European Academy
for the Study of Consequences
of Scientific and Technological Advance
Bad Neuenahr-Ahrweiler GmbH

Director:
Professor Dr. Carl Friedrich Gethmann

Modelling Climate Change and its Economic Consequences - A Review -

by

Meinhard Schröder and Stephan Lingner (eds.)

June 1999

Graue Reihe Nr. 15

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Preface

This booklet documents the results of a workshop, organized by the European Academy, Bad Neuenahr-Ahrweiler on December 14-15, 1998. The workshop aimed at a review of goals, approaches, efforts and problems of scientific modelling considering its stringency and limitations for climate forecast and political advice, especially regarding the problem of action under prediction uncertainty. Corresponding contributions were addressed to following key issues:

- State-of-the-art and near-future perspective of climate (impact) modelling,
- current and principle limitations of prognoses for political advice,
- conclusions for mitigation.

The meeting contributed to an kick-off of the interdisciplinary research project „Climate Prediction and Precaution“ of the European Academy.

Trier and Bad Neuenahr-Ahrweiler, June 1998

Meinhard Schröder, Stephan Lingner

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Introduction. Climate Prediction and Precaution

Meinhard Schröder

The long-term variability of the climate and probable influence thereupon by human themselves lead us to suppose grave repercussions for man and the environment. These consequences will be particularly visible where life and economic processes make high demands on stable environmental conditions. In conjunction with possible, significant global warming in the 21st century, severe consequences are feared by large parts of the world's population with regard to health and the provision of food and drinking water. Migrations of peoples and resource conflicts could overtax the political routines for the solving of problems and give cause for international crisis.

Findings and projections on the part of research into climate and its consequences to date have for the first time led to the formulation of internationally binding commitments to reduce the emission of greenhouse gases. Questions, which for the time being remain unresolved (e.g. trading with emission rights), are to be dealt with in the near future. The legitimation of appropriate measures, however, is to be reviewed with regard to several points: Problem areas are the existing uncertainty in principle of climatological assessments, as well as ongoing controversial public and scientific debate, especially with regard to the consequences of a global change in climate and the conception and implementation of adequate interventionary controls.

This background gave reason for the establishment of an interdisciplinary working group on „Climate Prediction and Precaution", initiated by the European Academy. The project is aimed at working out rational, scientifically based statements with regard to dealing with the climate problem. Its duration is December 1998 to November 2000. The working group members are, as from December 1998:

- Professor Dr. jur. M. Schröder, University of Trier (Chairman)
- Professor Dr. rer. nat. M. Claussen, Potsdam Institute for Climate Impact Research
- Dr. rer. nat. A. Grunwald, European Academy, Bad Neuenahr-Ahrweiler

• Professor Dr. rer. nat. A. Hense, University of Bonn
• Professor Dr. phil. K. Ott, University of Greifswald
• Professor Dr. rer. pol. D. Schmitt, University of Essen

The project is managed by Dr. rer. nat. S. Lingner, European Academy, Bad Neuenahr-Ahrweiler.

Objectives and tasks

The basis of the interdisciplinary investigations will be a critical stocktaking of the current status of scientific knowledge with regard to future climate development and its consequences for society and the environment. Here we must, on the one hand, emphasise any firm insights from climate research and on the other determine any unanswered questions and gaps which exist in order to formulate any immediate need for action and/or further requirements for clarification and research. Further reflection from the point of view of science, philosophy of science, ethics, law and the economy is to analyse the criteria for action in the climatic context and produce a comparative evaluation.

In detail, relevant system interrelations between the human impact sphere and climate shall first be recorded. Based upon this, further analyses will give insights in conditions and implications for the possible application of the precautionary principle on the climate problem. Furtheron, it will have to be analysed , if and to which extend societies are capable to meet climate induced risks, and how these risks may be fairly distributed among them. This includes also the question of possible longterm obligations of our generation for safe-guarding of essential living conditions and business options of future generations. In conducting this research, conflicting goals in the protection of the whole environment and between climate protection and economic development will have to be addressed and evaluated. Finally, conclusions for the climate research and policy will be given.

The results of the interdisciplinary effort will be published in 2001 and will be addressed to the relevant disciplines, to the politics and to the public.

Understanding and Predicting Climate Change

Ronald G. Prinn

The possibility of significant climate change resulting from human activity is arguably the most challenging and most complex environmental issue facing the world over the next century. I will discuss this topic under a number of convenient headings.

Natural variability

Before addressing the possible human influences, it is important to emphasize that climate changes substantially due to purely natural processes. This natural variability operates on time scales from days to hundreds of thousands of years. These variations include changes associated with the weather, the seasons, El Niño and the Southern Oscillation, the North Atlantic Oscillation, the little ice age, the medieval warm period, and the great ice ages. To illustrate these changes on the longer time scales, we can examine in Figure 1 reconstructed temperature records for the present back to 250,000 years ago from the Antarctic (Vostok) and Greenland (Summit) ice cores. Shown there are temperature differences in degrees Centigrade from the present values based on Dansgaard et al. (1993). Note the partial north-south asymmetry of temperatures from the Greenland and Antarctic ice cores and the sometimes rapid changes on century-to-millennium time scales. The cold ice ages and warm interglacial periods like the Eemian (which was warmer even than today) are obvious at both polar regions. Humans played no role in these documented great climate changes.

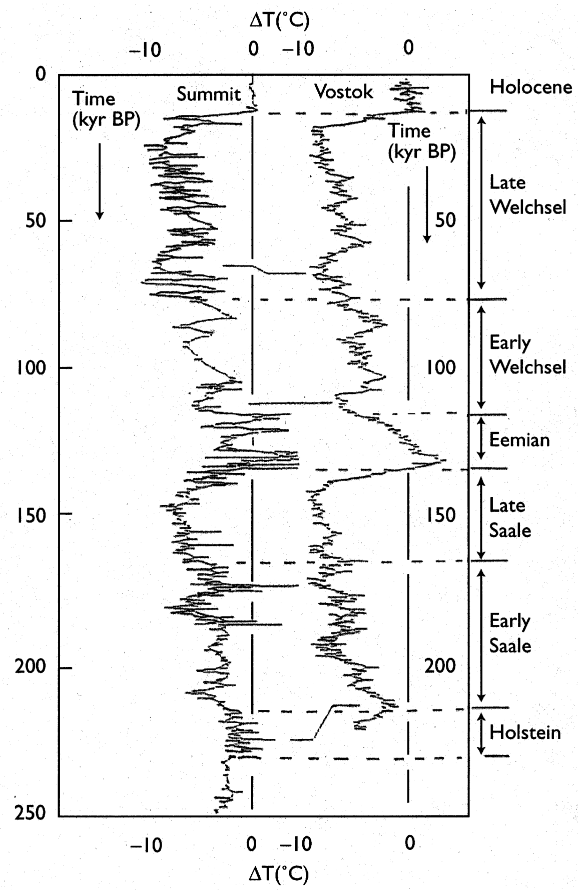

Figure 1. Climate records for the present back to 250,000 years before present (250 kyrs BP) from Antarctic (Vostok) and Greenland (Summit) ice cores. Shown are temperature differences in degrees centigrade from the present (Holocene) values at each site. [from Dansgaaed et al., 1993].

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Quality of climate models

To predict climate, scientists use climate models of great complexity which challenge the computational power of the world's fastest computers. First, I want to emphasize that the greenhouse effect due to rising greenhouse gases is real, but the magnitude of the response of the climate system to these gases is uncertain. This uncertainty is due to our incomplete understanding of the oceans, clouds, aerosols, and other factors in the climate system. The difficulty is that a wide range of plausible forecasts exist, and to illustrate this I am going to show you later some sample forecasts. What I am going to say from the beginning is that we need to take account of the uncertainty in the climate forecasts when talking about policy responses.

What is required to improve these forecasts? In general better climate forecasts will require improvements in these key issues:

(1) The way we handle the oceans, particularly the deep ocean circulation. The ocean carries heat from equator to pole and from the surface to the deep ocean, thereby delaying the warming (or cooling) of climate. It also absorbs carbon dioxide and takes it to great depths, thus acting as a temporary sink.

(2) The way we handle sulfate aerosols. These are very tiny suspended particles in the atmosphere that are different from clouds in an important way. Aerosols, like clouds, can reflect sunlight into space, but unlike clouds, they are too small in size to contribute to the greenhouse effect. Sulfate aerosols cool the earth.

(3) Clouds reflect sunlight into space and they also contribute to the greenhouse effect. Of course, reflecting sunlight into space cools the earth while the greenhouse effect is a warming influence. So while aerosols are one-way, specifically a cooling mechanism, clouds are two-way. They cool by reflection of sunlight and they warm by contributing to the greenhouse effect.

(4) Glaciers are an important part of the climate machine. They are very good at reflecting sunlight into space because they have very bright, white surfaces. But they also store huge amounts of water, and that water, if it is released, will increase sea level. And so any prediction of sea level in the future has to take into account the way glaciers work. Glaciers are very complex. They are not static but, on time scales of centuries to millennia, they are very dynamic.

(5) Then there is the issue of chaos. We know that the system of equations that we solve to predict weather is chaotic. That was

discovered by Edward Lorenz at MIT in the sixties. He had that famous saying: „could the flap of a butterfly's wings in Brazil cause a tornado in Texas?“ And according to his work the answer is yes, it could, and it does in current weather prediction models but not quite in those very specific terms. We do not know whether the climate equations contained in coupled ocean-atmosphere climate models are also chaotic on the time frame of decades to centuries. That is research that needs to be done, I think, as soon as possible. To see if it is chaotic, we start with an initial condition for the ocean and the atmosphere today, and we run the model, and look at what its climate prediction is, say for the year 2050. Then we change the initial state by amounts well within our uncertainty in knowledge about the current state of the ocean and the atmosphere, and run the model to get another forecast. We do about ten or fifteen of these runs and see whether they look similar or quite different. If they are quite different, then, of course, we are in trouble. It is a signal that the system may be chaotic on the time frames we are interested in.

(6) And that leads us to a related issue which is predictability. Is climate on the time frame of a decade to a century even predictable since we cannot define the initial state of the ocean in particular with very great accuracy? The deep ocean has been probed over a period of twenty or thirty years by a few ships, going up and down the world's oceans, and they are watching a system that is changing while they are measuring it. And so, if they come back ten years later and do another measurement, there is a change. It is different. And with that sparse sampling they are supposed to define today's deep oceans.

Impacts of climate change

I want to emphasize that the forecasts of the impacts of climate change are even more uncertain than the climate forecasts themselves. In other words, the effects of a climate change – even if we believe the climate forecasts – are poorly understood. What is the effect of climate change on natural land and oceanic ecosystems? These natural systems are huge parts of the world's biosphere, and they are vulnerable to local, regional or global climate and air quality changes.

We also need to be very concerned about the stability of the great ice sheets, particularly Antarctica and Greenland. Many of you may have read stories about the West Antarctic Ice Sheet, and the controversies among glaciologists as to whether it is stable or unstable. The West Antarctic Ice Sheet contains enough water to cause sea level to rise about five meters. The chances of it being unstable, by the way, are very slim, based on current understanding. The impacts of climate change on coastal regions are also of special concern. Critical questions involve sea-level changes and changes in severe storm frequency and amplitude. We do not know the answers to these questions at the present time.

Finally agriculture, of course, is vulnerable to climate change but particularly agriculture that is rain-fed. Irrigated agriculture in very advanced countries is much more adaptable, but rain-fed agriculture, particularly in developing countries is very vulnerable to changes in climate.

MIT Model

To illustrate climate forecasting, I am going to use a model that we have developed at MIT. We call it the Integrated Global System Model (IGSM, see Figure 2). If we want to predict climate for the next fifty or a hundred years, we cannot just assemble a group of climate scientists to do this. We need to know also what the emissions are going to be of all of the climate-relevant gases – not just carbon dioxide but also methane, chlorofluorocarbons, nitrous oxide, hydrofluorocarbons, hydrochlorofluorocarbons and many others. Therefore, to predict climate we must also predict the world's economies and their associated emissions. Henry Jacoby is going to be talking more about that aspect this afternoon. I am going to focus on the climate science in my talk here. Later I am going to show you seven climate forecasts from the IGSM, but let us first go over quickly the elements of the IGSM. There is an economic model called the Emissions Prediction and Policy Analysis (EPPA) model, which addresses twelve major economic regions in the world. It predicts not only economic development but also the emissions of key gases (carbon dioxide, methane, etc.), which are long-lived greenhouse gases, and also short-lived gases (nitrogen oxides, etc.) that are important in the chemistry of the atmosphere and help determine the lifetimes of long-lived gases. A very important short-lived gas is sulfur dioxide, because it is the source of the aerosols mentioned before. Sulfur dioxide comes mainly from coal burning. These various emissions are fed into a coupled model of atmospheric chemistry and climate. This is the most complex part of the Integrated Global System Model. It handles the ocean carbon cycle internally, it has a fully coupled atmosphere and ocean in it, and it predicts all of the usual climate variables: temperature, rainfall, clouds, CO_2, sea level, and many other quantities. These climate variables, in turn, are used to derive a Terrestrial Ecosystems Model (TEM). This model was developed at the Ecosystems Center at Woods Hole which participates in the integrated global system modeling program at MIT. TEM predicts the state of ecosystems, with critical variables being the net primary production of those ecosystems, the amounts of carbon in the vegetation, the amounts of nitrogen in the soil, and many other variables that tell us the state of land vegetation. Both the ecosystem model and the climate model drive a natural emissions model. Two gases, methane and nitrous oxide, have large natural emissions. If we look back in ice cores up to 250 thousand years old, we see little trapped bubbles of air and in those trapped bubbles of air are methane and nitrous oxide and, of course, carbon dioxide (CO_2). These gases were around long before humans had any effect on the system. So we must model the natural emissions and then compare them with the human-driven emissions. Then there are a variety of feedbacks that you can look at. For example with rising CO_2 the land vegetation can take up the carbon dioxide and so that is a sink for carbon dioxide in the context of this model. Solid lines in Figure 2 show included feedbacks, whereas dotted lines are feedbacks or connections that we are in the process of making, but they are not yet completed. I think there is no doubt that the MIT IGSM is the most complex model of its type in the world. For each of the models that we see in Figure 2 we have a group of experts, and so we should think of the MIT effort as comprising a group of cooperating experts. There is no one person with broad enough knowledge to be able to understand all of this. Henry Jacoby and I will occasionally give talks and unwittingly give the impression that we know everything. In fact, we are experts only in a particular area. The power of the effort lies in the fact that we have experts in all of the key areas, who are working together. The complexity is so great that this is the only way, in our opinion, to approach the study of a such a complex system.

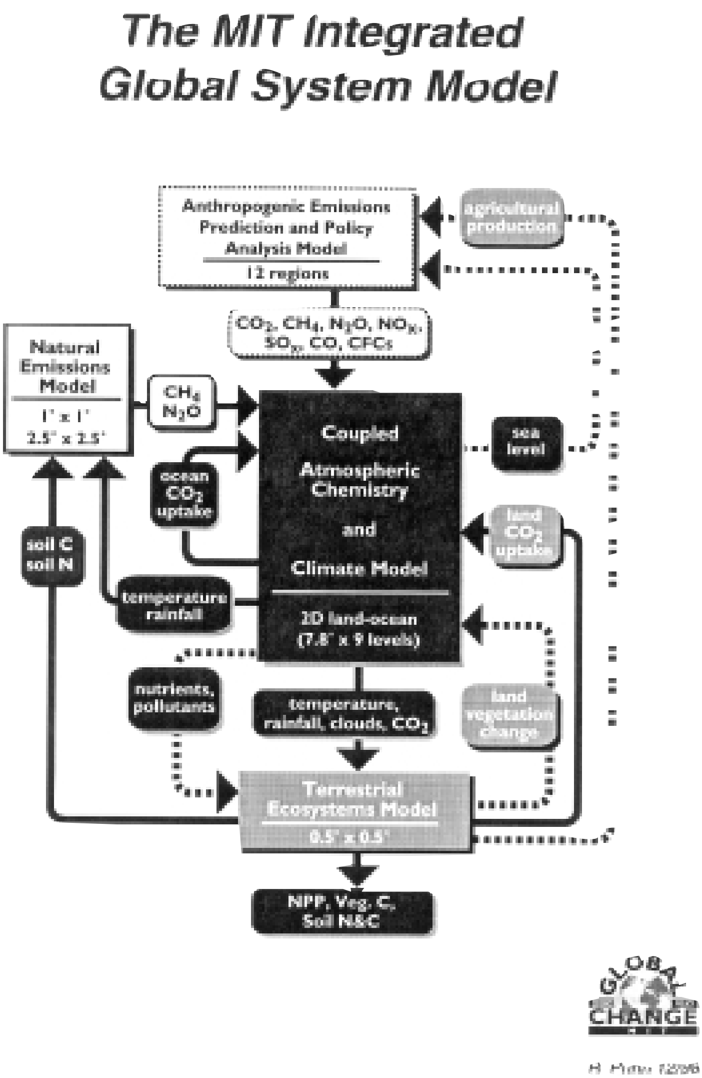

Figure 2.

A sample forecast

Outputs from a sample run of the IGSM are given in Figures 3 and 4. Output from the economic model are emissions as a function of time from 1990 to 2100 of all of the relevant gases. Here is one particular prediction for CO_2, methane, nitrous oxide, sulfur oxides, nitrogen oxides, and carbon monoxide. The dotted lines we see here in Figure 3 are the current-day natural emissions that have been estimated. We see for some of them that the natural emissions are small relative to human-driven emissions, while for others, like nitrous oxide, the natural emissions are comparable or more than the human emissions.

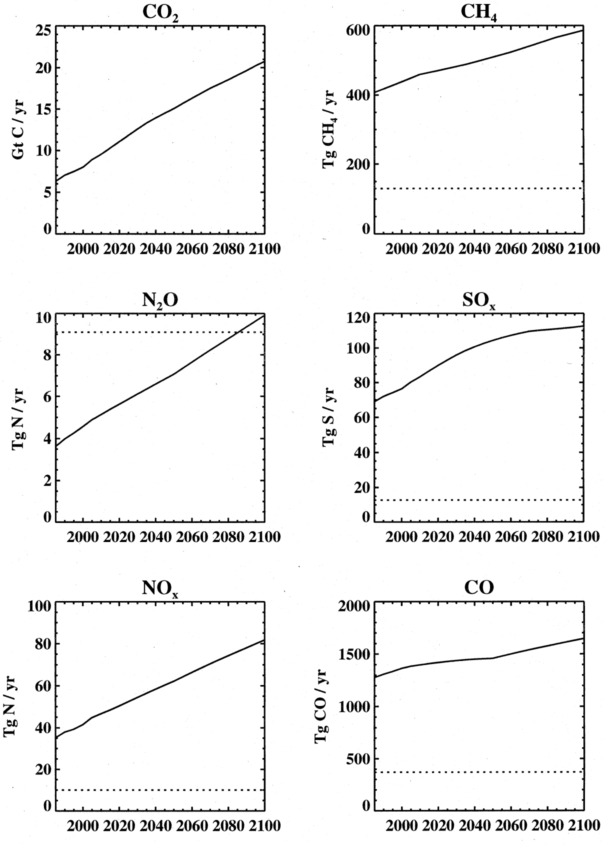

Figure 3.

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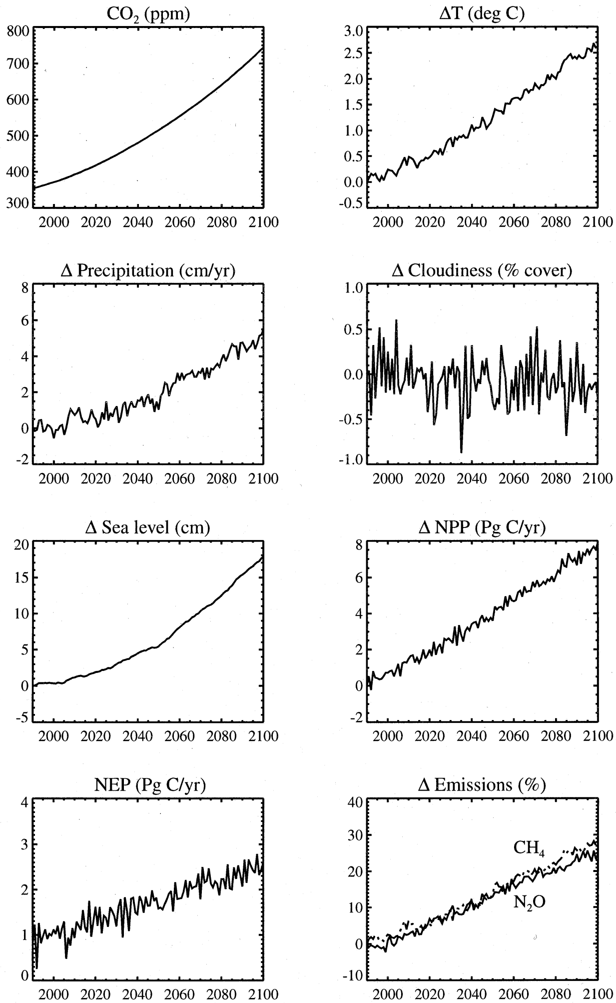

Figure 4.

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The coupled chemistry-climate model predicts atmospheric CO_2 levels as shown in Figure 4. To predict CO_2 we also need to predict or specify the uptake of carbon by the ocean and the land and that is done in the model. Next is the temperature, which in Figure 4 is the global average from the model. The precipitation which is predicted in this run of the model actually increases by a small amount. Shown also is the difference between predicted precipitation in the year of interest and 1990 precipitation. Because precipitation globally averages about one meter per year, we can see we predict about a five percent increase in the global amount of precipitation. Cloudiness is bouncing around in this forecast in Figure 4, and not doing anything in particular. Sea level is increasing. This is sea level due only to the thermal expansion of the ocean. It does not include the melting of ice sheets and mountain glaciers, which is not currently in the model but will be incorporated shortly. Shown next is the net primary productivity of the land ecosystems, which as we see, increases by about 8 gigatonnes (or 8 petagrams) of carbon per year relative to 1990 levels. Net ecosystem production, which is the net uptake of carbon by the land system, is positive and predicted to be one gigatonne per year in 1990, and is rising to about two and a half gigatonnes of carbon per year in 2100. Why did the model's land biosphere respond in this way? Because the fertilization effect of rising carbon dioxide on photosynthesis overwhelmed the detrimental effects of increasing temperature and changing rainfall patterns on the land ecosystems when they are globally aggregated. But are we handling the CO_2 fertilization effect properly? We do not know. People do it as best they can and so we have to look very carefully at results like this and do more research. Finally Figure 4 gives us news that we have to consider bad news. The natural emissions of methane and nitrous oxide grow about 30 percent in the time frame from 1990 to 2100. Why do they rise? It is because the natural emissions are very sensitive to temperature and rainfall. More rainfall and higher temperatures lead to more natural emissions. Therefore, this is a positive feedback in the natural system. It gives us a flavor of the way we are trying to include every process for which we have some reasonable level of understanding.

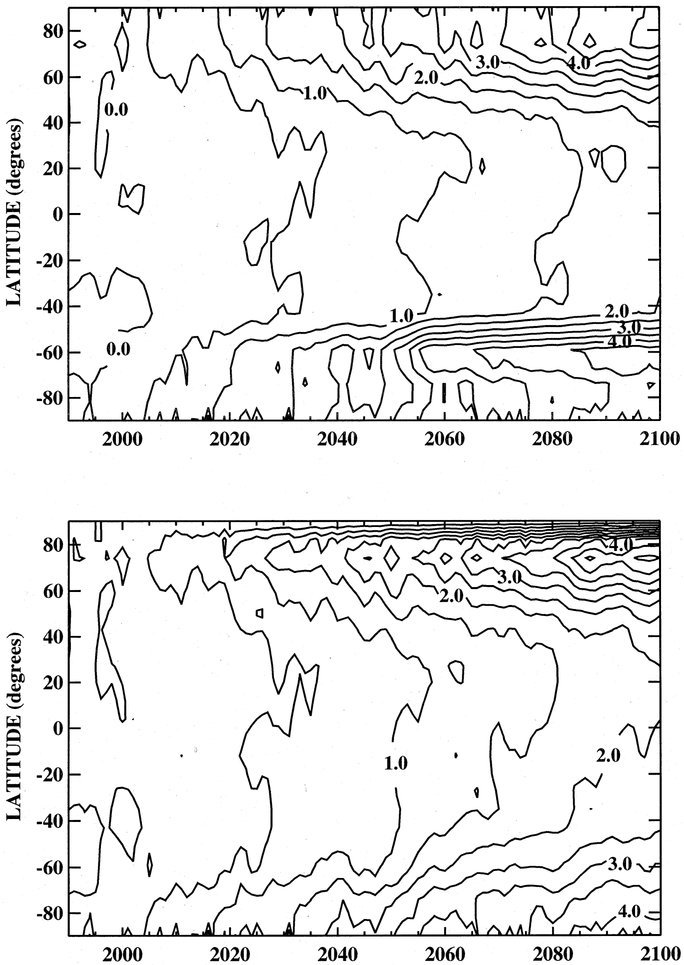

Figure 5. Changes in longitudinally-averaged surface temperature (°C) from 1990 levels for land and ocean (upper panel), and land only (lower panel), are given as functions of latutude in degrees, with positive values in Northern Hemisphere and negative values in Southern Hemisphere and time (in years). [Prinn et al., Climatic Change, 41, 469-546, 1999]

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So far I have shown only global averages. Figure 5 shows temperature changes from 1990 as a function of latitude. At the top is the average temperature change of the land and ocean at each latitude and at the bottom of the land only. We see that the temperature rises in the tropical regions and increases by perhaps one-and-a-half to two degrees by

2100. But the northern polar regions warm much more rapidly, getting up to four or four-and-a-half degrees warmer here than in 1990, and similarly in the southern hemisphere. This is very common behavior seen in all climate models. They show stronger heating at the poles than at the equator. I will not go into all of the reasons why this occurs, but one reason is that the ocean plays a significant role in the system. But in our model another important role is played by aerosols. We have aerosols being produced in the northern hemisphere, which makes the northern hemisphere cooler than it would otherwise be. The oceans and aerosols in combination are making the high latitudes different from the equator and the northern hemisphere different from the southern hemisphere. But our result is a typical result. I could have shown a similar result from the Max-Planck Institute models, the NASA models, and the UK Meteorological Office models.

Model flexibility and uncertainty

I want to comment briefly about certain unique aspects of our coupled chemistry-climate model. It predicts both atmospheric circulation and atmospheric chemistry predicted. It includes ocean circulation, but treats it in a very simple way compared to the atmospheric component. This model was put together to be flexible. We have versions of this model that behave similarly to each of the big climate models around the world. For this purpose we need to define the sensitivity and strength of vertical ocean mixing of each climate model such as the Max-Planck (Hamburg) model. The sensitivity to a scientist is defined as the difference in temperature between running the model to equilibrium at today's levels of CO_2 (or sometimes pre-industrial levels), and then to equilibrium with double that amount of CO_2. Models vary in their sensitivity by a factor of three or more from the lowest to the highest. What is less well realized is that the different models also have a remarkably different rate of uptake of heat and carbon into their oceans. So climate models differ in a big way in at least these two variables. And the special thing about our model is that we can vary the way we handle the ocean mixing and the sensitivity.

The big determinant of sensitivity in particular is the way we handle clouds and water vapor in the model, which is governed by convection and larger scale circulation. So in the MIT model, we can change both the sensitivity and the way the ocean is handled, and thus produce a whole variety of versions of it. Why is that so important? It is because uncertainty is huge in this problem and we cannot rely on one single climate model and say that is a benchmark. We are much better off trying to see the full range of uncertainty.

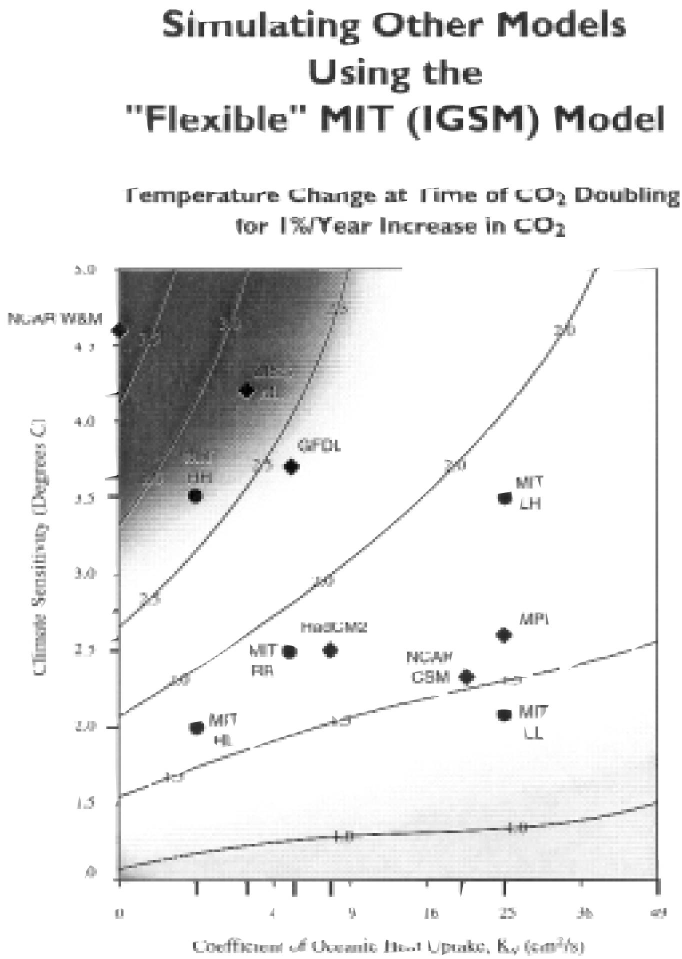
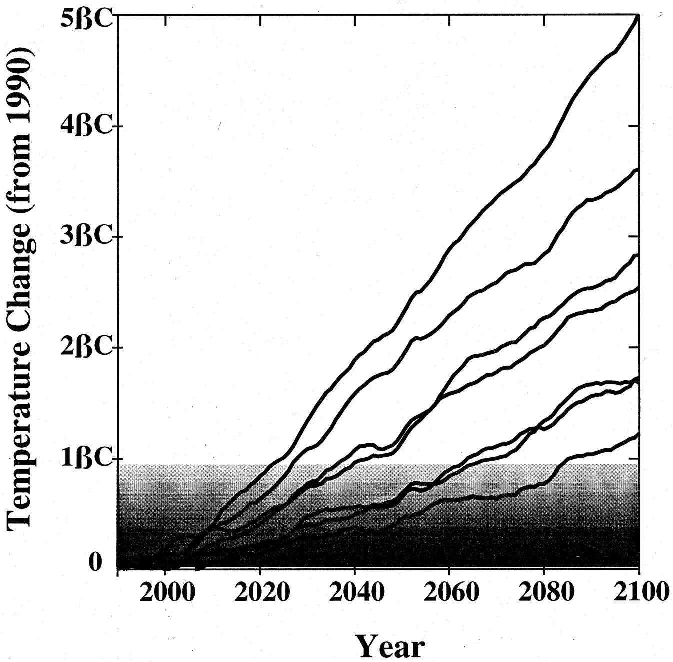


Figure 6.

I am going to refer now to Figure 6 which gives us a sense of the huge differences between climate models that exist today. This is just a sample of them. The vertical axis in Figure 6 is climate sensitivity. This is the sensitivity of the National Center for Atmospheric Research model (CSM as it is called). Here is the Max-Planck Institute model (not the latest version, but the IPCC 96 version). Here is the Hadley Center model. Here is the Geophysical Fluid Dynamics Laboratory model from Princeton. Here is the NASA-GISS model and here is an early National Center for Atmospheric Research (W and M) model. On the horizontal axis is an ocean circulation intensity parameter. The way we simulate the ocean behavior of other models in our model is to vary the vertical coefficient of heat uptake in our ocean. Here we can see a measure of how rapidly the ocean in each of these models is mixed vertically. So the bigger the mixing coefficient, the more rapidly that model is taking up heat and carbon. What is remarkable is that there is a model over here whose ocean is essentially not taking up any heat, and there is a model over here, a very different model, but developed at the same Center, taking up heat very rapidly. And then we get everything else in between. It is well known that the version of the Max-Planck Institute model shown here is taking up heat probably faster than we could, in fact, justify. We do know roughly how rapidly water from the top of the ocean goes to the bottom because we can look at transient tracers like tritium and chlorofluorocarbons that were put into the atmosphere from nuclear bomb explosions and refrigerators. These suggest that valid values of this parameter for ocean mixing lie in this middle range here rather than up above. The contours in Figure 6 are the temperature changes at the time of CO_2 doubling in a transient experiment in which we run the models for 70 years with one percent per year increase in carbon dioxide. Now we are getting closer to the experiment that we want to do for predicting climate. At one percent per year we get doubling of CO_2 after 70 years, approximately. So the CSM predicts a warming of about 1.5 degrees Centigrade, while the Max-Planck Institute and Hadley Center models are getting, say, between 1.6 and 1.8 degrees. This GFDL model here is predicting close to 2.4 degrees warming, the GISS model predicts about 2.8 degrees, and finally the NCAR W&M model predicts a warming above 3.5 degrees.

If we read the IPCC 1996 report, we see much discussion of the differences between the sensitivities of the various models, and it was pointed out that there was a range, say between 1.5 and 4.5 degrees Centigrade in the sensitivity of these models. From this alone it was not clear why some models were much cooler in their predictions than others. The further we are along this horizontal axis, the cooler are the predictions (in Figure 6 the regions shown as blue are cool and those that are red are warm). We can see from Figure 6 that we need to specify or understand the way that each model handles both the ocean and sensitivity. Clouds – I am putting this rather simply – are a big determinant of climate sensitivity. So the importance of sensitivity has been emphasized correctly by the IPCC. But not much emphasized by the IPCC in their 1996 report is the fact that there is a big range in the rapidity of heat uptake by the oceans in various models. And that is just as important on the hundred-year time frame, as worrying about clouds and convection. So we must put both of them together. The important point here is that we can mimic or simulate any one of these models with the flexible MIT model. Very importantly, that enables us to look at the problem of uncertainty. We do not want to believe or disbelieve any one model. I want to stress that, in fact, the truth lies somewhere in this vast region in Figure 6 – and I am being rather vague about where this vast region is. We can see it is much better for me to talk about probability or sensitivity analyses than to try to pretend that one model or another is the best model. I do not know which is the best model.

Sample Forecasts of Future Temperature Change *



* extreme forecasts less probable than central forecasts

Figure 7.

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Some plausible forecasts

Here in Figure 7 are seven sample forecasts produced by the MIT model. To produce these seven forecasts we took some alternative but defensible choices within the economic model, and the chemistry-climate model. For each uncertain parameter in the models we had three choices: one we call the reference (R) choice, one we call lower (L) and another one we call higher (H). Lower means it led to lower temperatures predicted in the year 2100, and higher means it made those temperatures higher. The choices were made by the experts in each of the modeling groups. It is impossible, of course, to do this completely objectively. It was done subjectively by the experts. By combining high, reference, or low choices in the various models we can produce a specific forecast. Hence we might have a forecast that took economic projections with an assumption of a low rate of technological advance due to new inventions, and a high price of (backstop) technologies that would be useable in the future which do not have carbon emissions associated with them. In the climate model, we could take a version of our flexible climate model that has rapid ocean heat uptake, similar to that of the Max-Planck model, combined with a low climate sensitivity and strong cooling effects by aerosols. Obviously, I could show hundreds of such runs but I show in Figure 7 just seven carefully chosen examples intended to illustrate the range of the full set of potential forecasts. The sensitivity and oceanic heat uptake parameters for the five versions of the climate model used in the forecasts are shown in Figure 6 (RR, HH, HL, LH, LL). Another important constraint that we have on forecasts shown here is that the climate model settings must provide simulations for the temperature rise over the past 140 years which are not in obvious conflict with the observations of past temperatures taking into account observational uncertainty. We can see that one of the forecasts shows a warming between 1990 and 2100 of only a little over one degree Centigrade while another forecast shows five degrees Centigrade. Realizing from Figure 5 that the polar temperatures increase more rapidly than the equatorial temperatures (what I have shown in Figure 7 is the global average), this five degrees Centigrade global warming corresponds to nine to ten degrees Centigrade warming at the poles. As a scientist, I would be deeply worried if that forecast were correct. At the same time, to provide the opposite side of the coin, if the one degree Centigrade forecast is correct, I could argue that this is similar to what has happened in the last 140 years and the world has survived that amount of warming. If this low warming forecast is correct and all the others are wrong, then there are plenty of other environmental problems that we ought to instead worry about. Of course, the extreme forecasts are less probable than the central forecasts, because they combine lower probability choices together. This is the dilemma that faces us. Some people say they can defend this low warming forecast and therefore we shouldn't be worrying about it. But others can point to the high warming forecast and say it would be catastrophic and we must take major action right now to avoid such an outcome.

Fingerprints of human influence

I have already made the point that climate changes substantially due to natural processes. I have not dwelled on the evidence of significant human influence on the warming over the past 140 years. What is particularly important is not just human influence but a distinct greenhouse gas fingerprint. The 1996 IPCC Summary for Policymakers when it referred to human influence was talking about the combined effects of warming by greenhouse gases and cooling due to aerosols. Because the aerosol effects are so uncertain, and because we need to model natural variability very accurately, the issue of the greenhouse gas fingerprint is presently being publicly debated among scientists. I think it is fair enough to say that the answer is not yet in as to whether the greenhouse gas fingerprint has been quantitatively and unequivocally, in other words without argument, discerned by scientists. There are still a lot of disagreements among groups. But there is no doubt about the fact that the warmer the forecast the sooner the detection will occur in the future. The good news is that there are a lot of groups now working on this issue of detection. It is not the most important scientific question, but it is significant because detection potentially enables us to assign some numbers to how rapidly the ocean takes up heat, to better constrain the role of clouds, and to assign some numbers to the role of aerosols. I mention those three items as arguably the three greatest uncertainties in trying to do fingerprint analysis.

My personal feeling is that, of course, there is a human influence on climate because we are producing carbon dioxide and other greenhouse gases and their atmospheric levels are visibly increasing. However, the real issue is how the human influence compares to the natural variations. Is it a big natural signal and a very weak human signal, or vice versa? To answer this question, one of the biggest difficulties right now is that we cannot model well the natural variations in climate. I pointed that out at the beginning of my talk in a summary sort of way by saying we cannot model the changes during the ice ages and warm interglacial periods. If we cannot model the behavior of climate in the absence of human influence, that is model the noise or natural variability in the system, then detecting the signal of human influence by comparing uncertain models with observations is obviously difficult. But there are, in principle, statistical methods by which we can look at the patterns in space and time and how they change and ultimately, with better models, discern how much of what we see is human influence and how much is natural variability. I think that is where we are heading at the present time. I think most responsible scientists realize that there is a human influence. The trouble is, is it five percent of what we see? In that case it is not a big issue. Or is it twenty of thirty percent of what we see? If so, we begin to get worried about it.

Again, the good news is that now there are now many more groups working on this issue. While there is still going to be a lot of debate, there is growing appreciation of the fact that the fingerprint of interest is not just that of all human influences combined, but rather the individual quantified fingerprints of greenhouse gases, aerosols, ozone, and land-use changes. In this way we can sort out what the most important human influences really are.

Needed policy response

A question often asked is, „Is action required now?“ One viewpoint that you hear, although lately less and less, is that the forecasts are uncertain and more research is needed to provide a sensible basis for policy action. A second viewpoint, which reinforces that conclusion, is that predicted warming depends on the accumulated emissions over the long term. Higher near-term emissions can be offset by lower emissions later on for CO_2 and other long-lived greenhouse gases. However if we choose to increase emissions in the near-term we must be prepared for the likelihood that we may have to drastically reduce those emissions later on. It is the total accumulated emissions over the hundred years of these forecasts that really drives the climate predictions. The predicted climatic differences resulting from choosing different economically feasible ways of distributing the emissions over the hundred-year time frame are quite small. In fact, we are slightly better off putting all of the CO_2 emissions in the beginning, because that gives us maximum uptake by the oceans so that by the year 2100 we will have less CO_2 in the atmosphere than we would otherwise have. So these two viewpoints argue that we need not take action right now.

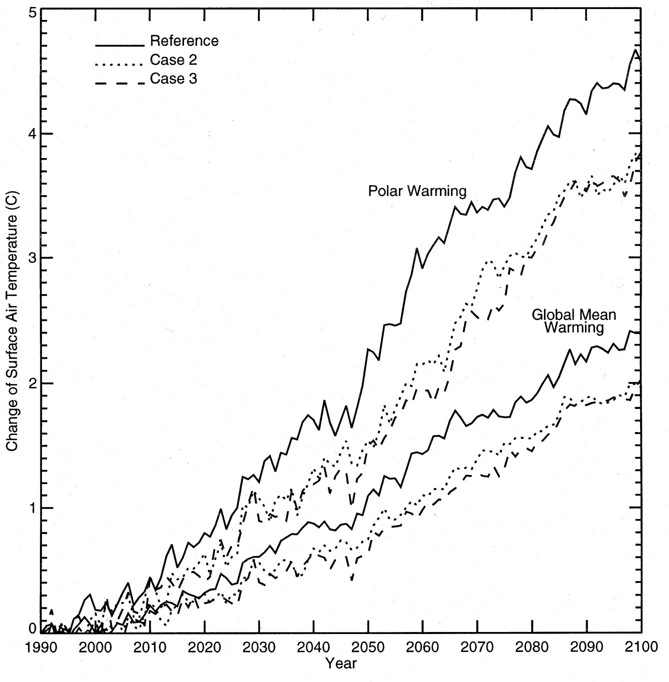
On the other hand, there are also compelling reasons why we should be taking action right now. Here are three very important ones. First, the long-lived greenhouse gases will last decades to centuries in the atmosphere. It is not a case that when the human fingerprint is considered unequivocal and forecasts of warming are considered accurate and substantial, we can simply go charging ahead and do something about it. The CO_2 that is already there is there for another 50 to 150 years. I give that rough range because it depends on the way that the ocean and the land systems take up that carbon. The point is that we cannot quickly eliminate the problem by stopping emissions. The greenhouse issue is not like the acid-rain issue in this respect. Once we decided to lower sulfur emissions in the acid-rain context, within a few weeks sulfur dioxide and sulfate levels in rainfall dropped nearly back to the natural values. We do not have that luxury in this case. Once CO_2 is in the atmosphere, it will remain there for generations to come.

Second, we know the energy infrastructure has long turnover times. If we were to try to turn over the entire energy infrastructure in five years it would be unbelievably expensive. But if we could turn it over in a time frame of fifty years or so, and we knew why, and what would be achieved by doing so, then it makes sense to start making changes sooner rather than later.

Third, and very important from my viewpoint, is that scientists cannot rule out the rapid warming forecasts that I discussed from the MIT model or similar ones from other models. By rapid, I mean a warming of three to four degrees Centigrade or more by the year 2100. Therefore I would argue that we should something, because, while I cannot tell you that those are the correct forecasts, I cannot rule them out. So there is no doubt in my mind that some action should be taken now. The important question then becomes exactly what sort of action should be taken now? Is it the Kyoto Protocol or something quite different?

Kyoto Protocol analysis

I have so far shown some results from our Integrated Global System Model that pertained to this issue of uncertainty in the climate forecasts and the implications of that uncertainty for action. I now want to show how we use our modeling system to look at a proposed policy, specifically the Kyoto policy. I won't go into all of the details of how we handle this – how in the economic model we incorporate the Kyoto protocol restrictions, and what we assume after the year 2010. Kyoto only goes through to the year 2010 (or more strictly the 2008–2012 time frame). The assumption made is that the regulated (Annex B) countries will maintain their 2010 obligations for the rest of the century. And, of course, developing (non-Annex B) countries have no restrictions. So with those assumptions we predict greenhouse gas emissions estimates through to 2100 and input them into the climate model. I show in Figure 8 the resultant temperature projections. I specifically show temperature projections for a reference case, which did not include Kyoto, and temperature projections for two other cases which do include Kyoto. I could show many other variables that we predict in the MIT modelling system including rainfall, sea level and net primary production from ecosystems. But given the time available here I am just going to show temperature. This is one way in which we can judge the effectiveness of the Kyoto protocol.



Average global and polar regional warming trends in reference and Policy Cases 2 and 3 runs.

Figure 8.

R. Prinn 12/98

Figure 8 shows changes in average temperature relative to 1990. This is the base year of the climate convention, and we decided 1990 was as good as any other base year for discussing warming. The global mean warming is shown in three sets of curves and the polar warming in another three sets of curves. I emphasized earlier that polar warming is more rapid than the global average, which is in turn more rapid than the equatorial warming. Among these three curves, the reference is the solid line and then the other two (dashed and dash-dot) lines are simulations of the Kyoto Protocol done in two ways. There is one in which all the gases are controlled, including hydrofluorocarbons, sulfur hexafluoride, and perfluorcarbons as well as methane, nitrous oxide and CO_2. The other one has controls only on CO_2, but uses what are called global warming potentials (GWPs) to convert any other reduction that a country has, say in methane, into an equivalent amount of CO_2. And so the difference between these two approaches from a scientific viewpoint hinges on whether including or excluding chemical interactions in the atmosphere causes a difference. In the reference run in the year 2100 it is about 2.4 degrees Centigrade warmer than 1990. With the Kyoto Protocol, as I have defined it, going through to 2100 we see that we have lowered the warming from about 2.4 to about 1.9 degrees Centigrade. So we don't lower the warming drastically but lower it a little. So Kyoto simply extended to 2100 does not solve the problem at all. Temperatures are still rising, albeit not quite as rapidly. The extended Kyoto has a bigger effect measured in degrees Centigrade in the polar regions, where, as we see here, the reference run shows a warming of about 4.6 degrees Centigrade. The polar region is defined as the areas poleward of 50 degrees north or south. With the extended Kyoto the warming is lowered to about 3.8 degrees Centigrade in that region. This is significant because these are regions which we ought to be concerned about (i.e. they contain the natural tundra ecosystems and the great glaciers). Even in these polar areas, what we take away from this analysis is the firm conclusion that Kyoto even extended to 2100 does not do very much. It just slows warming down a bit, but the warming is still going to occur. I realize that many argue that Kyoto is merely the first step, but any truly effective steps beyond that would require all nations to participate – the current negotiations are far from being focussed on that requirement.

Limits to predictability

I want to end by discussing possible limits to predictability of climate. Natural variability is folded into this. We do know that the phenomenon of chaos compromises our weather predictions. An important question is whether it also compromises climate predictions. Now the problem with studying possible chaos in a huge coupled chemistry, ocean, atmosphere, biosphere, climate model is that we do not have enough computer time. Dealing with the issue of whether the system shows chaos requires in part hundreds of runs, basically with different initial conditions. We also need to have a very careful consideration of what different initial conditions could be justified on the basis of the current observing network. So far the needed work hasn't been done, so it is a big question mark. If the system is chaotic, that may say that we do not have much capability of predicting on the decade-to-century time frame.

Quite apart from the issue of possible chaos, current climate models are far from perfect and need improvements in several areas. I will close with a summary of some of the critical research areas.

(1) Clouds and convection. We model clouds and convection using models in which the distance between points where the calculations are done can be a few hundred kilometers apart. But we all know that clouds and convection have scales of one to ten kilometers. So we are trying to simulate something of small scale in a domain in which these small scales are not resolved. We need to improve model resolution as well as our understanding of the physics of these processes and how to model them.

(2) Aerosols are a huge question mark. How big is the cooling effect of aerosols? Pure sulfate aerosols reflect sunlight back into space. There is no doubt about that. There are some things we do understand. But there is a key question. When we throw sulfate aerosols into an existing cloud they will take up water vapor. What should then happen, is that from the same volume of water we have in that cloud we will create more cloud particles. Water vapor evaporates off the existing droplets and condenses onto the sulfate aerosols we threw in. We will now have more numerous but smaller droplets. That cloud should now reflect more sunlight into space and this so-called „indirect effect“ can increase the overall effect of aerosols very significantly. The „direct effect“ is where the pure aerosols themselves reflect sunlight out to space.

(3) I have already mentioned the importance of the deep ocean circulation and ocean-atmosphere coupling. In the context of chaos or

otherwise, errors in defining the initial state of the ocean compromise decade-to-century time scale predictions. We will be faced for decades to come with the fact that the initial state of the ocean is not well defined.

(4) I have also already mentioned the fact that a lot of groups are working on definitive detection and calibration of the human influence, particularly the human-produced greenhouse gas fingerprint. Achievements in this area will help calibrate the science and, of course help to calibrate the needed level of policy response.

(5) I have not had time to discuss predictions of the effects of climate change on natural and human-managed systems. Suffice it to say that uncertainties here often exceed those in climate prediction. Progress is being made but much research remains to be done.

I will conclude with the observation that more accurate predictions of climate changes and their impact on natural and human systems will enable specific policies to be better evaluated. I gave an example of our analysis of the Kyoto Protocol. I took a particular reference version of our model for that study but we should not believe this reference as being an accurate prediction itself. I could have taken any of our other model forecasts and compared the results with and without the Kyoto policy with them. Ongoing is the IPCC 2001 report process that will provide further input to policy makers. It is clear, however, that this is not the only scientific input and it should not be considered the only scientific input. The notion that only once every five or six years will science say something important on this issue is untenable, given its complexity and importance.

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The background for this talk can be accessed through Report numbers 1, 32, 36, 45 and 46 at the MIT Joint Program on the Science and Policy of Global Change's Web Site (http://web.mit.edu/globalchange/www/).

Summary of Recent German Climate Research Activities

Andreas Hense

This short contribution for the workshop „Modeling Climate Change and its economic Consequences“ is intended to present a summary of physical climate research activities in Germany during recent years. A considerable part of this work has been funded by the Federal Ministry of Education, Science, Research and Technology.

Model development

During the last ten years a hierarchy of global climate models for the coupled atmosphere - ocean - ice system has been developed mainly at the Max-Planck Institute for Meteorology and the German Climate Computing Center (DKRZ) in Hamburg. The atmospheric model component is based on the European Center for Medium Range Weather Forecasts (ECMWRF) atmospheric weather prediction model supplemented by a variety of modification done at Hamburg. This defines the acronym ECHAM. Presently the fourth generation of the ECHAM model (ECHAM4) is in use. It has been described e.g. by Roeckner et al (1996).The standard spatial resolution for climate simulations is the so called T42 (equivalent to about 2.5° x 2.5°) or T30 (equivalent to about 3.6° x 3.6°) version both with either 19 or 39 vertical levels from the earth surface up to 30 km (65 km) height. At both resolutions it has been shown that very realistic simulations of the mean atmospheric state (the climate) and its variations are obtained. For the oceanic component there do exist four comprehensive models with differing complexity. Three models (the Large Scale Geostrophic model LSG, the Hamburg Ocean Primitive Equation model HOPE as well as the Ocean model in isopycnic coordinates OPYC) have been developed in Hamburg and have been coupled to the atmospheric ECHAM model. The latest version of the coupled system which has been used in climate change scenario experiments is the ECHAM4 – OPYC model. The so called Modular Ocean Model (MOM) has been developed at the Geophysical Fluid Dynamics Laboratory in Princeton

(USA) but it has been adopted for a variety of ocean simulations in Germany including a coupling to the ECHAM4 / T30 model (this has been funded by the European Union in the MILLENNIUM project) In contrast to the atmospheric and oceanic models the sea ice component describing the large ice areas floating on top of the arctic and antarctic ocean is poorly simulated. International research efforts are needed to obtain a quality comparable to the atmosphere and ocean models.

During the last ten years there have been also considerable activities in modeling the major bio – geochemical cycles like carbon, sulfur or nitrogen. These efforts are strongly related to the interaction of the atmosphere with the land based vegetation or the influence of oceanic processes upon biological factors such as phyto-plancton (e.g. Heimann et al., 1998).

Regarding the modeling and prediction of regional climate variability with a special emphasis on climate impact research (e.g. on agriculture or natural eco-systems) there have been research activities with models of a wide range of complexity. At one end statistical methods are in use which connect as predictands variables from the coarse grid coupled climate models (ECHAM3-LSG or ECHAM4-OPYC) and (as predictors) the desired variable for the climate impact study. The statistical model is estimated from a co-existing data set of predictand and predictor. Afterwards the estimated model is applied to simulations which are not covered by the common data set assuming that the statistical relations are insensitive to climate changes (Zorita and Storch, 1999). The other end of these regional climate modeling strategies is defined by the so called regional climate models. These are high resolution (e.g. horizontal grid size 50 km x 50 km and less) atmospheric models (at present) which do cover only a portion of the global domain. These models are fed by boundary conditions derived from the coarse but global scale models. The intention is to model the interaction of a large scale flow with a complex topography, land - sea distribution or other small scale surface characteristics like soil moisture generating for example a detailed distribution of precipitation and its variability.

Detection and attribution of climate signals

One of the major questions within the public discussion of climate change is the question of detecting anthropogenically induced climate signals masked by the natural variability in observed climate records of various types. A related but different question is the attribution of statistically significant climate signals to some external forcing mechanism such as increasing greenhouse gas concentrations, solar variability or aerosol burden of the atmosphere. There has been considerable work on the theory of detection and attribution (Hasselmann, 1993) and on applications of the methods basically using a long record of observed near surface temperature anomalies (Hegerl et al. 1996). Very recently also other variables like temperature of the free atmosphere (Paeth and Hense, 1999) have been shown to possess signals significantly different from the natural variability. The main conclusion of all these studies is that with an error level of about 5 to 10% the Null hypothesis that all observed variability is natural has to be rejected. Regarding the attribution question Hegerl et al. (1997) found that it is not possible to explain the observed near surface temperature trends during the last decades from solar variability alone. Progress has been made also in the analysis of regional climate changes especially in the Atlantic - European sector and in the equatorial Pacific. From circulation indices derived from the atmospheric pressure field in the North Atlantic - European sector (Paeth et al. 1999, Ulbrich and Christoph, 1999) or from indices derived from the sea surface temperature in the central equatorial Pacific (Timmermann et al. 1998) it becomes evident that - at least in the ECHAM3-LSG or ECHAM4-OPCY models - natural regional climate variability like the North Atlantic Oscillation NAO or the El Nino - Southern Oscillation system ENSO are affected by increasing greenhouse gas concentrations. E.g. for the NAO Paeth et al. (1999) can show that a weak but statistically stable and significant signal arises on time scales larger than 40 years.

Rapid non-linear variability

From a more theoretical point of view studies of the stability of the oceanic circulation have revealed very interesting features. It has been shown by Rahmstorf (1997) or Schiller et al. (1997) in a series of numerical experiments using a hierarchy of oceanic circulation models with very simple atmospheric forcings that the so called thermohaline circulation especially in the Atlantic can undergo dramatic changes (rapid climate transitions) even in cases of small changes of the atmospheric forcing. Connected to the thermohaline circulation is a strong northward transport of heat which is responsible for the relatively mild European climate. It has become clear that the strenght of the thermohaline circulation shows a hysteresis with respect to the fresh water flux from the atmosphere into the ocean. The rapid changes in the models provide a reasonable explanation for paleo climatic variability about 12 to 13000 years before present. There is clear evidence from a variety of proxy data that a climate optimum (Alleroed) was replaced within about 50 years by a near glacial state (Younger Dryas) in Europe indicating a strong shift / breakdown of the thermohaline circulation in the Atlantic.

Ongoing research and future key issues

Besides other areas ongoing research will concentrate upon the following points. These points are also defined in international programs like CLIVAR or PAGES.

- *Estimates of uncertainty of climate scenarios:* Up to now only single realisations of climate change scenarios have been computed, not taking into account the stochastic nature of the predictions. Estimates of predictability can be made from ensemble integrations by using a fixed external forcing of greenhouse gases, solar variability and aerosol burden but starting integrations with different initial conditions in atmosphere and ocean. The British Hadley Center for Climate Prediction and Research has realized such an ensemble as well as a cooperation between DKRZ and the Meteorological Institute of the University of Bonn. Both ensembles cover the period 1880 - 2050. This type of numerical experimentation has to be continued and intensified.

- *Centennial variations of the atmosphere - ocean system:* Present day computer resources do allow integrations of global coupled atmosphere - ocean models up to one to two thousand years of model time. This gives statistically stable estimates for variability with time scales less than 100 – 200 years. On the other hand historical and paleo data show that pronounced periods with different climatic conditions have prevailed for even longer scales. Examples are the medieval optimum, the little ice age or the so called 6000 BC (Before Christ) event which is also associated with the „green Sahara“. If climate models will simulate similar climate anomalies, this will give a better confidence in future projections using these models. Within the next years it is therefore necessary to perform long-time integrations with complex coupled ocean – atmosphere – cryosphere climate models.
- *High resolution predictions on seasonal and interannual time scales*: One of the major tasks of the meteorological – oceanographical community in the near future will be the forecast of seasonal and interannual anomalies of the atmosphere – ocean system on a regional scale. The most pronounced example is the forecast of El Nino events in the central Pacific together with its effects all over the tropical belt and parts of the extratropics. Whether there is useful predictability in extratropical anomalies is still an open question. Nonetheless, producing forecasts ahead of standard weather forecasts are thought to have a profound economic benefit.

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The Climate System Model CLIMBER

Martin Claussen & Andrey Ganopolski

Abstract

We present a new model for climate system analysis, called CLIMBER-2 (for CLIMate and BiosphERe, level 2). This model fills the current gap between simple, highly parameterized climate models and computationally expensive coupled models of global atmospheric and oceanic circulation. We outline the basic assumptions implicit in CLIMBER-2 and we present examples of climate system analysis including a study of atmosphere-ocean interaction during the last glacial maximum, an analysis of synergism between various components of the climate system during the mid-Holocene around 6000 years ago, and a transient simulation of potential climate change during the next millennium. These studies demonstrate the feasibility of a computationally efficient analysis of climate system dynamics which is a prerequisite for future climate impact research and, more generally, Earth system analysis, i.e. the analysis of feedbacks between our environment and human activities.

Introduction

Human interventions are currently altering the Earth's surface and the chemical composition of the atmosphere at an increasing rate, and the „balance of evidence suggests a discernible human influence on global climate“ (Houghton et al., 1996). Consequently, a major challenge for the scientific community today is to explore the dynamic behaviour of the climate system as well as its resilience to large scale perturbation (such as the continuing release of fossil fuel combustion products into the atmosphere or the fragmentation of terrestrial vegetation cover). To address the problem of stability of the climate system one has to analyse the dynamic processes between its subsystems, the geosphere, or the abiotic world, and the biosphere, the living world. For this sake, the geosphere itself can be subdivided into the atmosphere, the hydrosphere (mainly the oceans), the cryosphere (inland ice, sea ice, and snow cover), and the lithosphere (the upper solid earth). There is increasing evidence that the dynamics of the climate system cannot be determined by studying its subsystems alone. Due to the (nonlinear) synergism between subsystems the response of the entire system to external perturbation drastically differs from the sum of the responses of the individual subsystem or a combination of a few of them. Hence an integrated analysis of the fully coupled climate system is required to approach a solution of the problem.

As human society affects global climate, it is likely that it will respond to climate changes by some means either to avoid or to adapt to these changes, thereby trying to modify or even to control the climate. Therefore, integrated analysis will not stop at the climate system. Instead, it will eventually include anthropogenic activities, i.e. the anthroposphere. Currently there are only very simple models of global environment and society (GES, e.g. Hasselmann et al., 1997) exist, but as computer technology and, perhaps more important, the methodology of integrated Earth system analysis develops (e.g. Schellnhuber and Wenzel, 1998), more powerful and realistic models of the climate system are required as component of a full Earth system model.

Marked progress has been achieved during the past decades in modelling the separate elements of the geosphere and the biosphere. This stimulated attempts to put all separate pieces together, first in form of comprehensive coupled models of atmospheric and oceanic circulation, and eventually as climate system models which include also biological and geochemical processes. At the Potsdam Institute for Climate Impact Research, a new approach in simulating the climate system has been developed. The philosophy of this model as well as some examples of its application are presented in the following sections.

The new approach

General structure

Currently there are basically two classes of climate system models - comprehensive ones and simplified ones (Houghton et al. 1997).

Comprehensive models of global atmospheric and oceanic circulations describe many details of the flow pattern, such as individual weather systems and regional currents in the ocean. Similarly, complex dynamic vegetation models explicitly determine the growth of plants and competition between different plant types. The major limitation in the application of comprehensive models arises from their high computational cost. The troposphere, the lowest 15 km of the atmosphere in which weather occurs, reacts within a few days to changes in boundary conditions, for example insolation. However, it takes several hundred years for the deep ocean to respond and a few thousand years to reach equilibrium. The response time will increase enormously if more „slow“ elements of the climate system, like glaciers or the upper Earth’s mantle, are involved. Even using the most powerful computers, only a very limited number of experiments can be performed with such models.

Another problem is the necessity of ad hoc flux adjustments to obtain a realistic present climate state (e.g. Cubasch et al., 1992). Flux adjustments are artificial corrections of simulated heat and freshwater fluxes at the interface between atmosphere and ocean models. The use of flux adjustments prevent the coupled atmosphere - ocean models from drifting into unrealistic climate states; however, they impose strong limitations on the applicability of the models to climate states which are substantially different from the present one.

Due to these problems, simplified and computationally efficient models of the climate system are used for a variety of applications, in particular palaeostudies as well as climate change and climate impact projections (Houghton et al., 1997). These models are spatially highly aggregated, for example, they represent atmosphere and ocean as two boxes, and they describe only a very limited number of processes and variables. The applicability of this class of model is limited not by computational cost, but by the lack of many important processes and feedbacks operating in the real world. Moreover, the sensitivity of these models to external forcing is often prescribed rather than computed independently.

There is an obvious gap between simple and comprehensive models which has been filled by CLIMBER (for CLIMate and BiosphERe) developed at the Potsdam-Institute for Climate Impact Research (see Claussen et al., 1999, Petoukhov et al., 1998). CLIMBER is a climate system model of intermediate complexity. CLIMBER computes many processes and feedbacks in the climate system like comprehensive models, but it has a fast turnaround time. Currently some 4000 simulated years take roughly one day on a workstation of the latest generation or some 30 minutes on a supercomputer.

The fast turn-around time of CLIMBER (in its current version labelled level 2) is partly a result of its low resolution. CLIMBER-2 resolves individual continents, subcontinents and ocean basins (see Figure 1). Latitudinal resolution is 10 degrees. In the longitudinal direction the Earth is represented by seven equal sectors in the atmosphere and land modules (for convenience hereafter called „atmosphere grid").

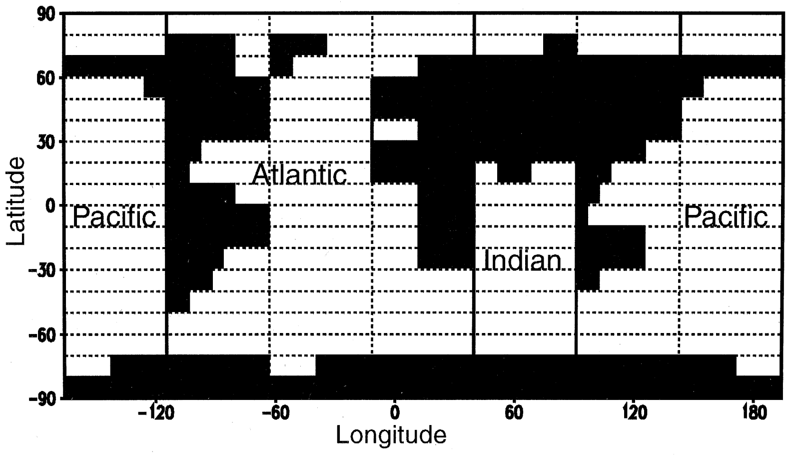

Figure 1. Schematic representation of the Earth's topography in the CLIMBER-2 model. Dashed lines show the atmospheric grid, solid lines separate ocean basins. This figure is taken from Petoukhov et al. (1999).

CLIMBER-2 encompasses six modules, an atmospheric module, an ocean and sea-ice module, a vegetation module, an inland ice module, and modules of marine biota and oceanic biogeochemistry. The atmospheric module is based on the so-called statistical-dynamical approach (Saltzmann, 1978, Petoukhov and Ganopolski, 1994). Implicit in this approach is the assumption that the general structure of the atmosphere can be expressed in terms of large-scale, long-term fields of the main atmospheric variables and ensembles of synoptic-scale eddies and waves, i.e. weather systems like depressions, areas of high pressure, storms, etc., represented by their statistical characteristics. In other words, we parameterize the average transport effects of the rapidly varying weather systems on the large- scale, long-term atmospheric motion, rather than simulating them explicitly. However in contrast to earlier models (e.g. North, 1981), we do not generally parameterize atmospheric transport as a diffusive process. This would lead to cumbersome hydrological pattern as for example in nature, moisture is advected from the arid subtropics towards the humid tropics – certainly not a diffusive process. Instead, we prescribe the existence, but not amplitude and extent, of a Hadley cell regime, thereby allowing for counter-gradient meridional transports of moisture from the subtropics to the innertropical tropical convergence zone.

The ocean module describes the ocean hydro- and thermodynamics, sea ice and the ocean carbon cycle. It is based on the multibasin zonally averaged model of Stocker et al. (1992). In the longitudinal direction CLIMBER-2 resolves only three ocean basins (Atlantic, Indian, Pacific), but in the latitudinal direction the ocean boxes match the atmospheric boxes. Ocean module and atmospheric module are coupled without flux correction - a technical task which can be achieved much easier than in comprehensive models, because it simply takes too much computing time to tune the details of the coupling in comprehensive models.

Simulation of terrestrial vegetation is based on a continuous description of plant functional types (Brovkin et al., 1997). Hence for each continental grid cell, the vegetation module computes fractions of vegetation cover and desert. The vegetation module includes a simple carbon model in which allocation of carbon to four pools (short living matter such as leaves, long living matter such as stems and roots, humus, soil) is evaluated. Vegetation structure is estimated by using a bioclimatic description of the two plant functional types, forest and grass. Vegetation adapts to climate on a time scale proportional to the turn-over time of carbon in the pool of slowly varying biomass, i.e. stems and roots.

The inland ice module and modules of marine biota and oceanic biogeochemistry have been implemented into the CLIMBER-2 framework, but not yet fully tested. Therefore we will, in the following, present model simulations in which the ice sheets and the atmospheric CO_2 concentration are prescribed from data rather than computed internally. 3 Examples of Climate System Analysis.

So far, CLIMBER-2 has been verified for present-day climate. Furthermore, it has been compared with other comprehensive models (Petoukhov et al., 1998, Ganopolski et al., 1999). It has been shown that CLIMBER-2 not only recaptures the large-scale patterns of atmospheric and oceanic motions and vegetation structure. CLIMBER-2 also reveals quite the same sensitivity to external perturbation, such as a doubling of carbon dioxide in the atmosphere, changes in solar radiation, changes in Earth's orbital parameters, and changes in the North Atlantic current, as complex models do (Ganopolski et al., 1999). For example, CLIMBER-2 computes a 3.1°C global, near surface warming as an equilibrium response to a doubling of present-day atmospheric CO_2 concentration. In the following we present results of a validation of CLIMBER-2 using palaeoclimate data and a long-term global warming scenario.

The last glacial maximum

The last ice age reached its peak around 21,000 years ago. Ice sheets up to three kilometres thick covered the northern parts of America and Europe. The reason for the periodically recurring ice ages is believed to be slight changes in the Earth's orbit which caused changes in the solar radiation reaching the Earth. But exactly how these gradual and subtle changes in the distribution of solar warmth led to such rapid and drastic glaciation is still one of Nature's unsolved puzzles.

Experiments with CLIMBER-2 suggest that changes in ocean currents were a crucial factor in the cooling of the climate during the ice age, particularly in Europe (for details, see Ganopolski et al., 1998a). These changes encompass the southward shift of North Atlantic Deep Water (NADW) formation by about 20° in latitude during the glacial maximum, a stronger penetration of Antarctic Bottom Water (AABW) into the northern Atlantic, and a substantially reduced heat transport into the high latitudes of the North Atlantic with a corresponding southward movement of the winter sea-ice margin to between 50°and 60°N. The overall rate of NADW formation is only slightly reduced, but because the northern North Atlantic current was less salty and hence less dense, NADW flow was shallower than today. Compared to today's climate, CLIMBER-2 further obtained enhanced formation of intermediate water in the North Pacific.

The entire Northern Hemisphere was on average almost nine degrees Celsius colder than it is today, according to the simulation results. When comparing the simulation of the fully coupled system with a similar simulation in which, however, the oceanic heat transport is fixed at present-day values, it can be concluded that three degrees of this cooling were caused by a shift of the North Atlantic ocean circulation. Some areas even cooled by more than 20 degrees as a result of the altered currents (see Figure 2).

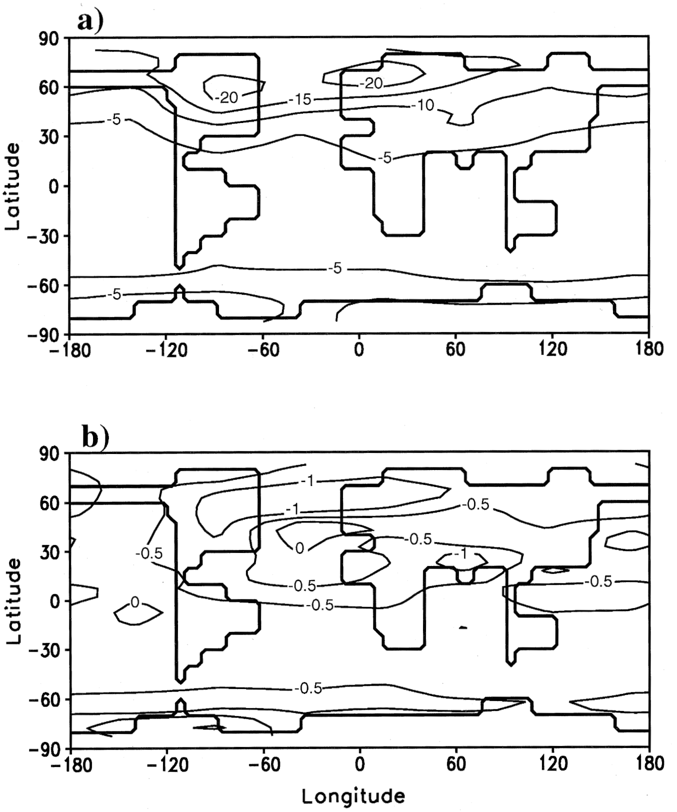

Figure 2. Simulated change in annual air temperature (in °C) near the Earth’s surface (a) and annual precipitation (in mm/day) (b) at the height of the last ice age, 21,000 years before present, compared to today. (Before plotting the model output has been interpolated bi-linearly.) This figure is taken from Claussen et al. (1999).

The middle Holocene

Remnants of the last glaciation had disappeared by about 7000 years ago and since then, the inland ice masses have changed little. Also the CO_2 concentration in the air was roughly the same as some 150 years ago, before the industrial revolution. Nevertheless, the climate some 6000 years ago, was quite different from today’s climate. Generally, the summer in Northern Hemisphere mid- to high latitudes was warmer as palaeobotanic data indicate an expansion of boreal forests north of the modern treeline (Foley et al., 1994). In North Africa, palaeoclimatological reconstructions using ancient lake sediments and archaeological evidence indicate a climate wetter than today (Yu and Harrison, 1996). Moreover, it has been found from fossil pollen that the vegetation limit between Sahara and Sahel reached at least as far north as 23° N (Jolly et al., 1998).

It is hypothesized that differences between modern and mid-Holocene climate were probably caused by changes in the Earth's orbit. Particularly, the tilt of the Earth's axis was stronger than today. This led to an increased solar radiation in the Northern Hemisphere during summer which amplified the African and Indian summer monsoon, thereby increasing the moisture transport into North Africa. However, the response of the atmosphere alone to orbital forcing is insufficient to explain the changes in climate. Sensitivity studies have suggested that positive feedbacks between climate and vegetation may have taken place at boreal latitudes as well as in the subtropics of North Africa. These feedbacks tend to amplify the climate change such that the boreal climate becomes warmer (than without vegetation-atmosphere feedback) and the North African climate becomes more humid.

Using CLIMBER-2, the response of the atmosphere to changes in the Earth's orbit was investigated, including various combinations of climate subsystems (for details see Ganopolski et al., 1998b). It appears that the year-round warming over the northern hemisphere (see Figure 3a) is caused by a synergism between vegetation-snow-albedo feedback and sea-ice-albedo feedback. Without this synergism, there would be only a slight warming in summer and a cooling in winter owing to the orbital forcing. Precipitation changes are strongest over North Africa (see Figure 3b), mainly owing to an interaction between atmosphere and vegetation.

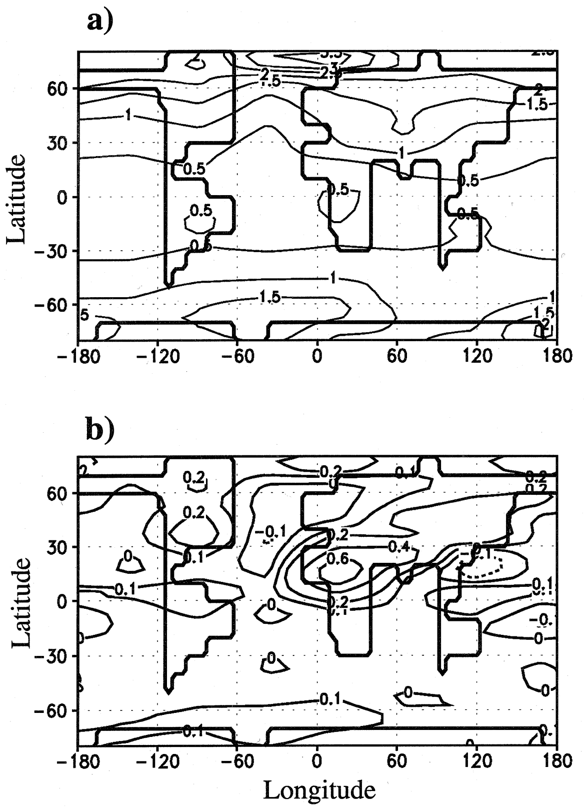

Figure 3. Simulated changes in annual air temperature (in °C) near the Earth’s surface (a) and annual precipitation (in mm/day) (b) during the mid-Holocene, 6000 years before present, compared to today. This figure is taken from Claussen et al. (1999).

From the middle Holocene until today, the climate has changed to a more arid state in which the present-day subtropical deserts developed. The climate did not change gradually. In our simulation, the climate system smoothly reacted to the orbital forcing for several thousand years, then it changed rather abruptly, around 5500 years ago, within a few hundred years, according to the results of CLIMBER-2 (for details see Claussen et al., 1999b), The abrupt change itself seems to be a regional atmosphere-biosphere feedback, whereas the timing of this event depends on the state of the climate system and the large-scale meridional temperature gradients.

Scenarios of the next millennium

Rahmstorf and Ganopolski (1999) present a set of long-term greenhouse scenarios which demonstrate that a global warming and, at the same time, a permanent and large cooling over the northern Atlantic and parts of Europe may be triggered by anthropogenic greenhouse gas emissions. Their scenarios assume that greenhouse gas concentration will increase (according to the IPCC scenario IS92e, Houghton et al., 1996), will peak in the 22nd century, and decline afterwards (see Figure 4a).

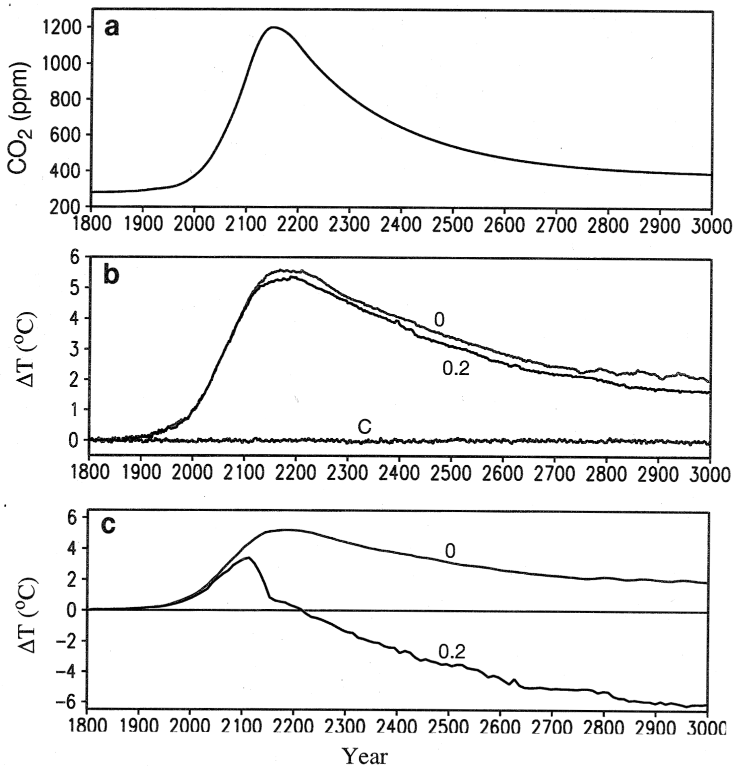

Figure 4. Times series of (a) prescribed atmospheric CO_2 concentration, (b) global annual mean surface air temperature change, and (c) winter (December, January, February) surface air temperature change over the Atlantic at 55° N. The experiment labelled 'c' is a pre-industrial control run, '0' is the standard scenario, and '0.2' is a scenario with enhanced freshwater forcing. This figure is taken, with modifications, from Rahmstorf and Ganopolski (1999).

As changes in hydrological cycle affect the ocean circulation and are one of the most uncertain aspects of model simulations, Rahmstorf and

Ganopolski have computed a range of scenarios with different hydrological changes. Only two of them are depicted in Figures 4b,c. A significant reduction in North Atlantic Deep Water formation over the next 50 years occurs in all simulations using CLIMBER-2. Obviously, this initial reduction is largely due to surface warming induced by the increase in greenhouse gases, not to changes in the water cycle. The water cycle does, however, determine whether a critical threshold is exceeded and the Atlantic thermohaline circulation breaks down, or whether it gradually recovers throughout the next millennium. Both increased precipitation and meltwater from continental ice could contribute significantly to a critical threshold in the climate system. An oceanic breakdown would lead to a very rapid cooling over the North Atlantic and adjacent land areas, and could leave north-west Europe several degrees colder and much drier than at present (Figure 4c).

The study of Rahmstorf and Ganopolski does not indicate how likely an abrupt regional climate change in a globally warmer world is. It merely states that it is possible, from the theoretical point of view.

Conclusion

Climate system analysis is a prerequisite for climate impact research at the global scale. It can be viewed, more generally, as a first step towards Earth system analysis which focuses on the (bi-directional) interaction between the climate system, i.e. the geophysical part of the Earth system, and the anthroposphere. Climate system analysis necessitates a climate system model which, on one hand, has to be computationally inexpensive and, on the other hand, must not be too simple. The important processes of atmospheric and oceanic circulation as well as the feedbacks between the subsystems of climate, i.e. atmosphere, ocean, vegetation, and, if long time scales are considered, ice masses and the upper Earth's mantle, have to be described realistically.

Here we have presented a new approach to bridge the gap between simple climate models and complex climate system models. We have developed a climate system model of intermediate complexity, CLIMBER-2. This model consists of several modules which simulate the large- scale, long-term patterns of atmospheric and oceanic characteristics as well as vegetation structure. The main reduction in required computer resources is gained by the atmospheric module as it resolves only the large-scale circulation and parameterizes the effects of heat and momentum transports by weather systems on the general circulation.

In our examples of validation against palaeo data and of long-term scenarios, attention has been focused on the coarse-scale pattern of climate and the question of synergism and stability in the climate system. Important questions are on how we can explain climate variability in the past and whether we are able to predict long-term climate variability in the future. As the first steps are quite promising, we believe that CLIMBER-2 could be coupled with models of anthropogenic activities, say socio-economic models, to build an Earth system model.

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Economic Effects of Greenhouse Gas Mitigation Strategies

Henry D. Jacoby

Introduction

The title I suggested when I first spoke with the Academy organizers was the one above, and I will deal with some economic issues here. However, from reading more about your concerns, and observing events in the recent Buenos Aires meeting of the Conference of the Parties, I also am going to talk about where we are headed in policy terms. I would like to question what the world may look like at the time when you anticipate finishing your Academy study of the climate issue. I will suggest that, a few years hence, the issue will not be how to implement the Kyoto agreement but how to salvage it from failure.

My discussion will focus on uncertainty in the climate issue, as it influences the policy discussion. I will begin with the structure of climate uncertainty, extending the analysis that Professor Prinn showed. Then I would like to talk about the implications for collective action, and the timing of policy. Along the way I will talk about capital malleability, the rates of turnover of capital stock, and the time available to meet prescribed targets, and that will lead me to some personal views about the prospects for implementation of the Kyoto Protocol, and the longer-term challenges and the opportunities that we all face.

I will review the cascade of uncertainties that characterize this issue, beginning with economic growth and technical change and how they influence emissions, then re-visiting issues that Professor Prinn talked about: the carbon cycle and radiative forcing, and the response of the climate system. Next, I will say some words about the costs of mitigation (but not so much about adaptation). I will not talk specifically about the economic and environmental effects of climate change itself. We can come back to this topic in the discussion.

Now to the MIT Joint Program analysis. I will start with our Integrated Global System Model (Prinn, et al., 1999), which you have already seen, and describe the way that we have carried out uncertainty studies, moving beyond the conventional analysis which usually is based on a set of scenarios. What was done in the scenarios shown by Professor Prinn, for example, was to take a central value, and high and low values of various parameters, each chosen by the modellers responsible for the particular component of the analysis, and to combine these assumptions into seven cases, all of which can be defended as plausible. Now we go another step, eliciting of probability distributions for these same parameters, and running them through the model system to compute distributions of output variables. In this way we can not only talk about the range of possible outcomes on a scenario basis, but about the relative likelihood of outcomes. We can go into the analytical method in more detail if you want, but essentially it is a way of estimating a polynomial expansion which adequately reflects the behavior of a complex model, and which can then be applied in a computationally efficient Monte Carlo calculation (Sokolov and Webster, 1998).

One further other thing I would say before looking at the results is that it is the qualitative of the picture that matters when we are discussing policy. I would not worry too much about the numerical details. This is ongoing work at MIT, and we still have a great deal to learn.

Uncertainty in the climate issue

The first step in representing climate uncertainty is to analyze emissions, and here we apply the MIT Emissions Prediction and Policy Analysis (EPPA) model illustrated in Figure 1. EPPA is a model of economic growth, technical change and emissions of carbon dioxide and the other greenhouse gases. It is a multi-sector, multi-region computable general equilibrium model of the world economy. In our case the structure includes energy sectors (oil, gas, coal, electric power, refined oil) and non-energy sectors, (energy-intensive industries, agriculture, and other industries and services). The model is estimated using a data set for a 1985 base year, which reflects the detailed interconnections between these types of sectors. It solves for the supply and demand equilibrium, taking account of the demand for inputs of labor, capital, resources and intermediate inputs bought from other sectors. The version of the model used here has twelve regions, connected by international trade in all energy and non-energy goods. When we impose a policy influencing carbon emissions, a general system adjustment takes place across all those markets. It is a very useful device for analyzing the kind of questions we face in climate policy.

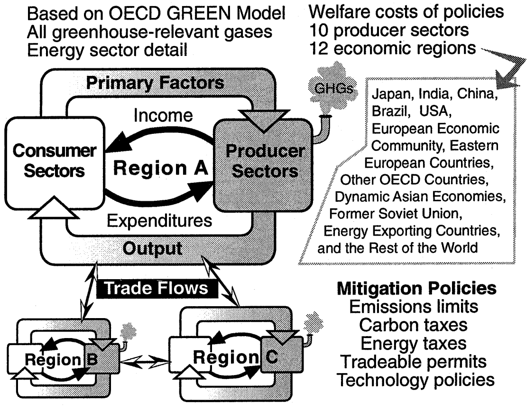

Figure 1. Features of the EPPA model.

Figure 1 is intended to give a feeling for what is involved in each country. Each is treated as having producer sectors that take primary factors (labor, capital and resources) and make goods. Consumers spend money earned from selling the input factors, to buy those goods. The model steps forward in time, driven by assumptions about population, labor productivity growth, and other aspects of technological change. These key parameters are used in the uncertainty analysis: labor productivity growth, autonomous change in energy efficiency, and the cost of future carbon-free technologies (e.g., solar, advanced nuclear).

I will talk about analysis considering CO_2 only. We have just completed a piece of work where we have imposed a policy on all gases, difference if Kyoto reductions are interpreted as applying just to CO_2, or to a carbon-equivalent total of greenhouse gases (Reilly et al., 1999). The differences in results are interesting, but they are not important to what I am going to say today.

So what happens when you impose expert judgements about these parameters, and look at emissions uncertainty? A sample result is shown in Figure 2. In 2020 there is some dispersion in emissions. By 2050 the spread is greater and, of course, by 2100 range of uncertainty is very large. Our more recent work is going to make that range even larger, so that any time you look at a single forecast you have to realize it is picked out of a wide range of possibilities. Here you can pick any number between 16 and 23 GtC in 2100. Too often people lose sight of this uncertainty in emissions. One problem with the IPCC, for example, is that they formulate the range of cases and then pick one (e.g., IS92A) as the canonical forecast. A key point to note, even at this first stage of the analysis, is that the cost of meeting any particular quantitative target, such as that agreed in Kyoto is highly uncertain. How difficulty of the task depends on growth rates and technological change, which in turn determine the amounts of carbon that must be reduced in different countries. This uncertainty is increased by uncertainty as to when the control effort might actually begin, as discussed further below.

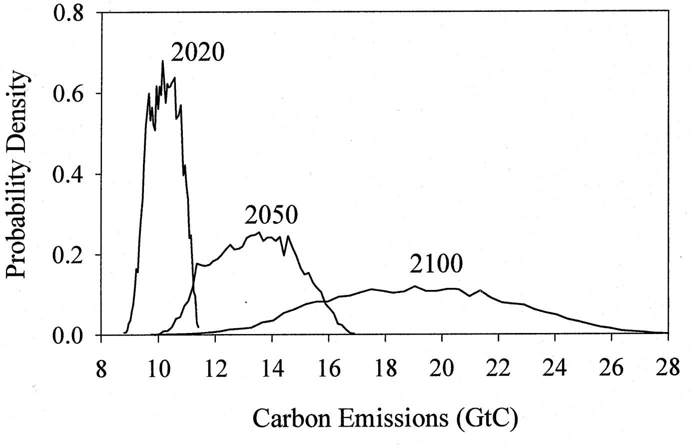

Figure 2. Probability distribution of CO_2 emissions in 2020, 2050, and 2100.

The next step in the cascade of uncertainties is to consider the carbon cycle, and how these uncertain emissions feed into uncertainties in radiative forcing. Here we apply subsequent stages in the Integrated Global System Model introduced earlier Professor Prinn (Prinn et al., 1999). I should say that, in this sample analysis, we are not yet considering the uncertainty in the land uptake of carbon. We consider only the uncertainty in ocean uptake, which is the bigger factor. Also, we are not considering uncertainty in the aerosol forcing, or other aspects of the climate chemistry. The result is shown in Figure 3, which shows confidence intervals for the radiative forcing. The dotted lines show the uncertainty contributed by the emissions alone; the additional uncertainty contributed by the ocean component of the carbon cycle is shown by the solid lines.

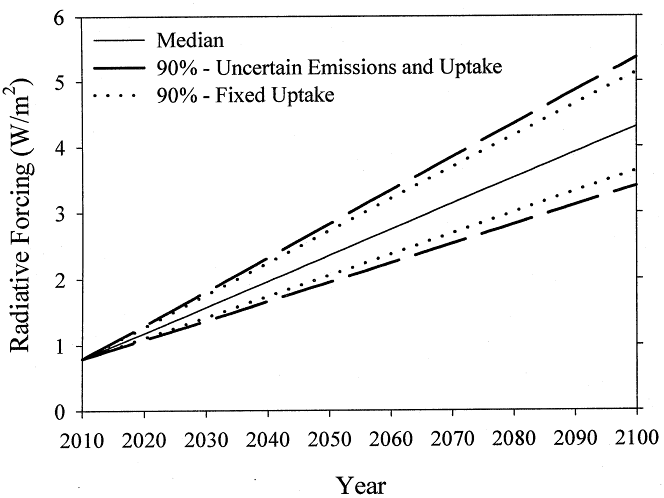

Figure 3. Radiative forcing due to emissions growth and the carbon cycle.

Then we add the next stage, which is uncertainty in the response of the climate system to radiative forcing, i.e., the climate sensitivity. This is represented by an uncertain cloud parameter, and then there is the heat uptake by the deep ocean, also uncertain. The ultimate climate result, stated in terms of a 90% probability interval of global mean temperature, is shown in Figure 4. In this preliminary example, the mean estimate is a change of about 2° C in 2100, which is not far from the IPCC central forecast, IS92A. And here you see the problem of formulating policy based on these estimates. The lower bound is below 1° C, which is well below the experience of the last century. The upper end is over 4° C, which is at the edge of what can be said to be consistent with the climate history up until 1990, but which represents a serious economic and environmental risk.

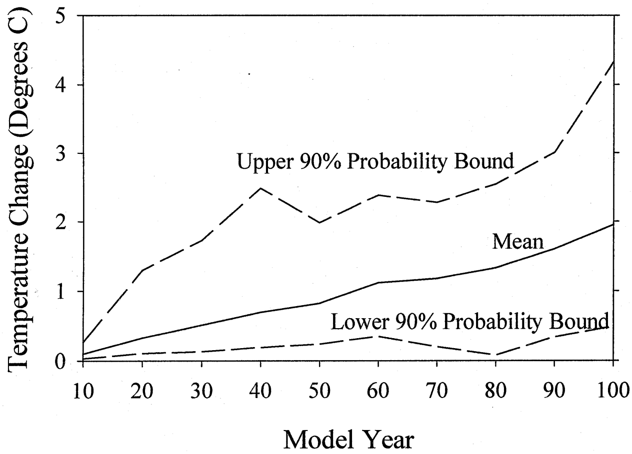

Figure 4. 90% probability interval for global mean temperature change over 100 years.

It is very difficult to know how to present this information to policymakers and the public, so they understand what it means. Even when it is understood, there are differences among people in their views of risk and the appropriate degree of precaution in response. Moreover, because the greenhouse gases only build up slowly over time, we face the additional complexity of a sequential decision strategy.

Figure 2, 3 and 4 reveal a serious, but highly uncertain environmental problem. However, the question faced now is not what to do about the climate for the next century. The question is what should we do about it over the next few years, considering the fact that we will re-visit this decision periodically in the future. Perhaps we will know more in ten years than we know now, both about the behavior of the climate system and the costs of emissions control. It is difficult to get this sequential decision aspect into the public discussion, and one unfortunate result is to create an open field for skeptics who want to do nothing, now or later. One side says climate change is terribly uncertain, and therefore we have to do something dramatic now. And the other side says that climate scientists obviously do not know anything, and therefore there is no reason to take action now; let us wait. The issue would be difficult even if we did not have this uncertainty. But the uncertainty takes an almost unsolvable problem and makes it even worse.

Kyoto issues

Now, with this background, what about the Kyoto Protocol? I will not spend much time on this topic, but I would like to recall a couple of things that were agreed (or not agreed) in Kyoto. First, we agreed to a 6% to 8% emissions reduction by most Annex I countries, below a 1990 baseline. To see the difficulty of meeting this target you have to look at what emissions would otherwise be in the 2008-2012 commitment period. If you take our definition of Europe and our median emissions forecast, the reduction is approximately one-quarter. The USA is closer to one-third. So how difficult is that? In the USA, for example, the whole automobile sector is about one-third of emissions. All the whole electric power sector is one third, or everything else is one third. So we are talking about a significant cut. (I should say, by the way, that our estimated reduction for Europe probably is too high, because our database does not include the former Eastern Germany as part of the unified country, and our assumed growth votes are higher than recent performance.)

Second, the Kyoto agreement mentions a number of provisions to provide flexibility in meeting the target. The EU was able to arrange for its „bubble“ procedure internally, and other nations can create their own „umbrellas“ and allocate their commitments accordingly. The protocol also includes mention of emissions trading, Joint

Implementation (which allows one country to get credit for reduction in another country within the Annex I group), and a Clean Development Mechanism (which is a way for developing countries to get credit for reductions in Non-Annex I regions). The problem is that there is disagreement about almost all of these provisions, and about the interpretation of the Protocol's various statements about the accounting of carbon sinks. In COP-4 in Buenos Aires a work plan was set in motion to resolve these issues by the time of COP-6 in 2000, but there is doubt as to whether agreement can be reached by then, or even if COP-6 will take place as scheduled. Finally, there is the fact that it has not proved possible to join any discussion of possible future commitments by developing countries.

All these matters – the uncertainty in the climate effects of human emissions and in the costs of any fixed target, the lack of definition of the agreement, and the absence of Non-Annex I countries from any discussion of the long-term architecture of the system – combine to create a circumstance where ratification and entry into force of the agreement is problematic.

As grist for our discussions, I will give some personal observations on the U.S. political scene, and how the issue might evolve there over the next few years.

US political scene

First, about the US political scene. It is worth emphasizing the well-known fact that the people who designed the U.S. political system had lived under a parliamentary government, and they didn't like it. So they designed a system with a diffusion of powers. Thus in the climate area we have a situation where, whatever the Clinton Administration's objectives in this area, it cannot achieve them without agreement by the Congress. The opportunities for the exercise of influence on the system are many so, in contrast to those countries where a parliamentary government can impose a policy, there is no smooth path from Administration policy to national action. Another thing to say about the

United States, in contrast to some other Annex I countries, is that industry is much more vocal in opposition. I do not know whether industry is less happy, but the whole political system allows them – supports them – in being much more active in opposition. Their way of influencing the policy is not only through the Administration but through the Congress and public opinion. Moreover, organized labor is opposed to the Kyoto agreement, largely on the jobs issue.

Finally, the U.S. public in general is less aware of the climate issue than, what I understand is the case in Northern Europe, although you will find more and more people who are genuinely concerned about it.

Question from the auditorium:

What about the press?

Up until 1997, the press in the USA had largely ignored the climate issue. It was not high on the political agenda, or the press agenda. However, I have observed over the last few years that the coverage has been growing steadily. Some of the better publications, such as the New York Times and The Washington Post, now have reporters who are printing a story every couple of weeks, some of them quite good. So I would say the press reporting is going up.

Question about the education system:

I believe that the people who write the newspapers that go into the public schools tend to be more activist on global environmental issues than the average in the population as a whole. So, for example, you will probably find more on environmental issues in what is called the Weekly Reader for children than you will find in the general press. As you know, primary and secondary education is under the control of local school boards in the United States, so there is no direct channel for Administration policy views to feed into the curriculum.

Follow-up comment on the press:

I do not doubt that in German newspapers there is more acceptance of the climate issue as an important question. In U.S. newspapers there is a well-established pattern that, whenever there is a weather event (it rains or it doesn't rain, it's hot or it's cold), the next day there is going to be a letter on the editorial page, saying: „You see! It's climate change!" My own view is that to claim that a warmer year, or a particular extreme event, is the result of climate change it is a very dangerous strategy. Global climate is a very noisy system, so that we could be experiencing climate change and it might be cooler next year, but one wouldn't want that event to convince the public that the problem was non-existent.

Further question on differences among countries:

Another difference among countries in the way this issue is received is the role of universities and think tanks. In some countries, for example, universities tend to be heavily government financed, and so there tends to be more coherence between public policy and ongoing intellectual discussion. In Japan, for example, it is hard to imagine a major university study attacking the government's position on an important issue. In the USA, on the other hand, there is a more open conflict. You might call it constructive criticism, you might call it noise in the system, but in either case it makes it harder to have a clear position on national policy.

Finally, another influence on climate policy in Europe, which is absent from the United States, appears to be its relation to fiscal policy. Many European countries have a long tradition of taxation of consumption, whereas we have a system largely based on taxation of income. I do not want to defend the well-known U.S. aversion to gasoline taxes, but it is important to recognize that these differences in fiscal structure have been in place for a half-century or more, and are very difficult to change.

This discussion then leads us to the current status of the Kyoto protocol and its prospects over the next few years. The way the Kyoto Protocol is written, it does not enter into force until it is ratified by countries that represents some 51 percent of 1990 emissions. As a practical matter this means that it requires ratification by the United States. As you know, there is opposition to the Protocol in the U.S. Senate which must ratify it. It will not even submitted to the Senate until its terms are clear, yet critical aspects of the agreement are not going to be resolved for another two years, or more. Thus even if one is optimistic, and assume that the year-2000 U.S. elections yield a Senate, more sympathetic the Protocol (and an Administration still committed to it), perhaps it is possible to see the Protocol submitted for ratification. Even then, however, the Senate procedures could take some additional years.

The effect of waiting on cost

Meanwhile, the clock is ticking. This fact leads to the question, of the effect of waiting on cost. Here is a little exercise that will illustrate the concern (Jacoby and Sue Wing, 1999). As illustrated in Figure 5, the Kyoto Protocol specifies a set of a targets for the 2008–2012 commitment period. We also have our reference emissions within the model, which are growing over time. So that, as noted earlier for the U.S., the Kyoto target is about a one-third reduction below the reference. The question is when do we you start action to achieve this reduction? We have done some analysis with our model to study how much it would cost to meet the target, depending on when we start. The EPPA model has multiple vintages of capital, and so can take account of how long it takes to turn over the capital stock. We ask what happens if you start at this change of period T, and phase down, as compared to letting the emissions continue to grow, and later phasing down more sharply.

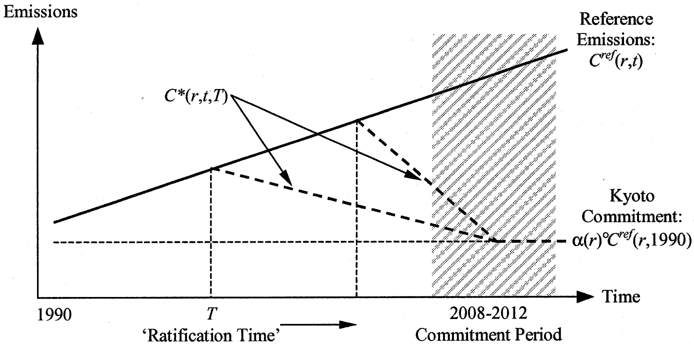

Figure 5. Carbon reduction profiles for alternative dates of ratification.

I suspect we all have the same intuition about this question, but not many people have tried to quantify the effect. The results are shown in Figure 6. If we had started in 1995, and phased-in a set of policies to achieve the Kyoto target, then we might have been able to achieve it with a carbon price in the U.S. rising to perhaps $150 per ton C. The longer we wait the higher the implied price, and the more costly the change, because there is less time to turn over the capital stock.

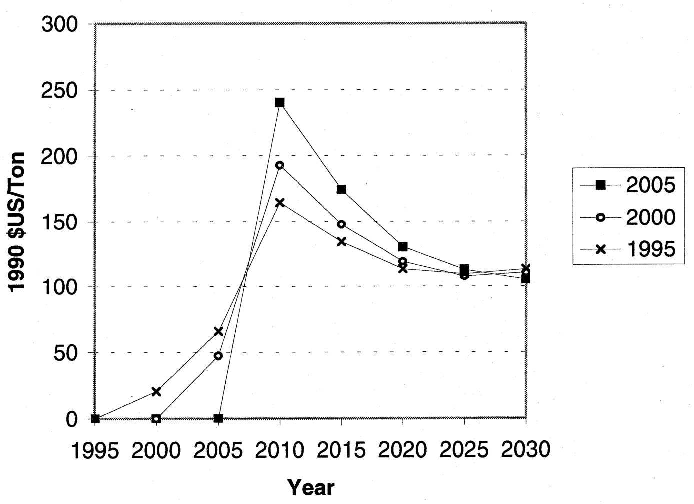

Figure 6. Effects of abatement start date.

Question:

Are these discounted prices?

> No, the figure shows the carbon price in a year. If you consider discounted cost, then at any real discount rate below 8 percent, you do not want to wait until 2005 (for details see Jacoby and Sue Wing, 1999).

Thus, if we wait till 2000 it takes a much steeper price change. But we are not going to be ready in 2000; even with my optimistic assumptions above it is hard to see the Protocol emxxx into force before 2005. I if wait till 2005, however, and try to achieve this change in one period, then prices must spike up even more sharply. This calculation is a simple way to make the point that, if we had started the control effort some time back, then the Kyoto target might have been feasible. But the longer we wait the more expensive it becomes. The argument I will make is that we are looking at a situation where, sooner or later, it will be publicly recognized that the Kyoto targets cannot be realized as currently specified.

Question about the time aspect of the model:

> Just a word to the non-modellers here. These kind of economic models come in two flavors. In one, the people making the decisions in the model look ahead, and they are assumed to see what is going to happen in the future. But other kind, which is the type used here, does not look ahead. It is myopic. The argument that we make in defense of this approach – and I think it is a good one – is that it is now almost the year 2000 and we still have a very wide variance of views as to whether Kyoto will be put into effect! So the expectation factor you are talking about is not zero, but I do not think it is very great.

My main point is that the effects of waiting on costs are great, and we are getting close to a point of infallibility in terms of the capital turnover. After 2004 or 2005, there is not even time to prepare engineering designs much less order the needed equipment. If you try to make the change very rapidly it is extremely costly. So the argument I would make for our discussion is that there is a very high probability, that because of the short-term Kyoto commitment and the peculiar timing of the politics of this issue, we are going to have to re-negotiate the Protocol.

This is the world into which you will be casting your Academy study. Thus, I would ask, how do we orient our work this circumstance, where the issue may not be how to meet Kyoto, but how to re-negotiate it. I make this provocative statement for your consideration, because I think this is very important challenge for all our work on the policy aspects of this issue. No governments have publicly stated this position yet, but I can tell you that our analysis shows that we are just getting too close to the target date for any other outcome.

A final summary

Where does that leave us? What are the key things that we should do? I have three suggestions. Because of the difficulty of reaching international agreement, I think a major mistake that we are making is that we do not have a serious long-tern R&D program. One key to this issue in the longer term is to bring carbon-free or low-carbon energy closer to the close to price competitiveness with conventional fossil fuels. Second, we are not going to get widespread agreements and major commitments unless we find some way to encourage participation by the richer developed countries, and to discuss intelligently when the other countries would enter. This is a crucial issue to try to solve. And finally we have got to re-think Kyoto. It is crucial to formulate an architecture that will be efficient, and that will be adaptive to evolving knowledge. In the process from Rio to Berlin to Kyoto we gave insufficient thought about how current targets and timetables might connect to the longer term.

And again my main point from all this is to question what the world will look like when your report appears. I believe it will be a world becoming more public about the fact that Kyoto, and indeed the larger architecture of the climate agreement, must be re-thought.

Assessing the Impact of Climate Policy

Gernot Klepper

Global warming belongs to the major topics in the international environmental debate. There is no doubt that the concentration of heat trapping greenhouse gases in the atmosphere has been rising in the past, in part due to human activity. There is also little doubt that over time this will alter the mean annual temperature, the sea-level, and the pattern of precipitation thus changing the climate in potentially damaging ways. However, the level at which greenhouse gas emissions become dangerous and the effects that can be expected are all a matter of dispute.

Despite the uncertainty about the exact changes in our natural climate system and the subsequent impacts on ecological systems there exists a broad consensus about the necessity for reducing greenhouse gas emissions in order to protect the world climate. But beyond this consensus there is little agreement about the necessary levels of reduction or the policy instruments to be used. The Kyoto-Protocol contains quantified emission limits and reduction objectives for the industrialized countries but it has not been accepted by many national legislative bodies because of its unknown impacts on their economies. In addition, the Kyoto-Protocol can only be seen as a very first step towards a much broader and world-wide policy of controlling greenhouse gas emissions. Since the climate problem is a global problem of local CO_2 and other greenhouse gas emissions eventually all states need to control their greenhouse gas emissions.

Nevertheless, each state has many good reasons for not committing to a specified reduction target: First of all, it is not clear how much greenhouse gas emissions should be reduced. Secondly, the economic costs of reducing emissions are unknown. Thirdly, the appropriate choice of instruments is not yet clear. Fourth, although an efficient pattern of emission reduction can be defined it will not be acceptable in terms of its distributional impact on different states. These facts taken together have made it impossible so far to reach an international agreement on limiting the emissions of greenhouse gases.

The activities of the scientific community in investigating all aspects of climate change are therefore of utmost importance for reducing these uncertainties. Especially the socio-economic research needs to address several conceptually difficult and new questions. Climate policy requires a very long run perspective because the objective consists of finding a technologically and economically feasible path of energy use from fossil fuels towards non-fossil sources of energy over the next generation. The policy choice is confronted with two basic uncertainties: First, economic theory, especially growth theory, has so far not been very successful in predicting the growth path of the world economy and of specific regions. Consequently, there is little knowledge about the future development of income and welfare in different regions of the world in the case in which no climate policy is taken. Secondly, on top of the uncertainty about this business as usual scenario there is little information as to how climate policy will influence the international division of labor and the distribution of per capita incomes in the world. This impact needs to be measured against the already fictitious business as usual scenario. Although both types of uncertainty are related they should be kept separate in the analysis. I would even say, the first type of uncertainty as to the business as usual development might be more serious than the second type of uncertainty.

Let me address a few of the problems that constitute this first type of uncertainty. Currently, the world economy is surely not on a steady state growth path. This means the different economies are not growing at the same rate and, in addition, for many of them it is unlikely that their current growth path will continue in the same way as it did in the past. Consequently, building a business as usual scenario requires some assumptions about the crucial growth parameters in different countries over a very long time. These assumptions concern the savings rate which determines the speed of capital accumulation within a region, the rate of capital accumulation which determines the growth rate of labor productivity, the rate of exogenous technical progress as well as the technology spill-overs from industrialized to developing countries, and finally the supply of non-renewable resources such as fossil fuels which may become scarce over the next few decades as reserves will start to decline soon. These factors together determine how fast the different economies in the world are converging towards the richer countries, if they are converging at all. They also determine the future development of demand for fossil fuels and consequently the regional emissions of CO_2. Some of these uncertainties have been explicitly addressed in the EPPA-model of the MIT. The slides in the previous presentation[1] have nicely shown how the probability density for specific events will change over time and how weak long-term predictions about emissions or economic development can become when we think ahead for more than half a century.

I think, this approach of explicitly looking at the uncertainties involved in creating a business as usual scenario should be continued. It not only helps the modeller to get a better feeling for the weaknesses of his model, it will also hopefully help to make the model results more convincing to decision makers. For the multiregional dynamic general equilibrium model of the Kiel Institute of World Economics we have done such sensitivity analysis for a number of important parameters. The globalization of the world economy already changes the integration of goods markets between countries. We have therefore looked into the sensitivity of the simulation results with respect to different assumptions about the degree of substitutability between goods from different origins. It turned out that the business as usual scenario was not significantly affected by different assumptions about the trade elasticities. The policy simulations had a somewhat stronger effect but the welfare effects were not significantly altered by changes in the trade elasticities. Hence, the simulation results seem relatively robust in terms of changes in the international trade system.

We are much more concerned about the modeling of the supply of fossil fuels. The climate policy models usually model fossil fuel supplies in a static framework. They simply assume a supply function with an exogenously given supply elasticity or they introduce some

[1] Henry Jacoby’s contribution (remark by the editors).

intertemporal flexibility such as it is done in the EPPA-model. However, in both approaches the assumption is retained that there is no scarcity of fossil fuels in terms of reserves. Even if the issue of scarcity of fossil fuels is ignored it is difficult to find meaningful regional supply elasticities for fossil fuels. Sensitivity analysis have shown that the supply of fossil fuels can strongly vary depending on the range of elasticity that one chooses. Consequently, the expected future emissions of CO_2 will heavily depend on these numbers. I think this is one of the major problems of climate policy models which needs to be looked into much more in the future.

Let me conclude with the following observation: The economic modeling of climate policy is going through a number of stages which are not unlike those taken in the climate modeling of the natural sciences. The first face of model building has resulted in a number of models serving different purposes. Some are more focused on the energy sector, others more on carbon leakage, others on price spillovers through international trade. In the second face interesting results of climate policy simulations have been derived. However, a unified picture has not yet emerged. We are now, I think, in the face where we need to go back and check the models for the sensitivity with respect to the crucial assumptions in order to find out where the sources for the differences may be located. An important step in this exercise is the explicit recognition of uncertainties about crucial model parameters as well as about complete model components. At the end of this process, I hope, we will end up with better models and, at the same time, with more robust and consequently more convincing simulation results of the likely impacts and economic consequences of climate change as well as climate policy.

Economic Impact of Greenhouse Gas Mitigation Processes: Two Views of the Problem

Hans G. Nutzinger

1. Professor Jacoby[1] has emphasized correctly the great uncertainty surrounding the problem of global climate stabilization. Therefore, I will start with a simplified pay-off matrix combining the possible events with the probable outcomes. In a first approximation, we can distinguish between an „optimistic strategy“ which either considers the potential results of the „greenhouse effect“ negligible or emphasizes a strong positive net effect of a more or less conventional growth strategy. If this view of the world conforms with the real state of the world, then the probable outcome is „very good“; if not, we have to face a „disaster“. A „pessimistic strategy“ which attempts to limit the growth of global temperature to 0.1° Centigrade, as recommended by the IPCC, implies a reduced modest outcome, due to avoidable sacrifices in available growth policies, if the real state of the world is „good“ ; hence it means the acceptance of certain losses in economic welfare due the strict observation of the „precautionary principle“ . However, if the state of the world is „bad“ in the sense that the unlimited growth of average global temperature would lead to a „disaster“ , the outcome of this precautionary „pessimistic“ strategy would be still tolerable. The following pay-off matrix summarizes the possible combinations.

2. Possible outcomes of alternative climate policies:

real state of the ...... world / **strategy**	**„good“**	**„bad“**
„optimistic“	very good (1,1)	disastrous (1,2)
„pessimistic“	moderate (2,1)	Tolerable (2,2)

[1] see this report

3. The traditional way of choosing among possible outcomes by calculating expected values is in this case very problematic as (1) different outcomes are very difficult to quantify in terms of expected costs and benefits and as (2) the probabilities of different outcomes are highly subjective. Finally, (3) if probabilities tend to zero, whereas outcomes tend to (negative) infinity, the mere „existence“ of expected values becomes questionable.

4. In this situation, a „maximin strategy“ recommends itself which tries to avoid the „disaster“ , even if this means sacrificing a very positive but highly risky outcome. In our case it would lead to element (2,2) of our simple matrix, the choice of a „pessimistic strategy“ which leads to a „tolerable outcome“ at the cost of missing the (risky) „very good“ result of a (justified) „optimistic strategy“ .

5. The two fundamental strategies outlined above are based on two different basic philosophies. *The philosophy of the IPCC* could be summarized as follows:

   5.1 *We don’t know enough, therefore* let’s choose a (modified) maximin strategy (downsizing the speed of climate change, which would imply slowing down the emissions of anthropogenic greenhouse gases). In economic terms this means: the goals of climate policy are exogenously given, optimization takes only place with respect to the choice of means/instruments for the given climate goals; instead of an optimization in terms of both costs and benefits, we have only „cost effectiveness“ instead of „full optimization“ , due to the fact that our lack of information implies the impossibility of a reasonable full optimization. Thus, „cost-effectiveness“ can be associated with a „pessimistic strategy“ .

   5.2 On the other hand, the *critiques of the IPCC philosophy* argue broadly as follows: *We know already enough* (or - alternatively - we are able to learn enough) about the „true“ problem situation in a sufficiently short time period. In this case, we should follow a (slightly modified) „business as usual“ policy avoiding growth losses unless there is a clear, indisputable evidence for a significant negative (net) impact of greenhouse gases on global temperature and of global temperature on overall welfare, taking into account the possibilities of compensation payments for particular negatively affected groups (such as some small insular states in the Pacific).

5.3 Some people also argue for a „optimistic strategy“ because we will never know enough about the future (in contrast to the known past). To proceed otherwise would be a „presumption of knowledge“ (*Anmaßung von Wissen*) in the sense of Hayek. According to this line of thought, we have to wait for solid evidence before we change to a „business as usual“ policy. However, in this line of reasoning there is also a „presumption of (future) knowledge“, namely the (tacit) assumption that the effects of the greenhouse gas emissions would be either negligible or at least could be „mastered“ in any case. This view in itself implies more knowledge about the future than Hayek could have accepted. Therefore it seems to me that one cannot easily argue for an „optimistic“ (or a „pessimistic“) strategy along Hayek’s lines.

6. „Recommended answer“: Under given conditions, I would argue for a mixed strategy which could be summarized as follows: Start with a modified maximin strategy and change to full optimization of both the degree and speed of „acceptable“ climate change and of prevention and adaptation measures. If afterwards sufficiently clear evidence for the superiority of the full optimization strategy evolves, taking into account the caveats mentioned at the beginning, then switch to full optimization. If not, stay with your maximin strategy and apply constrained optimization („cost-effectiveness“), perhaps tolerating a small amount of necessary ex post adaptation (which, for instance, is already implied in the IPCC proposal).

7. There are lots of ethical questions involved in this issue. Given the basic uncertainties surrounding climate change, correctly

emphasized by Professor Jacoby, sustainable policies have to be not only flexible and open to the future, but at the same time strict enough to prevent the disaster. In order to mitigate the contradiction between the two kinds of requirements, it is necessary to improve our research in this field: Although future research will never turn future (of the global climate and its consequences) into past and hence a basic uncertainty will be inherent in the problem, we can reduce our lack of information which will make it easier to reach a global consensus that is necessary, if not sufficient, for a global climate policy. Uncertainty does not mean inactivity but implies an ethical problem of dealing with uncertain situations. From the viewpoint of ethics, „inaction" is an action in itself and therefore neither inferior nor superior to any „activity" . But any global ethical evaluation cannot be based on abstract ethical rules which are accepted worldwide but on a practical global consensus on a necessary policy. Research and science have to provide as much information as needed for reaching this kind of global consensus.

Shaping Greenhouse Gas Abatement Policies. Notes on the Role of Economic Modelling

Christoph Böhringer

Scientific evidence suggests that global greenhouse gas emissions will have to be reduced significantly below current levels over the next decades in order to mitigate global warming. In Rio 1992, the global community has vaguely outlined a Framework Convention for climate protection. It took till Kyoto 1997, that at least industrialized countries agreed to quantified emission limitation and reduction objectives. These Annex B parties[1] committed themselves to reduce greenhouse gas emissions on average by 5.2% from 1990 levels in the budget period 2008 to 2012. The developing countries have refused so far any abatement commitment. The reason is that they fear negative effects of emissions limitation on their economic development and demand primary action by the developed world with large historical emissions.

Projections for the world economy indicate unanimously that a substantial increase in global emissions will take place due to the economic growth in the developing world. It is therefore obvious that stabilization of greenhouse gas concentrations in the atmosphere will not only require more stringent emission reduction by Annex 1 countries but also some emission cap for developing countries. The prospects of achieving such further international agreement will crucially depend on two issues of climate change policy which have already dominated the bargaining process and the final outcome of Kyoto. These are the magnitude and the distribution of potential abatement costs associated with the economic adjustment towards less carbon intensity.

Considering that benefits of mitigating global warming are uncertain and of rather long-term nature, abatement policies to achieve climate protection will be more acceptable to the current society the cheaper (the more cost-efficient) they are.

[1] Annex B countries include industrialized countries and countries with economies in transition, such as Eastern and Central Europe and the states of the former Soviet Union.

The second issue, i. e. distribution of abatement costs across countries inevitably involves ethically founded equity criteria. Agreement to future stringent QELROs is only likely when the international parties perceive the expected pattern of costs as fair. While economics has little to say on equity per se the description of economic effects across different agents due to policy interference is a prerequisite for any equity debate.

For rationale policy making both issues – cost magnitude as well as cost distribution of alternative strategies – require quantitative assessments. As it is not possible to simulate the economic effects of alternative abatement strategies within the real system modeling adjustment based on sound economic theory is an important tool to gain insights for policy making. The main challenge of economic modeling is to capture the key agents and their relationships for the question at hand in an appropriate way. Modeling of larger socio-economic systems requires quite heroic (simplifying) assumptions on system boundaries and system relationships. Obviously, the model's assumptions determine the sign and magnitude of quantitative results. Hence, policy usefulness of economic modeling always requires a careful check of the underlying assumptions.[2] Deliberate sensitivity analysis to assumptions is a prerequisite for gaining robust insights from economic modeling. While this is a major challenge it is at the same time the major strength of quantitative economic modeling. With recent advances in computer performance and computational methods even large-scale numerical modeling allows meanwhile for a „speedy“ systematic check what implications alternative assumptions or changes in key parameters (such as elasticities) have for model results.

Having said all this, the following sections present three illustrative examples at different regional levels how economic models may provide useful insights for the efficiency and „equity“ debate of greenhouse gas abatement policies. The numerical examples are based

[2] Böhringer, C., Die Kosten von Klimaschutz – Eine Interpretationshilfe für die mit quantitativen Wirtschaftsmodellen ermittelten Kostenschätzungen, *Zeitschrift für Umweltpolitik und Umweltrecht* (3), 1999.

on simulations with IMS, an integrated modeling system of computable general equilibrium models.[3]

1. The global dimension – Kyoto and thereafter: International spill-overs and the role of permit trading

The Kyoto Protocol entails quantified emissions limitations and reduction objectives for industrialized (Annex B) countries. Signatory countries are now obligated to adjust their production and consumption patterns through appropriate policy measures such that domestic emission levels get in line with the mandated emission constraints. Adjustment of economic activities in larger open economies such as the industrialized regions are likely to affect international prices via changes in export and import quantities. The changes in international prices imply a secondary burden or benefit in addition to the *primary* domestic policy effect. A large country could exploit international market power and influence international prices at the expense of its trading partners (*beggar-thy-neighbor policy*).

In this context, policy makers of developing countries which have not made any commitment for domestic emission abatement fear nevertheless adverse economic effects due to the abatement measures of industrialized countries.[4] Analysis with IMS confirms these concerns.[5] We find that emission restrictions for Annex B countries as mandated under the Kyoto Protocol will not only negatively affect gross welfare in abating industrialized countries but also trigger significant international spill-over effects to non-abating developing countries. In general, industrialized countries are able to pass on part of their domestic adjustment costs to their trading partners in the

[3] Böhringer, C., IMS – An Integrated Model System for economic policy analysis, ZEW working paper, Mannheim, 1999.

[4] The Kyoto Protocol explicitly reflects these concerns in stating that abating developed countries „...shall strive to implement policies and measures ... in such a way as to minimize adverse effects, including ... the effects on international trade, and ... economic impacts on other Parties, especially developing countries Parties ...“ (UN 1997, Article 2, paragraph 3).

[5] Böhringer, C. and T.F.Rutherford, World Economic Impacts of the Kyoto Protocol, in Welfens, P.J.J,Hillebrand, R. and A. Ulph (Eds.): *Internalization of the Economy, Environmental Problems and New Policy Options,* Springer, Heidelberg/New York, 1999

developing world by demanding fewer exports and shifting the terms of trade against the latter. As the induced welfare losses in developing countries are in the range of the adjustment costs in industrialized countries, *serious problems of fair burden sharing occur even without reduction obligations for the developing countries*. Although the Kyoto Protocol restricts carbon emissions by industrialized countries, global carbon emissions will still grow significantly for reasonable baseline assumptions of economic development and future fossil fuel consumption in non-abating developing countries. Given adverse international spill-over effects, much more stringent reduction targets on industrialized countries seems to be an adverse strategy for many developing countries as well.

Complementary analysis indicates that emission trading (joint implementation) between the developed and the developing countries can relax significantly the problem of equitable burden sharing.[6] The latter study investigates the economics of post-Kyoto abatement strategies where global CO_2 emissions are reduced significantly (*contraction*) and per capita emissions are gradually equalized across countries (*convergence*). In comparing a regime of tradable and non-tradable emission rights for implementing *contraction & convergence* trade in permits not only allows to reduce long-term costs of abatement by more than 50% percent as compared to the no-trade case. Under a tradable permit regime most developing countries which face significant economic costs under the no-trade case improve their economic welfare even beyond non-abatement baseline levels.

2. A European perspective on Kyoto: Burden sharing within the EU

Within the Kyoto protocol the EU is committed to cut back its greenhouse gas emissions by 8% by 2012 as compared to 1990 emission levels. This target will be binding on the member states of the EU as a whole, but there is no presumption that all should bear equal cuts. In fact, a key question for EU climate policy is how to allocate

[6] Böhringer, C. und H. Welsch: C&C – Contraction and Convergence of Carbon Emissions: The Economic Implications of Permit Trading, ZEW discussion paper No. 99-13, Mannheim, 1999.

reduction requirements across EU countries in order to achieve the overall EU target. The answer inevitably involves equity considerations. In fact, the EU Council of Ministers (environment) has agreed that „the initial distribution between Member States will be reviewed by the Council ... in any case after completion of protocol negotiations ... taking account of the principals and approaches of ... equitable burden sharing among Member States with regard to the overall emission reduction objective by the Community as a whole ...“ (EC [1997], paragraphs 17, 11-14). In 1998, the EU has agreed on a burden sharing rule between member states as listed in Table 1 below.

Table 1. EU burden sharing rule for Kyoto

Country	**Reduction commitments as compared to 1990 levels**	**Country**	**Reduction commitments as compared to 1990 levels**
Luxembourg	-28	France	0
Germany	-21	Finland	0
Denmark	-21	Sweden	+ 4
Austria	-13	Ireland	+13
United Kingdom	-12.5	Spain	+15
Belgium	- 7.5	Greece	+25
Italy	- 6.5	Portugal	+27
Netherlands	- 6	EU-15	- 8

Economic analysis of this European abatement policy involves the question to what extent this EU proposal for EU internal burden sharing complies with equity considerations. One difficulty that must be recognized in any calculation of an equitable sharing of the burden of abatement is that the underlying economy will react to the proposed allocation of the burden. That is, if „equitable“ carbon limits are varied across EU members then we would expect that there would be behavioral reactions, causing the assumptions under which the initial limits were determined to be equitable to become invalid. In short, *the burden sharing rule needs to be endogenous* (outcome based) to some model of the economy in order to derive an allocation of emission reductions across EU countries which is equitable by some welfare metric. To this purpose, IMS incorporates a horizontal output based equity rule which equates the percentage welfare loss (in terms of Hicksian equivalent variation in income) due to emission abatement across countries.[7] In other words, we can endogenously determine the emission requirements for the various EU countries which assure an equitable outcome consistent to the pre-defined equity rule. Application of the model shows that the EU proposal is far off from producing an equitable burden sharing. Based on the latest EU on economic growth and exogenous energy efficiency improvements we find that equitable burden sharing implies a much more narrower range of reduction targets across EU countries. More specifically, some countries such as Germany or Denmark should have significantly lower emission reduction targets whereas other countries such as the Netherlands, France and Spain should adopt higher reduction targets.[8]

3. The national issue: Revenue recycling and the double dividend

Global warming and the rationale for efficient abatement strategies provide the background for environmental tax reforms which are considered or getting implemented in various industrialized countries. The debate on environmental tax reforms has addressed the question of whether the trade-off between environmental benefits and gross economic costs of environmental taxes prevails in economies where distortionary taxes finance public spending. As environmental taxes (in our case: taxes on greenhouse gas emissions, in particular carbon taxes) raise revenue which can be used to reduce existing tax distortions, they may yield a double dividend, i.e., simultaneously improve environmental quality and increase the efficiency of the tax system.

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[7] Böhringer, C., Harrison, G. and T.F. Rutherford, Sharing the Burden of Carbon Abatement in the European Union, CU working paper 5-98, Department of Economics, University of Colorado, Boulder, 1998.

[8] When drawing policy conclusions, it should be noted, that the results are quite sensitive to changes in the equity criterion (e.g. varying degrees of inequity aversion) and exogenous assumptions on baseline.

The recent theoretical work is skeptical about the existence of the double dividend. The intuition behind is that environmental taxes induce market distortions similar to those of the replaced taxes (income or value added taxes of the consumption type), but introduce - in addition - new distortions of their own in intermediate or consumer goods markets. However, theoretical models on the double dividend hypothesis generally start form a second-best structure and are highly stylized in order to maintain tractability. The prospects for a double dividend may significantly increase in a *third-best* setting where initial taxation is inefficient and additional market distortions (labor market imperfections) exist. Given the limitations of the simplified theoretical models and the importance of empirical parameterization, the theoretical assessment of the double dividend hypothesis demands complementary empirical analysis which accounts for the complexity of a real-world economy.

Numerical calculations for Germany based on IMS however rejects the existence of a double dividend under a range of plausible specifications for revenue-replacement methods, parameters and pre-existing distortions.[9] The results confirm public finance considerations that environmental taxes not only introduce new distortions of their own in intermediate or consumer goods markets but cause market distortions similar to those of the replaced taxes.

Rejection of the hypothesis of a double dividend from environmental taxation does not imply that green taxes are undesirable under net efficiency considerations after accounting for environmental benefits. However, the lack of a second dividend indicates a trade-off between gross efficiency and environmental quality. Consequently, an environmental tax reform cannot be considered a „no-regrets“ strategy. Environmental taxes have to be justified on the basis of environmental benefits, which highlights the importance of research on external costs.

[9] Böhringer, C., Pahlke, A. and T.F. Rutherford: Volkswirtschaftliche Effekte einer Umstrukturierung des deutschen Steuersystems unter besonderer Berücksichtigung von Umweltsteuern, Forschungberichte des Instituts für Energiewirtschaft und Rationelle Energieanwendung, Band 37, Stuttgart, 1997.

Institutional Problems of Implementing Climate Change Policies

Eric C. Meyer

The analysis of climate change involves several systems that are usually treated separately by scientists of different faculties. By now there have been some attempts to integrate these different approaches to draw a more comprehensive picture of future climate development. Especially the integration of the economic system on the one hand and the biological, terrestrial and the climate system on the other hand has been reinforced in recent time. Among these approaches that have been reviewed by the IPCC[1] are MERGE by Manne/Richels, DICE by Nordhaus, IMAGE by GSI at the Columbia University and of course EPPA by Jacoby/Prinn.

The methodology that these models apply can be summarised as follows: First, the impact of a special policy on greenhouse gas emissions is explored by a model of the economic system depicting the behavioural changes in the economy. In case of the EPPA model this is an improved version of the GREEN model developed by the OECD. These models yield the input to integrated models of the atmosphere, the maritime system, the terrestrial system and the ecosystem simulating the reaction and interaction of these subsystems to the computed emissions of the economic system. Finally an impact module describes how agricultural, coastal and other systems of socioeconomic relevance are affected by the simulated climate change. This is where the analysis usually stops. A further step to investigate policy reactions to these impacts are not carried out, because these models lack a concrete concept of the political system. This objection is frequently refused, because the integration of the political system would raise too many modelling problems. But is the political system really too complicated to be part of a model? Why is it possible to model the complex interactions of atmosphere, oceans and the ecosystems, but

[1] IPCC (1995): Climate Change 1995 Economic and Social Dimensions of Climate Change. Cambridge. Chapter 10

impossible to take a similar step for the political system. I presume that this is not a problem of complexity but the lack of knowledge of transmission channels from the environmental to the political system and of some uncertainty concerning the transmission channels to the political decision makers within the political system.

Political economy and public choice theory provide some useful insight into the process of political decision making that can be applied to the climate change problem, too. Of course it will be hard to calculate a quantitative relation between greenhouse gas emissions and for example voting behaviour. („A one percent increase of greenhouse gas emissions induces an x percent increase in votes for a green party“). Nevertheless, it does not seem to be impossible to describe political behaviour in terms of probabilities. For this purpose one has to identify

– the relation between climate change and the political system
– the transmission of climate change effects from the affected individuals (households and entrepreneurs) to the political decision makers
– the impact of national climate change policy on the individuals
– the connection between *internationally* negotiated climate change agreements and their *national* implementation.[2]

1. The theory of emission reductions

Economic theory has developed criteria for the efficient reduction of emissions. Let B_i the benefit individual i from the emission reduction $r=\sum_i r_i$ by all individuals. This is typical of the climate change problem. Individual i’s benefit is not only affected by its own efforts to reduce emissions but also by the other individuals inclination to constraint their emitting activities. Moreover let C_i be the costs individual i incurs from reducing its emissions by r_i emission units. It is assumed that $C'_{i}, B'_{i}>0$ und $C''_{i}>0, B''_{i}<0$

[2] This item is currently part of a research project supported by the Volkswagen Foundation at the University of Münster.

The individual i strives to maximise the difference between its benefit and its costs of reduction:

$$(1) \quad \max_{r_i} B_i(r)\text{-}C_i(r_i)$$

The maximisation yields the necessary condition for the individual welfare maximum:

$$(2) \quad \frac{\partial B_i}{\partial r_i} = \frac{\partial C_i}{\partial r_i}$$

That is, the marginal benefit of the reduction of an additional emission unit must equal the marginal costs to achieve this reduction. If the marginal benefit of a reduction exceeded the marginal costs, the individual would decide to decrease its emissions since it draws an additional net benefit from abating emissions.

But this individual behaviour is not optimal in a global perspective. As the emissions by individual i cause negative external effects for all other individuals, the global benefit of emission reductions is underestimated by purely individual behaviour. Consequently, a globally acting agent, that economic theory usually conceives as the „benevolent planner“ , would maximise the difference of the sum of all individuals' benefits and costs:

$$(3) \quad \max_{r_1,\ldots,r_n} \sum_{i=1}^{n} B_i(r) - C_i(r_i)$$

This implies the necessary condition:

$$(4) \quad \sum_{i=1}^{n} \frac{\partial B_i}{\partial r_i} = \frac{\partial C_i}{\partial r_i}$$

This means that the emission reductions generated by individualistic behaviour are always less than the reductions achieved by a global benevolent planner (See Figure 1). To correct the divergence of the individually optimal path from the globally optimal one economists usually suggest two instruments.

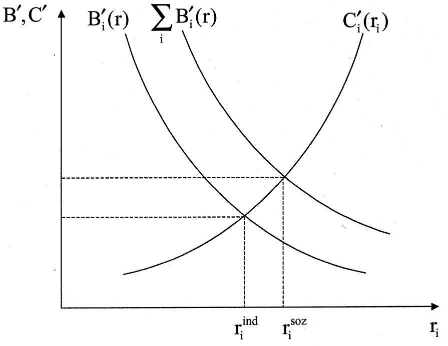


Figure 1. Individual and global reduction levels

a) *Taxes*

Assume that the initial level of emissions is e_0 e.g. the level of individually optimal behaviour. To accomplish the globally optimal emission level, which is determined by the intersection of marginal abatement cost curve and the marginal total benefit curve, the government imposes a tax rate t per emitted unit. The appropriate tax rate is equal to the ordinate of the intersection of the marginal benefit and the marginal cost curve. As long as the costs of abating emissions are less than the tax rate it is profitable to reduce emissions. This reduction stops, if the marginal abatement costs equal the tax rate. In Figure 2 area A represents the total abatement cost incurred by the individual while the rectangle B is the tax payment for the remaining emissions.

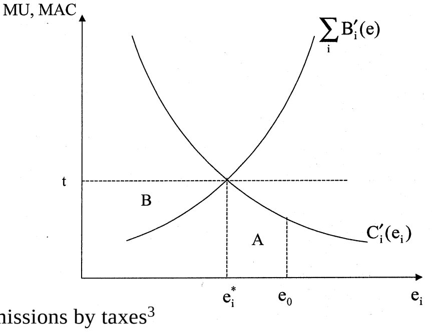


Figure 2. Reducing emissions by taxes[3]

[3] Notice that the abscissa now indicates the emissions and not the reductions. Consequently, the curves‘ slopes are reversed.

Figure 3 shows how emission taxes work to abate emissions efficiently for three different firms. Firm A may be conceived to produce with high energy intensity resulting in a high emission level, while firm B and C have lower marginal abatement costs. On the right-hand side of figure 3 the aggregated marginal abatement costs are depicted. If a tax t is applied, the total emissions are reduced to e_{tot}. Regarding the distribution of the abatement efforts the left panel shows that firm A does not abate emissions at all since its marginal abatement costs at e_0 are higher than the tax rate. Thus, firm A is better off in paying the tax, since every abated unit would be more expensive than paying the tax for this unit. In contrast firms B and C do abate to emission levels e_B and e_C according to their marginal abatement costs. Firm A has no abatement costs but the largest tax burden while firms B and C incur some abatement costs but have lower tax payments.

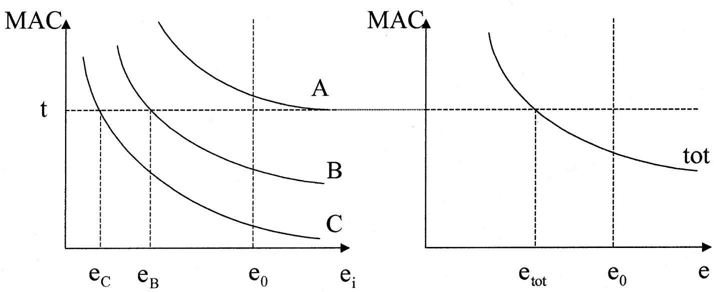


Figure 3. Efficiency of taxes

The considerations above only refer to the allocation of reductions due to the steering target of a tax to correct the (globally) suboptimal allocation. As a side-effect it yields a significant tax income that is at the free discretion of the government and can be used to pursue distributional purposes.

b) Emission permits

Since the government does not dispose of perfect information on the individuals cost functions it is unlikely that the emission target will be met exactly. Another instrument to accomplish an emission target are tradable emission permits. The government issues permits for a specified amount of emissions. These permissions can be traded. Let us assume that the same level of emissions is conceded to every individual. Figure 4 shows two individuals with different marginal abatement costs initially granted the same stock of emission permits. In this situation individual A would have much higher marginal abatement costs than individual B. Therefore, individual A will bid for B's emission permits to reduce its marginal abatement costs and B will accept this bid provided that it is greater than its marginal abatement costs. Finally, they will arrive at an efficient market equilibrium characterised by equal marginal abatement costs for all individuals and market clearing for emission permits (i.e. the amount of emission permits B hands over at the market price equals the amount of permits accepted by A.). The allocative effects of permit trading and taxes are identical. But distributional impacts may differ widely depending on the redistribution scheme devised by the government in case of a tax solution and the distribution of permits in the case of permit trading.

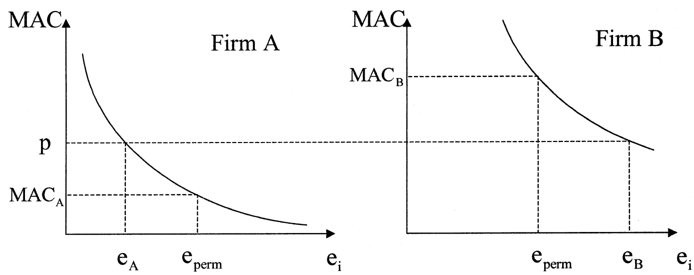


Figure 4. Efficiency of emission permits

2. Problems of implementing emission reductions

Both of the aforementioned procedures provide a theoretically efficient outcome for emission reductions. But to implement either an emission tax or emission permits some preconditions must be met:

– Existence of a sovereign distributing an initial set of emission permits or collecting taxes

– The taxpayer or buyer of emission permits must be able to control his emissions effectively i.e. he must be the genuine emittent.

– There do not exist different decision levels implementing different reduction schemes.

– Taxpayers or buyers of permits do comply with the installed regime excluding any kind of fraud.

– There are no monitoring costs.

– The distributional consequences of any regime are accepted by the public.

These conditions are clearly not met in the case of the international climate change problem. The real-life setting diverges from the theoretical requirements turning the theoretical recommendations doubtful.

Most importantly one has to recognise that there are autonomous national entities that cannot be submitted to an unagreed tax or quota regime since such an regime would lack necessary enforcement mechanisms. Therefore greenhouse gas emission targets and the corresponding institutional framework have to be negotiated between these independent nations. Although it may be conceived that some sovereign rights are passed to an international authority to implement e.g. an international tax scheme this outcome is very unlikely. Consequently, every government has a twofold task. On the one hand it has to bargain on an international agreement and on the other hand it has to implement a mechanism to accomplish the reduction target it has previously agreed on.

2.1 The international negotiations

Excluding the option of a benevolent global planner and an international tax regime the national governments have to negotiate how to reduce greenhouse gas emissions. Such agreements comprise with increasing complexity the following items:

– national emission targets

– an accompanying emission permit trading system

– accounting rules for greenhouse gas sinks

– details on national implementation schemes

The decision on these items is determined by cost-benefit considerations of the national government. It is important to stress that these national cost-benefit functions are unlikely to be founded environmentally but rather the result of a political cost-benefit-analysis that is only loosely tied to environmental considerations.

Moreover the economically optimal distribution of emissions (i.e. marginal abatement cost are equal across all countries) is unlikely to be the result of climate change negotiations since the biggest part of the reduction burden would be with emerging markets and developing countries whose marginal abatement costs are very low. Even if an agreement on national emission targets implying equal marginal abatement costs was achieved, the national implementation scheme could break up this equality by granting politically motivated tax exemptions. That means that any economically efficient scheme agreed on on the international level may turn inefficient due to the discretion national governments have on their national level.

2.2 The national implementation

On the national level the government decides on the implementation mechanism to accomplish the internationally negotiated emission targets. As laid out above these instruments could be taxes, emission permits or emission limits fixed by law or any combination of these instruments. Furthermore the government can decide to exempt some industries or particular groups from the implemented measures.

In the best of all worlds the government could determine a tax rate to abate emissions efficiently . Unfortunately, the theoretically efficient measure may be politically infeasible. The governmental decision is not based on a national cost-benefit-analysis concerning emissions but takes into account other impacts of taxes or any other abatement mechanism. Government decisions are mainly guided by their impact on voting behaviour. If the mechanism to reduce greenhouse gas emissions is incompatible to the vote maximising target of any democratically elected government the theoretical solution will prove to be infeasible. Therefore the theoretical solution does not yield any policy advise since it cannot be implemented. A useful economic advise will heed to political constraints because only suggestions taking into account these constraints may reveal to be implementable though it will be suboptimal from the theoretical point of view.

Consequently, we have to analyse what influences the government decision to carve out the political constraints the government is subject to. From a macroeconomic point of view the mechanism to reduce greenhouse gas emissions have allocative and distridutional effects.

The allocative change mainly stems from microeconomic substitution reactions by the individuals. The intention of any environmental tax or quota regime is to alter the cost structure (internalising external effects) and thus changing the individuals economic behaviour. The increased costs of consumption that is either greenhouse gas intensive by itself (e.g. driving) or related to products that have been produced greenhouse gas intensively induce individuals to change their consumption by substituting with other products. There are two different types of substitution relevant for the climate change problem:

Technical substitution: The individual may substitute more expensive products by products that are cheaper due to lower taxes. This requires that the substitution intended by the policy maker is technically possible and that there are no institutional obstacles. For example, a CO_2-reducing policy could be to substitute CO_2-intensive coal powered plants by gas powered ones for electricity production. This calls for a sufficient supply of natural gas that can be transported either by pipeline or by shipping LNG. If a country lacks either the access to pipelines or does not dispose of the industrial capabilities to deliquify LNG the above mentioned substitution strategy is infeasible for this country. Such technical shortcomings can only be resolved in the long run and thus are suitable to accomplish emission reductions in the short-run.

Local substitution: Local substitution becomes a serious option for mobile factors (i.e. enterprises), if the costs of emission diverge in different countries. As mentioned above this is a very likely outcome of any realistic climate change agreement, because can be excluded from any reduction obligation or may decide not to participate in such an agreement at all. Even if all countries participated and bore equal marginal abatement costs, different implementation schemes might impose differentiated costs to the enterprises. These cost differentials may induce some firms to decide to relocate parts of their production facilities to less costly countries. This moving of capital entails two effects. First, there is no global environmental improvement, since emissions occur just at different location. Second, the industrial break away implies additional costs to the government because tax income from corporate taxes will also decrease, thus, constraining governmental expenditure.

The distributional effect originates from the tax-induced behavioural change and the reditributional activity by the government.

Every change in prices has a twofold implication. It triggers a substitutional reaction as described above and it has a distributional income effect. If for example the price of gasoline increases due to a carbon tax the individual’s income will decrease. This fall in income crucially depends on the amount of consumption of the taxed good. Thus, a tax alters the income distribution through the income effect.

Secondly, a tax or quota regime may yield a considerable tax income. Usually governments promise to disburse all revenues from so called eco-taxes to lower taxes on wages or to reduce social security contributions. Therefore the government decreases the households’ and enterprises’ income according to their energy consumption and raises the income for those who have to pay wage taxes or social security contributions.

Since distributional effects crucially affect the voting behaviour governments will thoroughly assess the impact of their intended policy and will refuse an allocatively efficient policy if it entails undesirable distributional consequences.

A special problem is a country's endowment with energy resources that strongly influences the country's stance in climate change negotiations. The price for non-renewable energy resources is composed of the extraction and transportation costs and a mark-up. Taking the world market price as given a tax or permit regime will widen the wedge between consumer and producer prices and will reduce producer prices. This slump in producer prices will drive those resource owners out of the market whose marginal costs are greater than the now attainable producer prices. If a country only disposes of high-cost resource deposits, it will turn to import fossil fuels. Therefore, the market structure may alter as fringe suppliers exit the market and the remaining suppliers can extend their market share. Thus, even with total demand declining some resource suppliers may increase their total output due to the exit of fringe suppliers. Also within a country declinging producer prices may extinct some producers causing an additional distribution problem.

3. Fusing international negotiations and national implementation

After the international negotiations and the national implementation have been briefly sketched we can proceed to fuse these two approaches by considering their mutual impacts and interactions.

The set of politically feasible schemes constitutes the national input to the international negotiations. On the international level the government co-decides on the emission target, the number of participants and implementation specifications eventually constraining its discretion on the national level. The international agreement determines the framework for the national implementation which is constrained by technical, institutional and constitutional and distributional impediments that determine the political feasibility feeding back to the international negotiation level.

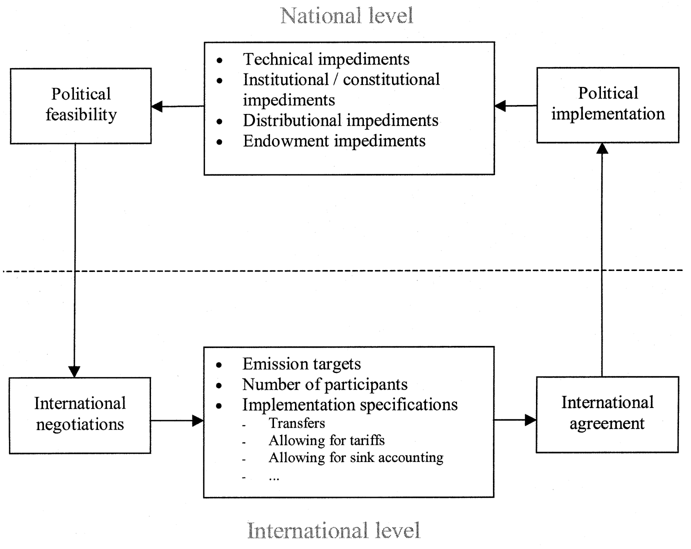


Figure 5. Interaction of national and international level

It is evident now that national implementation and international negotiation are not independent. Future research has to further identify these linkages by analysing impediments to the national implementation of climate change policy. Impediments in one country may alter the outcome of an agreement by two channels, the number of participants (if the country decides to reject an agreement) and the provisions made by the treaty. On the other hand we must further illuminate how regulations and provisions in international climate change agreements influence national implementation decisions and may conflict with certain impediments in some countries.

Eco-Efficiency and the Economy of Prevention: Future Energy Strategies

Peter Hennicke

I am an economist and have been working for seven years as an expert with the 'Enquête-Commission for Climate Protection' of the German Bundestag. Today, I hold a chair for energy economics at the University of Wuppertal. At the same time, I am Vice-president and Head of the Energy Division of an institute which is rather special, therefore let me just say a few sentences about it. About 130 colleagues are working at the Wuppertal Institute, which is a non-profit organisation, based on interdisciplinary and practice-oriented work on climate policy, material flows, transport and energy. Looking at climate protection policy, we have learned from our studies that scientists, politicians and managers must work together much closer; have to look at empirical evidence, learn how technical progress can be fostered, investigate in detail the costs of energy efficiency and the barriers and market failures of existing and future economies. With that background I hope to give you some useful information on two issues: first, I would like to talk about how to close the implementation gap and second, how to bridge the differences between top-down and bottom-up modelling.

1.) Let me start with a remark about our understanding of the differences between bottom-up and top-down modelling: of course, if everything is in equilibrium and you intervene in an ideally adjusted market economy, it will only cause costs. That's what we teach in basic seminars of micro-economics. But in reality we are confronted with a lot of barriers and market failures, therefore we find huge efficiency potentials which we call 'restricted, but cost-effective potentials' (Figure 1). The main question is: what does it cost to remove existing barriers, what transaction costs will occur to get rid of the barriers so **that markets for energy services** can really function; we need **markets for least-cost energy services, not for 'cheap and risky' kilowatt-hours,** because energy is only a means to an end and people and enterprises need energy services (e.g. warm or cold rooms, motive power). So if we can remove the barriers and establish functioning markets for energy services, bottom-up modelling shows that it becomes cost-effective to reduce CO_2 by up to 40 percent, without extra costs. The main question is: can this be true? Why hasn't it been realised? Are there any other hidden costs?

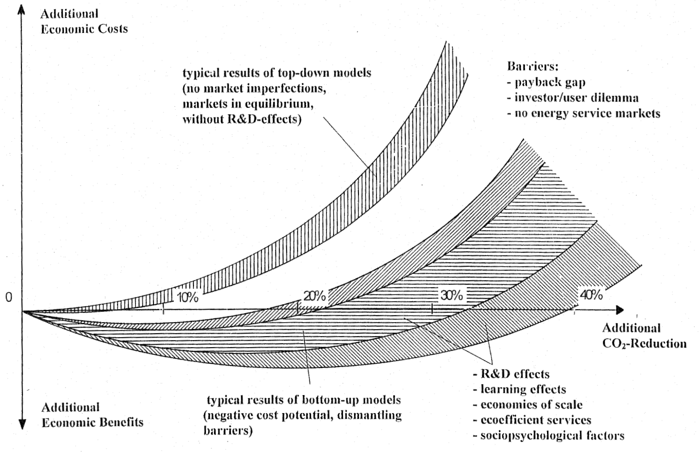


Figure 1. Differences in CO_2 mitigation costs: Top-down vs. bottom-up models. Source: ISI/WI (1998).

Let me tell you a little anecdote, which has been related by Amory Lovins from the Rocky Mountain Institute (USA). Amory Lovins tells this story to explain the rationale of traditional economics. A father and son are walking along the street; the son sees a one hundred DM note and says to his father, 'Let us pick it up.' But the father says, 'Don't bother it. If it were real, somebody would have picked it up already.' That is one story which I will elaborate further on. I would like to convince you with as much evidence as possible – because we have done more than one hundred studies, a lot on evaluation and some on modelling – that an impressive amount of so-called 'no-regret' options really does exist. Therefore, it would be worthwhile to concentrate on this rather than deal with it in footnotes, as the Working Group 3 of the IPCC did in its report, which estimated the options share to be about ten to thirty percent.

2.) Let me start with the international level. What is the challenge for industrialised countries and for the developing countries? I think they have some extremely important challenges in common for solving the question of climate protection and proceed in the direction of more sustainable energy systems. First of all they have to introduce – much more quickly than has been done so far – the t**hree pillars of sustainable energy systems:** giving highest priority to end use efficiency, implementing to a greater extent combined heat and power systems (CHP) in industry and district heating, and increasing the market share of renewable energy faster. These are common tasks for DCs and ICs. On the way towards a more sustainable development, we have to de-couple energy supply from energy services by de-materialisation, fostering eco-efficiency, product responsibility of the total product cycle and more sustainable modes of production and consumption mainly in rich ICs.

What does this mean in the context of the world energy system? Let me show you the results of the scenario analysis (Figure 2) of the World Energy Council (WEC; together with IIASA/Austria) which has been presented recently in Houston/Texas (1998). That analysis tells us that a broad range of energy futures is technically feasible, with an increase in CO_2 by 2050 of more than 300% (within the A-scenario), and a decrease of 50% within the C1 and C2-scenarios. The most exciting result of these scenarios is the calculation of the total investment costs, showing that it is more cost-effective to follow the scenarios C1 or C2 with less risks of climate change than other scenarios. There is even one scenario (C1) which shows that we will additionally be able to phase out nuclear power in the next century, and it will cost much less than the business-as-usual strategy B or other risk accelerating strategies (A). Please remember that the WEC is the world's biggest conference for energy suppliers. In this respect the following citation of the final Houston Statement is not only astonishing but also very encouraging: 'Increased efficiency in the end use of energy offers the most immediate, largest and most cost-effective opportunity to reduce consumption and environmental degradation ...'

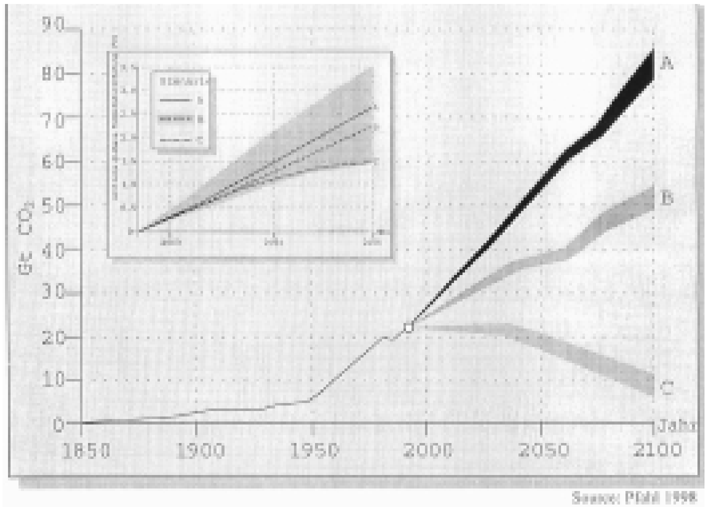


Figure 2. CO_2 emissions and temperature in the scenarios of the WEC. Source: Pfahl (1998).

3.) Therefore it could be stated that everybody talks about least-cost options on the demand side and the benefits of energy conservation – but (almost) nothing happens!

Within this context, let me make a short comment on what modellers call the ‘autonomous energy efficiency increase’ (AEEI). What really is ‘autonomous’ and how far can we accelerate the increase in energy efficiency when we take it as a target of policy and management? In this case the following energy conservation supply curves are a very useful screening tool for the amount of energy savings that can be realised and how much it would cost (Figure 3). One shows the energy conservation supply curve for the electricity sector in the US, one is calculated by the industry (Electric Power Research Institute (EPRI)) and the other has been worked out by Amory Lovins of the Rocky Mountain Institute (RMI). Though differing in some important methodological aspects and scales, all curves have one point in common: under the very conditions of the US economy, it seems to be cost-effective to reduce electricity by about 30 percent with less costs than the existing US electricity busbar costs of the electricity supply system. This basic result correlates with many studies for other OECD countries and with our own experience with the German energy system. In the copy of my transparencies you will find some energy conservation supply curves, e.g. for German industry (Figure 4), showing that some extra costs of between 4-8 Pfennigs per kilowatt-hour are needed to reduce German electricity consumption in industry by about 30%, calculating only the technical costs (without reducing the needed energy services). We must add up to 25% for transaction costs to get the whole cost story. So, under German conditions, the average costs to reduce electricity consumption by 30 percent are about 5-10 Pfennigs per kilowatt-hour. These figures have been calculated together with utilities, whose main business is, of course, selling electricity. Therefore I think these are the most reliable figures which are available for Germany, although there are still uncertainties, for example how the cost could decrease with mass production and technical progress embodied in efficiency equipment. To sum up: there is no need for new technologies **but for fostering market diffusion of existing most advanced technologies** to reduce total electricity consumption in ICs by about 30% with a societal benefit. These ‘no-regret’ options can be implemented if we could remove the barriers and market failures for energy service markets.

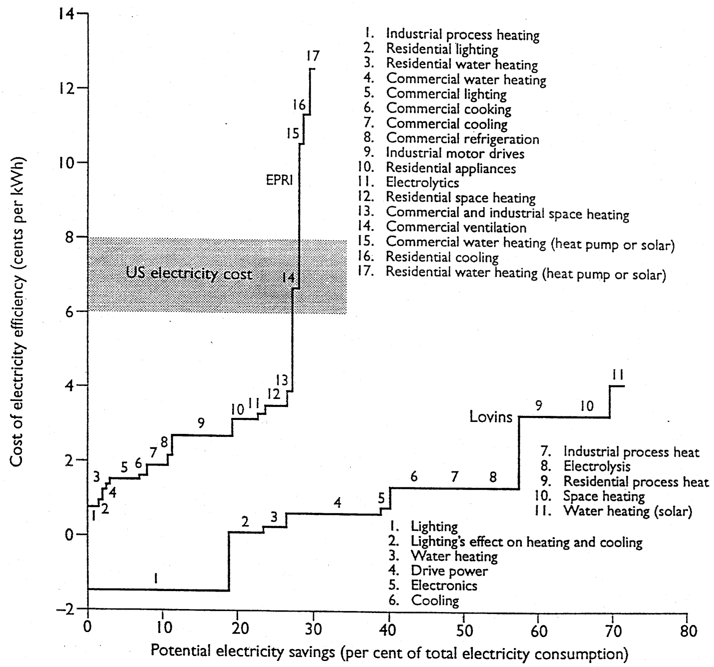


Figure 3. Energy supply curves for the US. Source: Joskow, P. & Marron, D. (1992) „What does a Megawatt really cost? Evidence from utility conservation programs“ , The Energy Journal 13 (4): 41.

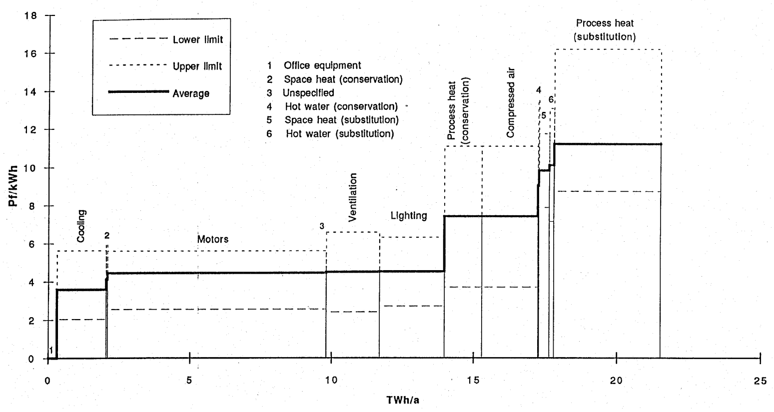


Figure 4. Supply curve of electricity conservation and substitution for the industrial sector in Germany (without primary industry; consumption 1993: 72,4 GWh).

4.) Now let us look at some details of the economy and the energy consumption of Germany. The German Enquete Commission for Climate Protection conducted the most comprehensive technical assessment of energy efficiency options for Germany, saying that it is possible to reduce primary energy by up to 45% (compared to base year 1987); a lot of indicators show that at least half of that potential could be cost-effective with existing relatively low energy prices.

Implementing this efficiency potential would be highly advantageous to the economy „ it would even be a job-creating machine, because all studies I know say that the perspectives of efficiency, CHP and renewables are positive. There is much debate whether 50 or more than 100 net jobs per PJ saved will be created, but the important message is: the signs show that the employment effect of efficiency measures is positive in any case. We worked out a large calculation with an extremely complex, dynamic input-output model together with Prof. Mayer of the University of Osnabrück, showing that about 500 thousand (net) jobs could be created by implementing an energy efficiency potential of 35% of primary energy .

Therefore, the potential of accelerating the so-called ‘A’ EEI in Germany by fostering market diffusion is high. When we looked at climate protection scenarios in Germany conducted by the Enquete-

Commission, we came across a very interesting figure of how energy efficiency can and must increase to achieve climate protection in comparison to a reference baseline trend. You see the baseline increase during the period 1990-2020 is about 2.5% p.a. If we want to have climate protection (CO_2-reduction of 45% by 2020) with nuclear energy, energy efficiency increases by 3.2% p.a; and if we want to get rid of nuclear energy at the same time, which is the position of the Red-Green government coalition, we must have a slightly higher increase of up to 3.5% p.a. (1990-2020). A 'Factor Four'-increase - that is the title of a new book and Report to the Club of Rome by our president, E. U. v. Weizsäcker and by Amory and Hunter Lovins - which means increasing energy efficiency by 4.7 % by 2020 is technically feasible, too!

Question from the auditorium:

Excuse me. This is percent „ energy efficiency measured as joules per dollar/GDP or what?

Yes, increase per year in the period 1990-2020, measured in joules per constant GDP.

5.) So, once more: if all this is technically feasible and within models and theoretical analysis economically benign, why doesn't it happen?

I think the most important point is that the markets for energy services – the competition between energy and efficiency equipment – are not functioning. If you look at the whole chain, right from primary energy to what we really want energy to do for us, namely services, in reality there are lots of efficiency losses all along the chain, which multiply. But this also holds true the other way round: if we have a more efficient transfer from primary energy to secondary and from secondary to useful and from useful to energy services, all those increased efficiencies multiply – sometimes up to a factor 4 to 10. This example of a typical pumping system illustrates the power of multiplied energy efficiency improvements (Figure 5). If you take an electric motor – coupling, pump and throttle – with traditional equipment you can gain thirty percent services from 100 percent primary energy. If you take the most advanced techniques which are available on the market (adjustable speed-drive, high efficient motors and pumps and low-friction pipes) you get the same output for less energy input. To foster energy efficiency increase, this kind of reasoning – optimising systems solutions and integrated planning – can and must be applied to buildings, to production processes, to lighting, cooling and heating, to transportation and so on.

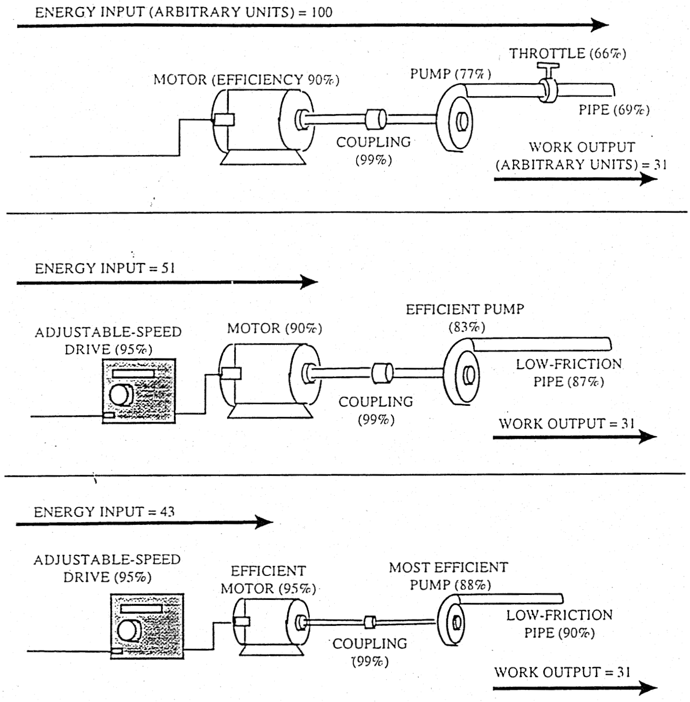
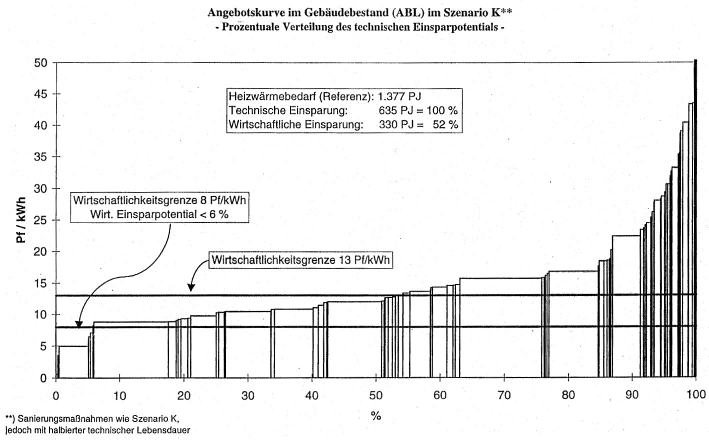


Figure 5. End-use efficiency measures can raise the efficiency of a typical motor pump system from 31% (top diagramme) to 72% (31/43, bottom diagramme) and can pay for themselves in two or three years (or less counting maintainance-cost savings). An electronically controlled adjustable-speed drive (middle) eliminates the need for throttle control and the resulting energy loss. A more efficient and properly-sized motor and pump, as well al larger and better pipes, can save even more (bottom). Source: Scientific American (1990).



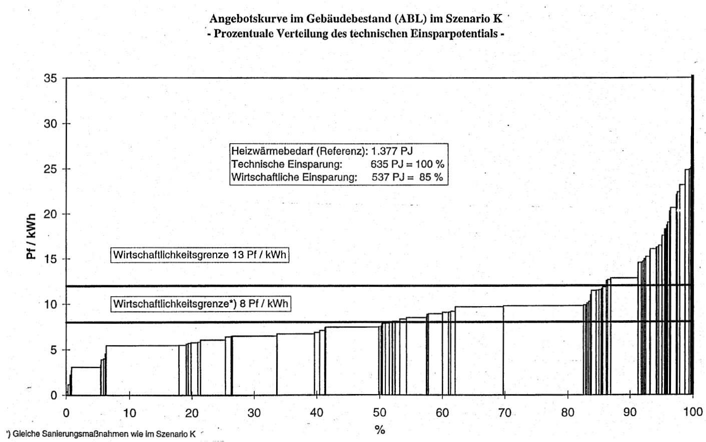


Figure 6. a)+b)

Another example: this is the energy conservation schedule (Figure 6) for the whole building sector in Germany, which we calculated for a representative typology of existing building stock in Germany. We asked, how much can we reduce energy consumption in existing buildings with more efficient retrofit equipment (e.g. insulation) and what combinations of efficiency measures are cost-effective compared to the average price for heat? If you take a price of 12 Pfennigs per kilowatt-hour, which is nearly 300% of the existing price for heat, you can in principle reduce the energy consumption by more than 80 percent with a profit. If you go down to 8 Pfennigs per kilowatt-hour, which is more than the existing price too but which could be reached in some years by implementing a green energy tax, a 50% reduction is theoretically cost-effective. But in reality a lot of barriers, mainly within the sector of rented houses, hinder the implementation. One barrier, for example, is the pay-back period. We calculated with an average technical pay-back period (20 years seems to be reasonable), but in reality owners of buildings don't calculate with twenty years. If you take ten years, you see the cost-effective potential reduces to 5 % with 8 Pfennigs per kilowatt-hour and to 50% with 12 Pfennigs per kilowatt-hour. Split incentives are another major barrier within the sector of rented houses, because the landlords has to invest, but the tenant gets the profit (or the extra cost) from well insulated (bad insulated) buildings.

Overcoming the barriers seems to be much easier in the electricity than in the heating sector. Let me show you one special success story (Figure 7): 'Bright North Rhine-Westphalia' seems to be the most comprehensive CFL-campaign (CFL: Compact Fluorescent Lamps) which has been conducted world-wide. Initiated by the Ministry of Economics of North Rhine-Westphalia (NRW) 79 utilities joined that action to introduce CFLs in NRW in a 6-month campaign; it was a real success story. With that campaign oriented towards Least-Cost Planning programmes conducted in USA and Scandinavia, 1.5 million new CFLs were introduced with a marginal cost per saved kilowatt-hours of about 3.5 Pfennigs per kilowatt-hour, all included (costs for CFL and for implementation and marketing). These figures are relatively reliable because they are based on utility information and evaluated data. 3.5 Pfennigs per kilowatt-hour is much less than the avoided costs of electricity supply (about 13 Pf/kWh). Therefore the campaign reduced the costs for the electricity bills of the customers by 140 million DM and CO_2-emissions by 450,000 tons. Therefore the customers, the utilities and environment have won: a 'Win-Win-Win' option.

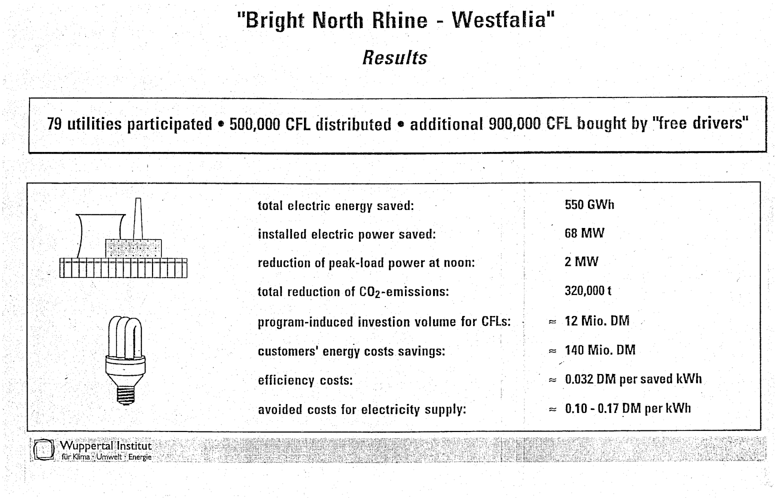


Figure 7.

This is only one example to prove the evidence of gaining profits by a more efficient use of electricity. Contracting is another example (performance contracting) and a rapidly growing business in Germany. Up to now, more than six hundred contracting firms are acting on the German 'NEGAWatt' market. As we come from the scientific community, I will show you just one example which we conducted together with a municipally owned utility in Heidelberg „ the university canteen in Heidelberg (Figure 8 and 9). This is a typical 'pie-chart' of the electricity consumption of a canteen. With our energy audit of that building we found that by installing more efficient equipment it is possible to reduce the electricity consumption by 20%, with a pay-back time of 2.5 years. This is a highly profitable investment, the implicit discount rate lies between 20 to 30 percent. However, it has not been implemented yet because of the lack of motivation, information and capital by the administration until the utility did it as a performance contractor.

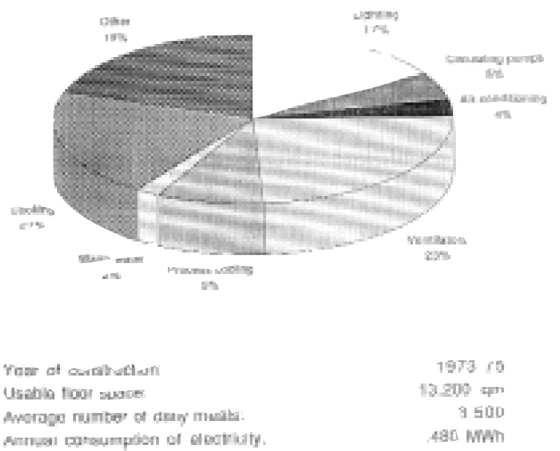


Figure 8. University canteen in Heidelberg.

Nr.	Measure	(expected) savings	(estimated) investments	pay-back time
		MWh/a	DM	a
1	Regulation of lighting	43	7.000	0,9
2	Exchange of light bulbs for ESL	13	3.000	1,3
3	Regulation of circulating pumps	41,7	49.400	6,6
4	Regulation of ventilators	117	30.000	1,4
5	Replacement of ventilators	47,5	30.000	3,5
6	Improvement of process cooling system	8,7	15.600	16,7
7	Regulation of pumps for warm water	16,8	1.500	0,5
8	Switch off of one transformer	13,1	0	0
	Total	300,8 (20,4%)	136.500	2,5

Figure 9. University canteen in Heidelberg.

Based on the success stories of performance contracting in Germany, the Wuppertal Institute now tries to intensify **international contracting activities** as profitable and flexible private options for climate protection. Here is one example, street lighting in Amman/Jordan (Figure 10). On behalf of the German GtZ (Gesellschaft für technische Zusammenarbeit) and in collaboration with the Jordan Energy Power Company (JEPCO) and Wuppertal Institute, a local consultant conducted a feasibility study of more efficient street lighting in Jordan. The feasibility study shows that it is possible to reduce electricity consumption of street lighting in Amman by 46 percent and peak-load by more than six megawatts with a pay-back period of less than 4 years. Though the investment is highly profitable, NEPCO or the city of Amman will not implement it because of lack of technical experience and capital. Therefore, an international tender for contracting firms will be conducted and the winning firm will realise the efficiency investment with a profit without any money from Jordan; this is an example of an international 'Win-Win-Win' option, which could work on a bilateral base at once without waiting for complex procedures for implementing Joint Implementation or Tradable Permits within the UNFCCC. You may transfer this example to every big 'Megacity' in the developing world, and not only for street lighting but for big hotels, administration buildings, industrial processes, small and medium-sized enterprises (SME) and so on.

Actual Savings at the Generation Side:

1. *Annual savings due to retrofit measures:*

Total Savings in Electricity	: 22129850 kWh
% of Energy Savings	: 33.5%
Total Reduction in Peak Demand	: 4300 kW
Total Monetary Saving	: 1,144,998 JD
Total Initial Investment Required	: 2,807,908 JD
Payback Period	: 2.45 Years (29.4 Months)

2. *Annual savings due to retrofit measures and general alternative no. 2:*

Total Savings in Electricity	: 25114832 kWh
% of Energy Savings	: 38.3%
Total Reduction in Peak Demand	: 4300 kW
Total Monetary Saving	: 1,299,441 JD
Total Initial Investment Required	: 3,037,443 JD
Payback Period	: 2.34 Years (28 Months)

3. *Annual savings due to retrofit measures, general alternatives no. 1 & 2:*

Total Savings in Electricity	: 30586823 kWh
% of Energy Savings	: 46.3 %
Total Reduction in Peak Demand	: 6734 kW
Total Monetary Saving	: 1,582,562 JD

Figure 10. Energy efficient refurbishment of street lighting in Amman (Energy Management Services International, December 1998).

6.) I have talked a lot about economics and profits. But to finish this short presentation, I would like to make a short remark on the lessons learned from an interesting socio-economic EU study[1] which we conducted together with international partners for the sector of small and medium enterprises (SME): for the real implementation process of

[1] Wuppertal Institute, AKF-Institute for Local Government Studies, Energieverwertungsagentur, Fraunhofer Institute für Systemanalyse und Innovationsforschung, Projekt Klimaschutz am Institut für Psychologie der Universität Kiel, Amstein & Walthert, Bush Energie (1998): Interdisciplinary Analysis of Successful Implementation of Energy Efficiency in Industry, Commerce and Service (InterSEE), Wuppertal, Kopenhagen, Wien, Karlsruhe, Kiel

energy efficiency, profits are not everything and sometimes not the main driving force for innovation. To get a deeper insight in the implementation processes, we took for example the Institute of Psychology/Kiel on board. Together with our collegues from Denmark, Switzerland, France, Austria and Germany, we looked at ‘success stories’ (of single firms and of efficiency programmes) and asked: why did they succeed although there are a lot of barriers, and what can we learn from them to transfer the successes to other firms and sectors?

In practice you will find a lot of small and medium-sized enterprises (SME) that make eco-efficiency investments although they are not profitable, and on the other hand, you are confronted with enterprises and managers who don’t like to invest in efficiency although those investments are very profitable. So you need further explanations „ economic reasoning is not the only motive. Therefore, one lesson learned from these success stories is: there is neither a simplistic confrontation between extrinsic economic versus intrinsic psychological motivation nor between (hard) command and control measures or (soft) informational or economic instruments. To foster energy efficiency on a broad scale we need **a mix of global and target groups or sector-specific instruments, collaboration and networks** among the actors. Therefore, another lesson learned was that the rational use of energy is not a single and purely market driven management decision. The initiation of social processes in the firms, involving internal and external actors, is necessary. As ‘bottom-up technocrats’ we learned that in reality we do not have this straightforward implementation process, examining the technical potential, overcoming the barriers with some instruments and then successful implementation. It is much more complicated. It’s a kind of cyclical approach like Figure 11. For a more successful implementation in long-term run processes, for example, you need far more feedback within the firms, and - concerning the design of programmes - you need a differentiated picture of your target group by market segmentation and to develope a market typology of SME actors. Therefore a lot of questions remain for further analysis (Figure 12), e.g. how to develop the markets for energy services, how to integrate them in the concept of micro-economic thinking, how to define new economic means for what we call substitutional competition between capital efficiency and energy, and how to integrate psychological barrier and behaviour research into micro-economic theory, and, last but not least, how to combine conventional bottom-up/top-down modelling and scenario analysis with the results of socio-economic research.

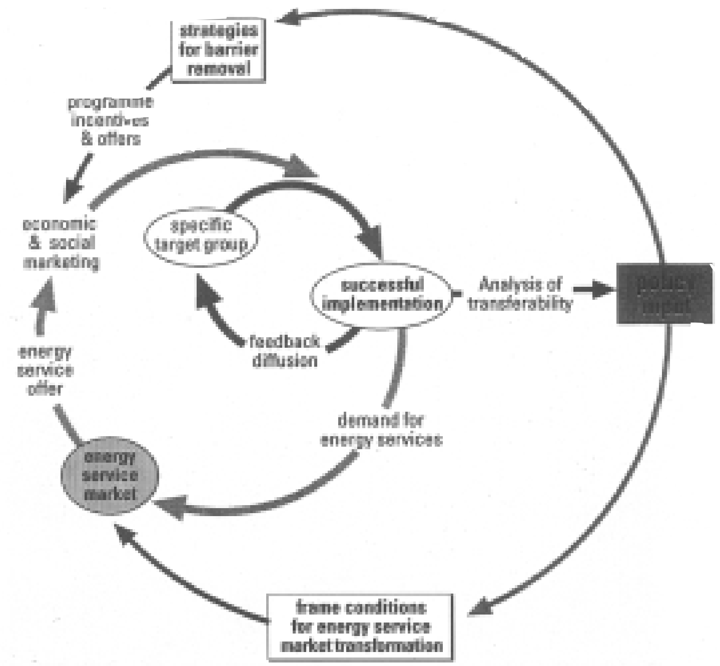


Figure 11. Integrative, cyclic and dynamic policy understanding (right dark box should read „policy input“). Source: Stefan Ramesohl (1998), Wuppertal Institute, EN-225e.

How to make energy efficiency important - getting the top management's commitment?

- enlarge pure economic considerations with additional benefits

- focus on multi-dimensional aspects of competitiveness (less insurance, higher product quality, improved work conditions, image gains, higher motivation of staff, lower operating costs, better relation to authorities etc.)

- use efficiency as a quality indicator for management performance

- promote energy efficiency as a core element of the broader concept of eco-efficiency (reduction of material flows, water and waste opens synergies and cuts costs)

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Prof. Dr. Peter Hennicke

Figure 12.

Summarized Discussions

Stephan Lingner

This summary is based on notes and tape records taken during the open discussions of the sessions „Climate Change“ and „Economic Impacts“. The following sections are not intended to approximate a transcript of the original wording of each statement given, but rather to sketch briefly the main issues that were discussed, giving some indication of where significant gaps remain in the collective research, and noting where revisions of individual views were suggested. In some cases institutions were explicitly identified. The summarizer apologizes to those of their representatives who might be misinterpreted.

Topic 1: Climate Change

When will we know better?

Substantial improvements of climate models are needed for reasonable policy advice and legimation of corresponding decisions. Refinements will have to be carried out concerning the effects of *aerosols*, *clouds* and *convection* and for modelling ocean dynamics, especially regarding the *mechanism of the thermohaline circulation*. They will – possibly in the next five (or ten) years – lead to substantial prediction improvements of climate models. But recall, that research may generally arise new questions and hypotheses, thus postponing the desired reduction of uncertainty for policy advice. This is the perspective, a sound prognosis cannot be given here.

PIK model and related afforestation recommendations

The climate model developed at PIK is optimized to computing speed, compared to other global coupled models. This is enabled by two-dimensional calculations, simulating three dimensions, and by significant reductions in resolution and in simplification of modelled system complexity.

The concept of afforestation for enhanced uptake of CO_2 and subsequent cooling is to be critically revised. From the PIK experience a differentiated view was given: The direct cooling effect of forests via carbon uptake will be partly compensated by undesired warming effects due to their lower albedos compared to grassland or agricultural land. These albedo-driven effects will be even worse at winter-times in higher latitudes, where snow covers are less stable on trees. Therefore, *forestation of the tropics* – and not the northern hemisphere – should be aimed at in favour of climate protection. Anyhow, the reality seems to be even more complex, as vegetation drives cloud formation, thus offsetting the albedo effect. Moreover, corresponding numerical calculations do not differentiate among tree types. This simplification seems to be reasonable at least in a first approximation, as different forest trees show similar respiration behaviors compared to other vegetation covers. Future, more sophisticated models may reproduce these more marginal differences better.

Ecosystem behavoir

CO_2-emission impacts to the ecosystems could be modelled and expressed in terms of changes in *net primary production* (fertilization effects) and subsequently, in *net ecosystem production* (warming, precipitation changes), which are currently simulated at MIT with 20 ecosystem types. Corresponding rough estimations of future realities have to be interpreted carefully with respect to

- warming and precipitation change lags, due to ocean heat uptake,
- saturation effects, which may offset fertilization processes,
- chemical productivity changes due to shifting of ecosystem boundaries/succession of ecosystems/biodiversity changes,
- bulk ecosystem diversity.

Uncertainty of cost benefits

Development of criteria for handling the climate problem needs economic impact data in terms of *losses* and *benefits*. A corresponding economic component is developed as a part of the MIT model. It aims at calculating least costly ways to respond to the problem of avoiding certain undesired impacts most efficiently. Additionally, direct economic costs of global warming damages on the environment may be assessed ahead from calculation of their particular abatement. This would enable to compare the least-cost consequences of any climate policy. But for principle reasons, corresponding reasonable numbers seem to be hard to generate.

Anyhow, concentration on cost-efficiency alone might be misleading in addressing the climate problem, especially when rationals for early actions (see Kyoto process) are discussed and when uncertainty will not be eliminated. Classical economics will therefore have to reflect its paradigms e.g., by communication with ecologists and ethicists.

Critical loads approach

Another approach might be given by investigation of critical temperature or warming levels, beyond which the climate system will get very unstable and chaotic, thus causing dangerous, *unacceptable thresholds*. The tolerable windows approach of the PIK aims at the same goal of preventing unpredictable, but theoretically possible or already documented phenomena. Example scenarios might be the possible shut-down of the *thermohaline circulation*, with severe consequences for the living conditions on the northern hemisphere and the rapid change of *temperature/precipitation patterns*, leading to the die-off of natural ecosystems and their functionalities. Climatic conditions, which lead to these dangerous thresholds may be modelled but – depending on calculation assumptions – the exact numbers are still uncertain and may remain uncertain in the next future. The challenge is that corresponding uncertain dangers have to be avoided, anyway.

Uncertainty analysis

Different climate models produce specific outputs, which are not (necessarily) stochastically related. This would be a disadvantage, as *over-arching probabilities* of climate modelling results cannot be reasonably calculated. As long as these probabilities cannot be estimated, assessments of risks remain impossible, which affect rational response and acting in the climate issue. Therefore, a corresponding tool for full uncertainty analysis of the global system will be developed at MIT, simulating complex models and giving a probability distribution function for emission-driven climate scenarios. Early versions show useful results for models with low to moderate non-linearity. The goal is to be capable to give reasonable, particular probabilities for occurrences of (undesireable) climate effects, affected by certain emission policies. This tool would therefore be valuable for policy analysis and advice.

Assumptions on risks

Climate research of the last 5 – 10 years allowed more differentiated views on climate-related risks for the society. One example is the possibility of *rapid and harmful temperature decreases* in central Europe due to a shutdown of the thermohaline circulation of the Atlantic, caused by global warming. This rapid regional cooling is not only possible from theoretical work; it has been also empirically shown by corresponding proxy-data of the past. Another more optimistic example is the possible *off-set of global warming* due to fertilization effects, thus limiting climate risks, at least theoretically. Ahead from their principal possibilities, probabilities of any thresholds cannot be given for risk assessment.

Expectations from future research and model developments

It may be expected from future models, that certain phenomena of the climate system, which are currently described as *chaotic*, might be partly extracted in terms of key parameters, thus decreasing uncertainty. Moreover, *knowledge gaps*, especially regarding the deep ocean circulation remain to be investigated in favour of more reasonable climate forecasts of the next decades to centuries. Anyhow, even (nearly) „perfect“ models will suffer from limited predictability, as long as chaotic behavior may not be reduced to zero. Uncertainty on *initial conditions* and corresponding initializations of models may still lead to different modelling results. Therefore, different ensembles of forecasts, typical for different emission options have to be performed, giving different sets of solutions for lowering the probabilities of undesireable climate change impacts. Interpretations of the results will have implications for policy advice and decision making in terms of decreasing the probability of detrimental consequences of human activity on Earth's climate.

Moral status of worst case scenarios

Decision making under uncertainty conditions arises ethical questions, especially with respect to less probable, but critical changes, like *rapid warming events*. It could mean, that rapid action has to be taken now for ruling out catastrophical consequences, despite of their low probability. It has to be investigated, if corresponding normative recommendations can be legitimized in a trans-subjective way or if they can only be left to (individual) value judgements.

Topic 2: Economic Impacts

The role of philosophy in the climate change discourse

The philosophical question arises, when humans loose their innocence by influencing the global climate. The dilemma of *uncertainty* with regard to the occurrence of good or bad impacts and the obligation to prevent very bad consequences at possibly high costs is real and needs for rational clarification. Uncertainty could lead to confusion among different positions and strategies of the public and among different advocates. Conceptual confusion may be resolved by means of philosophy and ethics, if *scientific criteria* for decision making could be developed. An often implicite used approach – the naturalistic obligation view to conserve the current holocene-type climate for the future – may be an early good operation assumption for climate protection.

- But it has to be proved even from a naturalistic view, as we know from the records, that the global climate changed over time and that the observed stable period for the last ten thousand years was unusual at least in Earth‘s late history,
- and further, it has to be answered, what we are trying to prevent and why, resp. what the responsible position of the humankind is in this issue.

Downscaling problem

The availability of *regionalised climate models* is desired for better policy advice in e.g., central Europe. They may be developed within the next five years with a resolution of a few hundred kilometres or even less. But it may be expected, that their *predictive power will be rather limited*, especially regarding precipitation prognoses, which may be for example crucial for agriculture. The reason is, that the models or model versions may produce different signals, which are caused by *inherent factors*, like specific initial conditions or different approaches to the sub-systems dynamics. These disagreements will be even worse in high resolution predictions because of their low aggregation level. The consequence of this methodological problem is, that one cannot wait for „perfect models“. Therefore, climate impact research and policy advice generally has to deal with disagreements of scientific data and problems of acting under uncertainty.

Evaluation of climate change impacts

A challenging goal for policy advice and information of the public is the assessment of impacts, favourable in terms of costs, as far as possible.

The actual MIT effort and perspective in this respect is as follows: The problem seems to be too complex to give corresponding cost-benefit analyses in numbers at now. Moreover beyond this, the fragile state of unmanaged, natural ecosystems - playing a major role in global cycles, and thus posing severe environmental risks - could hardly be expressed in numbers from „artificial“ cost-benefit analyses. Therefore, *non-*

market effects, like effects on ecosystems are seen as crucially important. They have to be fully understood before any economic assessment in terms of costs can be reasonably conducted and submitted to the public. Anyhow, modelling climate change impacts e.g., on areas of plant production, biodiversity or forest move will give market measures at some level on agriculture, which is therefore one currently focused sector of the relevant MIT research programme. Another problem area with economic importance is the research on global sea level rise, which is actually also conducted at MIT. Corresponding research results (indices) will give orientation for *implicit weighing* of ecological and economic goods in favour for consideration, prudent judgements and decisions on different options to handle the climate problem.

The audience claimed, that there is a basic problem of weighing goods, especially heterogenous goods, without having transcribed them into comparable exact data. Probably only these data – not intuitive weighing - will *enable prudent judgements* and rational decision making on a collective level. Corresponding necessary *economic calculations* may be

- postponed for some very uncertain domains,
- restricted to problem areas with high priority,
- and/or simplified by reducing system complexity e.g., by internalising indirect effects in order to match the complexity or uncertainty problem.

Modelling of politics response

Ahead from the integration of physical and economic model components, the incorporation of the politics response is to be questioned. The MIT model performs no direct connection in this respect. Insights from current analyses show that sectoral feedbacks of climate change (e.g., on agriculture) to overall growth are relatively small for most countries. Therefore it seems to be adequate to link political response to climate change effects simply in a sequential manner.

Mitigation strategies

Legitimations, applicability and timing of mitigation strategies, especially concerning „no-regret strategies“ in favour of climate protection were controversally discussed. Looking at the *energy sector*, two different main lines of argumentation were put forward:

1. The *supply-side argumentation* stated, that information deficites and conservative preferences of the energy suppliers will establish barriers, which inhibit the market introduction of new technologies and energy services. These barriers are seen as *market failures*, which have to be removed by appropriate instruments, in order to make use of the energy-saving potential of refused, but already existing technologies. The balance of overall costs for the enforced market introduction of new technologies might even lead to win-win situations, as deduced from example calculations.

2. The *demand-side argumentation* stated, that not market failures, but *consumer preferences* have to be carefully reflected. Instead of the above mentioned argumentation, they are seen as the main barriers for the successful introduction of energy saving technologies. Consequently, measures should principially be in-line with marked economy, as any potential market barriers would be subsequently removed by well-established mechanisms of marked economy - at least in theory. Therefore, corresponding information deficites concerning win-win options are unlikely to exist, as long as economic rationality takes place.

It is perceiveable, that *no-regret options* seem to be more convenient in a European than in a US- American context, despite of some american effort on this matter. Reasons may be explained on one hand by certain preferences of the Republicans, which dominate the Congress and affect the american climate policy. On the other hand, results of the often quotet „Five Labs Study“ on this topic, conducted by the US Department of Energy, received a lot of criticism for methodological reasons.

Ahead from the questionable potential of no-regret strategies in favour of overall climate protection goals, timing recommendations for these and more cost-intensive actions may be given by orientation on specific, to be determined discount rates.

Studies on discounting / instruments

The US American expertise on these issues is as follows:

Since ten years, intensive investigations on long-term discounting of environmental goods were carried out by different research groups. Actually, the Energy Modeling Forum will publish a book from a corresponding two-years study. Another, most recent report from the Harvard University gives a measure for a declining discount rate over time on a set of certain assumptions.

Studies on trading systems have been conducted under various focuses by MIT in collaboration with the World Bank and the Environmental Protection Agency. Key areas were impacts of trading systems on developing countries and the extension of the experience of the so called „US Sulfur System“ to the problem of emissions trading. More theoretical work had been done on how trading systems might grow and evolve.

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