of primary energy supply in 2030 rising to more than 27 % in 2050. The scenarios with the highest RE shares reach approximately 43 % in 2030 and 77 % in 2050.

14.5 Emerging climate change policy

The foregoing sections of this chapter presented the evolution of science regarding the enhanced greenhouse gas effect and its projected impacts. The remainder focuses on how the political process dealt with this emerging scientific knowledge base. The power to determine the ends and means of public policy is widely though not equally shared, and different groups will of course seek to shape perceptions of truth, information or analysis (Gregory, 1989). Among the various stakeholders that seek to influence government policy development are environmental NGOs and business organisations. Their influence is mentioned briefly here but is not analysed in detail in order to limit the length of the chapter.

Some environmental NGOs like the Climate Action Network (CAN, 2012) aim to influence the United Nations Framework Convention on Climate Change (UNFCCC) policy process directly by providing detailed feedback through newsletters during the negotiations. Others focus on awareness campaigns (e.g. Greenpeace, 2012) and others provide summary information on scientific aspects (e.g. WWF, 2012). Some businesses (e.g. parts of the fossil fuel industry) have aimed to influence the negotiations directly or through lobby groups (e.g. the former Global Climate Coalition) or have questioned the underlying science (as discussed below). Other businesses have focused on the opportunities provided by climate policy, for example members of the World Business Council on Sustainable Development (WBCSD, 2012). It appears that the perspective of many businesses has changed somewhat over the years from being against action on GHG emission reductions to being in favour of measures such as regulation, either to provide investment security or because certain industries see opportunities (e.g. the renewable energy industries).

14.5.1 The 1980s: initiatives to stimulate political debate on how to deal with climate change

The late-1980s saw several initiatives to stimulate political debate on how to deal with climate change. There was intense public debate in some industrialised countries on climate change, illustrated by reports from some national advisory bodies to governments and legislative bodies, such as in Germany (WBGU, 1993) and other countries (Oppenheimer and Petsonk, 2005). In 1987, scientists and policymakers discussed matters at workshops in Villach and Bellagio, leading to recommendations to formulate policy targets (Oppenheimer and Petsonk, 2005).

Two conferences in Toronto (1988) and Noordwijk (1989) provided opportunities to enhance the scientific input into political decision-making and came up with proposals that would become the heart of the legal climate change regime later on. This was made possible by the mix of government representatives, international agency staff and scientists participating in these conferences.

Encouraged by the international agreement on the Montreal Protocol on protecting the ozone layer in 1987, which set targets for phasing out ozone-depleting substances, many of which are also powerful greenhouse gases (IPCC, 2005a), the Canadian government hosted an international conference in Toronto in 1988. The Toronto Declaration (WMO, 1989) makes extensive reference to the signals of a changing climate and the projections of future changes. It calls for an action plan, including a framework convention on climate change and the stabilisation of GHG concentrations in the atmosphere, and calls for domestic action on reducing CO_2 emissions. The action plan set a political target of a 20 % reduction of global CO_2 emissions by 2005 from 1988 levels, with industrialised countries taking responsibility for most of it. It further called for the establishment of a global atmosphere fund.

The Noordwijk conference, bringing together a group of 67 concerned countries at ministerial level in November 1989, was provided extensive scientific information on climate change, its impacts and strategies to bring it under control. This led to a ministerial declaration, which called for atmospheric GHG concentrations to be stabilised 'within tolerable limits', reflecting the concern about increasing negative impacts of climate change. It asked the IPCC (which was working on its first assessment) to report on the best scientific knowledge to help define what that level should be. It also stated that GHG emissions should be reduced and sinks increased to a level consistent with the natural capacity of the planet, allowing for ecosystems to adapt naturally, food production not to be threatened and economic activity to develop in a sustainable manner (Oppenheim and Petsonk, 2005). This would provide the foundation for the later United Nations Framework Convention on Climate Change.

These events demonstrate the willingness of some political actors to take action based on emerging, but certainly not complete knowledge on climate change and its impacts: the precautionary principle in action.

14.5.2 *The 1990s: establishment of the framework of international law for dealing with climate change*

In the field of climate policy, the 1990s saw the establishment of the framework of international law for addressing climate change.

United Nations Framework Convention on Climate Change

The IPCC finished its first assessment report in June 1990 and was asked to present its findings at the Second World Climate Conference (SWCC), which took place in Geneva, Switzerland, in October 1990. The World Meteorological Organization (WMO) had changed the earlier main topic of the SWCC, climate variability, to anthropogenic climate change, indicating the increasing priority being given to the issue. The presentation of the first full assessment of scientific knowledge on climate change by the IPCC during the first part of SWCC in 1990 had a major impact on the later ministerial part.

As a result, ministers from 134 countries called for a framework convention on climate change, to be ready for signature at the Earth Summit in Rio de Janeiro, in June 1992. They urged the inclusion of a global objective of stabilising GHG concentrations in the atmosphere at a level that would prevent 'dangerous interference with climate' (language used in the Noordwijk Declaration) and, as a first step, to halt the growth of global GHG emissions.

As a result of the Ministerial declaration of the SWCC, the UN General Assembly decided in December 1990 to set up an international negotiating committee, consisting of government representatives of all UN member countries, to work out an agreement. To serve the negotiations, the IPCC brought out a supplementary report in early 1992 (IPCC, 1992) to provide a synthesis of the latest scientific knowledge about climate change. The work of the negotiating committee resulted in agreement on the text of the United Nations Framework Convention on Climate Change (UNFCCC, 1992) in May 1992, just before the World Summit in July 1992, where it was signed by 153 countries and the European Communities.

Interestingly, the Convention explicitly mentions several underlying principles, including, in Article 3.3, the precautionary principle:

> 'The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost.'

The central goal (or 'ultimate objective') of the UNFCCC reads as follows:

> 'The ultimate objective of this Convention […] is to achieve […] 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 food production is not threatened and to enable economic development to proceed in a sustainable manner.'

This article clearly shows the central role given to science, which was supposed to inform politics about the level of action to be taken. Specifically, this article raises four major questions (Box 14.4). Science had not progressed to provide definite and clear information on all these questions, so they were essentially unanswered when the UNFCCC came into force.

Operationally, the UNFCCC contains clauses in which industrialised countries commit themselves to:

> 'adopt national policies and take corresponding measures on the mitigation of climate change, by limiting its anthropogenic emissions of greenhouse gases and protecting and enhancing its greenhouse gas sinks and reservoirs. These policies and measures will demonstrate that developed countries are taking the lead in modifying longer-term trends in anthropogenic emissions consistent with the objective of the Convention, recognising that the return by the end of the present decade to earlier levels of anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol would contribute to such modification'.

This text is a complicated and not really legally binding way of saying that developed countries will try to stabilise GHG emissions by the end of the century at the level of some prior year. The vague formulation already reflected the trouble of getting all industrialised countries (and particularly the US) to agree on a binding formulation to stop the growth of emissions. Box 14.5 sets out the other key elements of the Convention. The UNFCCC was rapidly ratified. It became binding on 21 March 1994, 90 days after the threshold of 55 countries had been reached on 21 December 1993.

Box 14.4 Four major science questions associated with the central goal of the UNFCCC

- What is dangerous interference with the climate system? In other words, what climate change impacts constitute a danger? This is obviously a value judgement that cannot be made on scientific grounds alone but science has an important role to play in providing relevant information.
- How fast may the climate change while still allowing for ecosystems to adapt naturally? This seems largely a scientific question. However, any level of change will cause responses in ecosystems. Whether these responses are still considered as 'adaptation' or already as 'impacts' is partly a value judgement, which in turn may be influenced by considerations about how much these responses matter — e.g. fish stocks that we eat versus marine species that we do not.
- At which redistribution of precipitation and at which warming level is food production threatened? Again, it initially seems a scientific question but in effect it also requires value judgements, asking for political decisions related to e.g. food distribution and the population size of an area facing food insecurity.
- At what degree and rate of climate change is economic development going to be affected negatively? But also, what is the speed at which emissions reduction and adaptation measures can be taken so as to avoid disrupting economic development? Here scientific and economic knowledge is needed to inform politics.

Box 14.5 Key elements of the UNFCCC

Principles:

- 'common but differentiated responsibility'
- special consideration for vulnerable developing countries
- 'precautionary principle'
- 'polluter pays'
- promoting sustainable development

Goals: the ultimate goal (Article 2) is to 'stabilize 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.'

Participation: almost universal (191 countries and the European Union, as of 1 September 2008).

Actions required:

- All countries must minimise emissions and protect and enhance biological carbon reservoirs, so called 'sinks'. Industrialised countries ('Annex I countries') must take action to stop growth of emissions before 2000.
- All countries must promote development, application and transfer of low-carbon technologies. Annex I countries must assist developing countries.
- Cooperate in preparing for adaptation.
- Promote and cooperate in research and development.
- Report on emissions and other actions (so called 'national communications'), annually for Annex I countries and less frequently for others.
- Rich industrialised countries ('Annex II countries') must assist developing countries financially in their actions.

Compliance: reports are reviewed by the secretariat and by visiting expert review teams.

Institutions:

- The Conference of the Parties (COP) is the supreme decision-making body. Its rules of procedure for decisions have never been agreed.
- The Bureau (comprising officials elected by the COP) is responsible for overall management of the process.
- Two subsidiary bodies (for implementation and for scientific and technological advice) prepare decisions of the COP.
- The financial mechanism is operated by the Global Environment Facility of the World Bank, the United Nations Development Programme (UNDP) and UNEP, and replenished by Annex II countries on a voluntary basis. Two special funds — a least developed country fund and a special climate change fund — mainly finance adaptation plans and capacity-building but also provide for technology transfer and economic diversification.
- Expert groups exist on technology transfer, developing country national communications, least developed country national adaptation plans.
- The Secretariat is located in Bonn, Germany.

Other elements: a requirement to review the need for further action regularly.

Source: Metz, 2010.

Kyoto Protocol

At the time the UNFCCC entered into force (end-1994), the IPCC was still working on its second assessment report. Enhanced scientific understanding of climate change and stronger evidence of its man-made causes was becoming more widely known. At the first session of the Conference of the Parties to the UNFCCC (COP1), in Berlin from end-March to the early-April 1995, the vague and not legally binding commitment of industrialised countries to try to stabilise emissions by 2000 was recognised as being far from sufficient.

The Conference of the Parties therefore adopted the so-called Berlin Mandate, which contained as its key provision the need for a legally binding intergovernmental agreement to reduce greenhouse gas emissions by industrialised countries, ready in time for COP3 in 1997.

Developing countries pushed hard to be left out of this strengthening of commitments. Under the UNFCCC they are only subject to general obligations on matters such as taking national action to combat climate change and reporting their emissions. Their arguments were based on the principle of 'common but differentiated commitments and respective capabilities' in UNFCCC Article 3.1. The COP agreed that in the UNFCCC context this approach implied that industrialised countries should take the first step but that all countries would step up their commitments to address the problem over time, albeit maintaining proper differentiation of actions.

The demand expressed in the 'Berlin Mandate' for a binding legal agreement for greenhouse gas emission reductions was met at COP3 in Kyoto, Japan, with the unanimous adoption of the Kyoto Protocol to the UNFCCC by more than 150 countries on 10 December 1997 (UNFCCC, 1997). Industrialised countries agreed to reduce their GHG emissions, using a basket of six GHGs, to about 5 % below their 1990 level by the 2008–2012 period. This was a substantial deviation from the business as usual situation which, despite the commitments made in the UNFCCC, still showed strongly increasing GHG emissions from industrialised countries. The aggregate 5 % reduction was to be achieved by differentiated emission targets for each country, taking into account specific national circumstances. The principles of the Convention, including the precautionary principle and the principle of 'common but differentiated responsibilities and respective capabilities' apply to the Protocol. Other key elements are presented in Box 14.6.

Implementation of the Kyoto Protocol

Four years of negotiations and four further sessions of the Conferences of the Parties to the UNFCCC (COP4 to COP7) were needed to get the full 'small print' of the Kyoto Protocol finalised. It was not until ratification by the Russian Federation on 16 February 2005 that the 1997 Kyoto Protocol became binding, which required ratification by 55 countries representing more than 55 % of the total emissions in 1990 from countries with reduction commitments. Ratification by Russia was critical for the Kyoto Protocol to enter into force after the single most important emitter, the US, withdrew from the Protocol in 2001.

Will industrialised country ('Annex B') Parties achieve their collective target of reducing greenhouse gas emissions by 5 % below 1990 on average over the 2008 to 2012 period? Projected emission levels in the period 2008–2012, based on country reporting as of 2007 show that, other than Canada and New Zealand, most Parties are likely to meet their targets after accounting for emissions and removals from land-use change and credits from the Kyoto flexible mechanisms (UNFCCC, 2011a). Emission levels in 2009 of all Annex B Parties to the Protocol were about 22 % below the base year, in part due to the economic recession of 2008 (Figure 14.3).

The EU-15 ([4]) is on track to achieve its commitment under the Kyoto Protocol of reducing emissions by 8 % compared to base-year levels. This is due to a combination of domestic measures, EU-wide policies and measures, carbon sinks and Kyoto mechanisms. The closing of coal mines in the United Kingdom in 1985 and the German reunification after the fall of the Berlin wall in 1989 have helped these countries deliver on their respective 12.5 % and 21 % individual reduction targets. In recent years emissions were also reduced because of the short-term effects of the global economic crisis.

EU actions have included establishing the EU Emissions Trading Scheme; promoting renewable energy sources; promoting energy efficiency increases in the energy, transport and industry sectors; reducing methane from landfills; and cutting emissions of industrial fluorinated gases (EC, 2010; EEA, 2010; EEA, 2011).

Countries of the former Soviet Union and eastern European countries are significantly overachieving their targets because emissions fell dramatically after the breakup of the Soviet bloc and the expected rebound of emissions after economic recovery did not occur as a result of changes in their economic structure and modernisation of their industries. Collectively they are at around 35 % below their 1990 level.

([4]) The EU comprised 15 Member States when it agreed to a collective 8 % reduction target in 1997. That is still the basis for compliance with the Kyoto Protocol obligations, although the EU now has 27 Member States.

Box 14.6 Key elements of the Kyoto Protocol

Principles: same as the Convention

Goals: same as the Convention

Participation: 180 countries and the European Union (United States are not a Party)

Actions:

- Annex I countries jointly reduce emissions to 5 % below the 1990 level, on average over the period 2008–2012. Specific emission caps are set for individual countries (UNFCCC, 2012).
- Option to use flexible mechanisms, i.e. international trading of emission allowances (not to be confused with domestic emission trading systems), using the emissions reductions from projects in developing countries (through the Clean Development Mechanism, CDM) or other Annex I countries ('Joint Implementation').
- Option to develop coordinated policies and measures.
- Strengthened monitoring and reporting requirements for countries with reduction obligations.

Compliance: failures to achieve emission reduction targets are to be compensated in the period after 2012, with a 30 % penalty.

Institutions:

- COP of the UNFCCC, acting as the Meeting of the Parties of the Protocol, serves as the primary decision-making body.
- All other UNFCCC institutions are used.
- Compliance Committee, with consultative and enforcement branch.
- Executive Board for the Clean Development Mechanism.
- Joint Implementation Supervisory Committee.
- Adaptation Fund, managed by the Adaptation Fund Board and administered by the GEF. The Fund gets its money from a 2 % levy on CDM projects.

Other elements: a requirement to review the need for strengthening actions.

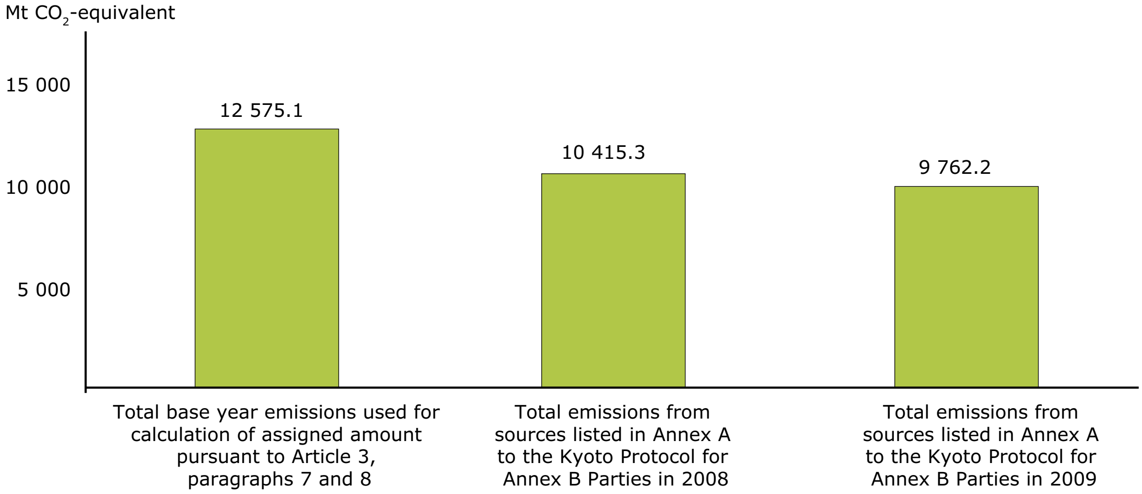
Source: Metz, 2010.

At the same time, however, global emissions increased from about 38 Gt CO_2-equivalent in 1990 to about 50 Gt CO_2-equivalent in 2010 (UNEP, 2011b), largely because developing countries increased their emissions as a result of spectacular economic growth. Compared to developing country emissions growth, the fact that the US stayed out of the Kyoto Protocol played a minor role in aggregate emissions growth. The global increase till 2012 was deliberately accepted (although underestimated at the time) in the design of the Kyoto Protocol, in line with the 'polluter pays' principle and the need to deal with equity concerns on the side of developing countries. The expectation was that in subsequent periods all countries would strengthen their actions to bring global emissions under control.

The Clean Development Mechanism of the Kyoto Protocol was increasingly employed. It allows developing countries to 'sell' reductions obtained from specific projects to industrialised countries and aims to support sustainable development in the 'selling' developing country. As of 1 January 2009, there were 4 474 CDM projects in the pipeline (i.e. either submitted to or registered by the CDM Executive Board). Of these, 1 370 had been registered and 465 certified emission reductions (CERs) had been issued. Together they equate to a reduction of about 0.3 Gt CO_2-equivalent per year in the period 2008–2012 and about 0.7 Gt CO_2-equivalent per year from 2013 to 2020. Given their relatively low price, it is very likely that Annex I countries will buy all the CERs originating from the CDM to meet their obligations.

To put things in perspective: the 0.3 Gt CO_2-equivalent per year is about 50 % of the total emission reduction (compared to the base year) that Kyoto Annex I countries are supposed to achieve. In other words, domestic emissions reductions in these countries will be only half of what they would have been without the CDM, if all available CERs are indeed bought (Metz, 2010).

Figure 14.3 Emission levels of Kyoto Protocol Annex B Parties in 2008 and 2009 (excluding land-use change emissions), compared to the base year



Source: UNFCCC, 2011b.

CDM projects cover a wide range of mitigation activities. The number of projects on renewable energy is the highest, with much smaller numbers for landfill gas (methane) recovery and destruction of HFC-23 at HCFC plants and N_2O at chemical plants. In terms of tonnes of CO_2-equivalent reduction expected before the end of 2012, however, renewable energy projects represent 36 % and HFC-23 and N_2O projects 26 %, which reflects the high global warming potential of HFC-23 (Metz, 2010).

Although the CDM is one of the successes of the Kyoto Protocol there are also some weaknesses. An example is the approval of some renewable energy projects (e.g. hydropower) but also efficient ('super critical') coal-fired power plants projects, where it is hard to prove that emission reductions are 'additional'. In other words, these projects possibly would have happened anyway without CDM credits. Another example is the approval of various industrial destruction projects of HFCs, which are emitted as a by-product of manufacturing the refrigerant gas HCFC-22, for companies that thus made profits selling credits. Such weaknesses are being addressed in current negotiations on a new international agreement for the period after 2012.

The US went its own way in dealing with climate change, as did Australia until December 2008 when it ratified the Protocol. Domestic climate action at federal level was given low priority in the US until the Bush administration concluded at the end of 2008. Although some action was taken at State and local level across the US, GHG emissions kept rising and net emissions were about 15 % above 1990 levels in 2008 (EPA, 2010b). After the election of President Obama at the end of 2008 there was hope that federal US GHG emission reduction policy would change, but this has not happened. Australia, although not part of the Kyoto Protocol until December 2008, nevertheless took domestic action in line with its Kyoto commitment. Australia is more or less set to meet its Kyoto target.

The ultimate objective of the UNFCCC and the EU two-degree target

It seems highly probable that the statement that 'The balance of evidence suggests a discernible human influence on global climate' in the IPCC second assessment report and the information on climate impacts and emission reduction options both played a strong role in facilitating the adoption of the Kyoto Protocol in 1997 by all countries attending the third session of the Conference of the Parties to the UNFCCC. The resistance that emerged in the US Congress prior to COP3 was primarily focused on the design of the Protocol, particularly its exemption of countries like China, and on the perceived risk for the US economy if significant emissions reductions were made (Byrd-Hagel Resolution, 1997).

In terms of the precautionary principle, political action was indeed strengthened at a time when scientific knowledge had improved but was still far from certain on the causes of climate change, the expected impacts and the feasibility and costs of emission reductions. It was not possible, however, to achieve political agreement on the exact meaning of the ultimate objective of the UNFCCC, i.e. what constitutes a 'safe' level of GHG concentrations in the atmosphere. In other words, there was no clear idea how big the challenge actually was and how fast global emission reductions would have to occur.

In 1996 an important decision was taken by the Council of Environment Ministers of the European Union. They decided that in the light of the scientific evidence as reflected in the IPCC second assessment report, global average temperatures should not be allowed to rise more than 2 °C above the pre-industrial level. This was a political decision, based on scientific evidence about the risk of expected climate change impacts on one hand and the perceived feasibility of deep emission reductions on the other. It would become the focus for EU climate policy for the next decade and beyond.

The decision was based on the following global risk management approaches (Metz, 2010):

- **Cost-effectiveness approach**: first determine what a 'tolerable' risk of climate change impacts is (a political judgement based on scientific evidence), then determine how this level can be achieved at the lowest possible costs, and finally consider whether this is politically feasible.
- **Cost-benefit approach**: perform a cost-benefit analysis that attempts to compare the monetised climate change damages with the cost of taking action, ensuring that the benefits of an action exceed its costs. As noted in Section 14.4.3, estimating these future costs and benefits poses some significant challenges.

The EU's 2 °C decision was arguably based on a mix of the two approaches. It was obvious that a 2 °C warming would still mean a significant increase of the risks of climate change with serious consequences in vulnerable countries. It was regarded as unrealistic, however, to turn around global emission trends fast enough to limit the temperature increase further. It was also felt that setting a maximum tolerable level of warming should not be based on an uncertain and disputed comparison with the monetised costs of climate change impacts. The precautionary element was to set a clear limit, despite the continuing scientific uncertainty about climate change impacts, and the costs and feasibility of drastic emission reductions.

Scientific literature published since the IPCC second assessment report confirmed that limiting global warming to less than 2 °C above pre-industrial temperatures would considerably reduce the risk of triggering irreversible large-scale changes in the climate system, such as a complete melting of the Greenland ice sheet, which would lead to large adverse impacts in many world regions. Nevertheless, significant risks would remain even in the event of a 2 °C increase above pre-industrial temperatures (IPCC, 2007b; CCSEG, 2010). This recently led to a large group of developing countries challenging the adequacy of the 2 °C limit, arguing for the necessity of a 1.5 °C limit, as discussed in the next section.

14.6 Debate on further international action after 2012

14.6.1 The post-Kyoto UNFCCC process

At COP11 in 2005 a decision was taken to start two processes: a negotiation among Kyoto Parties about a second commitment period (following the first period from 2008–2012), and a so called 'dialogue' among all UNFCCC Parties about the future evolution of international climate action under the UNFCCC.

The IPCC published its fourth assessment report in 2007 and was awarded the Nobel Peace Prize in November 2007, together with Al Gore. With the messages from IPCC being discussed widely, it was possible at COP13 in Bali in December 2007 to formally start negotiations on a new agreement for the period after 2012. A complex two-track negotiating structure emerged. The negotiations on a second commitment period of the Kyoto Protocol continued with all countries except the US. A new track was also started, known as the 'long-term cooperative action', which covered all countries and aimed to enhance national and international action to achieve the ultimate objective of the UNFCCC. COP13 agreed the 'Bali Action Plan', which called for negotiations to be completed at COP15 in Copenhagen in December 2009.

14.6.2 Copenhagen 2009

COP15 in Copenhagen failed to reach agreement on a legally binding agreement for the post-2012 period, jeopardising effective global action. The COP 'took notice' of the Copenhagen Accord (UNFCCC, 2010), a political declaration by more than 140 countries. The Accord includes the goal of keeping global temperature increase below 2 °C or possibly even 1.5 °C, it promises substantial financial resources from industrialised countries, and it contains an annex in which countries can include their intended national actions.

Although the COP did not formally endorse the Accord, it does reflect some significant progress regarding the policy response to climate change, including the endorsement of the 2 °C limit. It demonstrated the almost unanimous support for the 2 °C limit first proposed in 1996 by the EU. And the Accord even recognises that the climate change risks implied in this limit may already be going beyond what vulnerable regions, countries and people can tolerate and that a 1.5 °C limit might be needed.

The specific actions that have subsequently been pledged by almost 100 industrialised and developing countries show the intent of many countries to take domestic action to combat climate change. The EU specified internally agreed climate and energy targets to be met by 2020: reducing EU greenhouse gas emissions to at least 20 % below 1990 levels; providing for 20 % of EU energy consumption from renewable resources; and reducing primary energy use by 20 % compared with projected levels, to be achieved by improving energy efficiency (EU, 2012). It also pledged a 30 % reduction of emissions, provided other major emitters would made comparable efforts.

Unfortunately, the sum of these national emission reduction pledges for 2020 does not add up to what is needed to be on track to limit global temperature increase to 2 °C. In fact, current pledges imply a 2.5–5 degree trajectory, depending on how pledges for 2020 are implemented and what happens after 2020 (UNEP, 2010a and 2010c).

In Figure 14.4, the top coloured bands illustrate emission pathways over the 21st century, generated using integrated assessment modelling (IAM). The pathways were grouped based on ranges of likely temperature increase in the 21st century. Emissions corridors correspond to the 20th to 80th percentile range of emissions. The median of the Copenhagen Accord Pledge cases in 2020 is represented by the black bar.

The two bottom figures illustrate temperature increases associated with the different emissions pathways in the years 2020 (left) and 2050 (right): Thick, black lines show the median values, dark shaded areas represent the 20th to 80th percentile range, and light shaded ones the minimum/ maximum range.

14.6.3 Cancun and Durban

COP16 in December 2010 took place in Cancun, Mexico. It was the culmination of a year of very active diplomacy and consensus was reached among all Parties to the UNFCCC on a series of decisions that formalised the elements of the Copenhagen Accord as official UNFCCC decisions and agreed a number of organisational provisions on finance and technology transfer. This meant that the long-term goal for limiting global warming and the pledges made by countries to reduce their emissions were formally decided. However, the most contested issues in the negotiations, such as the future of the Kyoto Protocol, the legally binding character of a new treaty, commitments from major developing countries, the provisions on monitoring, reporting and verification and the provision of financial support to developing countries, were not addressed.

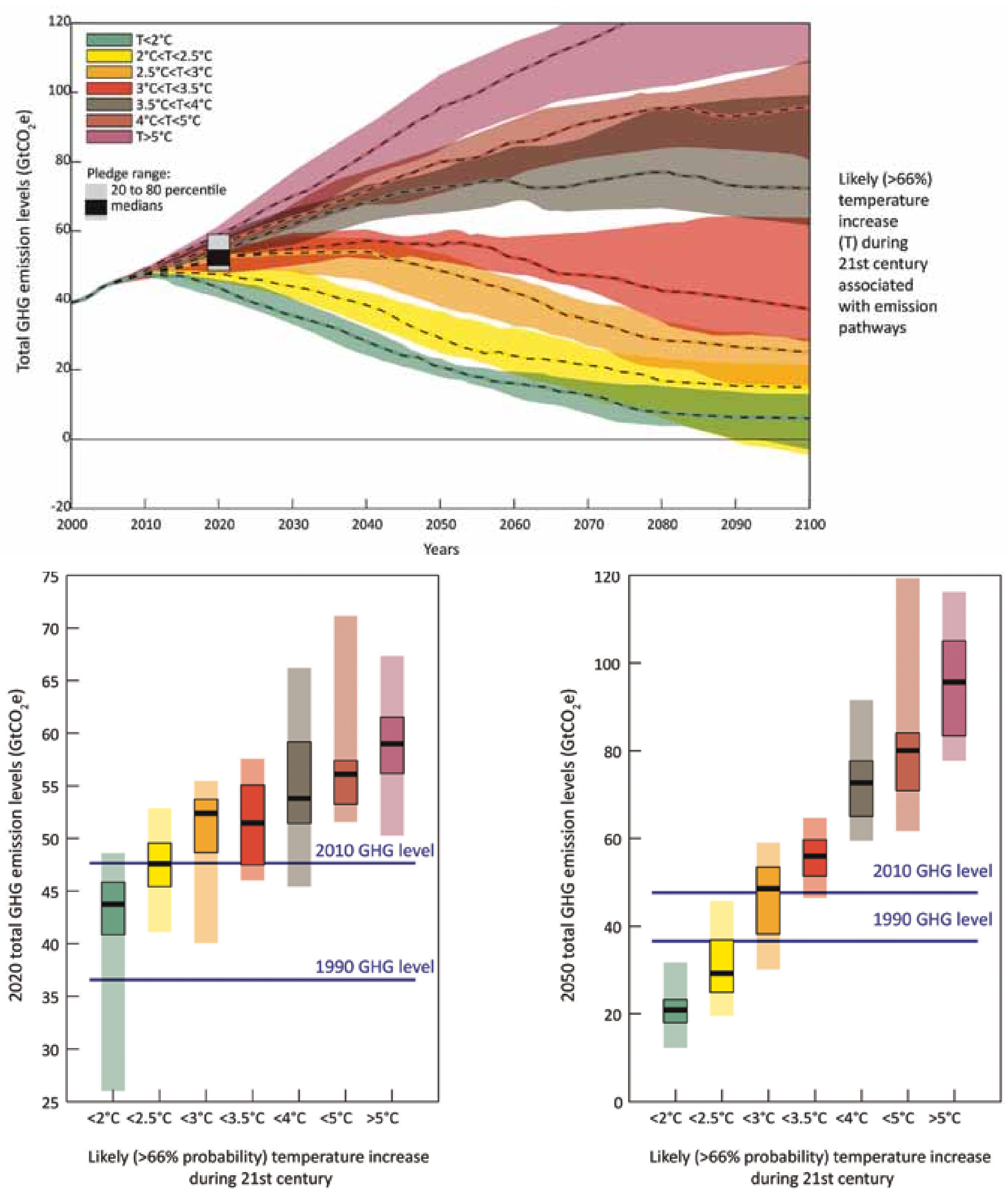
Despite difficult preparations, the next COP17 in Durban in 2011 delivered a series of decisions, although these did not include a new agreement for the period 2012–2020. Many countries were satisfied with the voluntary pledges that had been made in Copenhagen and Cancun. Only some Annex B countries agreed to put these pledges into a second commitment period under the Kyoto Protocol. It was agreed to hold workshops to clarify the pledges and were encouraged to strengthen the pledges, since the existing commitments would lead to a 3–4 °C trajectory, making it impossible to meet the 2 °C limit (UNEP, 2011b).

COP17 decided to start negotiations for a new legally binding agreement that would cover the period after 2020 and to complete negotiations by 2015 (UNFCCC, 2011d). Businesses require long-term agreements extending beyond 2020 to inform their investment decisions. Governments likewise need time to translate international agreements into national legislation and policies. In the short term, however, there is also a need for more ambitious action in the period up to 2020 if the 2 °C limit is to be taken seriously.

14.6.4 Creating doubt on the scientific knowledge base

Looking back at the 2000–2010 decade we see that international political action on climate change is moving forward only slowly. This is at odds with the increasingly strong messages from the scientific community about the man-made causes of climate change, the current and expected impacts of climate change, the urgency of deep reductions of global

Figure 14.4 Projected emission pathways over the 21st century



Note: In the above figure, the top coloured bands illustrate emission pathways over the 21st Century, generated using integrated assessment modelling (IAM). The pathways were grouped based on ranges of likely temperature increase in the 21st Century. Emissions corridors correspond to the 20th to 80th percentile range of emissions. The black bar represents emissions in 2020 resulting from pledges.

The two bottom figures illustrate temperature increases associated with the different emissions pathways in the years 2020 (left) and 2050 (right): Thick, black lines show the median values, dark shaded areas represent the 20th to 80th percentile range, and light shaded ones the minimum/maximum range.

Source: UNEP, 2011b.

GHG emissions and the feasibility of specific actions and technologies to realise such reductions.

One factor that caused this, although not the only one, is the doubt that was created about scientific knowledge on climate change. Other reasons, such as global economic and political developments and the growing ineffectiveness of the current approach to international agreements, have certainly contributed but are beyond the scope of this chapter.

Proper scientific conduct requires assumptions and findings to be challenged continuously in order to advance scientific knowledge. The IPCC has invested a lot in accurately reflecting in its assessments the certainty of findings and the continuing uncertainties (see Panel 14.1 on the IPCC and Uncertainty) — and it is important that these uncertainties be explored. While scientific method demands close scrutiny of certainties and uncertainties alike, however, honest scientists would not blatantly deny where the preponderance of evidence leads (Schneider, 2009). That is precisely what 'climate change deniers' or 'contrarians' are doing.

The science of climate change in general and the conclusions of the IPCC in particular have often been attacked by interested political actors and in the past years increasingly through a range of internet blogs, often in order to create doubt about the scientific basis for climate protection policies. These attacks have occurred despite significant scientific progress and despite the IPCC having stimulated research on topics that were identified as key uncertainties in earlier IPCC reports. Political lobbies supported by very few scientists — mostly from fields unrelated to climate change and without a publication record on climate issues — have often received prominent attention in the media, merely by opposing settled knowledge. Media in Anglo-Saxon countries have been much more inclined to support such attempts than in other countries (Painter, 2011). These campaigns have been able to delay the political process, in particular in the US, but also at the global level. It seems that the message that nothing has to be done is preferred to a call for global action.

The fossil fuel industry, for example, financed the 'Global Climate Coalition' in the US from 1989 to 2002. This group ran multi-million dollar advertising campaigns just before the Kyoto negotiations, which certainly had an impact on public opinion. These efforts have continued in different forms until now, the latest incarnation being a full 'denial industry' (Hoggan and Littlemore, 2009; Dunlap and McCright, 2010). Parallels between the climate change debate and earlier controversies over tobacco smoking, acid rain and the hole in the ozone layer have been identified, showing that spreading doubt and confusion was a basic strategy of those opposing action in each case (Oreskes and Conway, 2010).

Another line of attack on addressing climate change has come from economists who argue that climate change is not the most important problem ('not the end of the world') and that tackling it would divert scarce resources from resolving problems such as poverty, hunger, malaria and HIV/AIDS that claim more lives (Lomborg, 2007; Copenhagen Consensus Center, 2009).

Just before COP15 in Copenhagen, another attack on climate science was launched, accusing climate scientists that had worked for the IPCC of manipulating their results and keeping unwanted papers from scientists with different views out of the IPCC report. This accusation, dubbed 'Climategate' in the press, was based on a series of hacked emails from the computers of the University of East Anglia (UEA) in the United Kingdom. This attack was followed soon by the discovery of two mistakes in the Working Group II contribution to the 3 000 page IPCC fourth assessment report. Due to an erroneous statement on the melting rate of Himalayan glaciers, this problem became known as 'Glaciergate'. Attackers suggested that IPCC authors had deliberately manipulated the assessment to make it scarier than was warranted. A delayed and defensive reaction from the IPCC management to these accusations made things worse.

A number of different investigations in the United Kingdom of the behaviour of the involved scientists at the Climatic Research Unit (CRU) of the UEA cleared them from scientific misconduct (Russell et al., 2010; Oxburgh et al., 2010; House of Commons Science and Technology Committee, 2010). One of the recommendations given by the investigators was that climate scientists should take even more steps to make all their supporting data available — right down to the computer codes they use — in order to make research findings properly verifiable. The CRU (and other organisations) have meanwhile started activities to make more climate data accessible (e.g. UEA, 2010).

Investigations of the claimed mistakes in the IPCC report showed that only very few things needed correction and that they did not have any impact on the major conclusions contained in the Synthesis Report and the summaries of the working group reports (e.g. NEEA, 2010; EPA, 2010a). A review of the IPCC procedures and management structure requested by the UN Secretary-General and the IPCC suggested several changes to avoid similar problems in the future (InterAcademy Council, 2010).

Panel 14.1 The evolution of the IPCC's approach to assessing 'uncertainty'

Malcolm MacGarvin

Dealing with uncertainty has been a fundamental issue in assessing and communicating climate change. The IPCC generally distinguishes between 'statistical', 'value' or 'probabilistic' uncertainty (referred to as 'quantifiable risk' in *Late lessons from early warnings*) and 'systemic' or 'structural' uncertainty (termed 'unquantifiable uncertainty', 'ignorance' and 'indeterminacy' in *Late lessons from early warnings*).

The first and second IPCC assessments use terms such as 'almost certain', 'likely' and 'doubtful' inconsistently, even within each assessment. In preparation for the third assessment report, the IPCC therefore produced guidance for authors addressing the issue of reporting uncertainty. This included material on underlying theory, the practical pitfalls for authors and editors, and the communication of uncertainty to the wider world. The IPCC has since revisited its guidance on uncertainty for both the fourth and fifth assessments. This panel charts the various landmarks in the IPCC's evolving approach to uncertainty.

Guidance for the third assessment

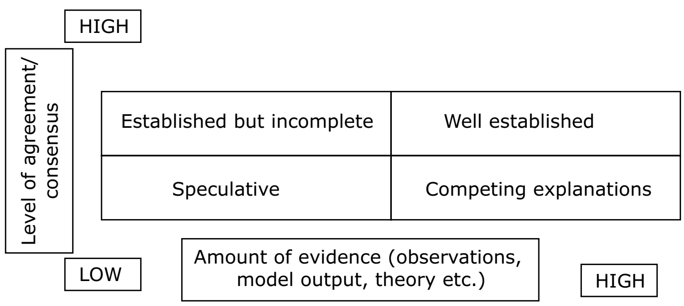
The third assessment report's guidance on uncertainties (Moss and Schneider, 2000) — which lists 37 reviewers, including some still influential in IPCC work — noted that uncertainty results from a lack of information, and disagreement about what is known or even knowable. Uncertainty exists even in carefully controlled laboratory studies. For climate research, however, this is compounded by factors such as the global scale and low frequency variability, with characteristic times greater than the length of most instrumental records; the impossibility of before-the-fact experimental controls; and the (particularly tricky) issue of long time lags between climate forcing and response. According to the third assessment report guidance, assessing the probability of events will inevitably be subjective. It reflects the 'degree of belief that exists among lead authors and reviewers that the event will occur, given the observations, modelling results and theory currently available.'

Other challenges include how best to represent differences in expert opinion; how to alert readers to 'long tail' events (outcomes believed to be unlikely but with serious implications should they occur); and 'poorly managed' projected ranges in impact assessments that may propagate a 'cascade of uncertainty'. Evidently there are communication and credibility challenges in emphasising quantified probabilities, while simultaneously communicating these as provisional and liable to (perhaps dramatic) change. The guidance stresses that it is vital that the specialists should **quantify** the probabilities to the best of their abilities because otherwise others, less expert, would do so on their behalf. The guidance introduced a five-point scale to categorise quantitative probabilities (presented on the left side of Figure 14.5).

The guidelines acknowledged that some reviewers and potential users of the guidelines were 'uncomfortable' with the quantitative ranking of uncertainty. It therefore proposed a qualitative scheme, based on the amount and strength of evidence of various types, and the level of consensus between experts (as shown on the right side of Figure 14.5). Together, these could be used to express high, medium or low confidence in particular findings, with specific formulations of words for various combinations. The guidance maintained, however, that this should be supplementary to the quantitative assessment, because qualitative terms 'do not always map well onto a quantitative scale', increasing the likelihood of inconsistent usage.

Figure 14.5 Quantitative and qualitative expressions of uncertainty as categorised in the third assessment report guidance

(0.95)–(1.00) 'Very High Confidence'
(0.67)–(0.95) 'High Confidence'
(0.33)–(0.67) 'Medium Confidence'
(0.05)–(0.33) 'Low Confidence'
(0.00)–(0.05) 'Very Low Confidence'



Source: Moss and Schneider, 2000.

Panel 14.1 The evolution of the IPCC's approach to assessing 'uncertainty' (cont.)

A separate practical dimension of the third assessment report guidelines is their acknowledgement of human shortcomings in producing assessments. The guidance notes that the means for ensuring consistency in assessing and reporting on uncertainty had not previously received much attention in IPCC reports and that lead authors need to be aware of bias. Group dynamics add complexity to report drafting and that lead authors 'need to guard against the potential for 'gaming' or strategic behaviour' from contributors negotiating a text. Uncertainty within a group arising from conflicting strongly held individual views is qualitatively different from that of a group of collectively uncertain individuals, and report users need this information. Moreover, lead authors should be aware of history, that overconfidence biases experts' judgements: experts 'are correct less often than their confident assessments imply'.

For all these reasons, the third assessment report guidelines advise the preparation of a 'traceable account', describing the 'reasons for adopting a particular probability distribution, including important lines of evidence used, standards of evidence applied, approaches to combining/reconciling multiple lines of evidence, explicit explanations of methods for aggregation, and critical uncertainties.' For particularly important outcomes, the guidelines suggest the use of formal decision analytic techniques, which may achieve 'a more consistent assessment of the subjective probability distribution'.

Learning from third assessment report and preparing for the fourth

Following the third assessment report, an IPCC workshop on uncertainty and risk again reviewed the issues (Manning et al., 2004). The workshop report states that:

> 'probability is the basic language of uncertainty and was originally developed to describe the chance of different outcomes for processes that are stationary over time (such as throws of dice) where observed frequencies are equivalent to probabilities. In general, assigning probabilities to future outcomes cannot assume stationarity or be based entirely on past observations. This leads to the subjective view of probability as a statement of the degree of belief that a person has, that a specified event will occur given all the relevant information currently known by that person. Such subjective probabilities have wider utility and are more relevant to the climate change context.'

Nevertheless, 'cognitive bias' will exist, influenced by a person's (selective) awareness of past events and future expectations; the roots of their perceptions; and the analogies that spring to their mind. A distinction was also drawn between 'likelihood' and 'levels of confidence'. Likelihood was 'the chance of a defined occurrence or outcome' whereas the 'level of confidence' refers to a broader 'degree of belief or confidence in a science community of the amount of evidence or information available and the degree of consensus in the interpretation of that information'.

The workshop also reported on how the third assessment report working groups had diverged from the guidance. Working Group I (addressing the physical science basis) had generally used mathematical-statistical methods and estimates of uncertainty in raw data, using likelihood 'as a basis for approaching uncertainty focused on the probability of outcomes'. It 'was clearly intended to be interpreted in that way despite the definition in the Working Group I Summary for Policymakers as 'judgemental estimates of confidence''. Working Group I never used the qualitative confidence terms introduced in the guidance because of 'discomfort' with the wording. Members agreed, however, that it was appropriate to provide separate indications of the amount of information and the degree of unanimity in the expert community on its interpretation.

Working Group II (addressing impacts, adaptation and vulnerability) addressed less material based on statistical methods, instead giving levels of confidence focused on the degree of understanding and consensus among experts. At times this was used as a proxy for the probability of outcomes. Chapter authors had exercised discretion in using qualitative or quantitative assessments.

Working Group III (addressing mitigation of climate change) did not adopt the guidelines, asserting that it was challenging for economists and social scientists to attempt to use a scale such as those employed by Working Groups I and II, and that there was very little literature to support such estimates for mitigation potentials and estimates of future emissions or drivers.

Panel 14.1 The evolution of the IPCC's approach to assessing 'uncertainty' (cont.)

According to the workshop report, 'structural' uncertainty had not been adequately addressed in the third assessment report. This applied to physical measurements (such as interpreting temperature trends from satellite data) and to biological consequences (such as significant differences between crop yield models, indicating structural uncertainties). Even less account had been taken of structural uncertainties for natural (unmanaged) ecosystems. Similarly, socio-economic structural uncertainties underlying future scenarios and the treatment of adaptive and mitigated capacity had not been explained well in the TAR.

While acknowledging that assessing structural uncertainty 'is generally more difficult and can normally only be done to a limited extent', the workshop concluded that there had nevertheless been a demonstrable tendency for it 'to be overlooked by expert groups'. Indeed 'structural uncertainties associated with analysis techniques … were not considered explicitly. This may have lead to more apparent certainty being given to results where only one or very few independent analyses had been carried out'. There is 'an obligation to identify what we are unlikely to be able to know before the changes actually occur'. So far 'the assessment community has not done very well' in addressing this point.

The workshop was clear that decision-makers need to be aware of events with low probabilities but large impacts, even though these are 'necessarily based on subjective views, usually of a group of experts, on how the future may evolve'. Qualitative explanations of uncertainties associated with costs and benefits, mitigation and adaptation potentials, and scenarios, may be more appropriate than quantitative confidence or likelihood estimates. Providing context will sometimes be more relevant to policymakers than trying to quantify the uncertainties. This includes indicating how robust predictions are, under different assumptions; identifying and explaining sources of uncertainty, including how the variables are defined; assumptions regarding system boundaries; and competing conceptual frameworks. Indeed, giving statements about confidence in probabilistic projections of likelihood raises basic issues, such as how do we measure confidence in unfalsifiable probabilities of future climate change, and to what extent convergence of models can actually be assumed to indicate increasing confidence. Given such deep uncertainties, it was argued, robust strategies that appear to work reasonably well across a wide range of outcomes should be favoured.

Fourth assessment guidance

Following the workshop, the *Guidance note on addressing uncertainties for the fourth assessment report* (IPCC, 2005) was drafted. In part drawing on the earlier work, the fourth assessment guidance was intended to 'assist' lead authors to have a consistent approach to uncertainty 'where possible', while acknowledging that there will be a 'diversity of approaches'. These, the guidance suggested, should be considered early, using a balanced process that reflects any divergence of views, and addressing value and structural uncertainty as well as fundamental unpredictability. Where expert judgements are made, their basis and the critical assumptions, should be traceable. Lead authors should be aware of group dynamics converging and becoming overconfident in an expressed view, or unjustifiably anchored on previous versions or values.

The guidance noted that the appropriate level of precision should be used to describe findings and it proposed a six-point **linear 'typology of uncertainties'**. This ranged from (A) 'Direction of change is ambiguous or the issue assessed is not amenable to prediction' to (F) 'A probability distribution can be determined for changes in a continuous variable either objectively or through use of a formal quantitative survey of expert views'. Three sets of terminology were given 'to describe different aspects of confidence and uncertainty and to provide consistency across the fourth assessment report':

- The first was essentially the same qualitative assessment of confidence (evidence versus level of agreement) set out in the third assessment report guidance, although this time accompanied by instruction that this should only be used to supplement quantitative assessment.
- Similarly, the second was the five-point quantitative confidence scale ranging from 'very high confidence' to 'very low confidence' from the third assessment report guidance. This could 'be used to characterise uncertainty that is based on expert judgement as to the correctness of a model, an analysis or a statement'.
- The third was a 'likelihood' scale, intended to serve as 'a probabilistic assessment of some well defined outcome having occurred or occurring in the future', based on 'quantitative analysis or expert views'. This ranged from 'virtually certain, greater than 99 % probability of occurrence' to 'exceptionally unlikely, less than 1 % probability'.

Panel 14.1 The evolution of the IPCC's approach to assessing 'uncertainty' (cont.)

The guidance did not specify how to ensure that the third assessment report's weaknesses in addressing structural uncertainty were rectified in the fourth report, other than to repeat the third assessment report guidance that 'structural uncertainty tends to be underestimated by experts'. Indeed, the proposed linear 'typology of uncertainties' proposed has the potential to contribute to this confusion as any classification will contain contingent elements of structural uncertainty. A situation classified as (F) inevitably includes elements of classification (A) — categorisation is neither linear nor exclusive.

That such dilemmas exist should not lead to policy paralysis, nor necessarily mean that the best option is further research to 'reduce' uncertainty. Moss and Schneider (2000), the 2004 IPCC workshop report, volume 1 of *Late lessons from early warning*s and the general literature on uncertainty all contain numerous proposals, such as weighing up the pros and cons of action or inaction.

Inter-Academy Council (IAC) review

Following 'Climategate', a critical Dutch review, and the revelation of an error regarding the fate of Himalayan glaciers (actually raised but unaddressed during the fourth assessment report review process) the IPCC asked the IAC to review the IPCC process. Issues raised (IAC, 2010) relevant to uncertainty included the need to improve on transparent selection criteria for authors; demonstrably improved and formalised handling of alternative viewpoints; the advantages of an open review process; policies and resources for handling the volume of comments likely to arise, including any orchestrated efforts, by those with strong views, to overwhelm the system; and demonstrable independence of the review process. Structural uncertainty was not raised.

The IAC recommended that all working group reports should use the qualitative level-of-understanding scale in their summaries for policymakers and technical summaries, 'as suggested in' the fourth assessment report guidance. Actually the guidance was ambiguous on this (c.f. paragraphs 7 and 11–12).

The IAC concurred with the IPCC's aspiration that the basis of the assessments should be fully traceable — although this has resource implications for expert authors and for recovering the information if queried. The IAC also argued that requiring quantitative levels of overall confidence, and a likelihood scale for specific observations, was redundant, noting 'One could have high confidence that obtaining two sixes when rolling a pair of fair dice is extremely unlikely. But why not just say that obtaining two sixes when rolling a pair of fair dice is extremely unlikely'.

Fifth assessment guidance

The IPCC has now produced a *Guidance note for lead authors of the IPCC fifth assessment report on consistent treatment of uncertainties* (Mastrandrea et al., 2010), taking into account the recommendations of the IAC review. The guidance states that:

'The fifth assessment report will rely on two metrics for communicating the degree of certainty in key findings:

- Confidence in the validity of a finding, based on the type, amount, quality, and consistency of evidence (e.g. mechanistic understanding, theory, data, models, expert judgment) and the degree of agreement. Confidence is expressed qualitatively.
- Quantified measures of uncertainty in a finding expressed probabilistically (based on statistical analysis of observations or model results, or expert judgment).'

To avoid any doubt about the strength of this guidance, the IPCC subsequently stated, in a response to the IAC report (IPCC, 2011), that working groups were now 'instructed to make this evaluation of evidence and agreement the basis for any key finding, even those that employ other calibrated language (level of confidence, likelihood), and to provide a traceable account of this evaluation in the text of their chapters.' This, nominally at least, represents a significant evolution in the approach to uncertainty by IPCC since the third assessment report guidelines.

The approach to communicating the certainty of key findings in the fifth assessment report is presented in Figure 14.6. The accompanying explanation in the guidance describes this as 'A depiction of evidence and agreement statements and their relation to confidence.

Panel 14.1 The evolution of the IPCC's approach to assessing 'uncertainty' (cont.)

Confidence increases towards the top-right corner as suggested by the increasing strength of shading. Generally, evidence in most robust when there are multiple, consistent independent lines of high-quality evidence.'

Figure 14.6 Fifth assessment report scheme for communicating confidence in key findings

Confidence scale

Agreement →

High agreement Limited evidence	High agreement Medium evidence	High agreement Robust evidence
Medium agreement Limited evidence	Medium agreement Medium evidence	Medium agreement Robust evidence
Low agreement Limited evidence	Low agreement Medium evidence	Low agreement Robust evidence

Evidence (type, amount, quality, consistency) →

Source: Mastrandrea et al., 2010.

Whereas the fourth assessment report guidance employed three sets of terminology to describe confidence and uncertainty, this is reduced to two for the fifth assessment. The five-point quantitative confidence scale is deleted, leaving only the likelihood scale to 'provide calibrated language for describing quantified uncertainty'.

For the first time, the fifth assessment report guidance asks authors to 'be aware that findings can be constructed from the perspective of minimising false positive (type I) or false negative (type II) errors'. Traditionally, academic science places its emphasis on avoiding false positives (falsely concluding that a result is significant, when it is not), and these form the basis of most statements of quantitative likelihood or confidence. Although the fifth assessment report guidance does not discuss it in such terms, from a precautionary perspective one is also interested in type II errors (concluding that a result is not significant, when it is), which requires a different approach. In essence, it can mean assuming that it is more important to be safe than to be right.

In other respects, as might be expected given the earlier effort, the fifth assessment report guidance largely reflects previous IPCC guidance, with some differences of emphasis and re-ordering of text. The guidance again refers to the importance of communicating low probability outcomes with significant impacts; the need to communicate the full range of views where expressing collective viewpoint is inappropriate; the need to make expert judgements and provide a traceable account of their derivation; the tendency of groups to converge on a viewpoint and become overconfident in it; the need to be wary of how the wording of statements affects interpretation by the reader; and the need for lead authors to ensure that they have considered all 'plausible' sources of uncertainty and to be aware that experts underestimate structural uncertainty arising from incomplete understanding.

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The IPCC has started implementing reforms based on these suggestions. In May 2011 the IPCC adopted guidance on a communications strategy; recommendations on how best to handle 'grey' literature; protocols on how to handle scientific uncertainties and corrections of errors in reports; and a conflict of interest policy. The IPCC also agreed to establish an Executive Committee to strengthen the overall management structure (IPCC, 2010).

Polls have shown that these attacks and other developments have had an impact on public opinion regarding the urgency of taking action, even though the accusations were shown to be unsubstantiated. In Europe in 2011 only 34 % of citizens consider climate change to be one of their five major concerns, compared to 57 % in 2007 (EC, 2011a), although 95 % of EU citizens still feel that protecting the environment is important to them personally. Media coverage of climate change has also decreased since 2009, although there are differences across the world (CSTPR, 2011). A survey in 15 countries (covering about 50 % of the global population) shows that climate change was still one of the top three concerns in 2010 (HSBC, 2010). But doubts about the reality of climate change have increased in the general population, and the pressure on politicians to take action on climate change has decreased.

This is not to say that the scientific community is completely free of blame for the situation. Scientists and the IPCC should be open to consider criticism seriously, even if it appears to be scientifically unfounded. In the attacks on the IPCC mentioned above, the response of the IPCC and individual scientists was defensive, which was one reason why the Inter-Academy Council recommended a more transparent communication practice for IPCC. Scientists in general are not necessarily good communicators, lacking understanding on how to communicate effectively to decision-makers and the general public. A lot can be improved here (Bowman et al., 2010).

14.7 Discussion

Can the evolution of climate change policy be understood as an application of the precautionary principle?

Climate change science has evolved over time. The IPCC was established to provide comprehensive policy-relevant assessments of the scientific knowledge relevant for developing climate change policies. These developments clearly had an effect on climate policymaking. IPCC assessment reports played an important role in raising awareness of risks as well as explaining potential solutions and their estimated costs.

At the international level, however, this science-policy dialogue can only be regarded as a partial success. Current policies will not achieve the emission reductions that scientists consider necessary to achieve the ultimate objective of the UNFCCC, as confirmed in the Cancun agreements concluded at COP16. Hence, the sum of international political action over the last 20 years is inconsistent with a strict interpretation of the precautionary principle, which would require taking necessary action in the absence of full information.

A key question is the level of scientific certainty that the international policymaking community needs to act to address climate change. The five criteria presented below correspond to increasing evidence that humankind is significantly altering the climate on a global scale, starting with the most basic criterion and ending with the most demanding one. The more society and its leaders are willing to adopt a precautionary approach, the fewer criteria have to be fulfilled before actions are implemented.

- Criterion 1: Observation of a long-term increase of long-lived greenhouse gas concentrations in the atmosphere.
- Criterion 2: Observation of mean global warming derived from nearly global long-term nearsurface air temperature measurements.
- Criterion 3: Paleo-climatic evidence of global warming caused by an enhanced greenhouse effect of the atmosphere.
- Criterion 4: Detection of a significant anthropogenic contribution to observed mean global warming using validated climate models and statistical fingerprint methods.
- Criterion 5: Attribution of specific aspects of climate change to anthropogenic causes. Examples include attributing thermal expansion of ocean water, the most important contribution to sea level rise, to mean global warming at the surface and strong cooling of the upper stratosphere and the mesosphere due to increased CO_2 concentration.

Criterion 1 was satisfied as far back as the late-1960s, although only for CO_2. For concentration increases of the other two long-lived greenhouse gases, CH_4 and N_2O, the 1990 report of IPCC Working Group I (climate science) presented the evidence. The halocarbons as new, artificial long-lived greenhouse gases became known as contributors to the enhanced greenhouse effect in the ozone assessment reports by WMO and NASA (WMO, 1986).

Criterion 2 was satisfied by the first assessment report of IPCC (IPCC, 1990). Criterion 3 was arguably also fulfilled by the first IPCC report from 1990, which showed very high correlation between greenhouse gas concentrations and temperatures (during snow-formation) for a 160 000 year record of air bubble composition and oxygen isotope content in Antarctic ice cores.

Criterion 4 was fulfilled by the sentence 'the balance of evidence suggests a discernible human influence on global climate', published in December 1995 in the Working Group I's summary for policymakers in the IPCC's second assessment report.

Criterion 5 was fulfilled by the IPCC's third assessment report in 2001. This report showed that the observed cooling in the lowest stratosphere is predominantly caused by depletion of ozone as a consequence of chlorofluorocarbon decomposition in the stratosphere and less by the enhanced greenhouse effect, which is the key reason for cooling in the upper stratosphere (above 30 km height) and mesosphere (above 50 km height). In addition, the IPCC fourth assessment report of Working Group I, published in February 2007, cites several new links such as 'sea level rise is largely a consequence of the warming of sea water in the upper ocean layers' (IPCC, 2007a).

An important factor in the IPCC successfully fulfilling the criteria above was the development of guidelines for assessing and expressing uncertainty systematically. As a result, important statements on the knowledge about changes in the climate system could be given qualifications such as 'as likely as not' (33–66 % probability it is true), 'likely' (67–90 % probability), 'very likely' (90–99 % probability) or 'virtually certain' (99–100 % probability).

In summary, for all these criteria scientific proof is by now largely or completely available at a high confidence level. Hence we are far beyond the knowledge level where the precautionary principle would still be needed for any action in the global climate change context — at least, if the precautionary principle is interpreted as referring to major anthropogenic changes to the global climate system.

Obviously, the list above considers neither the impacts of changes in the climate system on humans and ecosystems nor the costs and impacts of climate change policies. Some would say that attempts to consider the costs and impacts of alternative policies (including doing nothing) go beyond the precautionary approach — instead being characteristics of a comprehensive risk management approach. However, most authorities accept that precautionary policy actions need to take account of the pros and cons of action and inaction (See Chapter 27 on the precautionary principle).

It seems that when the precautionary approach has been applied in environmental policymaking in the years since the Rio Declaration, it has mostly occurred at regional scales and addressed air and water pollution. The stakes were much lower than in the case of global climate change and those implementing policies were generally also the ones benefitting from them. Global climate change is very different in many ways:

1. Climate change and climate policies have strong impacts on all of us. There is no readily available solution that could easily reduce the problem to a safe level.

2. Climate change is a global problem and efforts to reduce GHG emissions are cost-effective only if they are part of an agreement with others to act in a comparable manner. Furthermore those countries and population groups most negatively affected by climate change are generally poor countries and population groups who have contributed little to its causation. Hence, the motivation for reducing greenhouse gas emissions can differ substantially depending on the underlying ethical perspective. In the particular case of climate change, it appears that increasing information on the expected distribution of impacts, i.e. on expected 'winners' and 'losers', has unfortunately decreased the momentum for international climate policy.

3. Climate change is a problem characterised by the very long atmospheric life times of many greenhouse gases (from a decade to millennia) and a long inertia in the climate system (mostly due to the large heat capacity of the ocean). As a result, emissions reductions of long-lived greenhouse gases now will only have significant climatic effects after several decades. Hence, the moral dilemma outlined in the previous bullet point is even larger: the costs and benefits of emission reductions are not only unequally distributed across countries but also over time. Primarily self-interested high emitters have little incentives for costly emission reductions because they will experience only a small fraction of their benefits, if their scope is only the present

generation. However many emission reductions provide substantial non-climatic benefits in the short term, including reduced air pollution and reduced costs for importing fossil fuels. Contrastingly, self-interested motivation is particularly low for GHG reduction measures such as carbon capture and sequestration that do not provide large non-climatic benefits.

Apparently the precautionary principle did play a role when the UNFCCC was agreed after the IPCC first assessment report in 1990 (criteria 4 and 5 above were not yet fulfilled). If the UNFCCC had already contained binding emission reduction goals for industrialised countries, it would have provided evidence of full acceptance of the principle in the climate change context. The influence of the precautionary principle diminished however with subsequent actions. Now precautionary arguments appear to have only little, if any, effect on internationally coordinated climate policy action.

Is a risk management framework better for understanding the evolution of climate policy?

The history of climate change policy suggests that arguments based on a risk management framework had a much stronger impact on political action than arguments based mainly on a precautionary framework. In a risk management framework, it is necessary to know the risks of climate change impacts and the risks, costs and benefits of taking mitigation and adaptation action, including their distribution across regions and over time. Countries have only committed to significant action at the national level (in the context of the Kyoto Protocol and the subsequent pledges under the Copenhagen Accord) after having satisfied themselves that emissions reductions are technically feasible, and that they can be implemented at reasonable costs and in a politically acceptable way. In addition, cost-benefit analysis (such as the Stern review) is sometimes applied to evaluate how far mitigation measures should go in the light of the avoided climate change impacts.

So risk management approaches have been applied but other key factors are also important, including the perception of risk. Risks, costs and benefits of climate change depend on assumptions about future social, economic and technical developments and on the evaluation of uncertainties that cannot be presented in strict scientific terms. Perceptions of risks, costs and benefits of climate change and climate protection policies vary significantly across different people and stakeholders. In addition, risk perception depends on factors such as how the scientific community communicates its findings and interacts with stakeholders, how credible it is perceived to be, how the media handle the information, as well as human psychology and behaviour, cultural background, world views and political affiliations (Weber and Johnson, 2012; McCright and Dunlap, 2011).

The importance of risk perception became obvious in the uproar surrounding the attacks on climate science and the IPCC in 2009–2010. The public in several countries became less concerned about climate change and this affected the political prioritisation of action. The 'blogosphere' generates a huge amount of (dis)information, in which scientific arguments often are characterised as 'just another opinion'. This undermines the authority of bodies like the IPCC (Giddens, 2009), further altering risk perception. Misperceptions of risk partially, but not wholly, explain why climate change policy has so far been inadequate.

From threat to opportunity

Perhaps the biggest problem with establishing effective climate policy at the national and international levels has been the focus on avoiding climate change risks. Climate policy appears to require short-term sacrifices from particular economic actors and changes in the costs of services and human activities. Benefits accrue decades later in the form of avoided climate change impacts. Even if the benefits in monetary terms outweigh the costs measured over a long period of time, such propositions are not very attractive or understandable for many people. Those that could be worse off in the short term will lobby against a proposed policy. The focus on avoiding climate change risks does not appeal to immediate self-interest, at least not directly. A lot rests on solidarity with future generations.

What could be highlighted more both at the international and national levels is the fact that many interventions to stimulate development, wellbeing and economic growth, if well targeted, can contribute to a low emissions and climate resilient economy. Energy efficiency in industry, transport and buildings is good economic policy, leading to lower energy bills and lower greenhouse gas emissions. Renewable energy can provide much needed modern energy in rural areas, improve air quality and health, reduce dependency on imported energy, create new jobs and contribute to emissions reduction. Building new infrastructure, development of coastal areas, increasing food production — all good investments in development — can be done in such a way that they are more resilient against future floods and drought that result from climate change, and maximise the preservation of carbon stocks.

So if climate change is integrated into the agenda of development and economic growth, it aligns the benefits for the stakeholders interested in positive economic activities with the benefit of avoiding climate change damage. Climate change can be more mainstreamed into core economic decisionmaking, making it more likely that the necessary action will be taken. Rather than looking at positive economic and social effects as a co-benefit of reducing climate change risk, climate change risk reduction becomes a co-benefit of development and economic growth.

There is now a trend emerging to consider climate change as an integral element of socio-economic decisionmaking. New paradigms of 'low carbon growth' or 'low emissions development', 'climate compatible development' or in a broader sense 'green growth' are being adopted in many countries. The European Commission's statement in October 2011 is a good illustration:

> 'Just two weeks ago, the European Commission announced proposals on resource efficiency. Together with our proposals on a low carbon economy, they set out what is needed to transform Europe's economy to be sustainable by 2050. This package is our approach to green growth, and it builds on the efficient and sustainable management of our resources.' (EC, 2011b).

More and more countries see low-carbon growth, low emissions development or green growth as a promising way of integrating climate change action into core socio-economic decision-making. The green economy was one of the key issues for the Rio+20 meeting in 2012. UNDP, UNEP, the Organisation for Economic Co-operation and Development (OECD) and the World Bank, among others, have set up strong programmes to promote this development (OECD, 2011; UNDP, 2011; UNEP, 2011a; World Bank, 2009 and 2010a).

As a result, the main question for policy becomes 'how can we achieve the socio-economic goals of growth and development, while addressing climate change risks?' This question in turn demands answers to scientific questions: 'how can dependence on energy imports be reduced by developing domestic renewable energy resources?', 'how can air quality be improved to eliminate health hazards by shifting from fossil fuel-based energy production and transport systems to clean energy and electric cars?' and 'how can agriculture be made more productive and less vulnerable to climate change by sequestering more carbon in agricultural soils?' These questions require a more integrated analysis and assessment than earlier questions that regarded climate change mitigation as largely separate from other policy areas.

Such questions are also critical for determining the different technological pathways to the 2050 goal of a green economy that is not dependent on fossil fuels — pathways that must be determined, in part, by means of greater public engagement.

Table 14.1 Early warnings and actions

1896	Svante Arrhenius (Sweden) calculated that a doubling of CO_2 in the atmosphere from coal burning could lead to an increase in average global temperature of 3–5 °C. (In 2007 IPCC estimated that this would be 2.4–4.5 °C).
1938	Guy Stewart Callendar (United Kingdom) concluded that 'the principle result of increasing CO_2 … would be a gradual increase in the mean temperature of the colder regions'.
1958–1970	David Keeling (US) established two long term monitoring stations in 1958 in Mauna Loa on Hawaii and at the South pole to measure the background concentration of CO_2 without the influence of nearby anthropogenic (human) sources. By 1970 the Mauna Loa monitoring station showed clear rising trend in global CO_2 of 0.4 % per year.
1970s	Schneider, Twomey and Grassl identified critical interactions of clouds and air pollution that amplified or dampened the human induced greenhouse effect.
1980	The World Climate Research Programme organised and co-financed by the World Meteorological Organization and the International Council for Scientific Unions became the first global change research programme.
1980s	Models of atmospheric changes showed that both greenhouse effects and measures to avert them would take decades to be clearly seen because of inertia in the systems caused principally by the oceans.
1985	Neftel et al. (Switzerland) and Jouzel et al. (France) were the first to determine the CO_2 concentration in air bubbles of ice cores with enough precision to reconstruct the long-term history (160 000 years) of greenhouse gases.
1987/1988	Groisman and Hansen publish the first trend analyses of global mean air temperature covering a full century.

Table 14.1 Early warnings and actions (cont.)

1980 and 1985	At two scientific conferences at Villach (Austria) climate change scientists concluded that 'the increasing concentrations of greenhouse gases are expected to cause a significant warming of the global climate in the next century'.
1987	The global Montreal Protocol on protecting the ozone layer sets targets for phasing out ozone-depleting substances, many of which are also powerful greenhouse gases
1988	The Intergovernmental Panel on Climate Change (IPCC) was formed focusing on climate change science, the vulnerability of society and nature to climate change and means of adaptation, and on mitigation measures for limiting or preventing greenhouse gases and their effects.
1988	SCOPE scientists warn that human induced climate change could cause increases in climate variability and of extreme weather events.
1988/1989	Scientific conferences in Toronto and Nordwijk call for a global action plan, a Framework Convention from 1988 levels and for a reduction of 20 % in global CO_2 by 2003.
1990	The IPCC published its first assessment report concluding that: 'there is a natural greenhouse effect of the atmosphere which already keeps the Earth warmer than it would otherwise be'; 'there is a strong increase of concentrations of all three long-lived naturally occurring greenhouse gases (CO_2, CH_4, N_2O), which is due to anthropogenic activities, global mean near-surface air temperature had risen by 0.3 to 0.6 °C during the 20th century, there was evidence of a rise in mean sea level, of retreats in mountain glaciers and changes in regional precipitation'.
1990/1992	The UN 2nd World Climate Conference called for a Framework Convention on Climate Change (UNFCCC) which was later signed by 153 countries and the European Communities in Rio in 1992.
1995	The IPCC published its second assessment report stating that 'The balance of evidence suggests a discernible human influence on global climate.' This was the first time that scientific evidence enabled the human-induced change signal to be perceived against the background of natural climate variability. It also stated climate change impacts were happening and could pose serious risks in the future; and that policy measures were available to reduce GHG emissions.
1995	At the first session of the Conference of the Parties to the UNFCCC (COP1) the Berlin Mandate was adopted, which recognised the need for a legally binding intergovernmental agreement to reduce greenhouse gas emissions by industrialised countries, to be ready in time for COP3 in 1997.
1996	The Council of Environment Ministers of the European Union decided that global average temperatures should not be allowed to rise more than 2 °C above the pre-industrial level.
1997	The Kyoto Protocol to the UNFCCC was adopted by more than 150 countries. Industrialised countries agreed to reduce their GHG emissions, using a basket of six GHGs, to about 5 % below their 1990 level by the 2008–2012 period.
2001	IPCC's third assessment report in 2001 concluded that 'There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.' Projections of climate change impacts in the future were much more serious than in the past. The potential for strong reductions in global GHG emissions was clearly demonstrated and the costs of these reductions were shown to be modest compared to the projected increase in wealth.
2001	The USA withdrew from the Kyoto Protocol.
2005	The Russian Federation ratified the Kyoto Protocol which then became binding having required ratification by 55 countries representing more than 55 % of the total emissions in 1990 from countries with reduction commitments.
2007	IPCC fourth assessment report concluded that 'the understanding of anthropogenic warming and cooling influences on climate has improved ... leading to very high confidence that the global net effect of human activities since 1750 has been one of warming'.
2007	The UK Stern Review of the Economics of Climate Change stated that the costs of aggressive mitigation action are substantially lower than the costs of climate impacts and adaptation measures.
2008	Australia signs the Kyoto Protocol.
2010/2011	Some minor errors, and deficiencies in the handling of scientific uncertainty, in the 3 000-page 2007 IPPC report were identified but these did not affect its main conclusions. Recommendations were made to make all climate change data freely available so that research findings can be further verified. IPCC improves its communications and its guidance on handling scientific uncertainties.
2011	COP17 in Durban in 2011 agreed to start negotiations for a new legally binding agreement for after 2020 and to complete negotiations by 2015; acknowledged that businesses require long-term agreements extending beyond 2020 to inform their investment decisions and recognised the need for more ambitious action by 2020 if the 2 °C limit is to be taken seriously.
2011	Canada withdraws from the Kyoto Protocol.

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