Causes and Consequences of Global Warming

How Rational is Our Policy on Climate Change?

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Chapter I.

Social importance of climate policy

Is mankind heading for a climate catastrophe? The range of opinions on how dangerous the greenhouse effect really is comprises two opposing views. At the one extreme, there is exaggeration, apparently because the assumption is that only this will wake up the general public and make them aware of the whole issue. At the other, there is a tendency to play down the problem as there is concern about the costs that would ensue from a consistent climate policy. In other words, the debate about the greenhouse effect is not always conducted with full sincerity. Distorted presentations, strategically filtered information and shaky arguments make it extremely difficult to gain an objective insight into the facts. This book is an attempt to move towards more objectivity, presenting current scientific opinion on the climate problem. Wherever possible the sources that were used stem from first-class peer-reviewed journals or otherwise reliable publications. In many cases it was possible to base conclusions on original, first hand data from publicly available data bases, e.g. satellite raw data to document the temperature development over time. The aim of this book is not only to discuss the climate problem with up-to-date and unbiased arguments but also to provide the reader with a solid basis for forming a competent opinion of his own.

Not only the greenhouse effect is controversial. The ecotax is also a contentious issue. It can be regarded as an attempt to respond to fears of a climate catastrophe. However, critics of the ecotax consider it a sham, purely intended to get money out of taxpayers. Advocates of the tax, on the other side, see it as an ambitious attempt to remove the opposition between ecology and economy. They envisage double dividends. On the one hand, ecotax revenue is to be used to reduce additional wage costs and thereby cut unemployment. On the other hand, the levy of ecotax should bring about more environmentally sound behaviour on the part of citizens. In this view, ecotax is advocated in particular as an instrument of climate policy which, by taxing energy, should lead to a reduction in carbon dioxide (CO_2) emissions and counter the anthropogenic greenhouse effect. This is considered necessary to prevent a dramatic warming of the earth's climate.

The introduction of an ecotax is a national measure. While a number of countries, e.g. Denmark and Germany, have already introduced such a tax, it is not an EU-wide or indeed world wide uniform instrument. However, these purely national measures do form part of an international framework of global climate policy. In 1988, the IPCC (Intergovernmental Panel on Climate Change) was set up. It is an international body of experts charged with assessing the state of climate theory world wide and in particular bringing together data on which there is a consensus among scientists. On the basis of IPCC reports, international agreements on climate protection were concluded in the 1990s (see Appendix A): The United Nations Framework Convention on Climate Change (UNFCCC) was signed at the Rio Earth Summit in 1992. At the Kyoto Conference of 1997, a Protocol to this Convention was adopted in which the developed OECD countries as well as Russia and the East European Associates gave an internationally binding commitment to reduce their greenhouse gas emissions, calculated in CO_2 equivalents, by at least 5% below 1990 levels in the period 2008-2012. The Member States of the European Union set themselves an even more ambitious reduction target of 8%. Under an EU-wide offsetting scheme, Denmark and Germany have undertaken to reduce greenhouse gas emissions by 21%. But even this is regarded as grossly insufficient. The German Government's Advisory Council on Global

Change, for example, demands that *all* countries bound by the Kyoto Protocol should, based on 1990 levels, reduce their emissions on average by 23% by 2010, 43% by 2020 and 77% by 2050.[1]

The ultimate aim of all national precautionary measures of climate policy is either to cut primary energy consumption or reduce the concomitant emissions. In other words, climate policy is energy policy. This makes efforts to drastically reduce greenhouse gas emissions into a hazardous undertaking. The fact is that burning fossil energy sources (coal, oil, gas) not only releases CO_2 but also generates prosperity, hence the crucial importance of energy use for economic growth and general prosperity.

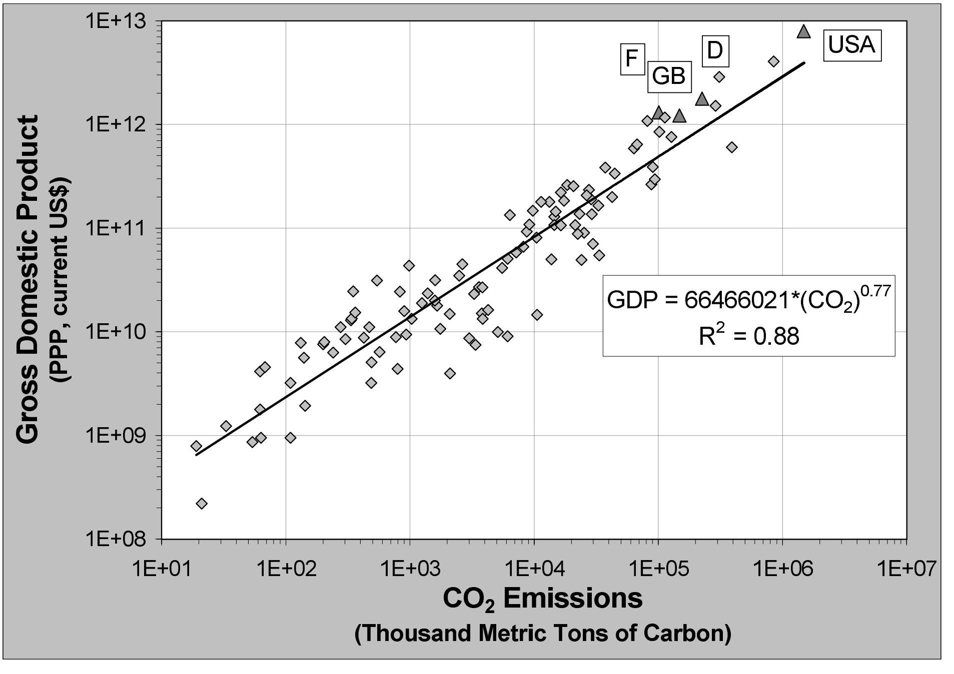

Figure 1. Worldwide correlation between Gross Domestic Product and CO_2 emissions (in 1998)

The consequences of this situation are displayed in Figure 1 which, based on cross-country data for 1998, shows empirically the close correlation between CO_2 emissions and general prosperity, measured here in terms of real Gross Domestic Product (GDP) and powers of ten (1E+3=1,000). This correlation applies world wide and for various stages of economic development as evidenced by the data for the 108 countries presented. (For a longitudinal analysis of time series data for single countries see Appendix B).

Because of this close link between energy and CO_2, this greenhouse gas can be regarded as a kind of production factor with the help of which useful goods and services can be produced (Figure 2).

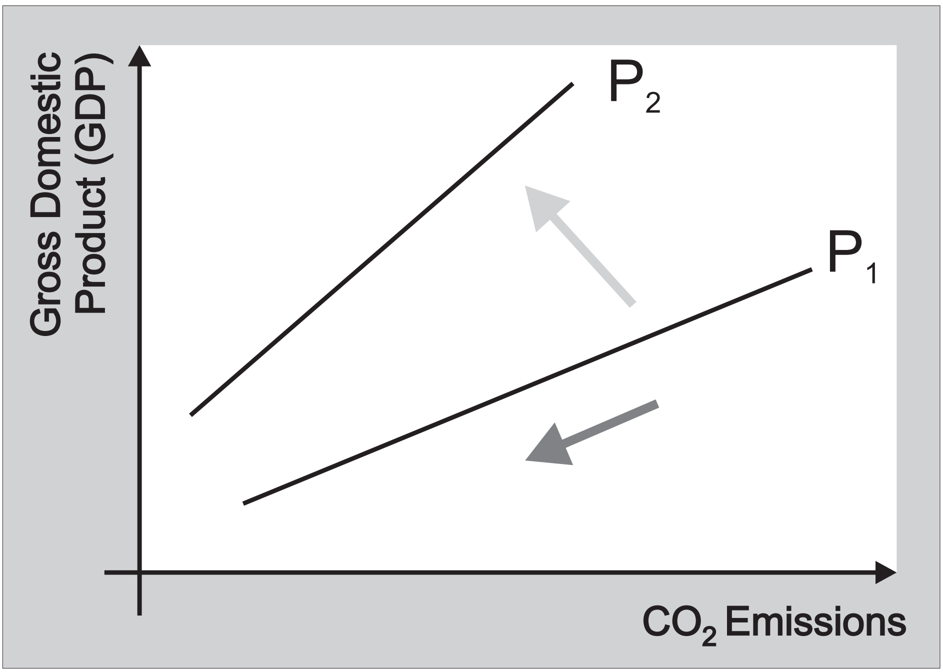

Figure 2. CO_2 as a "production factor"

Production function P_1 accurately reflects this relation between CO_2 and general prosperity. Two effects of climate policy instruments can be distinguished. On the one hand, technological and/or organisational innovations may cause a loosening of the close link between CO_2 emissions and prosperity. In the graph, this corresponds to a shift in production function from P_1 to P_2. This shift makes it possible to pursue climate protection objectives without adversely affecting the level of prosperity (light arrow). On the other hand, a straightforward energy saving, brought about for instance by an increase in the monetary and/or non-monetary cost of fossil fuels, may lead to fewer goods and services being produced. Graphically, this corresponds to a movement along the old production function P_1 (dark arrow). Accordingly, more climate protection automatically means less prosperity.

Energy use is the motor of modern civilisation. In the framework of climate policy, it is deemed necessary to bring about a radical shift in current energy use. Against this backdrop, the question is not only what the effects of the political instruments are, i.e. whether they cut greenhouse gas emissions purely quantitatively through savings (dark arrow) or qualitatively through investment incentives (light arrow). We also need to examine the objectives of climate policy for which such political instruments are pressed into service. In other words, what are the conditions on which current climate policy is based?

Chapter II.

Conditions for a rational climate policy

Current climate policy is based on two pillars: physics and social sciences. Overall, six conditions can be identified that have to be fulfilled to show that current climate policy meets an important democratic demand: the requirement of rationality. The three conditions to be ascertained through physics concern the consequences, extent and causes of the feared change in climate. The three conditions to be verified through social science concern the extent to which current climate policy guarantees that effective prevention strategies will be developed with regard to various greenhouse gases, regions and sectors.

1. Would climate warming be catastrophic?

The feared effects of climate warming range from melting polar caps, rising sea levels, sinking coastlines, via droughts, heat waves and resultant desertification, to storms and floods caused by heavier precipitation. Other effects that are deemed plausible are the proliferation of disease-causing agents and plant pests and eventually impairment of agriculture and forestry which could jeopardise the world's food supply. In popular science writing, long lists of potential risks are presented suggesting that climate warming is tantamount to a climate catastrophe.[2]

The *actual* consequences of climate warming depend on how strongly and how rapidly the earth's temperature will rise as the extent of any damage is also determined by how much time is left for adjusting to changed climate and how this time is used. In this regard, the scientific basis for such concern is not entirely clear. In 1990, the IPCC forecast – in a "business as usual" scenario, i.e. assuming a permanent absence of any climate change policy – a 3.3 °C rise in temperature by 2100. In the light of improved knowledge, this forecast was corrected downwards in 1996 to a range between 1.0 and 3.5 °C.[3] In its latest publication, the IPCC has projected a higher and at the same time larger range for the development of the global temperature. Currently, the IPCC holds the view that the global average temperature could increase by 1.4 to 5.8 °C from 1990 to 2100.[4] However, this projection has been heavily criticised because the IPCC does not provide a likelihood estimate for its finding. Once this information is added, the picture looks quite different: Absent any mitigation policy, the median expectation amounts to a temperature rise of 2.3 °C from 1990 to 2100, with a 95% confidence interval of 0.9 °C to 5.3 °C (see Appendix C). Even this improved information indicates huge uncertainties, resulting from difficulties in understanding and forecasting highly complex phenomena.

Similar conclusions apply to the expected rise in sea level. In 1996, the IPCC reduced its 1990 forecast by 25%. From 1990 to 2100, it expected sea levels not to rise by 0.66 metres but by an amount between 0.13 and 0.94 metres.[5] The current estimate ranges from 0.09 to 0.88 metres.[6] As for the possibility of an increasing frequency of more severe storms, it is emphasised that the state of knowledge does not allow any forecasts for the future.[7] Bearing this in mind, we can, in assessing the consequences, benefit from the knowledge that climate warming is not uniquely predicted for the future but has already taken place in the past. What lessons can we learn from this? Figure 3 shows a reconstruction of global average temperature over the past 1,000 years.

As it is not so much the level as the change in temperature that is of interest, the graph only shows temperature anomalies, i.e. variations in temperature from a particular average value.

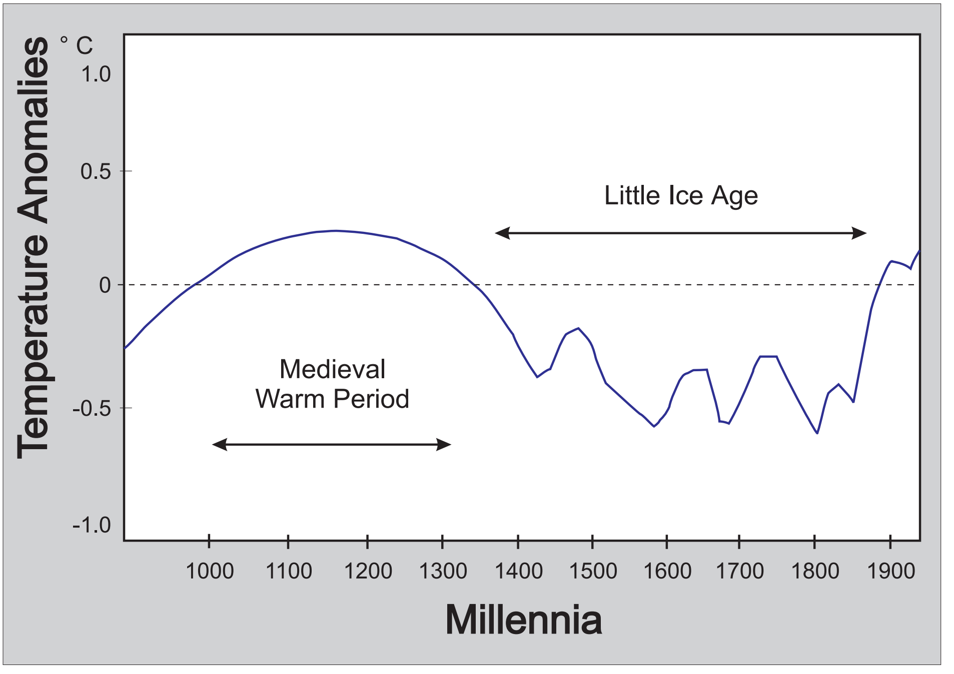

Figure 3. Average temperature over the past 1,000 years

The graph clearly shows that the first half of the millennium was warmer than average while the second half was colder than average. The warm period, which reached its apex in the 12th to 13th centuries, is often referred to as "climate optimum". At the time, wine was grown in England and the Vikings settled Greenland ("Green Land"). The "Little Ice Age" from 1450 to 1890, with an average global temperature up to 1 °C lower than today, must still be attributed to natural climate fluctuations because a noticeable human impact on the earth's temperature could at the earliest have commenced with industrialisation.

The consequences of climate warming observable in the 20th century are reflected in numerous statistics, e.g. compilations by insurance companies of weather-related damage caused by flooding, storms, extreme heat waves or cold waves, and droughts. These damage statistics show a distinct rise in the

1990s. The first impression could be, therefore, that the fear of a climate catastrophe is warranted. The fact is, however, that detailed investigations for the United States lead to a different conclusion.[8] While it is true that, in the US, damage caused by extreme weather conditions has since 1930 generally been on the increase, this cannot primarily be attributed to the greater frequency or intensity of such occurrences, but rather to the fact that the prosperity (and insured property) of the American society has grown over the years. In the case of hurricanes, for instance, it is found that the financial damage is continually increasing while the number of deaths caused by hurricanes is decreasing, especially owing to steadily improving early warnings. The increase in damage can be explained neither by increased frequency nor by increased intensity of such storms. Instead, it is due to denser settlement in endangered coastal zones. The situation is similar for other storms and storm damages (caused by lightning, hail, etc.). The weather occurrences as such do not show a positive trend. However, weather damage is on the increase in particular because the population and their prosperity is on the increase, entailing a steady growth in the value of insured property. Over the past 25 years, only floods have shown an upward trend. With the current state of knowledge, however, it is not possible to distinguish between damage due to climate change and that due to changes in society.

In evaluating the consequences of climate warming, it is not enough to look at developments in the past. One should also try to forecast future developments. This has been done repeatedly, in particular for agriculture. Numerous studies carried out for the United States agree that the warming expected by the IPCC up to 2100 would in any case have a limited impact on US farming.[9] One study for Germany in fact reaches the conclusion that farmers can raise their yield per hectare by 358 € if a doubling of CO_2 in the atmosphere causes an average rise in temperature of 1.9 °C.[10] This is because it is expected that there will then be an increase in precipitation and only half the number of days of frost. This would almost throughout have a positive impact on production. The forecast is for more than double the yield in vegetables and permanent crops, a one-third production increase for root crops, a virtually unchanged wheat production and a lower yield of oleaginous fruit.

In these predictions, no account has been taken of the positive effect of CO_2 on plant growth. The graph in Figure 4 results from a calculation of the extent to which, since industrialisation, the increase in atmospheric CO_2 concentration from 280 to 360 parts per million by volume (ppmv) has enhanced plant growth. Figure 4 also reflects information obtained from laboratory tests concerning the fertilising effect of an even higher CO_2 to be expected, in the worst case, up to 2100.

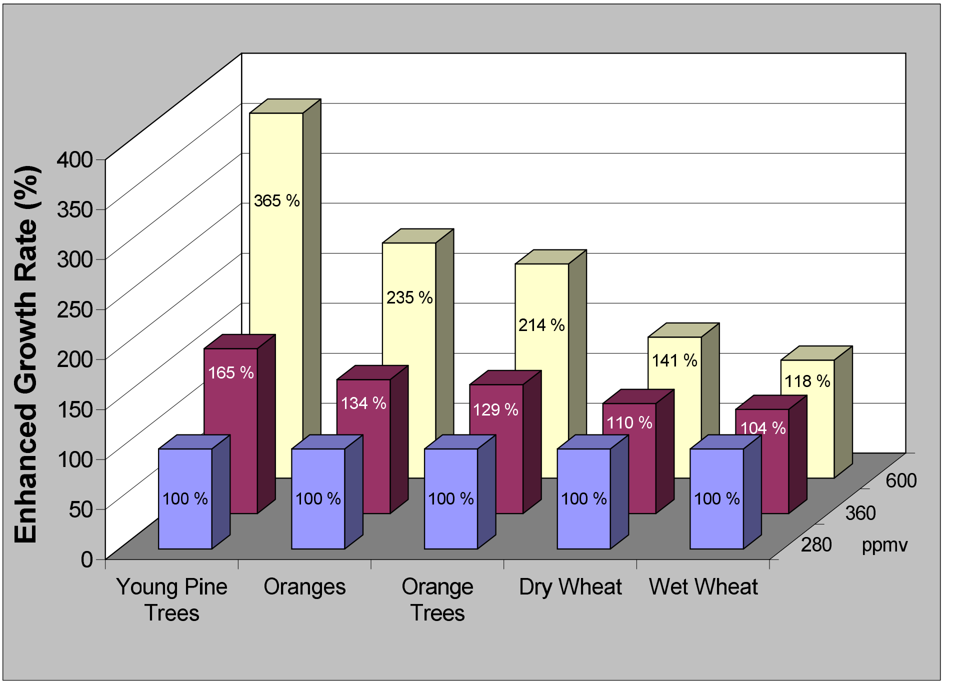

Figure 4. Increased plant growth through carbon dioxide

Even if – as newer studies suggest – the real fertilisation effect will be lower because other influences (like ground structure or precipitation) could be the limiting factor, a study covering ten European countries comes to the conclusion that the increase in atmospheric CO_2 concentration expected by 2050 and the resultant climate warming will generate an increase in wheat yield per hectare of at least one tonne in all ten countries, without exception.[11] Although local changes might be negative, in general it is to be expected that world wide the food situation will *not* significantly deteriorate.[12]

It also appears exaggerated to worry about a climate-induced increase in the incidence of diseases. Usually, such worries are based on the argument that higher temperatures might enhance the regional habitat of pathogens. Projections have been published suggesting that with a 3 °C warming by 2080 the number of persons at risk of malaria infection could rise by 290 million.[13] Yet, a more recent extensive investigation into this disease reaches a quite different conclusion.[14]

The historical finding is that during the Little Ice Age malaria was widespread in England and that it gradually subsided there only in the 19th century, i.e. at a time when there were distinctly higher temperatures. The only explanation is that the actual incidence of malaria is *not* primarily climate-related but mainly connected with other factors, including quality, quantity, price and general availability of health services but also the use of pesticides and hygienic living conditions. It therefore looks as though the concerns based on calculations of potential infections quite simply underestimate the extent to which a modern civilisation can appropriately respond to health risks.[15]

What does all this mean? Are all fears and concerns unfounded because of the historical evidence that technologically far less developed civilisations than ours managed to prosper despite a warmer climate? Or because of the statistical finding that the increase in insurance damage in recent decades cannot be attributed to more extreme weather conditions but to greater general prosperity? Or because of a consensus among scientists that the impact of climate warming on agricultural food production could well be positive rather than negative? Or because of the realisation that we would not be completely defenceless against a possible increase of pathogens? – The clear answer to these questions is: No. Many fears and concerns may well be dissipated by these facts and findings. What is certain, however, is that not all worries have been removed. This would require far more extensive knowledge than is currently available. What has been refuted, however, is the alleged certainty that a rise in the earth's average temperature *must* necessarily have disastrous consequences. The facts presented above suggest that the widespread view that climate warming equals climate catastrophe cannot be substantiated scientifically. Rather, scientific findings suggest that the likely consequences require a much more differentiated evaluation. There is even dissent among scientists, implying the need for more research, as to whether the generally feared climate warming can already be observed today.

2. Is climate warming already discernible?

Knowledge about the trends in earth temperature goes back a long way. The trend over the past 1,000 years is presented in Figure 3. It shows that the medieval warm period ("climate optimum") was followed by the "Little Ice Age". An even greater extent of natural climate fluctuation is apparent when one reviews an even longer period. It is clear from Figure 5 that over the past 18,000 years the earth's temperature rose by 4 to 5 °C since the last ice age, while Figure 6 (both next page) shows the alternation during the past 800,000 years between ice ages and relatively brief warm periods, on average lasting about 10,000 years, referred to as "interglacial periods".

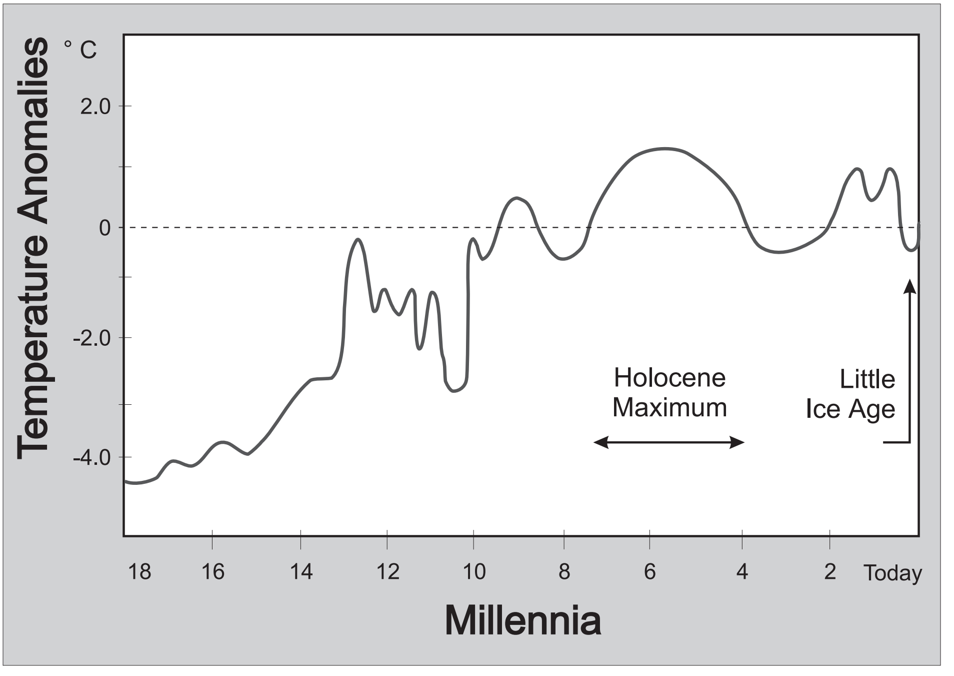

Figure 5. Average temperature over the past 18,000 years

Such palaeoclimatic temperature data series are not based on direct temperature measurements but on reconstructions for which use is made of a wide range of substitute data, e.g. tree ring analysis, sediment studies and ice core drilling. These local findings are compared and combined. Through spatial and temporal averaging, a global temperature trend can then be reconstructed. Though the use of the auxiliary indications and their aggregation to a world wide trend is a scientific challenge with numerous sources of error, this is the only way of reconstructing history temperature and emissions data.

Time series for global average temperature based on direct temperature *measurements* have only been available since the second half of the 19th century. These ground data result from measurements on land and water.

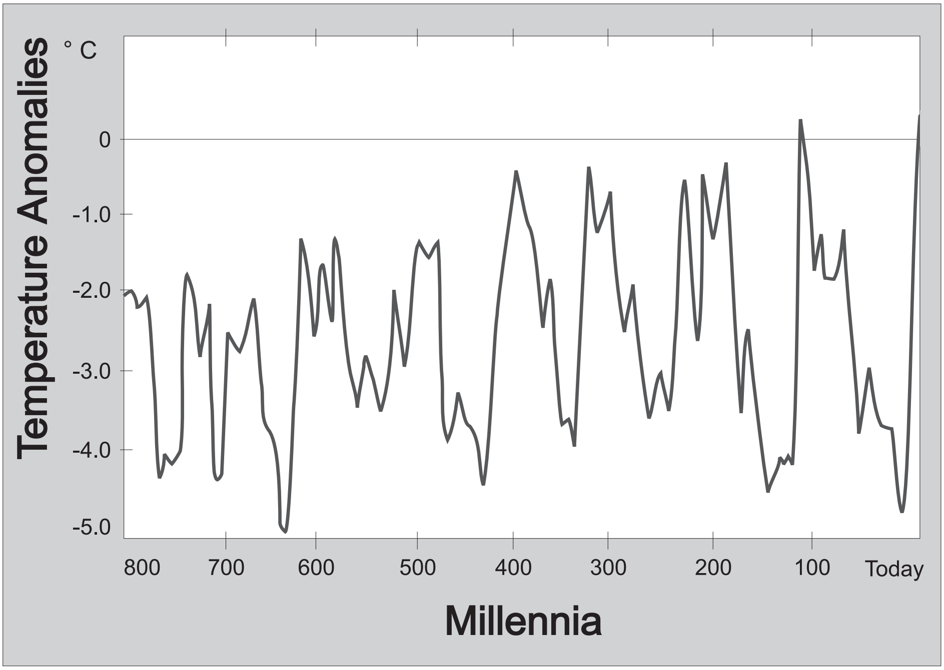

Figure 6. Average temperature over the past 800,000 years

Figure 7 (next page) shows the corresponding temperature anomalies, i.e. deviations of aggregate values measured from a fixed average value. Based on monthly data, the grey line presents a moving average over one year, the black line a moving average over 10 years.

At the bottom, one can see that the variance of monthly data for temperature anomalies has not increased in recent decades. Furthermore, it is worth noting that there was a temperature increase in the 20th century and that this increase was discontinuous. There was a first period of warming from 1910 to 1940. Then this trend was interrupted for about 30 years, with a renewed period of warming starting only in the middle of the 1970s and continuing to this day.

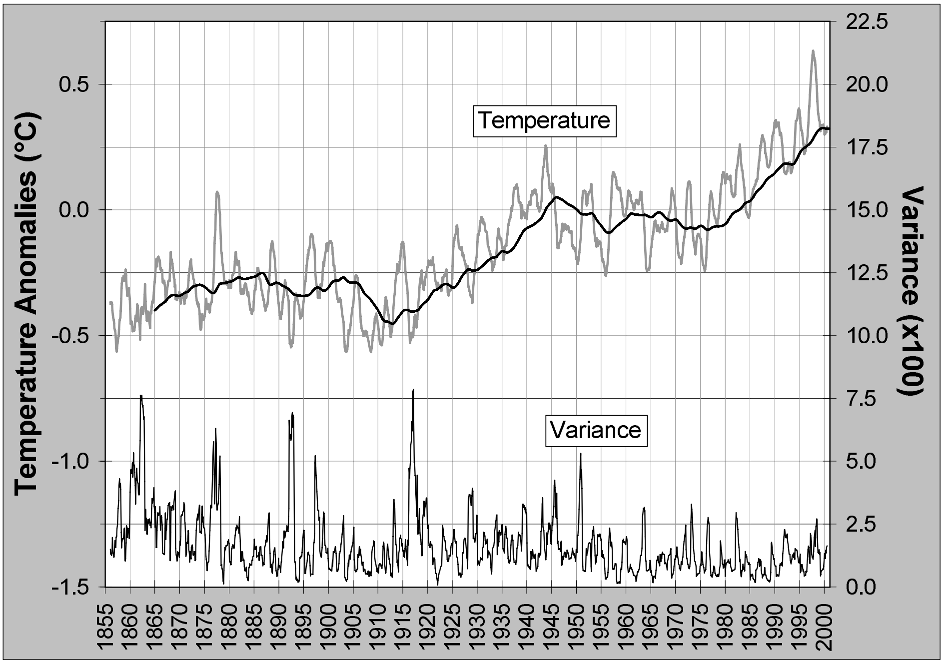

Figure 7. Near-surface temperature and variance since 1856

Measurements for the most recent years are naturally much more accurate and reliable than reconstructions for the remote past. However, the accuracy of the ground data is not entirely beyond doubt.

This is due to (at least) four different factors:[16]

First of all, measuring stations are not equally distributed across the globe. Land data are recorded in particular in areas where human settlements are concentrated while sea data are mostly recorded along shipping routes. Accordingly, the calculation of a global average value requires complex arithmetical corrections. Secondly, measurements are not made on a continuous basis. Old measuring stations are closed down and new ones set up. Consequently, there is no underlying constant database. This, again, requires arithmetical adjustments.

Thirdly, measuring techniques vary over time. The concomitant problems range from the type of thermometers used to the exact time of day when a measurement is taken. It also makes a difference, for instance, whether, in the case of sea water temperature measurements, the water was collected in wooden or metal buckets. It is also important to know at what depth the water was taken. Only in recent years has all this been documented in detail and has care been taken to keep measurement routines as constant as possible.

Fourthly, external measurement conditions have dramatically changed over time. This applies in particular to land measurements. Many measuring stations are located in towns and cities and are affected by changes in their size, with larger cities entailing local warming. This human settlement effect distorts the measurement data, again necessitating complex corrective calculations. Depending on the type of calculation of ground data, the temperature increase over the past 100 years is calculated as 0.4 to 0.8 °C.

Bearing these facts in mind, it is interesting to note that alternative data series have been available in recent years. They are partly based on balloon measurements, which were introduced in the 1940s but have only since the late 1950s been reliably and regionally extended to the point that *global* average temperatures can be determined for the lower to middle troposphere. The troposphere reaches from the earth's surface to an altitude of 8 km. Data series are also based on satellite measurements, which have been available since December 1978. Both balloon and satellite measurements produce a vertical profile for the earth's temperature in the lower atmosphere.

In these two alternative procedures, it is still necessary to carry out calculations and statistical corrections. While balloon data are based on direct temperature measurement, there are problems calculating a global average.[17] There are two main reasons for this. First of all, there are only about 900 balloon measuring stations world wide. In other words, their number is comparatively small. This problem is accentuated by the circumstance that less than half of these stations report monthly temperature data. Only two-thirds of them have in recent decades issued continuous reports. In the 1990s, a number of measuring stations in Africa and in the former Soviet Union were closed down because of their costs. Secondly, the stations are very unequally distributed geographically. The oceans in particular are hardly covered. The same applies to land masses located in the extreme north and south of the globe.

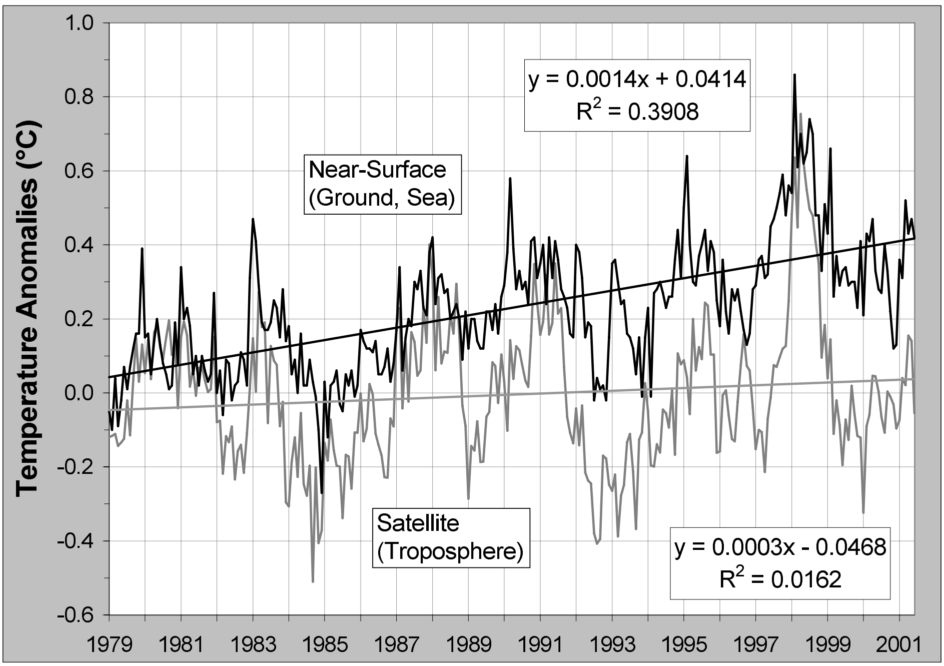

Figure 8. Near-surface and satellite temperature compared (1979-2001)

The situation is different for satellite data. Satellites do not measure temperatures directly but calculate them from microwave radiation measured. Numerous sources of errors must be checked in the process, ranging from the use of different satellites and satellite equipments over time via orbit decay to variations in the sensitivity of the high-precision measuring instruments used.[18] All this makes complicated corrective calculations necessary. However, satellite data have the advantage of truly global coverage: Every day 80% of the entire surface of the earth is covered; through slightly altered orbits 100% is attained in three to four days. More than 15,000 observation data are recorded each day.

Comparing the three data sources for the 22-year period from 1979 to 2001 shows that ground data – depending on the type of calculation – indicate warming between 0.25 and 0.4 °C while satellite data show a much more moderate increase, calculated at between 0.0 to 0.2 °C. According to Figure 8, the corresponding values are 0.35 °C and 0.08 °C, respectively. Satellite data very closely correspond to balloon data. For the period from 1979 to 1998 they indicate a temperature increase of about 0.1 °C. Consequently, only ground and satellite data are compared in Figure 8. The finding that satellite data (and balloon data) indicate a lower level of warming than ground data is all the more surprising as the greenhouse effect theory would lead one to expect that the atmosphere layers up to 8 km above the earth's surface would show a *stronger* temperature increase than that on the ground.[19]

3. Does an anthropogenic greenhouse effect cause the discernible warming?

The earth's climate is decisively determined by the sun.[20] Solar radiation supplies energy to the earth. The amount of radiation vertically striking a 1 m^2 area outside the earth's atmosphere is the equivalent of about 1,370 watts (W). As the earth's surface is rounded and as half of the earth is at any given moment turned away from the sun, the average solar energy reaching the earth outside the atmosphere is 342 W/m^2. 31% of this energy is reflected, in particular by clouds, leading to a residual radiation of 235 W/m^2 heating the atmosphere and the earth's surface.

Given this energy supply, the earth's temperature can remain constant only if the earth gives off as much energy to space as it takes up from there. The level of this equilibrium temperature depends on the extent to which the infrared radiation emitted by the earth's surface is absorbed and reflected by the atmosphere. The degree of this insulation is determined by atmospheric greenhouse gas concentration. In this context, a distinction should be made between a natural and an additional, anthropogenic greenhouse effect. As a result of the natural greenhouse effect, global average temperature has levelled out at about 15 °C. There are worries that the anthropogenic, additional greenhouse effect might cause this temperature to increase significantly.

The fact is that CO_2 concentration in the atmosphere has increased, namely by a global average of 27%, from 290 ppmv (parts per million by volume) in 1879 to 368 ppmv in 1999. The question is therefore whether the rise in temperature that is observable despite the uncertainty of the available data can be attributed to an anthropogenic greenhouse effect. This would be the case only if human activities were the only source of the CO_2 increase and if this in turn caused the rise in temperature. Doubts have been expressed on such a chain of causality on various grounds. Three of these are discussed below.

The first problem is determining carbon stocks and carbon flows in the global carbon cycle.[21] With regard to stocks, it is estimated that the atmosphere currently contains about 750 Gigatonnes ($Gt = 10^9$ t) of carbon (C), the landmass including vegetation about 2,190 GtC and the oceans nearly 39,000 GtC. Carbon flows between these three media are quite considerable. For the period between 1980 and 1989, it is estimated that about 60 GtC were exchanged between the ground and the atmosphere each year and about 90 GtC between the oceans and the atmosphere each year. In this connection, it is assumed that the atmosphere transferred a net quantity of about 1.3 GtC to the ground and about 2 GtC net to the oceans. Compared with these flows, anthropogenic CO_2 emissions appear rather modest. They are estimated at a total of 6.4 GtC a year. 5.5 GtC of this volume result from the burning of fossil energy sources and cement production, with a further 0.9 GtC due to the net effect of altered land use. By way of comparison, sea organisms alone absorbed 50 GtC a year from the atmosphere in this period and transferred 10 GtC back to the oceans and 40 GtC to the atmosphere. An additional problem is that all of these figures involve considerable uncertainties and it is therefore questionable whether the increase in CO_2 in the atmosphere between 1980 and 1989 by an average 3.3 GtC/annum is exclusively due to anthropogenic causes. Similar doubts arise from a more recent study according to which the carbon sinks of North America assimilate more CO_2 than the sources emit, entailing a *negative* net emission.[22] It is obvious that this requires further research to establish a more solid base for quantifying the global carbon cycle.

The second problem concerns the direction of causality. The greenhouse effect theory proceeds from the assumption that higher CO_2 concentrations engender a higher global average temperature. Recent palaeoclimatic research, however, shows that in the past the opposite was often the case. Ice core drillings not only allow us to determine the temperature in the past, but as ice cores also include air bubbles they at the same time constitute an archive for greenhouse gases.

On the basis of these data it can be concluded that during the last three interglacial periods – i.e. during the warm periods in-between the ice ages – atmospheric CO_2 concentration rose by 80 to 100 ppmv (corresponding to about 172 to 215 GtC), though with a *temporal delay* of about 600 years. This could be due to the fact that the oceans assimilate less CO_2 during warming and transfer it back to the atmosphere, though with a certain time lag. It is clear at any rate that the rise in temperature definitely preceded the rise in CO_2 instead of following it.[23] More recent findings point in a similar direction. For instance, after major volcanic eruptions entailing a cooling of the earth lasting several months, there is distinctly slower growth of CO_2 concentrations in the atmosphere. This suggests that there is *inter*-action between temperature and the carbon cycle.

The third problem, finally, springs from the possibility that climate warming, to the extent that it is discernible, could be (partly) caused not only by a greenhouse effect but also by other factors, in particular natural fluctuations in solar activity. This possibility has been investigated more intensively only since the early 1990s. Research was triggered by the empirical finding of a surprisingly close relation between the length of the solar cycle and temperature anomalies in the northern hemisphere between 1861 and 1989.[24] This finding encouraged a search for still unknown causative mechanisms through which the sun could contribute to natural climate fluctuations. Current scientific debate focused on two possibilities.[25] On the one hand, it could be that in periods of greater solar activity the earth is more strongly protected from cosmic radiation. This might affect cloud formation which in turn would cause a rise in the earth's temperature. On the other hand, particularly strong fluctuations in the UV range of solar radiation could influence ozone formation and thus trigger an energy process from the stratosphere to the troposphere which would eventually affect the earth's temperature. Empirical correlations support the first possibility.[26] The second possibility is supported by a computer simulation model through which at least a part of the earth's warming (in particular during the first half of the 20th century) can be explained as sun induced.[27]

Against this background, it is not surprising that leading IPCC scientists recently came to the conclusion that the measurable temperature trend was at the margin of its natural range of variation. Accordingly, it would not (at least not yet) be possible to identify with certainty a clear signal of anthropogenic climate warming. This would require improved basic data, necessitating more time and research.[28]

4. Should priority be given to reducing CO_2 emissions?

Carbon dioxide (CO_2) is not the only greenhouse gas. Denser concentrations of methane (CH_4) and nitrous oxide (N_2O) also enhance the insulating effect of the atmosphere. According to IPCC estimates, the heat insulation directly generated by these three gases in 1992 was 1.56 W/m², 0.47 W/m² and 0.14 W/m². While CH_4 and N_2O are far rarer than CO_2, they do contribute much more intensively to global warming. Because of the difference in the length of time they remain in the atmosphere (IPCC indicates 5-200 years for CO_2, 12 years for methane and 114 years for nitrous oxide)[29], index figures can be calculated that allow a comparison of the global warming potential of the three gases. Related to a 20-year period, the IPCC argues that the index figure for methane is 56 times and that for nitrous oxide 280 times the figure for carbon dioxide.[30] What this means is that the climate-political utility, as calculated by the IPCC, of reducing methane emissions by one tonne is 56 times and reducing nitrous oxide by one tonne even 280 times greater than reducing carbon dioxide by one tonne. In other words, if one wishes to achieve the climate policy objective by minimal means, i.e. with the smallest possible loss in prosperity, careful attention will have to be given to the relevant costs. The money spent on reducing greenhouse gas emissions should be used in such a way that it is certain that one Euro spent on reducing carbon dioxide reduces 56 times more CO_2 than a Euro used to reduce methane and that the latter in turn reduces five times more CH_4 than a Euro spent on reducing nitrous oxide. If this is not the case, money is being wasted.

By reallocating the means used, a given objective could be attained at lower cost or one could achieve a higher target level with a given amount of money. This being so, focusing the public debate and ecotax on CO_2 and separately dealing with reduction targets for various greenhouse gases is questionable. Such an approach does not contribute to balancing marginal abatement costs, which is the hallmark of a rational climate policy. This problem is even more severe when newer studies come to the result that substances other than CO_2, CH_4 and N_2O have a substantial effect on the earth's climate – not only in magnitude but also in sign.[31]

The imperative need to focus on the relevant costs does not only apply to a comparison between carbon dioxide and other greenhouse gases but also to a comparison between various options for reducing carbon dioxide. Here, too, one-sided concentration on particular measures for reducing CO_2 emissions contradicts the requirements of a rational climate policy. There are two reasons for this. First of all, there are various possible measures to reduce CO_2 emissions. On the one hand, one could strive for improved energy efficiency in the use of the fossil fuels gas, coal and oil. Yet, technical progress in this field cannot be stimulated at will and in particular not as rapidly as one might wish. On the other hand, one could try to replace fossil fuels by other energy sources, such as wind and solar energy, energy from renewable raw materials, but also nuclear energy. All these strategies involve serious problems. Renewable raw materials are relatively land-intensive, and their mass use would be questionable in particular from an ecological standpoint. Wind and solar energy are still far away from being able to compete against fossil fuels without the grant of major subsidies. For the foreseeable future, only nuclear energy can hold its own in this respect and significantly replace fossil fuels. The fact is, however, that nuclear power involves safety and acceptance problems. Accordingly, it would be of particular importance to carefully scrutinise all strategies for reducing CO_2 emissions. At present it is not apparent, however, that the various options have been equally pursued with cost in mind. The definitive phasing-out of nuclear power pursued by the German Government in particular raises doubt as to whether this ecologically motivated measure makes sense in the long run, i.e. in terms of climate policy. This realisation has led the German Council of Environment Experts (SRU) to conclude that Germany was not following a path towards reduction that could ensure that it would be on target for 2005. Instead, there would be a growing divergence between the emission situation and the climate protection target, unless additional efforts were made. The SRU has argued that the phasing-out of nuclear power would increasingly narrow down the path towards this goal.[32]

Secondly, there is an alternative to reducing CO_2 emissions: promoting CO_2 sinks. Preventing CO_2 emissions is not the only option; one could also foster absorbing carbon dioxide already emitted. In principle, there are three options available to achieve this. What they have in common is that they try to intensify the natural exchange process between the atmosphere and other media to take up CO_2. First, it would be possible to withdraw CO_2 from the atmosphere by planting tracts of land lying fallow. In this case, biomass would be specifically used as sinks. Another way might be to use deep soil strata – second option – or deep ocean layers – third option – for CO_2 storage. The first pilot projects are already in progress but research in this connection is only in its infancy.[33] However, current conditions for a cost-related comparison between measures for CO_2 avoidance and measures for CO_2 reduction are poor.[34] These are important tasks to be undertaken in the framework of climate policy. In the years to come, climate policy will be judged by the extent to which it enables CO_2 sources and CO_2 sinks to be considered in parallel – allowing reciprocal comparison – so as to ensure that the costs of achieving a particular climate protection target are optimally low. Regrettably, however, ecotax as it stands does not make any contribution to this.

5. Are self-commitments by the industrial countries effective?

The Kyoto Protocol lays down obligations for restricting and reducing greenhouse gas emissions (see Appendix A). Not all countries have undertaken such commitments. It is in particular the industrial countries, specifically the member countries of the OECD and the post-communist transforming countries of the former eastern bloc, that have committed themselves under the Kyoto Protocol to take measures of climate policy whereas the "developing countries" have not made any reduction commitments. This applies not only to the countries of Africa but also to China, India and Brazil. Apart from Japan, there is no Asian country covered by the Kyoto Protocol. This also applies to the rapidly industrialising countries known as the "Tiger States". In this context, it has become customary to refer to the countries named in Annex-B to the Kyoto Protocol – that have committed themselves to a reduction target – as "Annex-I States" and the rest of the world as „Non-Annex-I States". This is more precise than using the dividing line between rich and poor countries or between industrialised and developing countries as a climate-political distinguishing criterion.

The fact that the vast majority of countries are not covered by the Kyoto Protocol entails a large number of problems. Some of these will be very hard to solve. Three of these difficulties, of particular importance, are highlighted below.

First of all, the Annex-I States need not necessarily attain their reduction targets through measures on their own territory (see Appendix D). Supplementing their endeavours in their own country, they may also meet their obligations via trade in emission certificates and through joint implementation of emission reduction measures in another Annex-I State. This institutional innovation makes economic sense in that it helps to keep the overall cost of climate policy to a minimum: A country that can reduce carbon dioxide at lower cost is given the possibility of having others buy up this advantage through a mutually profitable act of barter. The result is that the marginal abatement costs – i.e. the costs for every additional tonne of CO_2 prevented – are progressively aligned. In this way, CO_2 emissions are reduced where they can be prevented at lowest cost.

It would indeed be desirable for this principle of alignment of relevant costs to be applied not only in Annex-I States but world wide. Otherwise huge resources would be wasted as it is in general cheaper to raise energy efficiency in a developing country than in an industrial country where the technical possibilities are already largely built-in. It is therefore to be welcomed that the Kyoto Protocol also makes provision for the inclusion of Non-Annex-I States. For instance, it will be possible for an industrial country to meet part of its own reduction commitment by financing afforestation projects or the use of CO_2 reducing techniques in a developing country. It is advantageous to both sides to allow such projects: The industrial country saves money by having a reduction realised in an area where this is cheaper, and the developing country gains money as it is able to benefit from a comparative advantage. However, the problem is that such mutually beneficial barter is currently connected with disincentives. The possibility of concluding such deals makes it interesting for Non-Annex-I States to build up huge capacities for relatively high CO_2 emissions in order to become attractive for modernisation projects or to clear their forests very rapidly in order to gain areas for reforestation projects. Consequently, there is a risk that wooded areas are transformed into CO_2 sources in order to receive subsidies for their subsequent use as CO_2 sinks. At the same time, the current arrangement may, especially in developing countries, distort investment decisions in a way which is undesirable both from an economic *and* ecological point of view.[35] Secondly, an important difficulty lies in the fact that even today the share of Non-Annex-I States in global CO_2 emissions is already quite significant and is bound to rise in the foreseeable future.

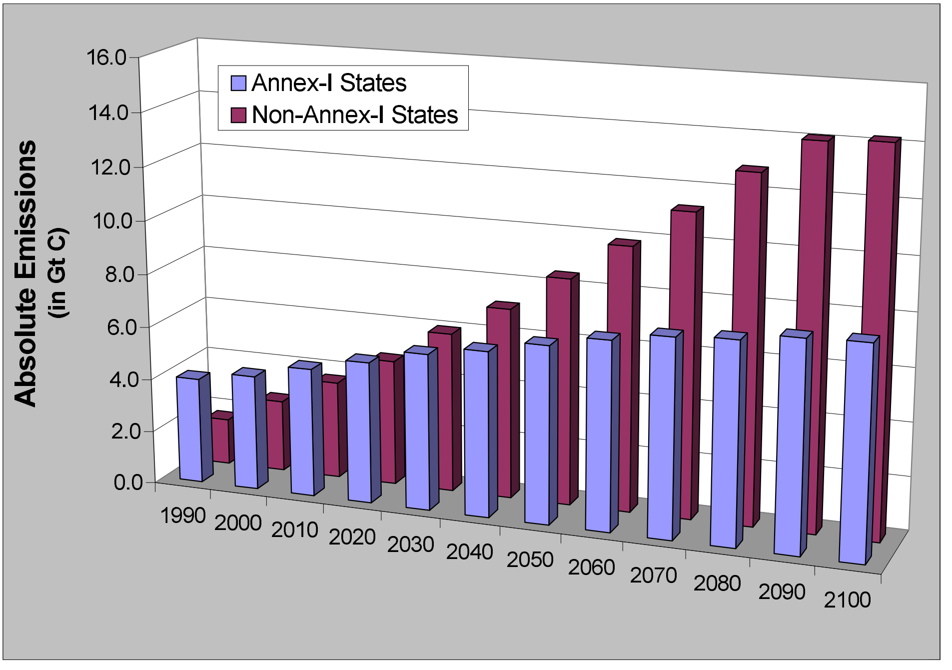

Figure 9. The development of absolute emissions (scenario A2)

On behalf of the IPCC several scenarios have been developed for the world wide forecast of CO_2 emissions until 2100 (see Appendix E for a scenario description). Figure 9 shows the development of absolute emissions according to scenario A2, which assumes high growth as well as strong energy efficiency improvements but no political constraint directed against CO_2 emissions. Even in this scenario where Annex-I countries do not restrict their emissions, their output of greenhouse gases would be overtaken by 2030 due to economic growth by developing countries. In 2100, the latter would emit twice as much as the former.

Other scenarios are even more pessimistic in this regard, as can be seen from Figure 10. It shows the ratio between emissions by Non-Annex-I countries and Annex-I countries according to IPCC "business as usual" scenarios. Values greater than one indicate that the former emit more CO_2 than the latter. In spite of huge differences between the scenarios, all agree in their expectation that already by 2030 countries currently not covered by the Kyoto Protocol will produce higher – perhaps even significantly higher – emissions than Annex-I States. In 2100, the ratio could rise up to a value of six. In that case, the share of emissions by Annex-I countries to emissions world wide would amount to 14% (again see Appendix E). However, even a ratio value slightly higher than one indicates the danger that national efforts to prevent climate change may be in vain and that, therefore, toleration of a "free-ride" on this international public good cannot last very long.

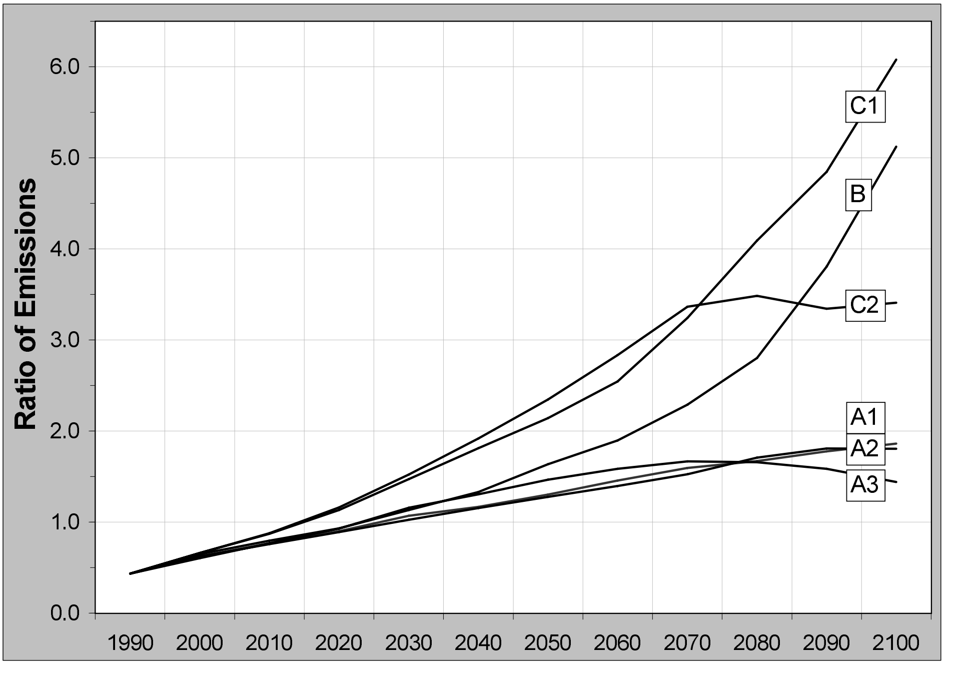

Figure 10. Emissions ratios according to different scenarios

Concluding, a common feature of all scenarios is that they make it crystal clear how important it is to include Non-Annex-I countries into the Kyoto Protocol (or some other legal framework for reliable self-commitments to reduce greenhouse gas emissions).

A third problem arises from the circumstance that climate policy requirements for Annex-I States will not make it easier but on the contrary more difficult – i.e. more costly – to involve the other countries and ensure that they share in pursuing climate policy targets. This can easily be demonstrated through a graph.

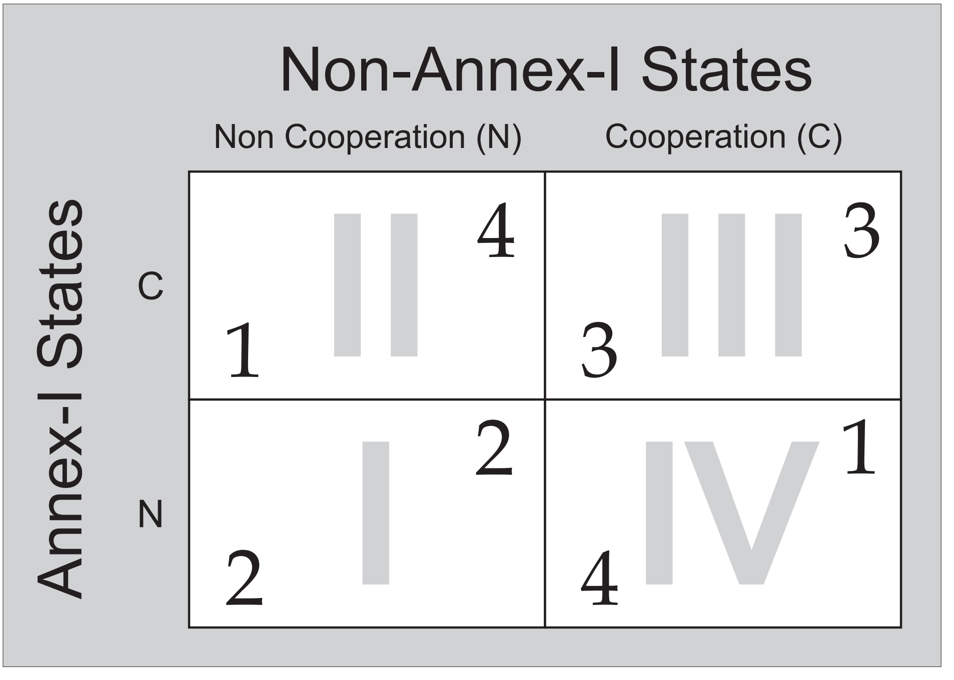

Figure 11. The political negotiating situation

Figure 11 illustrates the state of climate policy negotiations at the time the Kyoto Protocol was concluded. Here, both groups of countries are faced with the choice whether to adopt the cooperative strategy (C) of a reduction commitment or the non-cooperative strategy (N) of tagging along with the others, i.e. a strategy of letting the others move ahead without making one's own contribution towards solving the climate problem. Accordingly, the four quadrants correspond to four possible strategy combinations. The figures in the quadrants reflect the relative advantages in each case (4 > 3 > 2 > 1), at bottom left for the industrial countries and at top right for the developing countries. The figures show that developing and industrial countries have both common and opposite interests.

A common interest is apparent when comparing quadrant I and quadrant III. Both groups of countries would welcome a diminution of the climate problem (3 > 2). They prefer the strategy combination C/C over the combination N/N. However, divergent interests are apparent from quadrants II and IV, the first of which is of particular relevance. The developing countries are in the best position (4) when they can exploit the climate policy restrictions to which the industrial countries have committed themselves, by using those countries' CO_2 savings for their own CO_2 emissions. This is at the same time the worst position for the industrial countries (1) as they assume responsibility for costs and suffer loss of growth *without* achieving the climate policy objective of reducing overall emissions. In other words, from the standpoint of industrial countries there is in quadrant II no climate policy utility in exchange for climate policy costs as their local CO_2 savings are counteracted globally.

Figure 11 shows not only the incentives structure but also the development of climate policy negotiations. *Before* the Kyoto Protocol was concluded, there were no reduction obligations. The situation was that shown in quadrant I and the *common* aim was to reach quadrant III. Instead of pursing this objective directly through a treaty binding for all, the group of the industrial countries decided to follow a roundabout route and undertake unilateral commitments without linking these to concessions on the part of the developing countries. The conclusion of the Kyoto Protocol therefore corresponds to moving from quadrant I to quadrant II.

This situation, characterised by the strategy combination C/N, is untenable in the long run, both economically and ecologically. The underlying reason is that greenhouse gas concentrations in the atmosphere can be controlled only when all emitters work together; only if this is the case the efforts are justified that are undertaken by individual countries to help solve the global (public good) problem. A move to quadrant III is therefore absolutely necessary.

But it is much harder, from the viewpoint of the industrial countries, to persuade the developing countries to join in from quadrant II than from quadrant I. The reason is that the developing countries are currently in a privileged position. They would certainly lose real advantages by abandoning this position (4 > 3). Now that they have been allowed to tag along with the industrial countries, it will probably only be possible to persuade them to abandon this position if they can be offered financial reward for agreeing to emission reductions binding for all. Until this point is reached, the developing countries have an incentive to increase their CO_2 emissions as rapidly as possible and postpone a generally applicable agreement, which will ultimately prove unavoidable, for as long as they can.

Figure 11 makes clear that – if the negotiation situation is modelled correctly – self-commitments by the industrial countries are not only costly and ineffective but also *worsen* the prospects of an international agreement binding all nations alike without exception.

Further more the situation in quadrant II is latently unstable. States that have chosen the cooperative strategy have a strong incentive to abandon their group and return to a non-cooperative behaviour. By "changing sides" and joining the privileged free-rides they are better off (2 > 1). Therefore the solution in quadrant II is likely not sustainable in the long run: By and by the group of cooperative states could erode.

This possibility is less fictitious than the subjunctive implies. Currently the USA – under the Bush administration – refuse to restrict their CO_2 emissions according to the agreed levels of the Kyoto Protocol. This US negotiation strategy indicates that even for the Annex-I states strong incentives exist not to fulfil any emissions commitments. As a result of the structure of the dilemma situation, the non-cooperation strategy is a rational response when sanctions for such a behaviour are not to be expected because they are not part of the international agreement.

There are two possible ways to deal with the arising problem that states might return from quadrant II to quadrant I:

The first, seemingly obvious reaction is to blame the American government. At first sight it goes without saying that the United States use the weaknesses of the Kyoto protocol for strategic behaviour, i.e. for their own sake. From a moral standpoint this behaviour – defection in a group of cooperative actors – may be ascribed to egoistic motives. This interpretation leads to accusing states of immoral behaviour and a lack of international solidarity. As a consequence, the selfish motives have to be branded because otherwise the whole system of cooperation would collapse. Here strategic behaviour becomes a question of right or wrong motives, and moral suasion or pressure are the instruments to change the latter to the first. Blaming one party could therefore lead to a dead end in international negotiations.

The second reaction, from an economic viewpoint, is less intuitive but more constructive: In a world where incentives matter, the American government responds to the logic of the situation. The Bush administration just reads the incentive structure the right way. This can be interpreted as a prudent and even moral act since it protects the American people against unnecessary harm. But this behaviour is not a mere result of the motives but of the situation: The US are a major emitter of greenhouse gases while reductions in CO_2 emissions are costly and at the same time almost ineffective in preventing or at least delaying climate change.

If incentives are that way, sooner or later all members of the quadrant II group might return to quadrant I. In this case the American government would have been simply faster then the rest, not morally worse. This is the reason why the proposed solution of a local single-handed effort (of the EU) is not appropriate to mend the existing weak points of the Kyoto protocol.

Two points are decisive here: First of all, it is the situation not the motives of a single actor that must be improved. Otherwise defection sets an example which others are likely to follow. One way to change the incentive structure can be a system of sanctions for the case that a party falls back to quadrant I. In contrast to moral suasion, this instrument is not only fair, but self-enforcing and therefore far more effective because sanctions inhibit any party from defection ex ante.

This is where a second point comes into play: That all parties can or even must learn something from the defective behaviour. Interpreted as a hint towards a weak point in the treaty, the defection can lead to an improvement of the cooperative framework. When no-one except the party itself knows its motives, it is not only mere speculation to ask about the real motives but also idle to do so. No matter what the real motives are – selfish considerations or concerns about the nature of the treaty – the only productive way to solve the problem is to fill the gap in the framework.

Surprisingly the American rejection of the Kyoto protocol offers a chance to improve the protocol. Thereby it could be a step forward, not back, on the road towards a globally effective climate policy.

6. Should growth sectors be regulated with particular stringency?

According to information from the German Federal Environment Agency for 1997, the four principal sources of CO_2 emissions in Germany, not counting natural emissions, were households and small consumers (20%), the transport sector (22%), industrial processes and industrial firing (20%). Power stations and district heating plants accounted for the largest share (38%).[36] Among these four groups of emitters, the transport sector occupies a special place as it is generally expected that in the years to come this sector will not show a decrease but an increase in emissions.[37]

This leads to the question how the political objective of reducing emissions can be spread over the four principal emitters. Would it be fair to strictly reduce carbon dioxide emissions in particular sectors only to enable the transport sector to grow? Or would it make more sense to impose absolutely equal or relatively equal (proportional) reductions on all sectors? And, above all, which of the various possible paths are currently being pursued in Germany?

The following four arguments may help to answer these questions:

The first argument concerns the question who in fact bears the costs when emissions are reduced in specific sectors. Who shoulders the burden when, for instance, industrial production is made more expensive? The answer may at first seem surprising, but from an economic point of view it is perfectly clear: In the medium term, the burden is mostly on the consumer. In the end, all economic activity serves for consumption, be it directly as production or indirectly as investment, i.e. as a way of building up production potential. To this extent it is also consistent with the „polluter pays“ principle when producers pass on the costs they have to bear to the consumer. The extent to which this is possible, and how soon, may vary from one sector to another. Nevertheless, it is to be expected that the lion's share of climate policy-related cost increases for transport services, industrial products or generally for energy will in the end be borne by every individual end consumer.

The second argument concerns the question who should take the decisions on the necessary changes to individual behaviour. The following analogy may be useful here. When a group of individuals is faced with the need to save money, each of them has a wide spectrum of possible responses, some of which will be very similar and others very divergent. For instance, it would on the one hand be possible to reduce visits to restaurants and instead buy more bread and other reasonably priced food so as to eat at home. On the other hand, it would also be possible to move to more modest accommodation so as to still be able to go on holiday once a year or, conversely, give up holidays abroad in order to be able to pay for a more comfortable car which can then be used for more day trips and excursions. Accordingly, it is possible that despite overall *savings* specific items of expenditure will *go up* and various types of consumption are balanced against each other that from a production angle, i.e. "objectively", do not replace each other but are purely a matter of subjective consumer choice. Consequently, it is also quite unlikely that the consumption patterns of two different consumers fully coincide or that different individuals decide on exactly the same behavioural adjustments. The best approach therefore is to leave it up to each individual to respond as he sees fit. Only in this way can one be sure that the disadvantages (i.e. utility losses) resulting from necessary savings are as small as possible. This conclusion also applies in cases where one has to economise not on money but on greenhouse gas emissions.

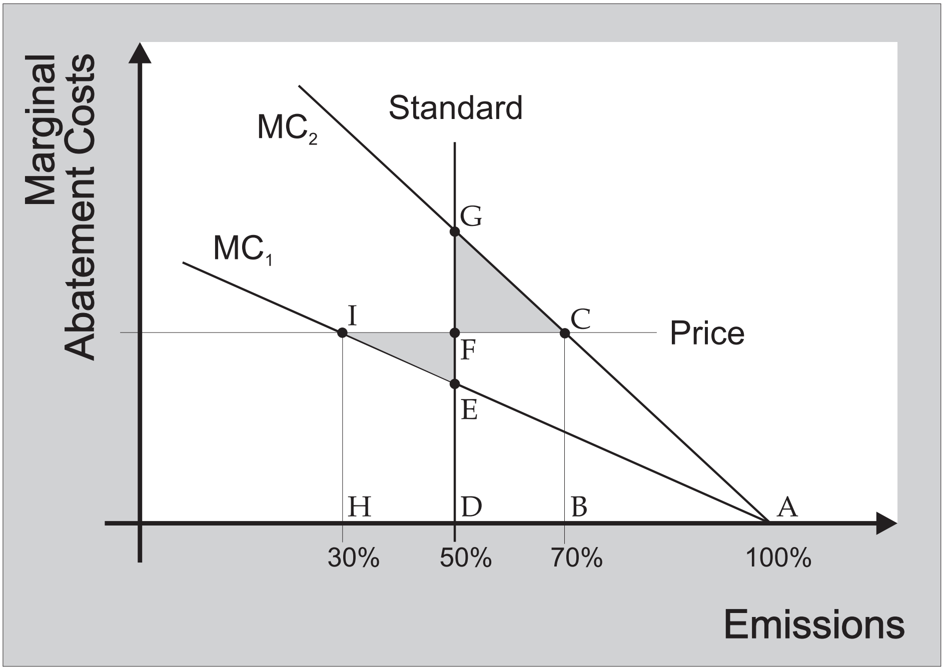

Figure 12. Fairness of results versus fairness of rules

The third argument concerns the use of climate policy instruments and the question of fairness. Fairness is always linked with the concept of equality. However, there are various criteria for equality. It can be related to results or to rules. In relation to the greenhouse issue, this means that in the case of fairness of results each sector ought to shoulder an (absolutely or relatively) equal share in greenhouse gas reduction. In the case of fairness of rules, it means that identical rules ought to apply to all sectors, i.e. each sector should without any discrimination be subject to the same conditions. A comparison of these two approaches is projected in Figure 12.

The graph shows the marginal abatement costs (MC) resulting from greenhouse gas savings in two sectors. The course of both curves reflects the fact that a reduction (moving from right to left) by each additional tonne gives rise to ever higher costs: it is more costly to reduce from 30% to 29% than from 70% to 69%

in relation to the 100% status quo level (A). The section below the curves indicates the relevant total costs. These should be compared for both approaches to climate protection policy: fairness of results versus fairness of rules. The case of fairness of results would for instance consist of imposing a requirement that each sector reduce its emissions by 50%. The resultant costs correspond to section ADE for sector 1 and ADG for sector 2.

In the case of fairness of rules, however, each sector would have to pay the same price. If both sectors are without discrimination made subject to the same rules, they can individually decide on different adjustments. Different from the hypothesis of obligatory results being imposed from above, this option would involve, at a political level, the adoption of framework conditions for the social process of individual adjustment while the specific pattern of results would be left to those involved in the process. For easier comparison, Figure 12 indicates the price leading to the same overall emission reduction as the level required. It shows that a climate protection policy based on fairness of rules leads to prevention costs for sector 1 corresponding to section AHI while those for sector 2 are represented by section ABC.

A comparison of the sections in the graph shows that the total costs in case of fairness of rules are distinctly lower than in case of fairness of results, namely both subsections CFG and EIF. In contrast with fairness of results, fairness of rules has the collective advantage that a particular climate protection objective can be attained at lower costs overall. A problem is, however, that the cost savings for sector 2 in BDGC are counterbalanced by a rise in prevention costs in sector 1, namely in DHIE. In order to be able to evaluate the magnitude of this problem, it should be remembered that these costs are in the end not borne by sectors but largely by end consumers. Yet, in specific sectors there may be difficulties or delays when they try to pass on climate policy-related costs to the consumer. Where this is the case, it may be necessary in the political process to offset burdens and reliefs of various sectors against each other. Accordingly, the grant of appropriate compensation may be a major component of democratic policy in general and democratic climate protection policy in particular. In principle, the aim is to work out arrangements in such a way that the collective benefit potential of fair rules can effectively be realised. This is to the citizen's advantage as the attainment of (climate) political objectives through the efficient use of resources will eventually be conducive to consumer sovereignty. Concluding fairness of rules is superior to fairness of results.

The fourth argument, finally, concerns the question as to the present status of climate protection policy in Germany. Generally speaking, most of the measures taken to reduce greenhouse gas emissions are of an administrative nature. They comprise intervention from above ("command and control") in specific cases which because of numerous inequalities of treatment are often not even consistent with the criterion of fairness of results. Different requirements apply in different sectors. Intervention and requirements are not uniform and often not conceptually coordinated. They do not add up to a uniform standard of environmental policy and even less a standard of climate policy.

Consequently, the extent of unused savings potentials in terms of sectoral prevention costs is quite considerable. In this perspective, the introduction of an ecotax is as a matter of principle a genuine step in the right direction, namely a first step towards fairness of rules. It is not surprising that this first step still has various shortcomings which makes one hesitate to speak of a rational climate policy. However, it should be realised that the present structure of the ecotax does not allow these shortcomings to be phased out in subsequent stages. Attention is drawn below to three particularly serious problems.

First of all, the ecotax was not designed as a greenhouse gas tax or even as a carbon dioxide tax, but as an energy tax applying arbitrary tax rates. This means that while it does provide incentives for saving energy, it at the same time provides disincentives for making individual adjustments to meet the climate protection target: At present, one tonne of CO_2 is taxed at different rates depending on the type of energy source. A system with fair rules would require identical rates for the greenhouse effect of all energy sources.

Secondly, the ecotax is not coordinated internationally. In order to ensure that German companies do not suffer competitive disadvantages, a whole range of exceptions and refund schemes has been introduced, requiring costly administration and detracting from the ecological impact. This applies in particular to companies with markedly energy-intensive production.

Thirdly, the ecotax contributes to sectoral distortions. For the first ecotax phase, which entered into force on 1st April 1999, it is estimated that the balance of energy tax *burden* and social contribution *relief* for employers is beneficial in particular to the public purse. If one disregards the effects of passing on the costs to the consumer and if one concentrates exclusively on the direct effect of the ecotax, it is found that public budgets benefit, in net terms, by 313 million € a year as because of their comparatively personnel (cost)-intensive provision of services they save more money (in contributions) than they spend on higher energy costs. A *lower* burden also applies to the energy sector, namely by 122 million € a year. This is because of the wide range of possibilities of obtaining tax refunds or concessions. There is an additional net *burden*, however, on the transport sector, which takes second place among net payers with 243 million €. In this respect it is only exceeded by private budgets which are burdened with 601 million € a year.[38] With the subsequent phases of the ecotax, this trend will continue, with concomitant special burdens on individual sectors. A case in point: Despite the importance of an inter-sectoral equalisation of abatement costs (see Appendix D), the German National Plan For Climate Protection defines sectoral quotas irrespective of any cost differences.[39]

In order to achieve reduction targets in the framework of climate policy, a whole set of measures is planned or has already been implemented. In this context, the ecotax is an important instrument of climate policy but in fact only *one* instrument among many others. Far less is known about the effects of numerous alternative measures. Not everywhere has provision been made for making transparent the costs citizens are meant to shoulder. For instance, a brochure of the United Nations Environmental Programme (UNEP) recommends that, in order to reduce greenhouse gas emissions, cities can "promote walking, bicycling, and car pooling by limiting automobile access to certain roads, increasing the fees for public parking, and converting existing roads into bicycle lanes, bus-access roads, or »High Occupancy Vehicle« (HOV) lanes during peak hours."[40]

Both ecotax and non-monetary measures to alter behaviour have a particular influence on the sectoral structure. However, it is not apparent that this influence has been primarily aimed at minimising losses in prosperity connected with the pursuit of climate protection objectives. The opposite is in fact the case.

Chapter III.

Conclusions for a rational climate policy

The review of the six conditions of current climate policy has shown that question marks hang over each of them. This applies on the one hand to the physics-related basis. In this domain, there is a long way to go before scientific knowledge will be as sound as would be desirable for a political goal whose pursuit will bring about very extensive (and expensive) changes in society. There is considerable uncertainty with regard to the likely consequences of climate warming, the extent of currently discernible climate warming, and the causes of this warming trend. What is still unclear is to what extent it is caused by an anthropogenic greenhouse effect. On the other hand, there are also question marks over the social science aspects. Current climate protection policy is still far removed from a comparison (and a consequent marginal adjustment) of the relevant abatement costs between various greenhouse gases, between various emission regions and between various emission sectors. Consequently, it has led to serious disincentives, increasing the social adjustment burden to be borne by each individual. This further restricts the room for manoeuvre, already quite limited, for dealing with the greenhouse effect in a way that will keep intra-societal and inter-societal conflicts under control rather than allowing them to escalate (see Appendix F).

The fact that there are all these question marks does *not* mean that one could simply sound the all-clear or that measures in progress ought to be withdrawn. Doing so would not make sense, if only because a large part of the mitigation costs has already been incurred and cannot be reversed. Moreover, there is certainly a need for political action, even if the „state of the art" in climate sciences is to be aware of an enormous range of uncertainties and of the need for additional research. The reason for this is as follows: Even if a climate catastrophe (to be averted if possible) is not an absolute certainty but only an eventual danger looming ahead, it is still a risk justifying particular preventive measures. A rational climate policy should heed the precautionary principle. Care should be taken that an uninsurable risk never materialises. In view of current uncertainties, such a policy must certainly leave room for errors so as to be able to flexibly respond to new knowledge as and when it emerges. This means that from the outset account should be taken of the need to rectify any under-reaction or over-reaction in time. In all honesty, this should be stated publicly. Herein lies an imperative requirement of democratic policy: It must not pretend to be omniscient if it is not – and cannot be – underpinned by hard facts. Otherwise trust could easily be shaken, which could detract from democratic governments' ability to govern responsibly.

Responsible government, however, is necessary if the pivotal problem is to be solved, i.e. finding a way of affording the desired protection against adverse consequences of climate change without engendering drastic losses in prosperity. This requires uncoupling economic development from energy induced greenhouse gas emissions (see Appendix B). Figure 1 shows how close this relationship is world wide. The climate policy challenge can be clarified through Figure 2: It is necessary to prevent a leftward downslide along the production function or the regression line. The global climate problem cannot sustainably be solved through a decline in prosperity. The point is, rather, to guarantee the necessary social acceptance of climate change policies world wide through technical and organisational progress.

A rational climate policy is such a huge challenge that it cannot be left to politicians alone. The challenge can be met only if all sections of society, and in particular organised special interest groups, work together. This requires rethinking of the issue. The discussions should be more open so as to foster a learning process. Environment activists in the media, associations and parties will have to face the fact that an alarmist attitude based on grotesque exaggerations is not effective and could even discredit the whole ecological issue. Those who object and those protecting vested interests in the media, associations and parties will have to realise that a purely obstructive policy cannot be sustained and that it is therefore better to come up with valid arguments in time so as to be prepared to respond to social change with *constructive* criticism. In this context, it is particularly the way in which politicians see their own role that must undergo a fundamental change. It is clear that there are three lessons to be learnt if modern societies are to adjust themselves politically to the ecological challenge of the climate problem.

First of all, in an era of economic globalisation and globalisation of the climate problem it will be increasingly difficult to lay down binding criteria if the policies pursued are purely based on those of individual nation states. Modern societies can no longer be controlled through political directives imposed from above. However, politics can provide institutional support for societal self-control. In this context, the concept of fair rules for all offers an appropriate guiding principle: It is not the task of climate policy to impose individual decisions from above but to create the institutional and legislative conditions to ensure that decisions on greenhouse gas reduction can be taken in full knowledge of the facts and in a responsible manner by the individuals themselves. Only this can in the long run lead to the acceptance without which – at least in a democracy – the measures required cannot be implemented in practice.

Secondly, the complexity of the climate problem is so enormous, and moves towards solving this problem are so strongly connected with drastic changes in society that these challenges cannot be met by removing market incentives but, on the contrary, can be achieved only by mobilising such incentives. The ecotax is a first timid step in this direction, but one that is partly misconceived. Moreover, it has all the drawbacks of an imposed surcharge. These range from ephemeral political considerations, i.e. arbitrary fixing of tax base and tax rate, to inadequate feedback between evolving possibilities and limits to reducing greenhouse gas emission. The point is not that citizens ought to adapt to prices rather than imposed charges but that such prices should be fixed at the right level. This, however, places an impossible burden on politicians and civil servants. The aim should therefore not be simulation but stimulation of competitive prices for greenhouse gases. The political task is to organise new markets which today do not even exist. The proposed EU wide emission trading system follows this idea and seems to avoid many problems of the German ecotax. Starting in 2005, it is planned to establish a market for CO_2 emission rights of large installations in energy generation and heavy industries. The obvious attempt was to start off small. Unfortunately this market arrangement (a defined local markt, one greenhouse gas and only 4,000-5,000 potential buyers or sellers) makes it likely that the largest amounts of cost savings potentials are not even touched.

Rational climate policy means finding, or inventing, market arrangements for reciprocally beneficial exchanges, i.e. institutional designs to ensure a quid pro quo so that greenhouse gas concentrations are – on a voluntary basis – effectively reduced where – world wide – this is easiest to achieve.

Thirdly, the hitherto predominant discussion about possibilities of *reducing* (not the concentration but) the *emissions* (not of greenhouse gases but) of *carbon dioxide* through *administrative intervention* instead of market solutions (not world wide but) predominantly *at home* does not set the proper course for a rational climate policy.

IV. Appendices

Appendix A: The Kyoto Protocol commitments

The legal basis for international climate change policy is the UN Framework Convention on Climate Change (UNFCCC). It was signed at the Rio Earth Summit in 1992. At the Kyoto Conference of 1997, a Protocol to this Convention was adopted in which several industrial countries – listed in Annex B of the Protocol – gave an internationally binding commitment to reduce their greenhouse gas emissions[41], calculated in CO_2 equivalents, by at least 5% below 1990 levels within the period 2008-2012 (Article 3(1)). The Kyoto Protocol list of Annex B countries is equivalent to the list of countries in Annex-I of the UNFCCC.

Country	Reduction
Bulgaria	8%
Romania	8%
Lithuania	8%
Latvia	8%
Estonia	8%
Slovakia	8%
Czech Republic	8%
Slovenia	8%
Switzerland	8%
United States	7%
Hungary	6%
Poland	6%
Canada	6%
Japan	6%
Croatia	5%
Ukraine	0%
Russian Federation	0%
New Zealand	0%
Norway	-1%
Australia	-8%
Iceland	-10%

Table A1. The Kyoto commitments

The European Union is a full party to the UNFCC and a signatory of the Kyoto Protocol. At the moment it is planning to ratify the Protocol in 2002. The EU has accepted a commitment to reduce its greenhouse gas emissions by 8% below 1990 levels within the period 2008-2012. Article 4 of the Protocol allows the European Union to allocate its target among the Member States. A political agreement on that burden sharing was reached at the Environmental Council meeting in June 1998. Under the EU-wide offsetting scheme, Denmark and Germany have undertaken to reduce greenhouse gas emissions by 21%. On the other hand, Ireland, Spain, Greece and Portugal were allowed to *increase* their emissions. That is why, for some countries, the table below shows *negative* reduction commitments.

Country	Reduction	Share of 1990 EU emissions
Luxembourg	28.0%	0.3%
Denmark	21.0%	1.7%
Germany	21.0%	27.7%
Austria	13.0%	1.7%
United Kingdom	12.5%	17.9%
Belgium	7.5%	3.2%
Italy	6.5%	12.5%
Netherlands	6.0%	4.8%
Finland	0.0%	1.7%
France	0.0%	14.7%
Sweden	-4.0%	1.6%
Ireland	-13.0%	1.3%
Spain	-15.0%	7.0%
Greece	-25.0%	2.4%
Portugal	-27.0%	1.6%
Total European Union	**8.0%**	**100.0%**

Table A2. The European agreement on burden sharing

Appendix B: Emissions efficiency for selected countries

While Figure 1 analyses the relationship between carbon dioxide and gross domestic product, i.e. the emissions efficiency of wealth, on a global scale for the year 1998, it is interesting to take a closer look at the development of this relationship over time. For this purpose, four industrialised countries were selected from the total sample of 108 countries world wide (marked with a dark grey triangle in Figure 1). For these countries (France, Germany[42], the United Kingdom and United States of America) the historic development of the gross domestic product and the carbon dioxide emissions is plotted, starting with the year 1870 – the outset of industrialisation – till 1998. The intertemporal change of the relationship between the economic input factor CO_2 and the output/wealth indicator GDP is shown in Figures B1 to B4. To allow comparison between the countries, in each case the GDP is given in billion 1990 US$.

Looking at the diagrams, it is rather unsurprising that not only for the year 1998 – as in Figure 1 – but also for a long period of time CO_2 has been a production factor that generates prosperity. In all countries analysed, the burning of fossil fuels was the motor of modern life and wealth. An increase in the production of goods and services almost always meant higher CO_2 emissions. This was the case during the 19th century and for most parts of the 20th century – for the United States it is true even today. But then in the middle of the second half of the 20th century, a different development is observable in the European states. Almost simultaneously in France, Germany and the United Kingdom, an increase in wealth became possible without more emissions – visible as the vertical part of the scatter plot. In France and Great Britain, this trend was rather stable for ten years, in Germany for almost 20 years. In these European countries the level of emissions was kept almost unchanged while the GDP rose. Thereby the emissions efficiency increased from year to year – most probably as a result of the energy crisis in the 1970s. Even more surprising than this limited release of carbon dioxide is the period that came after. Starting in the year 1979, absolute CO_2 emissions have diminished in France and Great Britain, i.e. the increase in GDP was overcompensated by the enhanced emissions efficiency with regard to CO_2. In Germany, this decrease in CO_2 use is observable since 1990. As a result of this development, the amount of absolute emissions has reached the level of 1967 in France, 1961 in Germany and even 1951 in the UK. Compared to then the GDP of 1998 was 2.27 times higher in France, 2.76 times in Germany and 3.03 times in the UK.

With regard to Germany, a principal cause of this trend lies at hand: The German reunification led to a collapse of the (vastly energy inefficient) East German industry and thereby significantly reduced CO_2 emissions. Furthermore, the evidence in the UK and France suggests that the use of nuclear power might to a large part explain why in recent times the economic development has been less closely linked to the consumption of fossil fuels.

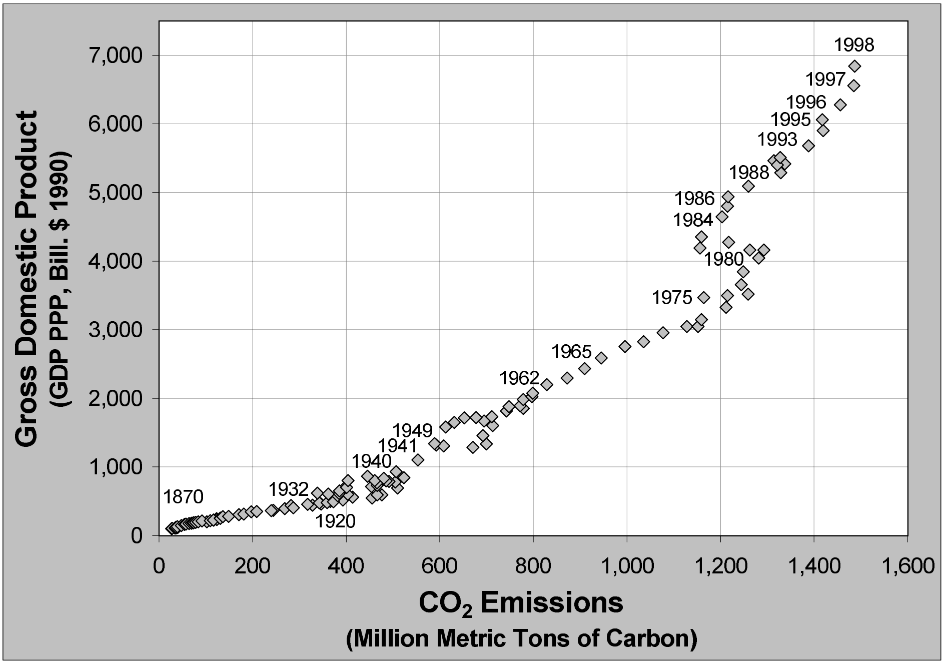

Figure B1. Development of wealth and CO_2 emissions – United States

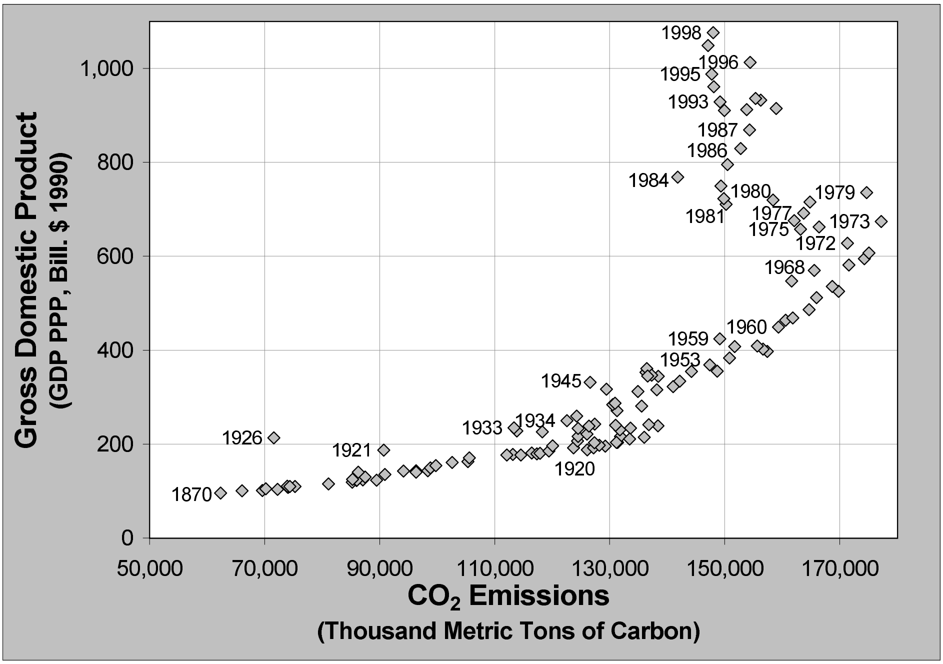

Figure B2. Development of wealth and CO_2 emissions – UK

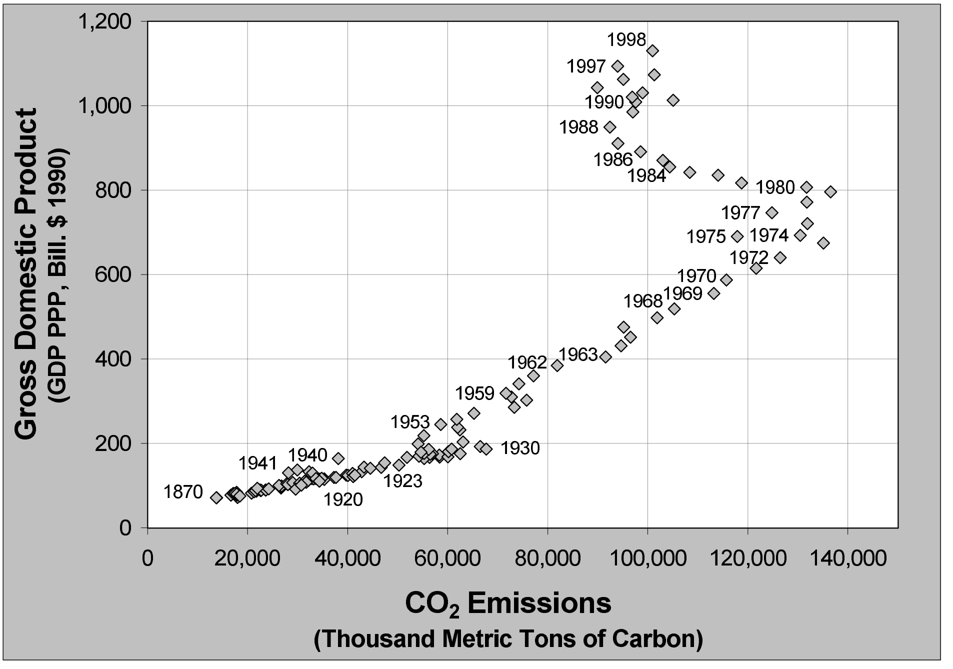

Figure B3. Development of wealth and CO_2 emissions – France

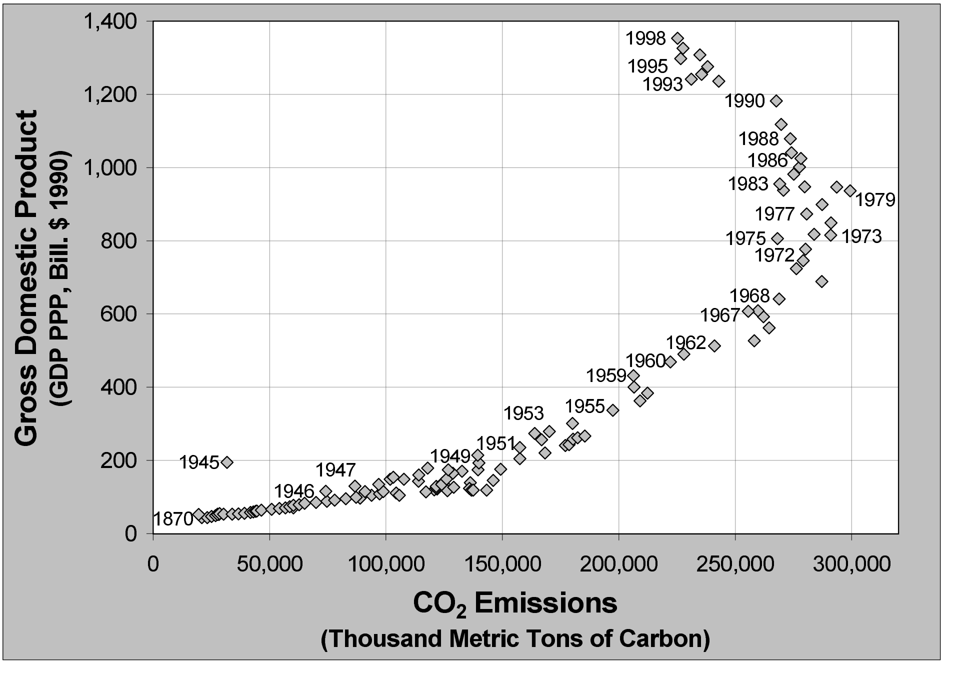

Figure B4. Development of wealth and CO_2 emissions – Germany

Appendix C: The IPCC dilemma: Between science and politics

The Intergovernmental Panel on Climate Change (IPCC) was set up in 1988. Its task is to document the scientific consensus on climate change. This is not an easy task. Research in this field is very dynamic, inter-disciplinary and characterised by different schools of thought with divergent views on the problem (and its possible solutions). Therefore, it is quite natural that the "IPCC Consensus" is the object of permanent debate involving disagreement and sometimes even radical criticism.

In spite of these difficulties, the IPCC "Assessment Reports" have become extremely influential. They provide the knowledge basis for the United Nations Convention on Climate Change (UNFCC) and for the international negotiations within this legal framework. The voluminous reports are condensed to relatively short (and sometimes tendentiously shortened) "Summaries for Policymakers", which are written not by the scientists themselves but by government officials. Especially these "Summaries *by* Policymakers", as one should call them, attract the attention of mass media and of the democratic public in general, although they tend to underrepresent the huge uncertainties and the extent of disagreement which are documented in the original scientific reports.

The IPCC consists of three working groups: Working group I "describes the current state of understanding of the climate system and provides estimates of its projected future evolution and their uncertainties"[43]. Working group II provides an overview "concerning the sensitivity, adaptive capacity, and vulnerability of natural and human systems to climate change, and the potential consequences of climate change"[44]. Working Group III is occupied with research concerning "climate change mitigation"[45].

The IPCC has just published its "Third Assessment Report" (TAR).[46] Here, Working Group I has projected that, assuming *no* climate change policy, from 1990 to 2100 the global average temperature could rise by 1.4 to 5.8 °C.[47] The upper value of this range is remarkably high and indeed has caused significant sensation in the media. However, just after publication the IPCC has been immediately criticised that, in contrast to its usual procedure, the projected temperature range was published without any accompanying information about the according likelihood estimate and that, therefore, the value range is highly misleading:

(1) Steve Schneider has shown that the IPCC temperature forecasts do not follow a normal distribution but an asymmetrical bell-shaped curve with a mean value quite below 3.6 °C and that the occurrence probability of a warming of 5.8 °C (or more) therefore amounts to only 0,2%.[48]

(2) Webster et al. provide an estimation for "business as usual" scenarios, assuming no efforts to reduce greenhouse gas emissions. Here, the distribution is skewed to the left, too (Figure C1 shows the probability density of a decadal mean temperature change in the next 100 years). Their report reads as follows: "[W]e find that, absent mitigation policies, our median projection shows a global mean surface temperature rise from 1990 to 2100 of 2.3 °C, with a 95% confidence interval of 0.9 °C to 5.3 °C. ... In contrast to our analysis the IPCC does not indicate whether there is a 1 in 5 or 1 in 10 000 chance of exceeding its upper estimate of 5.8 °C. Our illustrative results suggest that there is about a 1 in 100 chance of a global mean surface temperature increase by 2100 as large as 5.8 °C. ... There is a 12% chance that the temperature change in 2100 would be less than the IPCC lower estimate."[49]

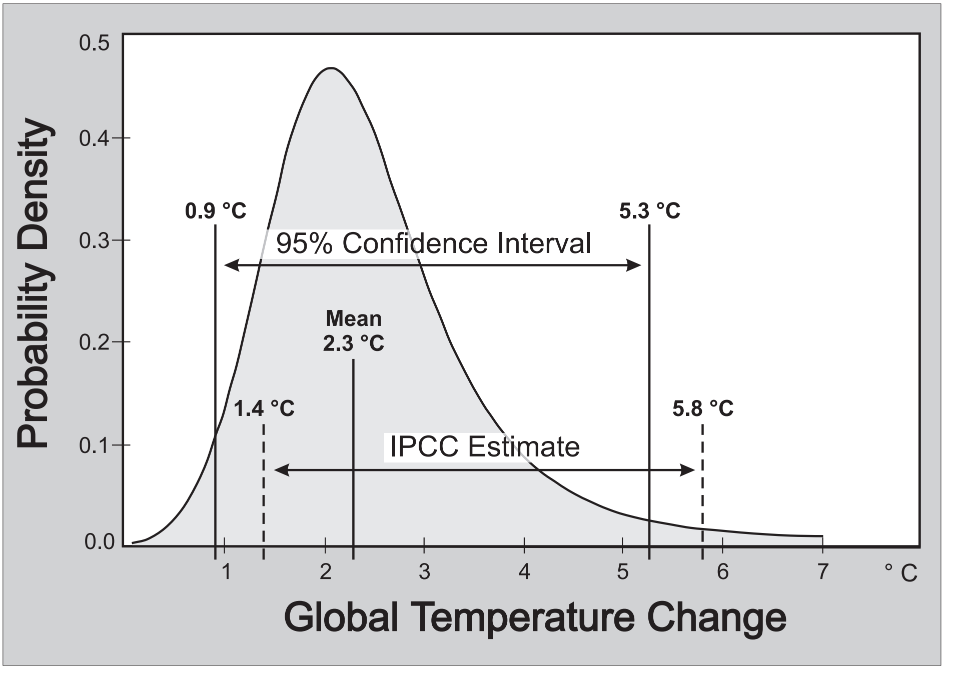

Figure C1. Probability of a global mean temperature change for 2090-2100 (relative to 1990)

Appendix D: The Kyoto Mechanisms and the costs of Kyoto

The Kyoto Protocol defines three “Flexible Mechanisms” which are meant to reduce the costs of complying to CO_2 reduction commitments.

(1) Article 6 of the Protocol allows Annex-I countries to engage in Joint Implementation (JI) whereby one country (or a corporation belonging to that country) finances a project-specific emission reduction activity in the territory of another Annex-I country and thereby earns “Emission Reduction Units” (ERUs), which are transfers of the “Assigned Annual Amounts” (AAUs) of greenhouse gases each country owns according to the Kyoto Protocol. The AAUs are simply the 1990 emissions minus the national reduction commitment. For example, a British company may finance a modern, energy efficient power station in Russia. Such a project reduces greenhouse gas emissions in Russia by a certain amount that is certified and then taken into account not for Russia but for the United Kingdom. Thus, JI offers the opportunity of mutually beneficial trade. It is a way to fulfil national reduction commitments abroad and thereby to economise on international abatement costs differences.

(2) Article 12 creates the Clean Development Mechanism (CDM) by which project-specific emission reduction activities can be conducted in *Non*-Annex-I countries. Apart from this important difference, CDM activities are similar to JI activities: Abatement projects abroad create a “Certified Emission Reduction” (CER) that can be used by an Annex-I country in meeting its obligations under the Protocol to reduce emissions.

(3) Article 17 allows Emissions Trading (ET) among Annex-I countries. The underlying idea is that a country may assign its AAUs to domestic legal entities, i.e. to corporations, that then might trade those AAUs across national borders. ET aims at an international market for the exchange of the right to emit green-

house gases. Such a market would lead to a unified price for the right to emit. Each corporation would compare this price with its marginal abatement costs and then decide whether to reduce its emissions or to buy licenses and thereby to make other corporations reduce their emissions. In this way, every corporation is provided with incentives for a decentralised, autonomous adaptation. Such a "cap and trade" system makes sure that the politically agreed reduction targets can be reached while minimising economic welfare losses.

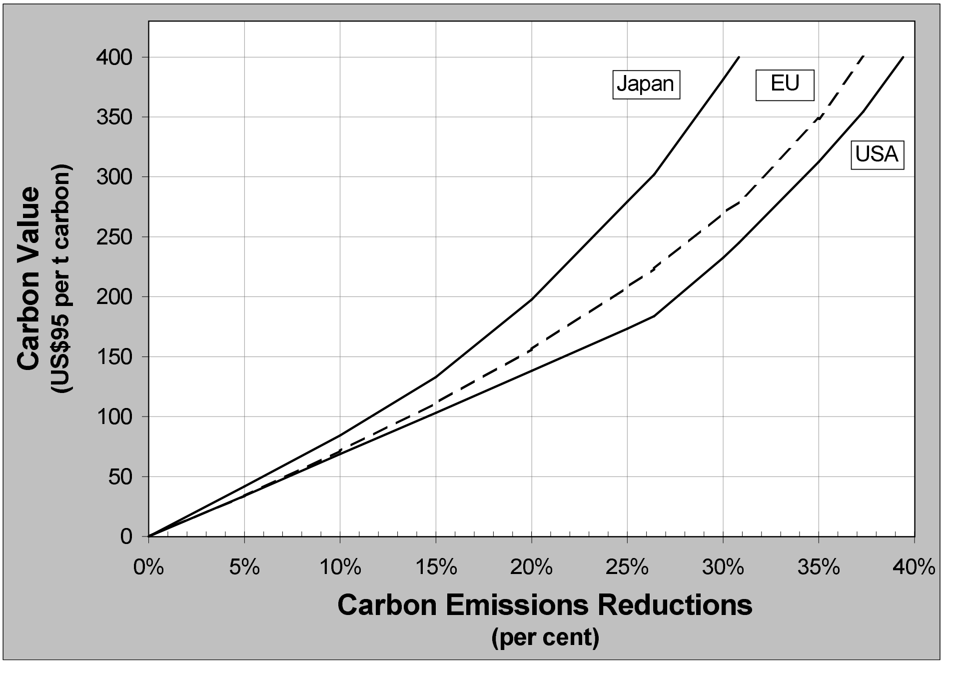

Figure D1. Marginal Abatement Costs for the United States, European Union and Japan

The importance of the Flexible Mechanisms stems from the fact that (marginal) abatement costs differ widely between different countries (see Figure D1). This means that there are potential gains from trade. They can be used either to minimise the cost of reaching a given reduction target or to set – at given cost – a more ambitious reduction target in the next negotiation round for the years after 2012. In either case, there is a strong complementarity between ecological effectiveness and economic efficiency. Therefore, it is to be welcomed that the European Union is planning to implement emissions trading by 2005.[50]

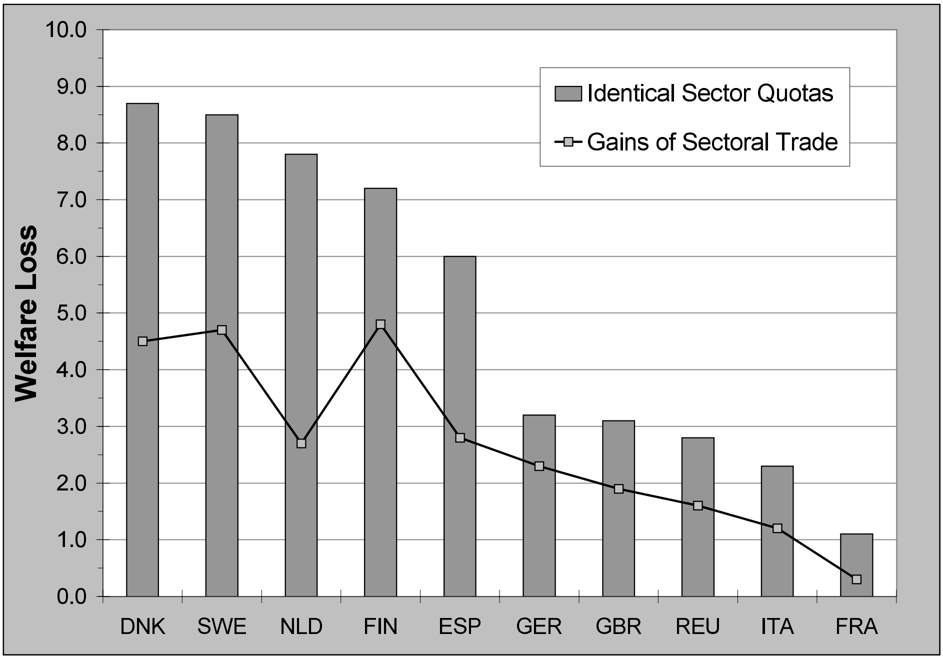

Figure D2. Welfare Effects of the Kyoto Protocol under different national policy arrangements until 2010

Figure D2 shows welfare losses from implementing the burden sharing agreement in nine European countries (REU stands for "Rest of Europe"). Welfare losses are expressed as percentage changes in the "Equivalent Variation" index for year 2010, a measure of welfare – comprising effects on GDP as well as terms-of-trade effects – that shows by how much regional well-being, roughly the level of consumption, changes as a result of meeting the Kyoto targets. Two policy arrangements are distinguished. The first "Identical Sector Quotas" means that each Member State uniformly assigns to its economic sectors the national reduction commitment. This would mean, for example, that in Germany the transportation sector as well as industry and agriculture and the household sector must reduce their emissions by 21% each. In contrast, the second arrangement allows for an economy-wide emissions trading within (but not across) countries. The according equalisation of marginal abatement costs across sectors greatly reduces the economic burden of the Kyoto Protocol.

However, if one wants to judge the rationality of the Kyoto Protocol, these costs have to be compared to climate benefits, bearing in mind that even a full compliance of the Protocol would prevent an amount of global warming of approximately only 0.07 °C by 2050.[51] On the basis of such cost-benefit analyses, several economists are sceptical that the Kyoto Protocol makes sense.[52]

Appendix E: Emission scenarios used by the IPCC

To estimate the level of future greenhouse gases in the atmosphere it is necessary to develop a model of how the world will look like in the years to come. Of course no model can predict the future exactly. In fact the task to build such a model is an attempt to square the circle: In most cases the predictions are more or less wrong because of the difficulties that any prediction brings about (like selection of input variables, estimates of functional relations and specification of output values). But even in the case where the models are realistic enough to take all necessary trends into account, the prediction changes the future because of its existence and therefore falsifies itself.

Nevertheless some key problems can be identified assessing a prediction. One key element is the time period covered. The longer the time period the harder is to give a valid prediction of the future world. Here climate models have the choice between a rock and a hard place: Most relevant climate phenomena will take place within next two to five decades. To be on the safe side the next century must be included in all climate models. In a fast changing world, however, it is almost impossible to predict key economic factor for such a long period of time. This becomes obvious when looking back: Nobody could have predicted today's world a century ago. And within the last 100 years the rate of change has increased, not decreased. This dynamic trend is likely to continue.

To give a more or less valid picture of tomorrow's world it is necessary to capture the characteristics of main influential factors very roughly. Factors like world population, economic growth or primary energy demand play an important role here. Unfortunately it is as difficult to forecast aggregated economic and social factors as to develop a model for the "whole" picture. One way out of this problem is the scenario technique: Key factors are not estimated but deduced from a coherent storyline, in which the other corresponding factors must fit. A number of storylines is then used to include all imaginable developments of the future.

All estimates of CO_2 emissions in this book – e.g. for the political negotiation situation in chapter II.5 – are derived from an emissions model by the World Energy Council/International Institute of Applied Systems Analysis. This model uses the scenario technique and is part of the IPCC emissions scenario database. In contrast to other models in the database, it allows a sophisticated analysis of emissions for all scenarios and, even more important here, for both groups of Annex-I and Non-Annex-I states.

	Scenario A "High Growth"	Scenario B "Middle Course"	Scenario B "Ecologically Driven"
Environmental taxes	No	No	Yes
CO_2 emission constraint	No	No	Yes
World population in 2050/2100 (Bil.)	10.1/11.7	10.1/11.7	10.1/11.7
World economic growth	2.7 % p.a.	2.2 % p.a.	2.2 % p.a.
Improvements on global primary energy intensity (1990-2050)	Medium	Low	High
	- 1.0 % p.a.	- 0.7 % p.a.	- 1.4 % p.a.
Resource availability fossil/non-fossil	High/High	Medium/Medium	Low/High
Technology costs fossil/non-fossil	Low/Low	Medium/Medium	High/Low
Technology dynamics fossil/non-fossil	High/High	Medium/Medium	Medium/Low

Table E1. Storylines and key assumptions of the different scenario families

The three different storylines of the WEC/IIASA are divided into the A, B and C family. The characteristics of each family are summarized in Table E1. Family B is included for reference purposes and describes a compromise between the fast growing but efficient world A and the ecologically driven development in world C. Though no political actions against CO_2 emissions are taken, it is not a simple "business as usual"-scenario.

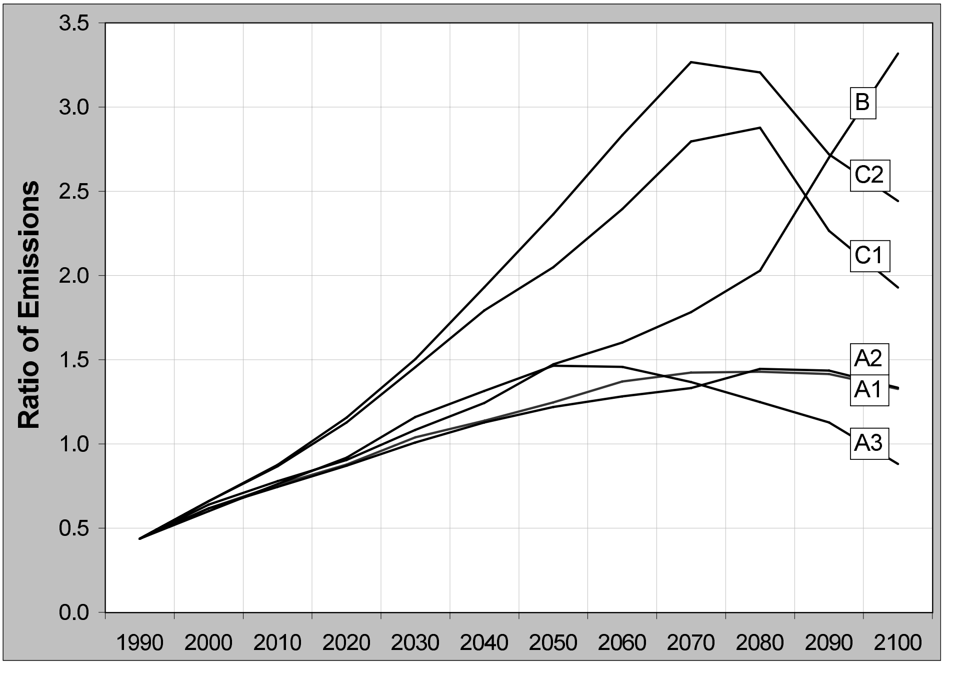

Figure E1. Emissions ratios according to WEC/IIASA scenarios (1998 data)

The results of the WEC/IIASE emissions model are shown in Table E2. Here a number of variants was used to take a closer look at possible trends. For example, A1 has strong emphasis on oil and natural gas use, A2 is coal intensive while A3 emphasises the use of natural gas, nuclear power and renewable energy. On the other side, C1 describes a world of renewable power (especially solar energy) and energy improvements. Here nuclear energy will phase out by 2100, while in C2 this energy source will play an expanding role. As expected, worldwide CO_2 emissions will be highest in A2 (22.09 Gt C), followed by A1 (15.14 Gt C) and B (13.71 Gt C). By far better are A3 (6.81 Gt C) and, of course, C1 and C2 (both 2.00 Gt C). The table also shows the distribution of the global emissions – the percentage of the Annex-I and Non-Annex-I states and, below that, the ratio between the emission groups.

To round up the picture newer, but unpublished data have been included. Table E3 is a more up-to-date version of Table E2. Figure E1 is the corresponding graph showing the development of Figure 10 with new data. Noteworthy is one point: Although this graph has a different shape than before, all conclusions drawn from the development of the emissions ratio are still valid. Even the new data confirm in fact the logic of the political negotiating situation in Figure 11.

	Absolute Emissions. Emissions Share and Ratio Annex-I versus Non-Annex-I States (in Gt C)																								
		1990		2000		2010		2020		2030		2040		2050		2060		2070		2080		2090		2100	
Scenario		abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.
A1	Annex-I	3.98	70%	4.29	62%	4.67	57%	4.99	53%	5.12	48%	5.12	46%	5.08	43%	5.13	41%	5.25	39%	5.47	37%	5.46	36%	5.29	35%
	Non-Annex-I	1.73	30%	2.67	38%	3.58	43%	4.48	47%	5.46	52%	5.98	54%	6.61	57%	7.48	59%	8.38	61%	9.13	63%	9.70	64%	9.84	65%
	World	**5.71**	0.43	**6.96**	0.62	**8.25**	0.77	**9.47**	0.90	**10.58**	1.07	**11.09**	1.17	**11.68**	1.30	**12.61**	1.46	**13.63**	1.59	**14.61**	1.67	**15.15**	1.78	**15.14**	1.86
A2	Annex-I	3.98	70%	4.32	62%	4.83	57%	5.31	53%	5.86	49%	6.20	46%	6.64	44%	7.06	42%	7.40	40%	7.53	37%	7.80	36%	7.87	36%
	Non-Annex-I	1.73	30%	2.70	38%	3.66	43%	4.73	47%	6.00	51%	7.14	54%	8.48	56%	9.86	58%	11.28	60%	12.86	63%	14.10	64%	14.22	64%
	World	**5.71**	0.43	**7.02**	0.62	**8.49**	0.76	**10.04**	0.89	**11.86**	1.02	**13.34**	1.15	**15.12**	1.28	**16.92**	1.40	**18.68**	1.53	**20.38**	1.71	**21.91**	1.81	**22.09**	1.81
A3	Annex-I	3.98	70%	4.20	62%	4.25	57%	4.26	52%	4.08	46%	3.88	43%	3.75	41%	3.76	39%	3.66	37%	3.37	38%	3.03	39%	2.79	41%
	Non-Annex-I	1.73	30%	2.54	38%	3.25	43%	3.94	48%	4.72	54%	5.05	57%	5.49	59%	5.96	61%	6.10	63%	5.59	62%	4.79	61%	4.02	59%
	World	**5.71**	0.43	**6.75**	0.60	**7.50**	0.77	**8.20**	0.93	**8.80**	1.16	**8.93**	1.30	**9.24**	1.46	**9.72**	1.59	**9.76**	1.67	**8.97**	1.66	**7.82**	1.58	**6.81**	1.44
B	Annex-I	3.98	70%	3.92	61%	4.14	56%	4.33	52%	4.26	47%	4.05	43%	3.80	38%	3.64	35%	3.53	30%	3.36	26%	2.87	21%	2.24	16%
	Non-Annex-I	1.73	30%	2.54	39%	3.29	44%	4.04	48%	4.83	53%	5.39	57%	6.21	62%	6.91	65%	8.09	70%	9.42	74%	10.93	79%	11.47	84%
	World	**5.71**	0.43	**6.46**	0.65	**7.44**	0.79	**8.37**	0.93	**9.09**	1.13	**9.45**	1.33	**10.01**	1.64	**10.55**	1.90	**11.62**	2.29	**12.78**	2.80	**13.80**	3.80	**13.71**	5.12
C1	Annex-I	3.98	70%	3.66	60%	3.41	53%	2.98	47%	2.51	40%	2.00	36%	1.73	32%	1.38	28%	0.99	24%	0.69	20%	0.47	17%	0.28	14%
	Non-Annex-I	1.73	30%	2.42	40%	2.97	47%	3.37	53%	3.69	60%	3.62	64%	3.70	68%	3.52	72%	3.21	76%	2.81	80%	2.28	83%	1.72	86%
	World	**5.71**	0.43	**6.08**	0.66	**6.37**	0.87	**6.35**	1.13	**6.20**	1.47	**5.62**	1.81	**5.42**	2.14	**4.90**	2.55	**4.20**	3.24	**3.50**	4.09	**2.75**	4.85	**2.00**	6.08
C2	Annex-I	3.98	70%	3.66	60%	3.37	53%	2.92	46%	2.43	40%	1.85	34%	1.50	30%	1.20	26%	0.92	23%	0.75	22%	0.60	23%	0.45	23%
	Non-Annex-I	1.73	30%	2.41	40%	2.96	47%	3.39	54%	3.70	60%	3.55	66%	3.51	70%	3.41	74%	3.11	77%	2.62	78%	2.01	77%	1.55	77%
	World	**5.71**	0.43	**6.07**	0.66	**6.33**	0.88	**6.31**	1.16	**6.13**	1.52	**5.41**	1.92	**5.01**	2.35	**4.61**	2.83	**4.03**	3.37	**3.37**	3.48	**2.61**	3.34	**2.00**	3.41

Table E2. Global energy scenarios by WEC/IIASA (1995 estimates)

Absolute Emissions, Emissions Share and Ratio Annex-I versus Non-Annex-I States (in Gt C)																									
		1990		2000		2010		2020		2030		2040		2050		2060		2070		2080		2090		2100	
Scenario		abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.
A1	**Annex-I**	4.13	70%	4.28	62%	4.66	57%	5.01	53%	5.15	49%	5.16	47%	5.17	45%	5.25	42%	5.53	41%	5.83	41%	5.95	41%	5.95	43%
	Non-Annex-I	1.80	30%	2.64	38%	3.53	43%	4.39	47%	5.35	51%	5.88	53%	6.45	55%	7.19	58%	7.87	59%	8.33	59%	8.41	59%	7.89	57%
	World	**5.93**	0.44	**6.92**	0.62	**8.19**	0.76	**9.40**	0.88	**10.49**	1.04	**11.04**	1.14	**11.62**	1.25	**12.44**	1.37	**13.40**	1.42	**14.16**	1.43	**14.36**	1.41	**13.84**	1.33
A2	**Annex-I**	4.13	70%	4.31	62%	4.82	57%	5.30	53%	5.82	50%	6.13	47%	6.61	45%	7.08	44%	7.49	43%	7.71	41%	8.19	41%	8.49	43%
	Non-Annex-I	1.80	30%	2.66	38%	3.59	43%	4.61	47%	5.87	50%	6.92	53%	8.06	55%	9.08	56%	9.97	57%	11.15	59%	11.76	59%	11.31	57%
	World	**5.93**	0.44	**6.98**	0.62	**8.42**	0.75	**9.91**	0.87	**11.69**	1.01	**13.04**	1.13	**14.67**	1.22	**16.16**	1.28	**17.46**	1.33	**18.86**	1.45	**19.96**	1.44	**19.80**	1.33
A3	**Annex-I**	4.13	70%	4.20	62%	4.24	57%	4.27	52%	4.07	46%	3.85	43%	3.77	41%	3.97	41%	4.15	42%	3.96	44%	3.53	47%	3.31	53%
	Non-Annex-I	1.80	30%	2.52	38%	3.23	43%	3.92	48%	4.72	54%	5.07	57%	5.52	59%	5.79	59%	5.67	58%	4.95	56%	3.98	53%	2.92	47%
	World	**5.93**	0.44	**6.73**	0.60	**7.47**	0.76	**8.18**	0.92	**8.79**	1.16	**8.92**	1.32	**9.29**	1.46	**9.76**	1.46	**9.82**	1.37	**8.91**	1.25	**7.51**	1.13	**6.23**	0.88
B	**Annex-I**	4.13	70%	3.92	61%	4.14	56%	4.33	52%	4.27	48%	4.11	45%	3.87	40%	3.77	38%	3.74	36%	3.69	33%	3.19	27%	2.63	23%
	Non-Annex-I	1.80	30%	2.51	39%	3.23	44%	3.92	48%	4.62	52%	5.11	55%	5.70	60%	6.04	62%	6.67	64%	7.49	67%	8.60	73%	8.72	77%
	World	**5.93**	0.44	**6.43**	0.64	**7.37**	0.78	**8.26**	0.91	**8.89**	1.08	**9.22**	1.24	**9.57**	1.47	**9.81**	1.60	**10.41**	1.78	**11.18**	2.03	**11.79**	2.70	**11.35**	3.32
C1	**Annex-I**	4.13	70%	3.66	60%	3.41	54%	2.98	47%	2.53	41%	2.02	36%	1.75	33%	1.41	29%	1.06	26%	0.83	26%	0.67	31%	0.49	34%
	Non-Annex-I	1.80	30%	2.42	40%	2.96	46%	3.36	53%	3.68	59%	3.63	64%	3.59	67%	3.38	71%	2.96	74%	2.38	74%	1.53	69%	0.95	66%
	World	**5.93**	0.44	**6.08**	0.66	**6.37**	0.87	**6.34**	1.13	**6.21**	1.46	**5.65**	1.79	**5.34**	2.05	**4.79**	2.39	**4.02**	2.80	**3.20**	2.88	**2.20**	2.26	**1.44**	1.93
C2	**Annex-I**	4.13	70%	3.66	60%	3.37	53%	2.92	46%	2.45	40%	1.88	34%	1.52	30%	1.23	26%	0.97	23%	0.82	24%	0.71	27%	0.58	29%
	Non-Annex-I	1.80	30%	2.41	40%	2.95	47%	3.38	54%	3.69	60%	3.63	66%	3.59	70%	3.50	74%	3.17	77%	2.63	76%	1.93	73%	1.41	71%
	World	**5.93**	0.44	**6.07**	0.66	**6.32**	0.88	**6.30**	1.16	**6.14**	1.50	**5.51**	1.93	**5.11**	2.36	**4.73**	2.83	**4.14**	3.27	**3.45**	3.21	**2.64**	2.72	**1.98**	2.44

Table E3. Global energy scenarios by WEC/IIASA (1998 estimates, unpublished data)

Appendix F: Thinking about the very long run

If one wants to stop global warming, greenhouse gas concentrations must be stabilised. In order to achieve this at lowest cost, an institutional framework must be established that fulfils the following conditions: Firstly, it must control *all* greenhouse gases according to their global warming potential. Secondly, it must provide a *symmetric* treatment of sources (emitting greenhouse gases) and sinks (absorbing greenhouse gases). Thirdly, it must lead to a *world wide* equalisation of marginal abatement costs across sectors and regions. Especially with regard to the third condition, it is doubtful whether the Kyoto Protocol is an appropriate legal basis for establishing such a framework.

Discussion in the literature is centred around the idea to stabilise greenhouse gas concentrations (in CO_2 equivalents) at 550 ppmv by 2150.[53] This makes clear that the Kyoto Protocol and perhaps even the United Nations Framework Convention on Climate Change (UNFCCC) must be regarded as a first step in what will become a long-lasting international negotiation process. However, due to path dependencies, action today may be very influential since it determines the status quo for future action. That is why it is so important to take care that the currently negotiated framework for climate change policies makes use of *all* potentials of low-cost adjustments.

While the UNFCCC (Article 2) promotes a world wide stabilisation goal and while the Kyoto Protocol, accordingly, concentrates on mitigation policies, one must not overlook another relevant alternative how to deal with climate change. The alternative is adaptation. Since today we do not know whether it will be technically possible and/or politically feasible to stop climate change, we must take into account that current and future mitigation measures might only postpone climate change. Therefore, it might be wise to think much more carefully not only about intelligent ways to reduce climate change but also about reducing our exposure to (a possible, still uncertain, maybe unavoidable) climate change.[54]

Adaptation today reduces damage tomorrow. Two kinds of damage reduction can be distinguished. Firstly, damage can be avoided ex ante. Secondly, damage can be insured ex post. Up to a certain degree, both kinds of adaptation may be regarded as no regret policies since they may be desirable in their own right, irrespective of climate change.

To illustrate, a few examples should suffice: A million dollar invested in a workable health care system in developing countries may yield a higher rate of return in terms of both longer lifespans and higher living-standards than a million dollar spent for greenhouse gas mitigation policies. In likewise fashion, it might be (an economically attractive!) act of solidarity to provide insurance against regional catastrophes (including, e.g. earthquakes) both within nations and across nations. Furthermore, it may be prudent to change regulations for settlement along exposed coast lines, river deltas etc. and, in general, help people to move away from dangerous places.

Notes

[1] Cf. WBGU (1997, p. 24).
[2] Cf. e.g. Bryant (1997, pp. 155 et seq.)
[3] Cf. Houghton et al. (1996, pp. 39 et seq.).
[4] Cf. IPCC Working Group I (2001, p. 13).
[5] Cf. Houghton et al. (1996, pp. 40 et seq.).
[6] Cf. IPCC Working Group I (2001, p. 16).
[7] Cf. Houghton et al. (1996, p. 44). This is confirmed in the review by Neumann/Yohe/Nicolls (2000, p. iii) who note that "Research on the effects of climate change on storm frequency and intensity is active, but currently inconclusive." However, the IPCC Working Group I (2001; p. 15) holds it to be "very likely" that during the 21st century nearly all land areas will experience higher maximum as well as higher minimum temperatures and more intense precipitation events. But they, too, lament over the current state of ignorance: "[T]here is currently insufficient information to assess recent trends, and climate models currently lack the spatial detail required to make confident projections. For example, very small-scale phenomena, such as thunderstorms, tornadoes, hail and lightning, are not simulated in climate models."
[8] Cf. Kunkel/Pielke/Changnon (1999).
[9] Cf. the review by Adams/Hurd/Reilly (1999). They sum up as follows on page 3: "The emerging consensus from modeling studies is that the net effect on US agriculture associated with a doubling of CO_2 may be small."
[10] Cf. Lang (1999).
[11] Cf. Hulme et al. (1999).
[12] On this aspect, the review by Adams/Hurd/Reilly (1999, p. 25) notes the following: "Research results indicate that global food production is most likely to be only modestly affected by climate change, although some countries could be more adversely affected than others. Consequently, global capacity to feed the world's population is not expected to be seriously threatened as a result of climate change in the foresee-

able future."
[13] Cf. HCCPR (1999).
[14] Cf. Reiter (2000).
[15] This is now generally recognized in serious studies. Cf. e.g. Fisher et al. (2000, p. 35): "It is useful to distinguish between risk and vulnerability. For instance, research might show that malaria-carrying mosquitoes would find more suitable habitat in a region that becomes warmer and wetter, giving the region a higher risk from malaria. However, the region could adapt to reduce its vulnerability through measures such as vector control, disease monitoring and medical treatment, or even development of a vaccine."
[16] Cf. NRC (2000, pp. 32-40).
[17] Cf. NRC (2000, pp. 50-57).
[18] Cf. NRC (2000, pp. 41-49).
[19] Cf. NRC (2000, p. 22).
[20] All the data in this paragraph are based on Houghton et al. (1996, pp. 55-60). For detailed information, cf. Kiehl/Trenberth (1997).
[21] Unless otherwise indicated, all the figures given in this paragraph are based on Houghton et al. (1996, pp. 77-79).
[22] Cf. Fan et al. (1998).
[23] Cf. Fischer et al. (1999) and Vilmeux et al. (1999).
[24] Cf. Friis-Christensen/Lassen (1991). Even longer data series are now available, going back to up to 500 years. Cf. Lassen/Friis-Christensen (1995).
[25] Cf. ISSI (1999).
[26] Cf. Svensmark/Friis-Christensen (1997) and Friis-Christensen/Svensmark (1997).
[27] Cf. Shindell et al. (1999).
[28] Cf. Barnett et al. (1999), pp. 2651 et seq.: "Greenhouse warming alone is insufficient to explain the observed pattern of climate change. ... The most probable cause of the observed warming is a combination of ... natural variability and anthropogenic sources ... But given the large model uncertainties and limited data, a reliable weighting of the different factors ... cannot currently be given ... [T]he anthropo-

genic signal is currently comparable in magnitude to the upper limits of the natural climate noise. Such a low signal to noise ratio makes clear attribution statements difficult at this time. ... In short, the current state of affairs is not satisfactory." - Similarly WBGU (1999, p. 137, translated): "On account of natural climate variability, it is quite difficult to prove whether these observed climate changes [in the 20th century] were partly caused by man. ... The data records on which the comparison between (model-aided) expected and observed developments are based are not complete and not sufficiently long in time to isolate without any doubt the anthropogenic signal in respect of all natural cycles and dynamic forces (including the most protracted ones)."

29 Cf. Albritton et al. (2001, Table 1, p. 38).

30 Cf. Houghton et al. (1996, p. 22, p. 92 and p. 121). If one takes a period of 100 years as the basis and if one fixes the carbon dioxide index figure at 1, the index figure for methane drops from 56 to 21 while that for N_2O rises from 280 to 310.

31 Hansen et al. argue that the use of fossil fuels is the main source of both CO_2 and a number of aerosols which almost have the same magnitude in climate forcing (1.4 W/m^2) but opposite sign. That is why the substances not only have a different effect but compensate each other. The authors assert – if their estimates are correct – that non- CO_2 greenhouse gases have been the primary drive for climate change in the past century. To conclude, however, from this study that CO_2 emissions are irrelevant for a global climate policy – as some critics suggest – is a misinterpretation of these results. The authors' intention was not to focus only on non- CO_2 gases but to broaden the view of the public debate and take into account substances like aerosols (with a negative climate forcing) or soot and tropospheric ozone (with a positive forcing). Cf. Hansen et al. (2000).

32 SRU (2000, point 137).

33 Cf. Herzog/Eliasson/Kaarstad (2000).

34 Cf. WBGU (1998).

35 Cf. WBGU (1998, pp. 12 et seq.).

[36] Cf. BVBW (1999, p. 280).
[37] Cf. for instance Schallaböck/Petersen (1999, p. 59).
[38] Cf. Hillebrand (1999, p. 13, p. 19).
[39] Cf. BR (2000).
[40] UNEP (1999, section 26).
[41] The relevant greenhouse gases (listed in Annex A to the Protocol) are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), partially halogenated hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulphur hexafluoride (SF_6). Their CO_2 equivalence is specified on the basis of their 100-year global warming potential.
[42] It is extremely difficult to come to a correct estimate of the Gross Domestic Product for Germany. Within the last 130 years Germany has changed its territory many times – starting with the Alsace and Lorraine in 1870 over the incorporation of Austria and Sudetenland in 1938 to the German reunification in 1990. The graph shows estimates for Germany corrected for territorial change, e.g. the former German Democratic Republic is not included in the GDP data. Because of lacking reliable data from official sources and the difficulties to calculate a GDP in terms of western purchasing power, it is almost impossible to compensate the available data for this problem. On the other hand, CO_2 data for the German Democratic Republic are available and therefore reflect Germany in its current shape. As a result of this procedure, the graph underestimates the real GDP while emissions are plotted correctly. Nevertheless a small displacement towards higher GDP values doesn't make any difference to the conclusions drawn from the data.
[43] IPCC Working Group I (2001, p. 2).
[44] IPCC Working Group II (2001, p. 1).
[45] IPCC Working Group III (2001, p. 1).
[46] Cf. Houghton et al. (2001) for Working Group I, McCarthy et al. (2001) for Working Group II and Metz et al. (2001) for Working Group III.
[47] IPCC Working Group I (2001, p. 13).
[48] Cf. Schneider (2001).
[49] Webster et al. (2001, pp. 1-2).

[50] Cf. European Commission (2000).

[51] Cf. Wigley (1998).

[52] Cf. e.g. Nordhaus/Boyer (1999).

[53] Cf. Jacoby/Schmalensee/Wing (1999).

[54] Fankhauser/Smith/Tol (1999, p. 68): „[G]iven the prevailing uncertainty, the best way to account for potential climate change would be to increase the flexibility of systems to function under a wider range of climate conditions, as well as their robustness to withstand more severe climatic shocks“.

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Figure 1.	Own calculations based on GDP data by World Bank Database on Global Development Finance and World Development Indicators (www.worldbank.org/research/growth/GDNdata.htm) and CO_2 data by Marland/Boden/Andres (2001).
Figure 2.	Own figure.
Figure 3.	Crowley (1996), fig. 1.
Figure 4.	Soon et al. (1999), fig. 14, p. 159.
Figure 5.	Crowley (1996), fig. 2.
Figure 6.	Crowley (1996), fig. 5.
Figure 7.	Own figure based on monthly near-surface data from the UK Met.Office (www.met-office.gov.uk/research/hadley centre/CR_data/Monthly/HadCRUG.txt).
Figure 8.	Own figure based on lower troposphere satellite data from the National Space Science and Technology Center Data Base (www.nsstc.uah.edu/data/msu/t2lt/t2ltglhmam.d) and near-surface data from the UK Met.Office (www.met-office.gov.uk/research/hadleycentre/CR_data/Monthly/HadCRUG.txt).
Figure 9.	Own figure based on WEC/IIASE data from the IPCC SRES database version 1.0, Tsuneyuki (1999) (www-cger.nies.go.jp/cger-e/db/dbhome.html).
Figure 10.	Own figure based on WEC/IIASE data from the IPCC SRES database version 1.0, Tsuneyuki (1999) (www-cger.nies.go.jp/cger-e/db/dbhome.html).
Figure 11.	Own figure.
Figure 12.	Own figure after Hartwig (1999), Fig. M-5, p. 160.
Figure B1-4.	Own calculations based on GDP data by Maddison (1995) and CO_2 data by Marland/Boden/Andres (2001).
Figure C1.	Webster et al. (2001), p. 4.
Figure D1.	Viguier/Babiker/Reilly (2001), fig. 13, p. 23.
Figure D2.	Own figure based on Babiker et al. (2001) , fig. 1, p. 8.

Figure E1.	Own figure based on WEC/IIASE data from the IPCC SRES database version 1.0, Tsuneyuki (1999) (www-cger.nies.go.jp/cger-e/db/dbhome.html).
Table A2.	Preparing for Implementation of the Kyoto Protocol, Commission Communication to the Council and the Parliament, COM(1999) 230 (europa.eu.int/comm/environment/docum/99230_en.pdf) Differences to 100% are due to rounding.
Table E1.	Global Energy Scenarios to 2050, World Energy Council (www.worldenergy.org/wec-geis/members_only/registered/open.plx?file=edc/default/scenario.htm).
Table E2/3.	Own figure based on WEC/IIASE data from the IPCC SRES database version 1.0, Tsuneyuki (1999) (www-cger.nies.go.jp/cger-e/db/dbhome.html).

The raw data of our own calculations and figures are available for download. These files and further information about climate policy can be obtained from the Policy Consult home page (www.policy-consult.de).

About Policy Consult

We are living in a world of rapid change. Technological progress offers opportunities which former generations did not even dream of. Global exchange has become possible in a historically unprecedented scale. Developing countries catch up. Formerly communist countries transform themselves to market-oriented democracies. The European Union widens and deepens. There is the chance to establish an international peace order, guided by the principles of law and mutually beneficial co-operation.

At the same time, our societies face huge challenges. Population growth and/or rising per capita consumption cause ecological stress. Systems of social security must cope with an ageing population, increasing health expenses and tight financial constraints due to high unemployment. Financial markets, labour markets, and the markets for goods and services require improved legal frameworks, both nationally and inter-nationally, in order to facilitate fair competition and productive exchange.

Furthermore, these three dimensions of a sustainable development are inter-dependent: Social security, prudently organised, can encourage private risk-taking behaviour, e.g. investments in human capital, and thereby set free risk productivity, thus fostering economic growth. In return, economic growth provides social benefits, a general rise in living standards as well as the capacity to invest in the institutional infrastructure of society (courts, schools, hospitals, libraries etc.). At the same time, economic growth intensifies the scarcity of natural resources. However, many ecological problems cannot be solved without the help of economic incentives in favour of resourceful behaviour as well as in favour of promoting technological progress, e.g. in terms of energy efficiency. In many cases, formerly public goods must be transformed into private goods in order to create new, artificial markets as the most efficient means to cope with ecological imbalances.

Therefore, in order to successfully handle sustainability problems like the ones mentioned above, social, environmental, and economic aspects have to be integrated systematically. This requires new thinking: We need to transcend ideological barriers, moral prejudices and simple ignorance in order to fully understand and finally solve these problems. It is of utmost importance to overcome the deeply rooted suspicion that there are inner contradictions between economic, social and ecological aspects, involving insoluble conflicts of interests and thus incommensurable value judgements. Instead, we must try to identify *common* interests with regard to the institutional framework best suited to cope with such problems. Specifically, we must search for win-win arrangements, yielding economic, social and ecological benefits.

Exactly this is the task of “Policy Consult”. As an “Institute for Scientific Policy Solutions”, this independent, non-governmental, non-partisan, non-subsidised think tank offers, on a strictly scientific basis, political advice to the general public. Faced with mass media which are obsessed with a wrongful personalisation of systemic problems, with moral appeals and corresponding accusations and assignments of guilt addressed to individual actors (politicians, bureaucrats, managers etc.), Policy Consult draws the public attention to structural causes for misbehaviour, especially to disincentives resulting from institutional arrangements, and to the according policy solutions by means of institutional reform.

Our faith is that by doing so purely scientific knowledge can have a substantial political effect, especially when it leads to a change in perspective: Of course, science cannot make political decisions on behalf of the citizens. But it can ensure that their political decisions are based on sound information, i.e. on a solid knowledge of all relevant alternatives and their consequences. Thus, scientific advice can enable citizens to see the world from different points of view and thereby change ingrained thought patterns and help to break free from ideological immobilisation.

Policy Consult attempts to comply with this understanding of scientific policy advice. Our main concern is to develop reliable arguments with regard to current political problems. However, Policy Consult does refuse to take sides for either pole of the political spectrum or for any political party or interest group or ideology. Instead, our declared intention is to enable those who are interested in political issues to form a sound and sophisticated opinion of their own. For this reason, Policy Consult is committed to scientific seriousness and objectivity. We supply public information to the best of our knowledge and belief.