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Toward Climate Conventions Scenario Analysis for a Climatic Protection Policy

The 1980s have seen an unprecedented growth in awareness of the problem of climatic change. The 1990s will be the critical decade during which collective concern must be turned into concerted action through global Climate Conventions and related Protocols. This article proposes such a strategy with the following elements: setting of a warming ceiling and a rate of change per decade; development of emission scenarios which come close to the set limits using climate modeling; allocation of emission shares by nation; assessment of emission reduction potential by gas, source, measure and nation; development of national emission reduction plans; agreement, implementation and supervision of such plans; establishment of a climate fund. This study addresses the first element of the strategy by making extensive use of model-based climate scenario analysis. The results of this analysis will help identify emission reduction measures which could limit the mean global surface warming to approximately 2 K in 2100 over the preindustrial level and restrict the average rate of global warming to about 0.1 K per decade. The effectiveness of these scenarios is assessed using a one dimensional(1–D) climate model from 1860 to 2100. The results of this research will help widen the scope for a more flexible climate protection policy.

FROM GROWING AWARENESS TO CLIMATE CONVENTIONS

Awareness that the emission of trace gases might alter global climate goes back more than 150 years. Fourier was probably the first to discuss the CO_2 greenhouse effect in 1827 by comparing the process with the warming of air isolated under a glass plate (1). Well over 100 yrs later, in 1957 Revelle and Suess concluded that human activities were initiating a global geophysical experiment that would lead to detectable climatic changes in a few decades. In 1972, the UN organized a global Conference on the Human Environment, and in 1979 the World Meteorological Organisation convened a First World Climate Conference in Geneva (2). An important outcome of this meeting was an urgent appeal to the world's nations:

- to take full advantage of man's present knowledge of climate;
- to take steps to improve signifcantly that knowledge;
- to foresee and to prevent potential man-made changes in climate that might be adverse to the well-being of humanity.

In preparation of the UN Convention on Environment and Development to be held in Brazil in 1992, a series of activities has been launched resulting in a number of recommendations for emission reductions. In summer 1988, the Toronto World Conference on the Changing Atmosphere called for a reduction in global emissions of CO_2 by 20% of the 1988 value by 2005 (3). In fall 1988, the Hamburg World Congress on Climate and Development called for action by nations to reduce the global CO_2 release by 30% by the year 2000 and 50% by 2015 as compared to the 1988 level. In November 1989, the Noordwijk Conference on Climate Change called for a CO_2 emission stablization of industrialized countries in 2005 at the 1989 level. At the fall of 1990 Second World Climate Conference, the participants of the scientific and the technical sessions concluded that technically-feasible and cost-effective opportunities exist to reduce CO_2 emissions in all countries and that such opportunities are sufficient to allow many industrialized countries to stablize CO_2 emissions from the energy sector and to reduce these emissions of the order of 20% by 2005. At the ministerial level, actions were proposed that aim at stabilizing the emissions of only CO_2 by the year 2000 at the 1990 level.

At the same time, the Intergovernmental Panel on Climate Change (IPCC) was convened under the auspices of UNEP and WMO in Geneva to set up three expert working groups to assess the scientific evidence on climate modeling, review the socioeconomic and environmental impacts, and to devise response strategies. The intention of this procedure was to gather the information necessary for a global Climate Convention to be negotiated and signed by 1992. To speed up this process, its framework could be modeled on the Vienna Convention for the Protection of the Stratospheric Ozone Layer. Likewise a series of climate protocols, similar to the Montreal Protocol on CFCs and halons, have to be negotiated.

The main challenge facing the IPCC process lies in the development of reduction protocols which can be rigorously enforced rather than just a general framework with nonbinding language (4). In order to avoid losing unnecessary time in overly complex negotiations, Tolba, head of the UNEP, has suggested a series of protocols, each focusing on individual gases or policy areas, which can be agreed upon one by one (5). There is, however, a strong interlinkage between the different greenhouse-gas emissions. Therefore, on the climate modeling level, it is crucial to derive global emission reduction values required for an agreed-upon climate protection. On the political level, the main challenge is to reach agreement on sufficiently strict reduction targets. On the policy level, the key problem is to ensure that the selected control responses are in agreement with the broader considerations of a ecologically sustainable future. This challenge is further complicated by the problem of international equity. While historically insignificant compared to that of the industrialized world, the contribution to the greenhouse warming by the Third World is growing rapidly. This problem must be dealt with in such a way as to build into the protocols compensating mechanisms that provide for financial and technical assistance for corrective measures in the developing countries as well as creating economic incentives for low-greenhouse gas investments in the industrialized countries.

Finally, to be effective, a Climate Convention should set a ceiling for global warming in order to ensure the protection of the Earth's climate. Such a warming ceiling rests on two pillars. The first pillar is provided by the best available global climate models which can be used to derive the required global emission reductions. The second pillar is provided by the best available systems analyses which can be used to derive a reduction strategy that will meet the requirements of climate protection and that is socially and economically sound and politically feasible. This study discusses specific aspects of the climate-modeling stage. By way of introduction, we summarize previous and on-going research work relevant to this topic, introduce a workable emission reduction strategy, discuss the required research, and, finally, present a cross-section of scenario results which are needed if effective policy decisions are to be taken.

CURRENT RESEARCH ACTIVITIES

Effective climate protection cannot be guaranteed without setting an upper warming ceiling. Currently, the IPCC and other groups are engaged in climate scenario analyses to provide the necessary information for the upcoming Climate Convention. We briefly report the most important activities and their results with special reference to the concept of warming ceiling and climate protection.

USEPA Report to Congress (6). The changes of six warming scenarios are calculated from 1985–2100 for CO_2-doubling climate sensitivities of 2–4 K. The global mean transient surface temperature increases (Ts) are given for 2100 relative to the preindustrial value: For SCW (slowly changing world no response) Ts = 2.5–4.0 K; for SCWP (slowly changing world stabilizing policy) Ts =1.2–2.0 K; for RCW (rapidly changing world no response) Ts =3.6–5.6 K; for RCWP (rapidly changing world stabilizing policy) Ts =1.4–2.3 K; for RR (rapid reduction) Ts =0.7–1.2 K and for AE (accelerated emissions) Ts =>6.0 K. As an upper warming ceiling is not given, there is no reference to climate protection.

The US/Netherlands Expert Group on Emission Scenarios (7). Detailed emission scenarios by gas and source are developed using the following guidelines: The equivalent CO_2 concentration (i.e. CO_2 and the other trace gases) is set to reach a CO_2 doubling (2 x CO_2) in 2030, in 2060, and in 2090 relative to the preindustrial value. The results are a global mean equilibrium surface temperature change (Teq) for a 2 x CO_2 (2030) of Teq = 5.3 K, for a 2 x CO_2 (2060) of Teq = 2.9 K, and for a 2 x CO_2 (2090) of Teq = 2.3 K. From a tractable decision-making point-of-view, time-independent equilibrium temperature calculations are not as useful as the time-dependent transient temperature changes. Because the oceans have a very large heat capacity, the temperature change realized in the atmosphere lags considerably behind the equilibrium level.

UNEP/IPCC scenarios. The Response Strategies Working Group III of the Intergovernmental Panel on Climate Change (IPCC) developed four scenarios for future greenhouse-gas emissions. The Scientific Assessment Working Group I used these scenarios as input to calculate global mean transient surface temperature (Ts) changes. The obtained temperature increases for climate model sensitivities of 2.5°C (1.5 to 4.5) in 2100 as compared to the preindustrial value are:

- For Scenario A (the 2030 High Emission Scenario) Ts= 4.5°C (3.0–6.6)
- For Scenario B (the 2060 Low Emission Scenario) Ts = 3.0°C (2.0–4.4)
- For Scenario C (the Control Policy Scenario) Ts = 2.5°C (1.6–3.6)
- For Scenario D (the Accelerated Policy Scenario) Ts = 2.0°C (1.3–3.0).

The emission scenarios B-D assume progressively increasing levels of controls. This results in average rates of increases in global mean temperature over the next century of the order of 0.2°C per decade (Scenario B), just above 0.1°C per decade (Scenario C), and about 0.1°C per decade (Scenario D).

Greenpeace (8). Greenpeace commissioned the calculation of four transient scenario runs for a middle climate sensitivity of 3.0 K with the lower (1.5 K) and upper (4.5 K) values given in brackets. All values refer to 2050 relative to the preindustrial level in the 19th century. The scenarios "business-as-usual", "first-step", "fifty-percent", and "stabilization" reach mean global transient surface temperature increases of 2.7(1.5–3.8)K; 2.4(1.4–3.5)K; 2.1(1.2–3.0)K; and 1.8(1.0–2.5)K, respectively. The latter scenario achieves a rate of increase of 0.11(0.05–0.17)K per decade between 1990 and 2050 with the rate well below 0.1°C a decade by 2050, but the global temperature continues to rise well beyond this point. This shows once more the sluggishness of the ocean within the perturbed climate system. This study is a big step toward climate protection in that it attempts, through respective trace-gas reductions, to stabilize the climate at a certain level.

The Netherlands Report (4). In this report, commissioned by the Dutch Government, an exemplary account of the concept of climate protection through a climate stabilization policy is given. It is shown that for a permissible mean global warming rate of 0.1 K per decade, or c. 2.0 K by 2100 relative to the preindustrial level, the atmospheric CO_2 concentration until 2100 may only increase to c. 400 ppm (the 1988 level is 350 ppm), and the cumulative carbon release into the atmosphere must not exceed some 300 billion tons (this amounts to half the current annual rate of some 5 billion tons averaged over the whole period). This holds only under the assumptions that the CFCs will be phased-out worldwide by 2000, that carbon storage in forests and soils will be restored to mid-1980 levels during the next several decades through a reduction in tropical deforestation and by afforestation in both temperate and tropical regions, and that the emissions of CH_4 and N_2O will be curtailed by limiting the releases from agricultural and industrial activities. The resulting reduction targets divided among the industrialized countries (ICs) and developing countries (DCs) and the world as a whole are discussed below.

If emission reduction studies are to provide useful information which can aid policy-making, they must ask the right questions. It is not simply a case of determining what temperature change will result from a particular percentage reduction in trace-gas emissions nor is it helpful to limit the range of possibilities by assessment, which must ultimately be subjective, of what is considered technologically or politically feasible. It is necessary to define what rates of emission changes are permissible if a specified warming ceiling, defined in terms of a rise above a past reference level by a certain date, is not to be exceeded. This new line of reasoning leads to a new workable climate protection strategy. Different versions have been introduced into the various reports of the Enquete Commission of the German Bundestag (9).

A WORKABLE CLIMATE PROTECTION STRATEGY

The strategy operating on different levels and following distinct goals consists of the following elements:

- Setting of a warming ceiling (10) through a global Climate Convention.
- Development of a diverse number of possible greenhouse gas-emission scenarios which limit the additional man-made global warming to the defined ceiling using climate modeling.
- Allocation of the required emission reduction shares by gas and nation through a global Climate Convention.
- Assessment of the existing emission reduction potential by gas, source, measure and nation.
- Optimization through comparison of required with existing national reduction potential.
- Development of national emission reduction plans.
- Agreement on emission reduction plans through a global Climate Convention.
- Implementation and supervision laid down in a protocol through a global Climate Convention.
- Establishment of a Climate Fund through a global Climate Convention.

To reduce the risk of impacts from climatic change, it is prudent to follow the above climate protection strategy. The appropriate methodology is scenario analysis based on climate modeling.

SCENARIO AND CLIMATE MODELING RESEARCH

Although many scenario analyses have been conducted, their value to decision-makers is limited. Adopting the concept of a warming ceiling, there is a need for studies which deal with different reduction combinations achieving a similar warming limit effect, use a more or less complete modeling system, and test a variety of different but plausible model parameters. From this it follows that there is an urgent research need for the following three types of sensitivity studies:

Analysis of the Results from Different Scenarios Obtained with the Same Modeling System.

This type of scenario analysis only makes sense when all major climate-influencing greenhouse gases are included. For example, the often quoted Toronto call for a 20 % CO_2-emission reduction by 2005 over the 1988 value has limited relevance for climate protection. The required global climate protection function is only fulfilled if a large number of scenarios is run using all major greenhouse gases in a great variety of possible reduction combinations. This is demonstrated in detail below.

Comparison of the Results Obtained with Different Models Using the Same Model Input.

The models usually consist of a combination of carbon cycle models (11–15) to calculate atmospheric CO_2 concentration, photochemical models (16, 17) to compute the atmospheric levels of the other greenhouse gases, biosphere models (18, 19) which take into account the terrestrial biosphere to various degrees of sophistication, and climate models which, for the type of temperature calculation considered here, usually consist of a radiative-convective model (20–23) of one or many layers in the atmosphere coupled to an energy balance model (24–28) usually consisting of an upper mixed layer and a deep ocean. The results of some model comparisons are given below.

Testing the Effects of Different Model Inputs and Plausible Model Parameters on the Results.

The production and emission values of anthropogenic and natural greenhouse gases are more or less uncertain. The various model parameters and the parameterized input functions of the carbon cycle, photochemical, mass balance, and climate models are all very uncertain. The effects of varying key inputs and parameters must, therefore, be tested. We have not yet performed these extensive sensitivity tests.

Some of the results of the sensitivity studies that have already been performed are presented below.

DESIRABLE SCENARIO RESULTS FOR POLICY DECISION

Sensitivity studies can generate a great deal of information which can be used in a variety of ways. In particular, they can be used to improve scientific understanding and to aid decision-making. In this first analysis, using 1 D models we concentrate on results which are useful from the point-of-view of policy decisions. From this perspective, it is important that the experimental design should:

- be simple and transparent;
- compare well with the observed data;
- provide results which compare well with those obtained from more complex 2 D and 3 D modeling;
- allow a quick check of the large number of possibilities and, in that way;
- augment the political room for action both nationally and internationally during the development of a Climate Convention.

This study covers the period 1860 to 1985 for past trends and, for scenario analysis, the period from 1985 to 2100. The three basic emission scenarios A, B and C are designed so that they satisfy one element of the climate protection strategy, namely, that they ensure that the realized warming does not overly exceed the mean global warming ceiling of 2 K by 2100 as compared to the 1860 value (10). In contrast to forecasting, this procedure has been dubbed backcasting. This concept has many advantages over the conventional approach of projecting global or at best regionally-disaggregated economic, population, and lifestyle developments far into an uncertain future, because it assesses the existing emission reduction potential in key nations for the first few decades, a time window enough to effect the reversal of the current trend. The socioeconomic side of this concept is not addressed in this paper. The purpose of this contribution is rather to demonstrate the results from the many physico-chemical emission-reduction combinations possible under the warming ceiling concept.

Emission scenarios. Table 1 gives the emission change of the main trace gases for the three emission scenarios A, B and C until 2100 as compared to the respective 1985 values. Scenario A, which comes close to the suggestions of the 1988 Hamburg Climate Conference, starts off with a steep 30% reduction for CO_2 by 2000 and reaches practically a phase-out in the latter half of the 21st century. The matching N_2O and CH_4 emissions show no or very slow reductions, while the CFC production shows an increase. This is due to the specifications of the Montreal Protocol, i.e. the legally-permitted exemptions. Scenario B corresponds approximately to the recommendation of the 1988 Toronto Conference of a 20% CO_2 emission reduction by 2005 followed by a reduction of 50% or more. Scenario C reflects the proposals of the Noordwijk Conference that global CO_2 emissions be brought back to the current value by 2000. The other trace gases require correspondingly higher reduction rates. Figures 1a–d show the emission rates for the five trace gases over time. It should be noted that, in each case, it will be necessary to offset the inherent rise in emissions that would otherwise take place as well as ensuring the specified reductions below the present-day level.

Concentration scenarios. The time-dependent CO_2 emission reduction rates serve as input into a carbon cycle model to calculate the historic and the future atmospheric CO_2 concentrations. For this sensitivity study we used a box-diffusion carbon cycle model developed by Oeschger et al. (11) which consists of four reservoirs acting both as sources and sinks, namely the atmosphere, the biosphere, a well-mixed ocean layer (c. 75m deep), and a deep sea (c. 4000 m deep) in which transport is by eddy diffusion. The airborne fraction and the buffer factor are calculated explicitly for each time step. The CO_2 contribution of the biosphere to the atmosphere has been calculated using a terrestrial biosphere model developed by Harvey(19). Figure 2, shows that the carbon cycle model including the biosphere reproduces satisfactorily the observed atmospheric CO_2 concentration. Ex-

Table 1. Shares of emission reduction and temperature change for individual trace gases and scenarios.

Gases	Global emission reduction (%) from				Temp. change (K) in 2100 rel. to 1860 for climate sensitivities (K)		
	1985–2000	1985–2025	1985–2050	1985–2100	1.5	3.0	4.5
Scenario A (Hamburg)							
CO_2	−30	−70	−90	−95	0.45	0.80	1.07
N_2O	0	−10	−20	−40	0.11	0.19	0.26
CH_4	0	−5	−10	−20	0.05	0.10	0.13
CFC11*	+49	+6	same		0.09	0.16	0.21
CFC12*	+46	+4	thereafter		0.17	0.31	0.42
Total global temperature change					0.87	1.56	2.09
Scenario B (Toronto)							
CO_2	−15	−30	−50	−80	0.68	1.22	1.63
N_2O	−10	−20	−30	−50	0.10	0.19	0.25
CH_4	−5	−10	−15	−25	0.03	0.06	0.07
CFC11*	−37	−45	same		0.49	0.08	0.12
CFC12*	−40	−47	thereafter		0.67	0.17	0.23
Total global temerature change					0.97	1.72	2.30
Scenario C (Noordwijk)							
CO_2	0	−15	−30	−50	0.85	1.51	2.01
N_2O	−20	−30	−40	−60	0.10	0.18	0.24
CH_4	−10	−15	−20	−30	0.01	0.01	0.02
CFC11*	−100	−100	same		0.00	0.00	0.00
CFC12*	−100	−100	thereafter		0.02	0.04	0.05
Total global temerature change					0.98	1.74	2.32

*the CFCs refer to production values

Figures 1a–d. Estimated changes in emission for trace gases CO_2, N_2O, CH_4 and CFC-11/12 and for scenarios A, B and C from 1985–2100.

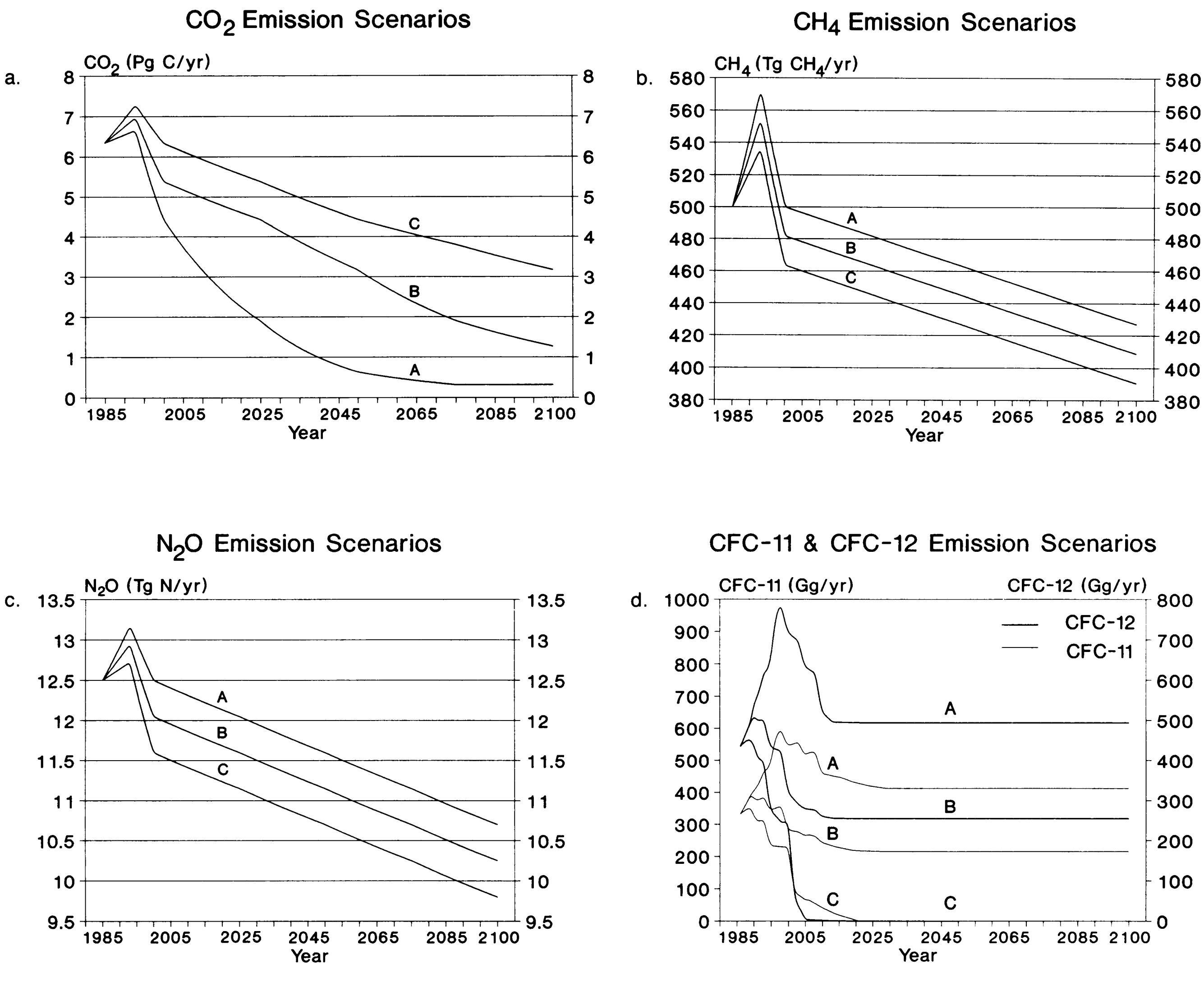
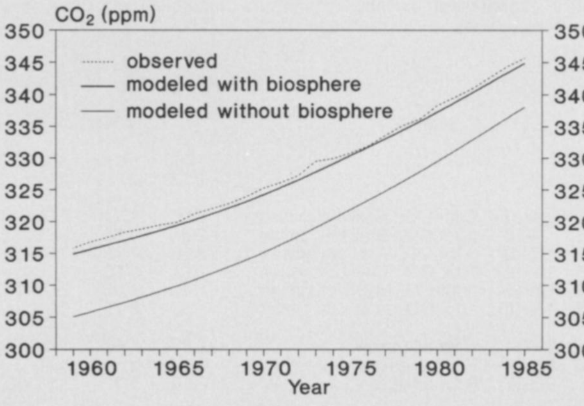


Figure 2. Comparison of observed and modeled (with and without the biosphere) atmospheric CO_2 concentration change from 1959–1985.



Figures 3 a–d. Estimated changes in concentration for trace gases CO_2, N_2O, CH_4 and CFC-11/12 and for scenarios A,B and C from 1985–2100.

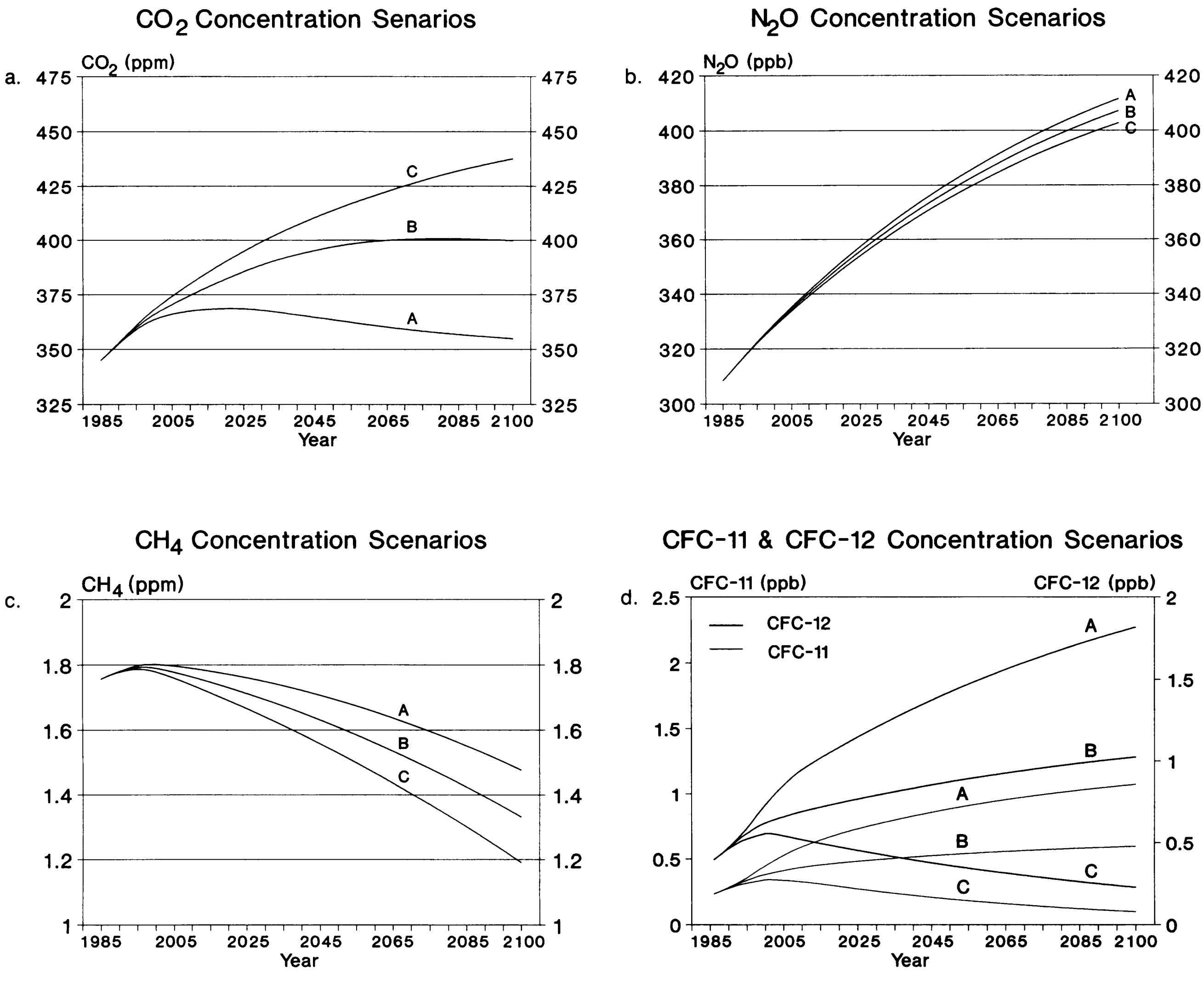


Table 2. Global mean surface temperature change (K) in 2100 relative to 1860, 1980 and 1985 for different scenarios and climate sensitives.

		Scenarios	4.5 K			3.0 K			1.5 K		
			1860–2100	1980–2100	1985–2100	1860–2100	1980–2100	1985–2100	1860–2100	1980–2100	1985–2100
ACE	1–3	C for CO_2; A all oth. gases	2.90	2.11	2.00	2.18	1.55	1.46	1.24	0.84	0.79
ACE	4–6	C for CO_2; B all oth. gases	2.61	1.83	1.72	1.96	1.33	1.24	1.11	0.71	0.66
ACE	7–9	B for CO_2; A all oth. gases	2.58	1.79	1.69	1.93	1.30	1.21	1.08	0.69	0.63
ACE	10–12	B for CO_2; C all oth. gases	2.01	1.23	1.12	1.49	0.86	0.77	0.82	0.43	0.37
ACE	13–15	A for CO_2; B all oth. gases	1.82	1.03	0.93	1.34	0.71	0.62	0.73	0.34	0.28
ACE	16–18	A for CO_2; C all oth. gases	1.53	0.75	0.64	1.11	0.49	0.40	0.60	0.21	0.15
ACE	19–21	C for all gases	2.33	1.54	1.44	1.74	1.11	1.02	0.98	0.58	0.52
ACE	22–24	B for all gases	2.28	1.51	1.40	1.70	1.08	0.99	0.96	0.56	0.50
ACE	25–27	A for all gases	2.09	1.32	1.21	1.55	0.93	0.84	0.86	0.47	0.41

Climate sensitivities

cluding the effects of the biosphere results in a significant underestimation. The atmospheric concentrations of CFCs, N_2O, and CH_4 have been calculated according to the methods described in Bach and Jain (30), Mintzer (31) as well as Rotmans and Eggink (32), respectively.

Figures 3a–d show the estimated concentration rate changes for the five major greenhouse gases. For CO_2, scenarios A and B stop the rise in concentration in 2030 and 2086, respectively, while in scenario C the rise continues to 2100 and beyond. In 2100 scenarios A, B and C have higher atmospheric CO_2 contents relative to 1985 of the order of 3%, 16%, and 27%, respectively, despite the rather drastic emission reductions until 2100 listed in Table 1. Because of the relatively long lifetime in the atmosphere of c. 170 years, N_2O does not reach any turning point until 2100 and beyond. Even substantial emission reductions (Table 1), in 2100 still lead to 30–33% concentration increases in scenarios C - A. CH_4 with only an atmospheric lifetime of ca. 10 years responds much more quickly. The concentration begins to descend in 1995,1997 and 1999 in scenarios C, B and A, respectively. Moreover, in scenarios A, B and C the 2100 concentration is respectively 16%, 25% and 32% lower than in 1985. Finally, it is important to note that Figure 3d shows the CFC concentrations in the troposphere. Emission phase-out scenario C in 2000 leads to an almost immediate reversal of the upward trend resulting in 2100 in a 57% and a 43% reduction for CFC-11 (lifetime c. 75 years) and CFC-12 (lifetime c. 110 years), respectively. Most significantly, in scenario A, in which all countries ratify the Montreal Protocol and take advantage of all legally permitted exemptions, and in scenario B, where people refrain from making use of any of the exemptions, by 2100 both CFCs will have increased 4.6-fold and 2.6-fold over the 1985 value. This very clearly shows how important it is to strengthen the present Montreal Protocol, which was done during the Summer of 1990.

Temperature scenarios. Comparison of different scenarios and climate sensitivities with the same model. The climate model we have used consists of a 1 D combination of a parameterized version of a radiative-convective model of the atmosphere (33) coupled to an energy-balance model of the ocean (24). The range of estimates derived from the current 3 D models suggests a climate sensitivity of 3.0 ± 1.5 K for a doubling of CO_2. To cover the total range of uncertainty we have made calculations for equilibrium temperature changes of Teq = 1.5, 3.0 and 4.5 K. Figure 4 shows a comparison of the observed global mean surface temperature given as anomalies from the 1950–1979 period (34) and the modeled anomalies for the indicated climate sensitivities as the upper and lower bounds. Considering that the modeled temperature curves reflect only the effects of the five man-made greenhouse gases, and the observed curve includes not only the natural climate variations but also all other anthropogenic influences (e.g. aerosols, land-use changes), it can be seen that, nevertheless, the overall trends are remarkably similar.

The scenarios listed in Table 1, in combination with the three climate sensitivities, result in 27 projections of global temperature as shown in Table 2. Recall that the intent of this scenario design was to come as close as possible to a global mean temperature rise of 2 K for the 4.5 K sensitivity, and 1 K for the 1.5 K sensitivity in 2100 as compared to 1860. Table 2 shows that, relative to 1860, the temperature increase falls between 0.60 K and 2.90 K. Together the various combinations provide a good assortment of possibilities from which decision-makers can make their choice. For target setting, decision-makers need time-dependent changes over a future course of change. This is demonstrated in Figure 5 for scenarios ACE 10 to 12, i.e. for the

Figure 4. Observed and modeled global mean-surface temperature anomalies from the 1950-1979 period.

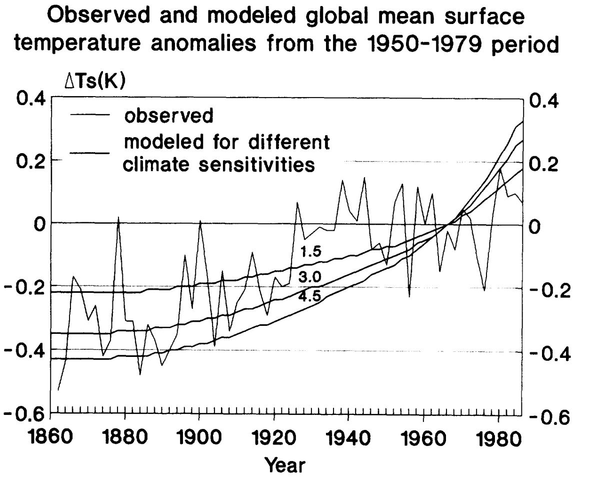
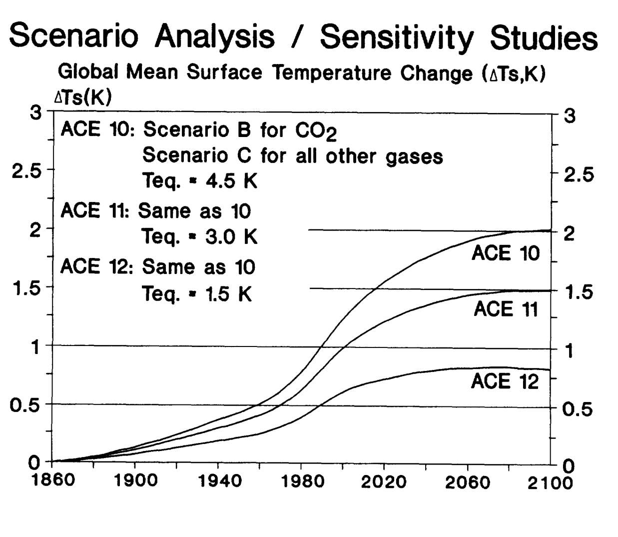


Figure 5. Estimated global mean surface temperature change for one scenario combination and different climate sensitivities from 1985 to 2100.



combination of scenario B for CO_2 and scenario C for all other gases as well as the three sensitivities 4.5, 3.0 and 1.5 K (Tables 1 and 2).

Temperature scenarios: Comparison of calculations with different models. Using the same scenario input, global mean surface temperature change has been calculated using the 1 D Max Planck Institute (MPI) climate model (16) in Mainz (35) and the Center for Applied Climatology and Environmental Studies (ACE) climate model in Münster (26). Figure 6 shows a sample run for scenario A. It can be seen that the MPI model run with a climate sensitivity of 2.0 K falls nicely between ACE model runs for climate sensitivities of 1.5 and 3.0 K.

Allocation of required emission reduction shares. This is one of the most difficult and sensitive parts of the climate protection strategy. Krause et al. (4) have used the Toronto proposal of a 20% gobal CO_2 emission reduction by 2005 to demonstrate the share in possible reduction targets. An upper warming ceiling of 2 K in 2100 permits only a cumulative emission of another 300 Gt C from 1985 to 2100. On a strict equity basis, considering past emission history and population distribution, the industrialized countries (ICs) would not be eligible for any additional carbon emission however small. Since this is not politically feasible, the CO_2 emission reduction plan shown in Figure 7 was worked out. It shows that a global CO_2 reduction to the 1985 value in 2005 requires at least a 20 % reduction in the ICs, while the developing countries, DCs, can increase their share by 60% - albeit starting from a much lower base. To secure the cooperation of the DCs and to make the indicated targets tractable, it is important that, as early as 2015, the DCs are given a larger share of the release cake than the ICs.

SUMMARY AND OUTLOOK

This study has been based on the premise that, in order to reduce the risk of impacts from climate-influencing greenhouse gases, it is necessary to adopt a climate-protection strategy. To become tractable, such a strategy requires a global warming ceiling for the protection of the Earth's climate. Such a warming concept rests on two pillars. The first pillar is provided by scenario analysis based on the best available climate models to derive the global emission reductions required by the warming ceiling. The second is provided by the best available systems analyses to derive a socioeconomically sound and politically feasible reduction menu that can meet the climatically-required emission reductions. This study has concentrated on some aspects of the climatic pillar.

The results of this research are summarized in Table 1. The specified CO_2 emission reduction scenarios A, B and C correspond to the conference statements of the 1988 Hamburg and Toronto Climate Conferences and the 1989 Noordwijk Environment Ministers Conference, respectively. For the first time, matching reduction schedules beyond 2000 and corresponding schedules for the other greenhouse gases are developed which meet the requirement that a warming ceiling of approximately 2 K in 2100 relative to 1860 is not exceeded. For the currently accepted climate sensitivity range of 1.5 to 4.5 K which reflects model uncertainties (the range is given in brackets) and the given scenario specifications, the total temperature change would be for the Hamburg scenario 1.55(0.86–2.09)K, for the Toronto scenario 1.70(0.96–2.28)K, and for the Noordwijk scenario 1.74(0.98–2.33)K. On the other hand, should the higher climate sensitivity prove to be more correct, and the more sophisticated 3 D climate models suggest this could be the case, then a stiffer emission reduction policy would be required.

Systematic work in this field has only just begun but it is bound to pick up momentum given the need for more specific information to aid the development of global Cli-

Figure 6. Estimated global mean temperature change (K) for different scenarios as calculated by MPI (Mainz) and ACE (Münster).

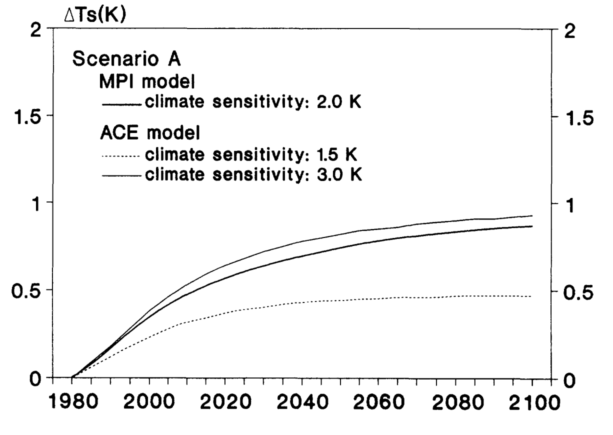
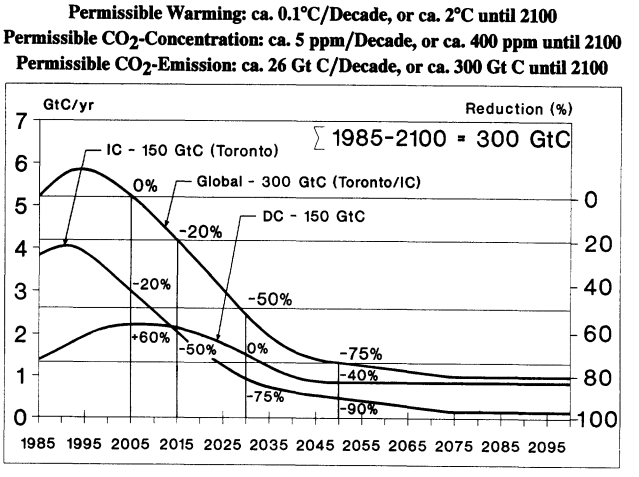


Figure 7. Estimated contribution of CO_2 emission shares to stay below a warming ceiling of c. 2 K in 2100 relative to the preindustrial level.



mate Conventions. There is a need for more contributions to this centenarian task, particularly at the national level. On the energy side, which is to assess the existing emission reduction potential, the Enquete Commission "Protection of the Earth's Atmosphere" of the German Parliament has commissioned a DM 5 million study the findings of which have made a major contribution. On the climate side, which is to assess the required emission-reduction potential, the necessary studies of similar magnitude have not yet been initiated.

As a society of climatically-aware individuals we are now faced with the consequences of our carelessness. An unprecedented challenge lies ahead of mankind. It remains to be seen whether we shall be equal to the monumental task of protecting our climate.

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