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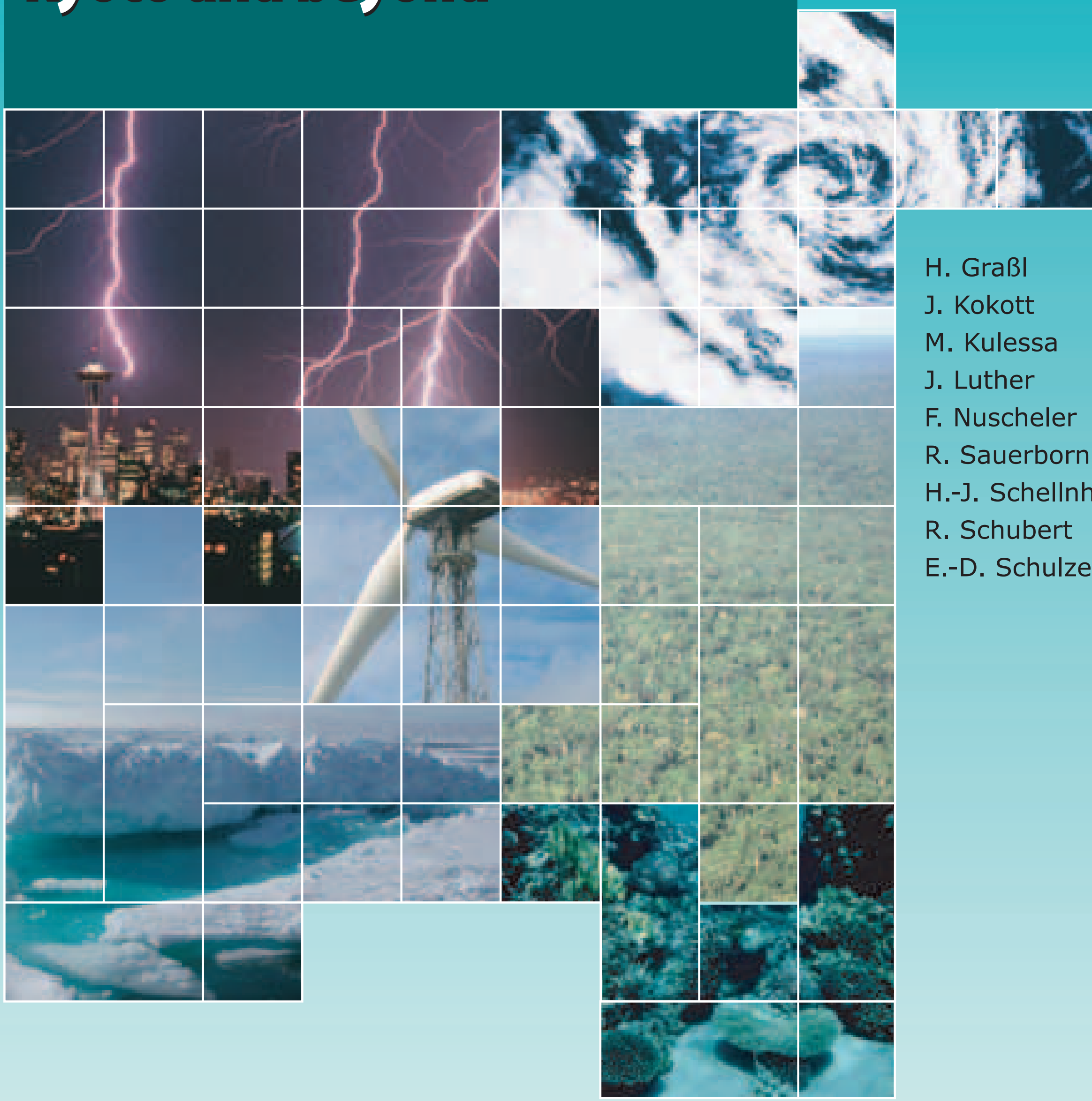
German Advisory Council on Global Change (WBGU)

Special Report

Climate Protection Strategies for the 21st Century: Kyoto and beyond



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German Advisory Council on Global Change

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Special Report

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Flashlight, clouds, rain forest (Pure Vision Photo Disc Deutschland), coral reef (Wunsch Media, Bremen), iceberg (Archiv AWI), windmill (Dr. C. Loose, WBGU)

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Summary for policymakers

Global climate change is a threat that is already having initial tangible impacts upon humankind and nature today. Due to the inertia of the climate system, this development can no longer be prevented entirely. However, it is still possible, through cooperation among the international community and through national-level efforts, to stabilize the CO_2 concentration in the atmosphere and thus prevent the most severe changes. Shaping the international climate regime will continue to be an urgent policy task over the coming decades. With this special report, the German Advisory Council on Global Change (WBGU) provides recommendations for future negotiations within the context of the United Nations Framework Convention on Climate Change (UNFCCC), particularly relating to the Kyoto Protocol to the Convention. The report centres on three questions:

- What is 'dangerous climate change' within the meaning of Article 2 of the UNFCCC?
- Which socio-economically and technologically viable pathways are available to prevent such dangerous climate change?
- How can all countries be integrated equitably within a system of emissions reduction commitments?

To address these questions, we must lift our gaze far beyond the time horizon of the Kyoto Protocol's second commitment period (after 2012), as the stabilization of greenhouse gas concentrations at a tolerable level can only be achieved by means of a long-term, ambitious reduction of greenhouse gas emissions. The report concentrates on the potentials to reduce the emissions of carbon dioxide, this being the principal anthropogenic greenhouse gas. The analysis focuses, on the one hand, on the economic and technological potentials to reduce energy- and industry-related emissions and, on the other hand, on the relevance of biological sinks of carbon dioxide and the options to preserve them. Finally, based on this analysis, the report contains specific recommendations on ways to shape political and economic instruments in the second commitment period of the Kyoto Protocol.

1 Defining dangerous climate change

The key goal of the UNFCCC is to stabilize greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system. Article 2 of the Convention defines this in specific terms: Ecosystems are to be able to adapt naturally to climate change, food production is not to be threatened and economic development is to be able to proceed in a sustainable manner. The Council has examined each of these three criteria with regard to the threshold from which climate impacts would no longer be tolerable. The present state of science does not yet make it possible to derive these 'guard rails' stringently and quantitatively from the climate impacts that must be prevented. The WBGU was thus limited to providing a qualitative assessment, based on its own expertise and on commissioned external reports and study of the literature.

With regard to ecosystems, the effects of climate changes are already apparent today. The threshold from which damage to the global natural heritage is no longer acceptable cannot be determined precisely. However, the WBGU estimates it to be in the range of 2°C global warming relative to pre-industrial values. For worldwide food security, too, the threshold appears to be in this range, as above this global warming level worldwide climate-related losses in agricultural production must be expected, as well as a steep rise in the number of people threatened by water scarcity. Concerning health impacts, no tolerance threshold can currently be appraised due to poor data availability and a lack of mature methodologies. However, it can be assumed that for some regions the effects of climate change would already lead to intolerable impacts at 2°C mean global warming. Moreover, climate change has the potential to trigger singular, catastrophic changes in the Earth System, such as a shift in worldwide ocean circulation, the melting of major ice sheets (West Antarctic, Greenland) or the sudden release of huge methane reserves. Quantitative assessments of the threshold values for these effects are beset with great uncertainty.

The WBGU's recommendation: A maximum of 2°C warming is acceptable

The WBGU reaffirms its conviction that in order to avert dangerous climatic changes, it is essential to comply with a 'climate guard rail' defined by a maximum warming of 2°C relative to pre-industrial values. As the global mean temperature has already risen by 0.6°C since the onset of industrialization, only a further warming by 1.4°C is tolerable. A global mean long-term warming rate of at most 0.2°C per decade should not be exceeded.

This climate window should be agreed as a global objective within the context of the UNFCCC process. The European Union should seek to adopt a leading role on this matter.

2 Acceptable emissions

The WBGU has developed tolerable emission paths for energy- and industry-related greenhouse gases that remain within the WBGU climate window. However, major uncertainty still attaches to the estimate of climate sensitivity, meaning the rise in temperature that follows a doubling of CO_2 concentration. Similarly, the role of the biosphere in the carbon cycle cannot yet be appraised with sufficient accuracy. It is also hard to assess to what extent other greenhouse gases can also be reduced.

The WBGU's recommendation: Adopt ambitious emissions reduction targets

In view of the major uncertainties concerning the climate system, the WBGU recommends a hedging strategy in which initially a CO_2 concentration target below 450 ppm is aimed at. This will only be possible if by 2050 global energy-related CO_2 emissions can be reduced by about 45–60% from 1990 levels. Furthermore, it will be essential to achieve substantial reductions of the other greenhouse gases (notably methane and nitrous oxide, but also the fluorinated compounds) and of further indirectly radiatively active substances (e.g. soot). Therefore, industrialized countries must reduce their greenhouse gas emissions by at least 20% by 2020.

3 Stabilization paths: Climate protection and sustainable development

Within the context set by the WBGU's hedging strategy, this report examines emissions profiles as to their technological and economic viability, comparing trajectories across regions and over time by means of scenario computations. For this purpose the Council has developed, in cooperation with the International Institute for Applied Systems Analysis (IIASA, Laxenburg, Austria) CO_2 stabilization scenarios based upon the scenario families used by the Intergovernmental Panel on Climate Change (IPCC). The present report examines emissions reduction paths in scenario worlds characterized by global convergence and rapid technological development (scenarios A1T and B1), and compares these with an emissions reduction path in a 'business-as-usual' world (B2). The A1T scenario presupposes rapid technological development, while the B1 scenario assumes that environmental aspects gain high prominence. Additional conditions are set in both scenarios in order to ensure compliance with sustainability criteria.

Building upon these scenarios and further assumptions on the reduction of other greenhouse gases, the WBGU's climate protection goal is attainable for climate sensitivity values of up to 2.0ºC (at a stabilization level of 450 ppm) or, respectively, 2.4–2.9ºC (stabilization at 400 ppm, depending upon assumptions regarding other emissions). If it should emerge that climate sensitivity is in fact higher than these values (the IPCC estimates climate sensitivity to be in the range of 1.5–4.5°C), even lower CO_2 concentrations would need to be aimed at in order not to move outside of the WBGU climate window.

The necessary measures to reduce energy- and industry-related CO_2 emissions can be organized in three groups: intensified energy saving, structural changes (in particular the use of renewable forms of energy and low-carbon conventional technologies) and geological CO_2 storage as a bridging technology. In the scenarios characterized by sustainable energy supply systems and dynamic technology development (A1T, B1), the assumption concerning structural change is that by the end of the century energy supply is based essentially upon solar electricity and solar hydrogen.

When assessing the costs of climate change mitigation paths, the costs of CO_2 reduction need to be compared to the damage and adaptation costs arising due to the climate change that will take place if no mitigation activities are undertaken. The comparison also needs to take into account the other forms of avoided damage (such as damage resulting from air pollution). Very high uncertainties attach to the currently available assessments. The overall damage that will result if no climate policy action is taken is generally underestimated because damage to goods not traded on markets is usually neglected or undervalued. Moreover, assessments regularly fail to consider the damage resulting from singular changes or from the increasing frequency of extreme events.

The WBGU's recommendation: Align financial and capital transfers to developing countries with sustainability criteria

It is essential for efficiency reasons to link climate policy consistently with global governance and development policy. This means that development cooperation activities must focus more firmly on sustainability, markets should be opened to the greatest degree to products from developing countries, and official development assistance funding should be clearly raised.

The Council refers to its recommendations on global energy policy (WBGU, 2004) for further supporting measures in this field. These include the adoption of a Multilateral Energy Subsidization Agreement (MESA) ensuring the internationally coordinated removal of subsidies, as well as international commitments to substantially raise the proportion of renewable energy sources in energy supply.

The WBGU's recommendation: Increase investment in research and development

The WBGU reaffirms its recommendation to achieve a ten-fold increase in investment in researching and developing sustainable technologies by 2020. Focal areas should include, in particular, energy efficiency and renewable energies, but also R&D on the use of sustainable potentials to store carbon dioxide in geological repositories (WBGU, 2004).

4 Reduction of emissions caused by fossil fuels use

Compliance with a target path for stabilizing CO_2 concentrations entails a specific global emissions budget. The WBGU considers that the allocation of the emission rights available within this budget to individual countries should be oriented above all to the egalitarian principle and to targetedness in terms of CO_2 emissions. Abrupt changes in the permissible emissions of individual countries should be avoided.

The Council's recommendation: Aim towards equal per-capita emission rights and linear harmonization of emissions shares

The WBGU recommends that emission rights for the greenhouse gases covered by the Kyoto Protocol be allocated according to the 'contraction and convergence' approach, taking 2050 as convergence year. This means that global emissions would need to be reduced substantially over the long term (contraction). In a further step, it would be agreed that the per-capita emissions of all states must reach equal levels in a continuous process extending until 2050 (convergence). In particular, this means that the per-capita emissions of industrialized countries, which are still comparatively high at present, must be reduced, while some developing countries can initially increase their per-capita emissions. The principle of constancy requires that there be no sudden switch to equal per-capita emissions, because of the resulting stresses on the global economy. The approach further presupposes a functioning global emissions trading scheme, in order to reduce the costs of the transformation process.

The WBGU's recommendation: Provide opt-out clause for the poorest developing countries as a compromise

In the event that various developing countries are initially unable or unwilling to accept absolute emissions caps from the second commitment period onwards, an opt-out clause could be considered for countries with low levels of economic capacity and relatively low per-capita emissions. Such an approach requires criteria for mandatory participation in the contraction and convergence process. In such a scheme, the opt-out clause could not be made use of once a threshold value has been exceeded, which could be oriented, for example, to per-capita emissions and per-capita income. The reduction burden of developing countries making use of the opt-out clause would be distributed among the participating countries in order to safeguard attainment of the stabilization target and thus compliance with the climate window.

5 Conservation of carbon stocks of terrestrial ecosystems

The terrestrial biosphere plays a major role in the carbon cycle. Near-natural forests, wetlands and grasslands are important carbon reservoirs as long as they are not cleared, drained or ploughed. Thus deforestation, above all in the tropics, is currently the cause of 10–30% of present anthropogenic carbon dioxide emissions. Nonetheless, the biosphere is currently a net carbon dioxide sink. The present way in which biological sources and sinks are accounted under the Kyoto Protocol is not suitable, however, to provide incentives to conserve these natural stocks (WBGU, 1998).

The WBGU's recommendation: Engage in full carbon accounting

From the principle of 'moderate anthropocentrism' and the precautionary principle, the Council derives the recommendation to give greater consideration in climate policy to terrestrial biological carbon stocks and sinks. All carbon fluxes and stocks should be accounted fully ('full carbon accounting'). However, at the present time the Council advises against seeking to regulate the conservation of biological terrestrial carbon stocks within the same system, with the same allocation procedure and with the same instruments as reduction commitments for fossil carbon stocks. Such an approach could cause an unacceptable delay of the entire climate protection process.

The WBGU's recommendation: Take the role of the biosphere into account through a special agreement

The WBGU recommends agreeing a special intergovernmental commitment to preserve the carbon stocks of terrestrial ecosystems. Such an agreement could be implemented as a 'protocol for the conservation of carbon stocks' to the UNFCCC. This approach should not distinguish, as the Kyoto Protocol has done until now, between direct and indirect human impacts (such as CO_2 fertilization or climate change) or natural factors (such as natural climate variability). Rather, it should involve measurement and accounting of the full carbon balance of the terrestrial biosphere.

The WBGU recommends for the conservation of natural ecosystems, which are major carbon reservoirs (e.g. primary forests, wetlands, grasslands), an international system of tradable non-utilization commitments similar to that already presented by the Council for the global biodiversity policy (WBGU, 2002).

6 Reviewing and enhancing instruments

In recent years, the international community has devised a range of instruments for global climate protection. These have partly been tested in pilot phases, and in some cases the practical deployment of these instruments has begun. Building upon past experience, the WBGU recommends further developing these instruments, in order to be able to attain the climate protection goal more efficiently and effectively.

The WBGU's recommendation: Harness the opportunities of emissions trading and minimize uncertainties

In order to preclude uncertainties relating to global emissions trading, the Council recommends establishing a Climate Central Bank, hosted by the UNFCCC Secretariat. The primary task of the bank would be to smooth price surges on the certificates market. An automatic mechanism would need to ensure that only extreme price fluctuations, but not longer-term price trends, are prevented. Furthermore, the introduction of a variable bottom price limit for certificates merits consideration.

In order to generate permanent innovation pressure to develop new mitigation technologies, the scope for purchasing emission rights to meet national reduction commitments should be limited. Intensified and continuous innovation activity is essential in order to attain the climate change mitigation goal.

The WBGU further considers it urgent to integrate the emissions of international aviation and shipping into global emissions trading. Alternatively, charges could be levied on the use of airspace or oceans at a global or at least European level (WBGU, 2002).

The WBGU's recommendation: No emissions trading without reliable inventories

The environmental targetedness of the climate protection regime should not be jeopardized through trade with possibly incorrectly assessed emission rights. In order to ensure the integrity of the regime, the WBGU recommends making participation in emissions trading conditional upon the compilation of high-quality inventories. Developing countries should therefore receive greater support than in the past in compiling inventories with a high information content.

The WBGU's recommendation: Use the CDM as a transitional instrument

Countries that do not possess sufficiently high-quality inventories or do not participate in 'contraction and convergence' can be integrated into emissions reduction efforts through the Clean Development Mechanism (CDM). To this end, special incentives should be created for CDM projects in the least developed countries, and the investment additionality approach should be made mandatory for large-scale projects. In view of the dubious effects of past projects in the field of biological sinks, and building upon the Council's recommendation to establish a special protocol on the conservation of the carbon stocks of terrestrial ecosystems, sink projects should be excluded from the CDM in the future. Nuclear projects should not be supported by the CDM as a matter of principle. With regard to Joint Implementation (JI), the WBGU recommends reviewing to what extent JI should be subsumed fully within emissions trading, or whether it can be merged with the CDM. The CDM should not be the sole instrument to be burdened by a tax for the financing of the Adaptation Fund. Instead, the WBGU argues that charges should be levied on all transactions within the context of the flexible mechanisms, but only to the amount of the administrative costs incurred by handling emissions trading or the CDM and JI.

The Council's recommendation: Finance adaptation and compensation funds according to global warming responsibilities

Neither is the financing of the Adaptation Fund through a charge raised on CDM projects purposeful, nor will replenishment of the LDC Fund and the Special Climate Change Fund by means of voluntary ad-hoc contributions suffice. The resources available to these climate protection funds created under the GEF umbrella need to be expanded substantially and fund design needs to be improved in order that the deployment of resources contributes in a targeted manner to sustainable development in the recipient states. Furthermore, an additional Compensation Fund should be set up for the second commitment period, from which payments providing compensation for climate damage would be financed.

The contributions of individual states – specially their contribution to compensation and adaptation funds – should be oriented to their respective contributions to global warming (cumulative emissions). However, only emissions from 1990 onwards should be taken into account, as the publication of the IPCC first assessment report was the point at which the international community clearly recognized the problem and the severity of its consequences.

The WBGU's recommendation: Discuss sanctions against free riders

The Council does not consider it an urgent priority at the present time to reform the mechanisms envisaged for imposing sanctions on countries that fail to meet their commitments. However, there should be debate early on about the incentives and sanctions to be applied against countries that refuse to join the climate protection regime on principle. The WBGU recommends that the international community retain from the outset the option of imposing hard political and economic sanctions, particularly on large-scale emitters.

7 Key strategic decisions lie ahead

In the coming years, the international community will need to take key strategic decisions in international climate policy, if dangerous climate change is to be prevented. With every further delay of consistent climate protection policy, the scope for action narrows. The UNFCCC provides an indispensable framework for upcoming negotiations.

Introduction

Six years after having been adopted in Japan, the Kyoto Protocol (KP) to the United Nations Framework Convention on Climate Change (UNFCCC) has still not entered into force. Nevertheless, many countries have already started implementing the Protocol, expecting Russia to finally ratify and the Protocol thus to enter into force. Scientific findings on climate change indicate ever more clearer that greenhouse gas emissions reductions need to be substantially more ambitious than defined by the Kyoto Protocol. Further developing the international climate regime will therefore certainly remain an urgent international policy task over the next decades.

The UNFCCC, the Kyoto Protocol and the Marrakesh Accords comprise a package of agreements for international climate protection that was negotiated over more than 10 years. At its core are quantified emission limitation and reduction commitments, embedded within a system of reporting, monitoring, review and compliance. The architecture is based on the principle of common but differentiated responsibilities (Art. 3.1 UNFCCC). Commitments are so far differentiated between two country groups – industrialized and developing countries. Binding targets for emission reductions have been agreed upon only for industrialized countries, including countries with economies in transition. OECD countries have adopted additional financial commitments to support developing countries.

The complex structure of the Kyoto mechanisms (emissions trading, Joint Implementation, Clean Development Mechanism) allows, in principle, for flexibility in meeting the targets and therefore reduces compliance costs. The Clean Development Mechanism (CDM) further has the purpose of assisting developing countries in achieving sustainable development and in contributing to the mitigation of climate change (Art. 12 KP). It remains to be seen whether these expectations will be met. Particular attention will need to be given to the new climate fund created with the Marrakesh Accords which is intended to lead to an additional transfer of financial resources for adaptation measures in particularly vulnerable developing countries.

Questions can be raised with regard to the environmental effectiveness of the Kyoto Protocol as it stands: Even if the 5% emissions reduction for industrialized (Annex-I) countries was achieved, this would only have a marginal attenuating effect on the anticipated temperature rise. Real reductions will be lower than the already very modest nominal reductions, because of the accounting of sinks as emissions reduction and because some countries have been allocated emission rights above their business-as-usual projections. Moreover, the withdrawal of the United States of America from the Kyoto Protocol leads to a potentially large surplus of tradable emission permits, as a state with potentially high demand is then absent from the system. This leads to reduced incentives to lower emissions. However, countries are free to decide to market only a part of their assigned emissions.

Any assessment of the Kyoto system should consider that the first commitment period (2008–2012) is only a first step, and that further steps should and must follow. Considerably deeper emissions cuts will be necessary in future commitment periods in order to achieve the joint objective of the Protocol and Convention, namely stabilization of greenhouse gas concentrations in the atmosphere at levels that would prevent dangerous anthropogenic interference with the climate system. The scope in terms of global emissions available to prevent dangerous climate change has further narrowed in recent years. The second commitment period will be crucial because the reductions agreed for this period will determine whether dangerous climate change can be prevented or not.

The German Advisory Council on Global Change (WBGU) wishes to underscore that, as there are no alternatives, calling the Kyoto Protocol into question throws global climate policy back by many years and severely hampers efforts to prevent dangerous climate impacts.

Steps forward for the climate regime

The international community is faced with a dilemma. To attain the Kyoto targets, global emissions have to decline steeply after having reached the peak. This implies, on the other hand, that emissions from developing countries have to depart from their business-as-usual path very much earlier than these countries may consider just. In particular, developing countries will need to attenuate their rise in emissions and, ultimately, also reduce their emissions, before they have reached a level of income comparable to that of Annex-I countries.

How to deal with this dilemma and to find a sustainable and equitable solution is the focus of the present report and will presumably lie at the heart of the challenges to be faced by the forthcoming negotiations on the second commitment period of the Kyoto Protocol. These negotiations should start no later than 2005 (Art. 3.9 KP). It is therefore crucial that industrialized countries show demonstrable progress towards achieving their targets as soon as possible to build confidence among developing countries in the climate policy regime. Technology transfer to the developing countries can also contribute to this. Furthermore, negotiations on second commitment period targets should leave the option open for the USA to rejoin.

The negotiation of the second commitment period thus faces a series of challenges and will be immensely complex. As the number of countries committed to emission limitation and reduction has to be expanded, negotiations necessarily will involve much more discussion on equity principles and on fair differentiation of commitments than was the case in the first commitment period. The need for deeper emission cuts will spur the discussion on what is dangerous climate change and on what emission cuts are economically and technologically feasible.

Perspective beyond 2012

With this report, the WBGU aims to present scientifically consolidated options for action to the Federal government on its way to successful agreements on the future of the climate regime. To do so, we need to cast our gaze far beyond the time horizon of the second Kyoto Protocol commitment period (after 2012), as it will only be possible to stabilize greenhouse gas concentrations at a safe level if emissions reductions are both deep and long-term. There are three key questions:

- What is 'dangerous interference with the climate system' within the meaning of Article 2 UNFCCC?
- Which socio-economically and technologically viable paths can be travelled to prevent such dangerous interference?
- How can all countries be integrated equitably within the system of emissions reduction commitments?

The present report concentrates upon the potential for reducing emissions of carbon dioxide, this being the most important anthropogenic greenhouse gas. Nonetheless, consideration is also given to the need to reduce other greenhouse gases. In a first step (Section 2.1) the Council defines what is to be regarded as 'dangerous interference with the climate system'. After discussing implications of the WBGU climate window for the definition of 'safe' concentration targets and emission pathways (Section 2.2), the report examines mechanisms to allocate emission rights or reduction commitments (Section 2.3) and the economic and technological feasibility of ambitious reduction paths (Chapter 3). The report bases these analyses on detailed scenarios generated with an energy system model with an integrated macroeconomic model. Besides climate protection, the discussion also takes into account other, especially socioeconomic guard rails.

During the negotiation of the Kyoto Protocol, the accounting of land use, land-use change and forestry activities was very contentious. Very early, the Council warned against the possible negative incentives and risks associated with the present system of accounting (WBGU, 1998). Chapter 4 of the report discusses the issue of how to deal with sources and sinks in the terrestrial biosphere in the future.

Chapter 5 draws conclusions with regard to the further development of the institutional architecture of the Kyoto Protocol, with particular emphasis on the institutional modifications needed to strengthen the emission reduction obligations and enlarge the number of countries to which these apply. Chapter 5 also elaborates initial proposals on how to deal in future with all the carbon sources, sinks and stocks of the terrestrial biosphere. There is an emphasis on two aspects: On the one hand there is a particular emphasis on the institutional modifications needed to strengthen the emission reduction obligations and enlarge the number of countries to which these apply. On the other hand initial proposals on how to deal in future with all the carbon sources, sinks and stocks of the terrestrial biosphere are elaborated. Chapter 6 summarizes the WBGU's recommendations on the further development of the international climate policy.

Avoiding dangerous climate change

2.1
What is 'dangerous' climate change?

2.1.1
The Tolerable Windows Approach

Article 2 of the UNFCCC sets out the ultimate objective of the Convention as follows:

> 'The ultimate objective of this Convention [...] is to achieve [...] stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.'

Article 2 UNFCCC consists of two components: First the objective itself (stabilization of greenhouse gas concentrations) and second the criteria for the time frame in which the objective should be achieved (concerning ecosystems, food production and sustainable economic development).

The WBGU notes that the focus on concentrations of greenhouse gases rather than on climate change itself is problematic, as many uncertainties complicate an assessment of the impacts of specific concentrations upon the climate (Section 2.2). Therefore, the Council defines dangerous climate change in terms of changes to climate parameters. Global mean near surface air temperature is chosen as the leading parameter because it can be related to greenhouse gas concentrations better than other indicators (Smith et al., 2001). Global mean temperature will be used as a global proxy for the different types of climate change factors that impact at the regional or local level. Depending on the region, an increase in global mean temperature by a certain amount may convert to an increase in the local sea level, reduced soil moisture, increased peak wind speeds or even reduced local air temperature.

In previous reports (WBGU, 1995, 1997, 2004), the Council has defined and used a 'Tolerable Climate Window' based on a normative setting of non-tolerable climate change conditions. The climate window is defined by two upper limits – one for total global mean temperature change and one for the rate of change: +2°C (relative to pre-industrial levels between 1861 and 1890) and 0.2°C per decade. The Council also assumed that the adaptability of ecosystems, economies and societies will decline with increasing proximity to the +2°C temperature limit. However, with the setting of such a tolerable climate window the Council did not imply that compliance with its limits would guard against all ecosystem damage or threats to humankind, because global maxima are unable to reflect the substantial variations between regions and sectors with respect to the precise impacts of climate change (WBGU, 1997).

The primary limit: Global mean temperature

The upper limit of absolute global warming of 2°C relative to the pre-industrial temperature was based on the observed range in the recent Quaternary period (over the last several hundred thousand years), that has shaped today's climate and the development of humankind. The highest observed global mean temperature in this period was 1.5°C above the pre-industrial global mean temperature. The Council added 0.5°C in its 1995 annual report to account for improved adaptive capacity. As the global mean temperature has already risen by 0.6 (±0.2)°C, the leeway up to this limit only amounts to approx. 1.4°C. The Council concluded that intolerable changes in the composition and functioning of today's ecosystems could not be ruled out if the global mean temperature rises by more than 2°C (WBGU, 1995). However, substantial impacts are already to be expected below this limit. Because the scientific basis for this limit has become firmer in the meantime, and considering that the limit can also be derived from other criteria (Sections 2.1.2 to 2.1.6), the Council reaffirms this argumentation.

The secondary limit: Rate of climate change

The maximum rate of change of 0.2°C per decade defined by the Council refers to the change of global mean temperature averaged over several decades. Temperature changes on regional scales have been observed to be much higher than 0.2°C per decade without causing harm to ecosystems. The global tropospheric mean temperature is currently rising at a rate of 0.22°C per decade, but was only averaged across 24 years (Vinnikov and Grody, 2003). The longer the period over which the average is formed, the smaller do the observed rates of change become. Analyses of hemispherical or global long-term time series show that multi-decadal average rates of global mean temperature change above 0.1°C per decade are quite unusual (Hare, 2003).

Global and, in many cases, local rates of climate change are likely to exceed any seen in the last million years (Overpeck et al., 2003). The 0.2°C per decade was based on the estimation that an additional climate-change induced monetary burden of more than 5% of global GNP would not be tolerable (WBGU, 1995). Other bases would include the concern that rapid climate change could harm ecosystems due to limits to the adaptive capacity of species. The projected global warming may require species migration rates far in excess of those observed during postglacial times (Malcolm et al., 2002), and thus likely threaten the survival of many species (Davis and Shaw, 2001). Moreover, a high rate of change can increase the risk of large-scale singular events (Section 2.1.6). Since the publication of previous Council reports on this issue (WBGU, 1995, 1997), only little additional scientific insight has been gathered on the tolerable rate of change of global mean temperature. The scientific basis for this limit thus remains less robust than for global mean temperature.

The ecological and economic impacts beyond this limit are hard to assess, but may potentially be very large. Thus, the Council maintains the limit of 0.2°C per decade (averaged over several decades) based on the precautionary approach, but stresses that more research is needed in this field.

Climate impact analysis

Moreover, with this report the attempt is made to add to the so far used 'top-down' a 'bottom-up' approach to derive the primary limit of global mean temperature, based on our present knowledge on climate change impacts. This impact analysis is structured along the three criteria of Article 2 UNFCCC (ecosystems, food production, and sustainable economic development), as these will probably be the key point of reference in the political negotiations on the second commitment period under the Kyoto Protocol. The Council supplements these with further criteria, including the IPCC's 'reasons of concern' (IPCC, 2001b). The WBGU thus treats the criteria of 'health', 'water availability' and 'large-scale singular events' in separate sections of this report. The consequences of extreme weather events are of relevance to several of the criteria applied by the Council, and are thus treated in the respective sections.

The WBGU interprets 'dangerous interference with the climate system' as an interference that leads to dangerous climate-change impacts. In judging whether a certain impact should be defined as dangerous, the adaptive capacity of natural and social systems has to be taken into account. Adaptive capacity varies greatly between regions and systems and also depends on the speed of climate change. The evaluation of costs and benefits of adaptation, also in comparison to mitigation, is still incomplete and certainly beyond the scope of this special report.

The Council defines anthropogenic interference with the climate system as dangerous if it leads to severe impacts across large regions or if it leads to a globally significant accumulation of distributed regional impacts. When defining severe climate change impacts, the Council has to rely on value judgements that are inter-subjective (i.e. equally valid for all; WBGU, 2000b) based upon on the current state of scientific knowledge – above all the Third Assessment Report of the IPCC (2000) and subsequent relevant publications. The WBGU assesses levels of hazard from a 'moderately anthropogenic' perspective. This stresses the uniqueness of humankind, but derives from the life-sustaining and life-enhancing importance of nature the commitment of humankind to preserve it for future generations (Chapter 6; WBGU, 2000b). In some cases, this judgement is easier because it can be based on known thresholds in natural or social systems, beyond which impact levels rise rapidly or large-scale irreversible changes are triggered.

In the following sections, possible impacts are analysed and then translated via expert reasoning into levels of global mean temperature. These levels will generally differ among the criteria outlined. Based on this analysis the Council finally identifies a threshold, beyond which any increase of global mean temperature will be regarded as dangerous.

2.1.2
Impacts of climate change upon ecosystems

2.1.2.1
Ecosystems and climate change

Natural ecosystems of today have already suffered huge losses of area due to human-induced land-use change, causing large-scale habitat destruction and fragmentation. Land use has substantially altered the face of the Earth (Vitousek et al., 1997) and left e.g. only 20% of forests worldwide untouched (Bryant et al., 1997). Additional to this major factor are other human interventions, such as overexploitation (e.g. through hunting, grazing, fishing, non-sustainable use of forest products), the introduction of invasive alien species, or pollution have further environmental impacts. Taken together, these human-induced stresses are causing species extinction rates 2–3 orders of magnitude higher than the 'background' extinction rate seen in the fossil record (May et al., 1995).

Man-made climate change is a new and additional anthropogenic factor. Ecosystems and their biological diversity may experience irreversible damage due to climate change because of limited adaptive capacity of species. Climate change impacts today still are small compared to the human interventions mentioned above. They are, however, expected to increase very rapidly in scale and importance over the coming decades (IPCC, 2001b). Even if we could 'magically' relieve the ecosystems from all other damaging human-induced pressures, rapid climate change alone would still have the potential to lead to significant loss of our planet's biodiversity.

In the 20th century the global mean temperature has increased by 0.6 ± 0.2°C and is already causing a discernible impact in wild animal and plant populations (IPCC, 2001b; Root et al., 2003). They are responding with the expected trend to move to higher elevations and polewards (shift of approx. 6 km per decade toward the poles; Parmesan and Yohe, 2003). The geographical extent and level of damage, and the number of ecosystems affected increase with both magnitude and rate of climate change (IPCC, 2001b). The consequences are changes in the subtle balances of species interactions (e.g. competition, predation, parasitism) in both managed and natural ecosystems, which in turn may lead to species loss, disruption of species communities and ecosystem succession (Hughes, 2000). An example of such a risk is the serious damage suffered by coral reefs due to the rapid rise in sea level and sea temperatures (Hughes et al., 2003; other examples in Hare, 2003).

Not all ecosystems are endangered by moderate climate change, e.g. if their species can cope by migration upwards or polewards without being blocked by geographical or anthropogenic barriers. This adaptation can be assisted by planning, managing and networking protected areas, removing barriers to migration and adjusting the management of landscapes or bioregions.

The following discussion briefly presents the state of knowledge on the impacts of climatic changes upon ecosystems. There is a large body of literature on the impacts of climate change on ecosystems and biodiversity, which has been reviewed and assessed by the IPCC in its Third Assessment Report (IPCC, 2001b) and a Technical Report (IPCC, 2002), and by an Ad-hoc Technical Expert Group of the Convention on Biological Diversity (CBD, 2003). However, any analysis done today that is based on case studies is limited by their coverage. The lack of comprehensiveness with regard to both ecosystem types and regions covered demonstrates the urgent need for more systematic research, especially in the field of integrated regional impact studies.

Building on these findings, and on a study commissioned by the Council (Hare, 2003) and further recent literature (cf. quotes in the bullets below), the Council arrives at the following conclusions (see also Fig. 2.1-1):

- *Rise of up to 1°C above pre-industrial levels:* Up to 10% of ecosystem areas worldwide will shift (Toth et al., 2002; Leemans and Eikhout, 2003). Some forest ecosystems will exhibit increased net primary productivity, increased fire frequency and pest outbreaks. Some hotspots and protected areas of global importance will begin to suffer first climate-change induced losses. Coral reefs will suffer increased bleaching (Hughes et al., 2003). Range shifts of species and higher risk for some endangered species are likely. Most of these impacts can already be observed today.
- *Rise of 1–2°C above pre-industrial levels:* Up to 15–20% of ecosystem areas worldwide will shift. Some protected areas of global importance and hotspots are likely to suffer severe losses of both area and species. Wildlife of arctic ecosystems will be harmed (e.g. polar bear, walrus). Bleaching events will likely be so frequent that coral reef recovery is insufficient to prevent severe losses of biodiversity.
- *Rise of more than 2°C above pre-industrial levels:* The global share of ecosystems shifting due to climate change will likely be above 20%, and much more in some regions. Global losses of coastal wetlands may exceed 10% (Arnell et al., 2002). At a

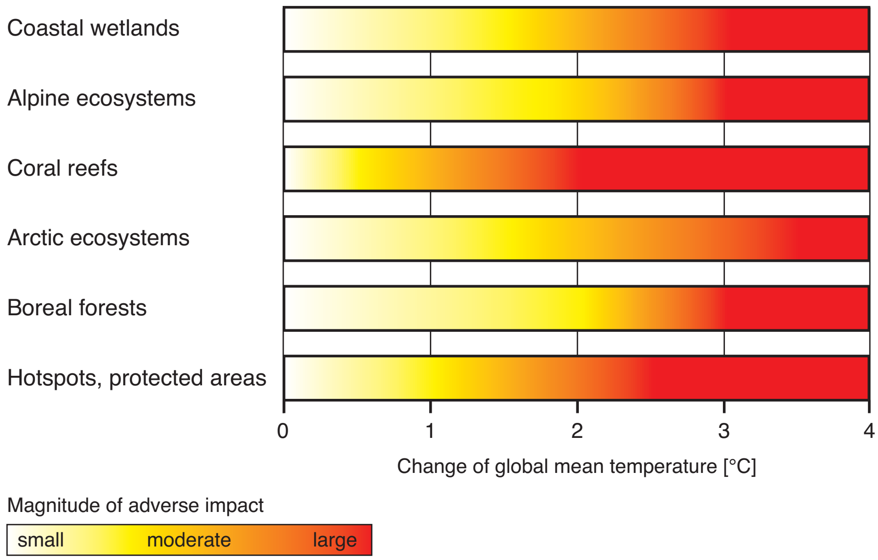


Figure 2.1-1
Visualization of climate change impacts on some ecosystem types. The risk of adverse impacts due to different climate-related parameters increases with the magnitude of climate change. Global mean temperature rise since 1861–1890 is used as proxy. The figure presents a global summary of expected adverse impacts upon some examples of global ecosystem types, in the form of a highly aggregated conceptualization. Regional impacts may be more or less severe than the global averages shown. The figure does not reflect a quantitative approach but a fuzzy assessment of risks, based on case studies and reviews, in a manner similar to that of the IPCC (2001b). The assessment takes into account only the magnitude of climate change, not the rate of change.
Source: WBGU

global scale, reefs will undergo major disruptions and species loss, but will possibly not disappear completely (Hughes et al., 2003). A large number of species will be endangered by range shifts. There is a risk that some protected areas of global importance and hotspots will lose most of their area due to climate change.

2.1.2.2
Tolerance limits for impacts on ecosystems

Article 2 UNFCCC refers to the capacity of 'ecosystems to adapt naturally to climate change'. This translates into both an absolute maximum of change and a maximum rate of change of ecosystems. Once these limits are exceeded, species loss increases which in turn can lead to ecosystem degradation or loss. This matters not only because losing biodiversity means losing its intrinsic, recreational and cultural values (WBGU, 2001). It matters even more because human society directly or indirectly depends on the goods and services the biosphere and its ecosystems supply. The composition of the atmosphere and soil, the cycling of elements, and many other assets are all the result of living processes – and all are maintained or replenished by ecosystems (Alcamo et al., 2003). Therefore, there will be limits beyond which the climate-change induced losses of ecosystem goods and services will have to be declared intolerable.

Because of its importance to human society, biodiversity conservation has been established as principle of international law. The Council founds its assessment of the danger or severity of expected biodiversity losses upon rules stipulated by the Convention on Biological Diversity and other international agreements (CITES, Ramsar Convention, World Heritage Convention) and principles (e.g. precautionary approach; UNCED, WSSD).

However, not all biodiversity losses are necessarily unacceptable for humankind. Some are more severe than others, and therefore less tolerable. To describe the value of ecosystem goods and services and their importance to nature conservation in detail would be beyond the scope of this special report. These issues have been covered extensively by the Council in a previous report (WBGU, 2001).

Based on this work and a review of the state of scientific knowledge, the Council arrives at the following statements:

1. Shifts of more than 20–30% of the area of any large-scale ecosystem type due to climate change are considered dangerous within the meaning of Article 2 UNFCCC. Such a large loss would mean a steep increase in risk to regional and global ecosystems, mainly due to lack of adaptive capacity in these systems, leading to suboptimal func-

tioning of these ecosystems (Leemans and Eickhout, 2003). Many biomes have already suffered large losses and degradation due to land-use change, so that additional climate impacts will be all the more severe.

2. Losses of areas of high conservation value should be avoided. The hotspots of biological diversity (Myers, 1988; Myers et al., 2000; Mittermeier et al., 1999) are of particular importance, since a large number of species are concentrated in these 25 areas that cover only 1.4% of global land area. The Council notes that these hotspots and other important areas such as wetlands of international importance (Ramsar Convention), world heritage sites (UNESCO's World Heritage Convention), tropical wilderness areas with low human population density (Mittermeier et al., 2003) or gene centres of agrobiodiversity (Hammer, 1998) harbour biological diversity of the highest conservation value. They should not only be protected from further habitat destruction and fragmentation due to land-use change, but also from climate-change induced losses. This is all the more important, as population growth in the hotspots is above average (Cincotta et al., 2000) and ecosystem destruction through land-use change appears to continue unabated.

The conversion of these two specifications to levels of tolerable global mean temperature is a very difficult and complex task. The knowledge and findings represented by case studies available today do not allow for straightforward quantitative deduction of tolerable temperature limits. Therefore, the Council had to rely on expert assessments based on reviews of the scientific literature (e.g. IPCC, 2001b; Hare, 2003). An expert judgement of this sort emerged from a recent international conference in the UK, where there was agreement that global warming has to be contained at +2°C (Green et al., 2003).

The WBGU concludes that even low levels of climate change can lead to significant impacts on ecosystems. The risk to several globally important ecosystem types appears to rise considerably when warming exceeds 2°C global mean temperature above pre-industrial levels (Fig. 2.1-1). If warming exceeds 2°C, there is a risk that the climate-induced shift of biome areas will exceed the stated extent of 20–30%. Analysis of further case studies similarly suggests that severe impacts may be expected beyond 2°C warming (Hare, 2003). With regard to impacts on ecosystems and biodiversity, the Council thus deems a rise in global mean temperature by more than 2°C intolerable.

2.1.3 Impacts of climate change on food production and water availability

2.1.3.1 Food production and climate change

The impacts of climate change on food production and agriculture depend on a range of factors, including the vulnerability of regional agricultural systems, populations and their adaptive capacities. Relevant factors in determining the response of agricultural systems to climate change include temperature, precipitation, CO_2 fertilization and socio-economic conditions such as market access, technology and the availability of resources needed for adaptation (IPCC, 2001b). In the mid latitudes, a moderate increase in temperature may raise crop production provided that water availability is not compromised. In the tropics, in contrast, crops are often close to their thermal optimum, so that regional warming may instead result in reductions. Extreme weather events are likely to negatively influence crop production substantially, either directly or through increase of pests (Iglesias et al., 2001; Rosenzweig et al., 2002). However, most studies do not account for the interactions of food production with droughts, heavy rains, hail storms or pest outbreaks and therefore tend to underestimate the damages. Use of specially designed genetically modified organisms could be a way to increase the adaptive capacity of crops, but is fraught with major risks (WBGU, 2000a; The Royal Society, 2002). Recent debate has not produced a fundamentally different assessment of these risks.

2.1.3.2 Tolerance limits for impacts on food production

Article 2 UNFCCC requires 'to ensure that food production is not threatened'. In assessing climate change impacts on food production, the adaptive capacity of agricultural systems has to be taken into account. This capacity differs substantially between regions. Unfortunately the regions affected most are the ones with least adaptive capacity – i.e. above all the developing countries (IPCC, 2001b).

To some extent, climate-change induced regional disparities of crop yields can be alleviated by trade and transport of food. It is albeit questionable whether the agricultural market alone would lead to the required compensation, as many of the most affected regions so far are not integrated into the global market. Thus international trade policy, as well as the degree of international cooperation (e.g. development cooperation, agricultural research policy) influences the level of impacts that might be called 'dangerous'.

The IPCC concludes that in many developing countries (e.g. India) the effects of climate change are likely to result in net losses in terms of agriculture goods and water resources, with some regions being especially vulnerable (IPCC, 2001b). In contrast, agriculture may be fostered by warming of less than 2°C global mean temperature in many developed countries in the mid and high latitudes. The available models suggest that global production may not be threatened dangerously up to a rise of 2°C or even 3°C. However, the global disparities will increase, as the gains are expected in the developed world and the losses in developing countries. At all levels of warming, a large group of poor, highly vulnerable developing countries is expected to suffer increasing food deficits. Table 2.1-1 summarizes findings of studies on the link between climate change and food production.

Above 2–3°C global warming, net food production losses on a global scale set in. In this temperature range, the number of additional people at risk of famine globally due to climate change may reach more than 50 million (Parry et al., 2001). Models project that at 3°C warming by 2080 cereal production on a worldwide aggregate level will decline, although total yields could theoretically still meet needs if properly distributed (Fischer et al., 2002a). The Council notes that these model results still incorporate a high level of uncertainty.

GMT increase [°C]	Impacts	
	Developing Countries	Industrialized Countries
1,0-1,7#	Cereal yields decrease in most tropical and subtropical regions (* to **). Reduced frost damage to some arable crops (***). Increased heat damage to some arable crops and animal herds (***).	Cereal yields increase in many high- and mid-latitude regions (* to **). Reduced frost damage to some arable crops (***). Increased heat damage to some arable crops and animal herds (***).
1,4-3,2#	Stronger decrease of cereal crops in the tropics and subtropics (* to **); mixed effects in high- and mid-latitude regions (* to **).	Mixed effects upon cereal yields in high- and mid-latitude regions (* to **).
1,5-2,0#	Income of poor farmers in developing countries declines (* to **).	
1,6-2,6#		Australian crop yields begin to decline after initial increase.
>2,0#	Large drops in yield of maize and sugarcane in small island developing states.	European crop production increases (except Portugal, Spain, Ukraine). US agriculture suffers losses after previous gains.
>2-2,5*	Crop yield losses in developing countries.	
>3+	Crop yield losses in developing countries. A group of 65 countries loses 16% of agricultural GDP; Africa and India lose, China gains.	
>2,0-6,4#	General reduction in cereal yields in most mid-latitude regions (* to **). General increase in food prices (* to **).	General reduction in cereal yields in most mid-latitude regions (* to **). General increase in food prices (* to **).
>2,6#	Asia: net losses in rice production begin.	
>4,2#		Entire areas in Australia out of production.

Table 2.1-1
Global warming and impacts on food production in developing countries and industrialized countries. The asterisks indicate confidence levels (where given in the literature):
*** high (67–95%),
** medium (33–67%),
* low to medium (5–33%).
GMT global mean temperature, pre-industrial level.
Source: # IPCC, 1990;
* Parry et al., 1999; + Fischer et al., 2002a

The Council notes that a situation in which all regions suffer significant crop yield losses due to climate change must clearly be termed unsustainable. Threats to a growing number of people due to climate change would jeopardize efforts to attain the Millennium Development Goals, which establish the target of halving the proportion of people who suffer from hunger by 2015, with the ultimate goal of eradicating hunger.

The Council concludes that a warming above 2°C constitutes a dangerous range for food production both in terms of net global food production as well as in terms of increasing international disparities. This temperature limit takes into account accumulated regional effects, possible negative feedbacks between climate change and land degradation and effects of extreme weather events not represented in the model runs.

2.1.3.3
Tolerance limits for impacts on water availability

Water is the most important limiting factor for food production. Therefore, the models estimating future food production take into account the impacts of climate change on both temperature and water availability. Moreover, water in itself is the most essential food of all. 1100 million people do not have access to clean drinking water today (UNEP, 2003), and contaminated water is the cause of 5 million deaths every year. One third of the world's population lives in countries under water stress, defined as those using more than 20% of their renewable water resources. This proportion is predicted to increase to almost two thirds in the coming decades (IPCC, 2001b). Thus, even without the additional stress of climate change, water security already is one of the most pressing issues in developing countries (WBGU, 1997).

While mean global warming leads to increased overall precipitation, this does not lead directly to improved water availability. For availability, not the amount of rain is decisive, but soil moisture and groundwater recharge. If temperatures rise, there must be more rain merely to maintain the status quo, as the increased evaporation means that the additional precipitation cannot be utilized in the region. Only in regions where the growth in precipitation is far above the average can water scarcity be reduced. Furthermore, in many regions warming will lead to more precipitation per rainfall event; the result of this is that, due to the more rapid runoff, often a smaller proportion of the precipitation contributes to elevating soil moisture and thus to groundwater recharge.

According to climate model analyses, the number of people at risk of water scarcity increases rapidly with temperature towards the second half of the century, with impacts in arid and semi-arid regions expected to be much larger that global averages suggest (IPCC, 2001b; Parry et al., 2001). Thus in regions already under water stress today, climate change will exacerbate the situation. For many water distressed regions global mean temperature increases above around 1.5°C are identified as leading to decreases in water supply and quality and to an increase of both floods and droughts (Table 2.1-2; IPCC, 2001b).

Models predict 500–3000 million additional people under water stress in 2050, with most numbers being in the range of 1000–2000 million. There seems to be a systemic threshold around 1.5–2°C global mean temperature rise; when this is overstepped, the number of people affected by water shortage grows from approx. 600 million to over 2000 million, as megacities in Asian developing countries begin to be severely affected (Parry et al., 2001). Such a steep increase in the numbers of people under water stress in such a short time span is likely to overburden available adaptive capacities such as sea-water desalinization or long-range transport, and thus can-

Table 2.1-2
Impact of climate change on water resources. The asterisks indicate confidence levels:
*** high (67–95%),
**medium (33–67%).
GMT global mean temperature, pre-industrial level.
Source: IPCC, 1990, modified

GMT increase [°C]	Impacts
1,0–1,7	Water quality degraded by higher temperatures (**). Increase in saltwater intrusion into coastal aquifers (**). Water demand for irrigation will respond to changes in climate (***). Increased flood damage due to more intense precipitation events (**). Increased drought frequency (***). Peak river flow shifts from spring toward winter in basins where snowfall is an important source of water (***).
1,2–3,2	Water quality degraded by higher temperatures (***). Water quality changes modified by changes in water flow regime (***). Water demand effects amplified (***).
>2,0	Water supply, demand and quality effects amplified (***).

not be termed tolerable. The Council concludes that water availability would deteriorate to a degree that must be termed dangerous at a global mean temperature increase above 1.5–2°C.

2.1.4 Impacts of climate change on economic development

2.1.4.1 Economic development and climate change

Article 2 UNFCCC states that stabilization of greenhouse gas concentrations should be achieved within a time-frame sufficient 'to enable economic development to proceed in a sustainable manner'. This implies that the costs of stabilization measures must not exceed the short-, medium- and long-term benefits. It needs to be kept in mind here that the benefit of mitigation measures results from the prevention of climate damage and thus from the prevention of costs at an unaltered high level of emissions. Thus two contrasting groups of costs need to be considered: The costs that arise if emissions are reduced, and the costs that arise if emissions are not reduced. Costs of climate change incurred in the case of non-reduction of emissions further break down into damage costs and adaptation costs (WBGU, 2002).

The Council focuses here on the second group of costs, as these are the ones of relevance when assessing the impacts of climate change on economic development. The costs of mitigation are addressed in Chapter 3 where they are compared with the estimated costs of climate change damage and of adaptation, as well as with the ancillary benefits of climate mitigation, arising from avoided damages not related to climate change, such as air pollution damage.

This section focuses on estimates of aggregated monetarized effects of climate change. These mainly concern market sectors already dealt with in previous sections (e.g. agriculture). Other sectors relevant for such an aggregated estimate are impacts on human settlements and infrastructure. In particular, socio-economic impacts of sea-level rise on coastal regions are relevant here. These include direct loss of economic, ecological, and cultural values through loss of land, infrastructure, and coastal ecosystems, as well as increased flood risk and other impacts related to changes in water management, salinity, and biological activities (IPCC, 2001b). A large portion of the human population now lives in coastal areas, and the rate of population growth in these areas is higher than average. Many large cities are located near the coast. Nicholls et al. (1999) indicate that by the 2080s, the potential number of people flooded by storm surge in a typical year would be more than five times higher than today, assuming a sea-level rise of 0.38 m since 1990. Between 13 and 88 million people could be affected even if the application of protective measures is taken into account.

Climate change impacts on natural systems such as wetlands and coral reefs can have profound effects on socio-economic systems (IPCC, 2001b). For example, severe coral reef bleaching events with high mortality rates like the one observed in the Indian Ocean in 1998 are expected to lead to reduced fish catches and permanent negative effects on tourism. Degradation of reefs will also lead to diminished natural protection of coastal infrastructure against high waves and storm surges. Wilkinson et al. (1999) estimate the costs of the 1998 bleaching event to be between US$ 706 and 8190 million over the next 20 years.

Aggregated climate change effects are usually measured as changes in gross domestic product (GDP). Their scale is highly uncertain due to methodological problems associated with monetarization as well as the regional and temporal aggregation of damage. Assessments generally exclude effects of changes in climate variability and extremes, as well as the possibility of abrupt climate change (Section 2.1.6). They only partially account for impacts on goods and services that are not traded in markets. Non-market damages are likely to be very high, but difficult to quantify. Thus, economic losses are likely to be underestimated and economic gains overestimated. Furthermore, impact estimates are highly sensitive to inequity aversion or risk aversion assumptions (IPCC, 2001c).

Quantitative evaluation of benefits and costs of adaptation measures is still incomplete. Greater and more rapid climate change poses greater challenges for adaptation. Although studies show large potential benefits of adaptation measures such as coastal protection, these cannot appraise the likely benefits with sufficient accuracy, as they generally use arbitrary assumptions on adaptation options and obstacles, and often omit changes in climate extremes and variability, as well as imperfect foresight (IPCC, 2001c).

Models indicate that for a 1°C warming a significant number of developing countries appear likely to experience net losses, whilst developed countries are likely to experience a mix of damages and benefits. Some models even predict net benefits for developed countries (IPCC, 2001c). The projected distribution of economic impacts is such that it would increase the socio-economic disparity between developing countries and developed countries, with disparity growing in step with warming, as impacts will fall disproportionately upon developing countries and the poor persons within all countries. IPCC (2001b) assesses the results of different modelling studies for aggregated damage costs. A broad picture emerges: Developing countries are more vulnerable to climate change than developed countries. Some regions or countries like India and Africa, but also the EU, are estimated to suffer losses between 2% and 5% of GDP for a warming of about 2.5°C above pre-industrial levels.

However, the numerical results as such remain speculative. The results are difficult to compare, as different assumptions are made in different studies. Few estimates factor in the possibility of catastrophic impact. Some of them show a rapid increase of damage with temperature rise, while others make optimistic assumptions about adaptive capacity and baseline development trends, which results in lower damage estimates (IPCC, 2001b). In general, the greater the concern about distribution issues, the higher the estimated aggregate impact as losses to the poor cannot be compensated by equal gains to the rich.

2.1.4.2
Tolerance limits for impacts on economic development

In setting a tolerance limit for sustainable economic development, the distribution of impacts, both within regions and over time, needs to be analysed and evaluated. In a previous report, the Council (WBGU, 1997) suggested a normative ceiling – all damage and adaptation costs attributable to climate change beyond 5% of GDP were deemed intolerable (Section 2.1.1). This very rough estimate was based on the experience gained with German reunification, from which many economists conclude that pressures and stresses of an order greater than 3–5% of GDP are critical to a national economy. The Council concluded that a warming rate of more than 0.2°C per decade is not tolerable as it could lead to damage and adaptation costs that reach the upper limit of 5% of global GDP, taking into account extreme events and synergies with other environmental problems.

Alternatively, it would be possible to simply base the guard rail on the number of people affected by climate change damage. Calculations suggest that a majority of people may already be negatively affected at an average global warming of 1.5–2.5°C above pre-industrial levels (IPCC, 2001b).

Given the high uncertainties of damage estimates, the Council does not set a quantitative guard rail for economic development, but only uses the normative 3–5% GDP threshold as a tentative benchmark. In view of the major uncertainties of damage cost estimates, and the strong likelihood of underestimating damage when assessing only market impacts, the Council concludes that already at a global mean temperature increase of 2°C above pre-industrial levels large regions may have to face an intolerable burden to their economies (3–5% of GDP).

2.1.5
Impacts of climate change on human health

2.1.5.1
Human health and climate change

Health is an important feature of the climate change debate for three reasons:

1. Health is recognized by all cultures, religions, states and social groups worldwide as an asset worthy of protection.
2. Health is affected by all drivers of global environmental change (universal sensitivity).
3. A population's state of health can be used as an indicator to measure the impacts of climate change (Krafft et al., 2002), in a manner comparable to the key role of health within the Human Development Index (HDI).

According to a new study by the World Health Organization, climate change is already the cause of 150,000 deaths every year. Campbell-Lendrum et al. (2003) have estimated the present health impact of climate change (in 2000, compared to the baseline scenario over the years from 1961 to 1990). They concentrated on four impacts: malaria, malnutrition, diarrhoea and flood-related accidents. They estimated an annual health impact of 5.5 million DALYs. DALYs (Disability-Adjusted Life Years) represent the loss of healthy or productive life years (WHO, 2002). This cumulative measure has been developed as an indicator of a population's total disease burden (premature mortality, disease and disability; Murray, 1994). Drastic regional disparities were found (Fig. 2.1-2), the greatest health burden arising in the regions where vulnerability and population growth are greatest: sub-Saharan Africa and south Asia.

Detailed analysis of the health damage triggered by climate change permits a distinction between direct and indirect health impacts (WHO, 2000; IPCC, 2001b).

Direct impacts include, for instance, the effects of extreme weather events (e.g. cardiovascular disease, asthma) or weather-related disasters (e.g. coastal or inland flooding, landslides). The latter not only lead directly to accidents, but also damage healthcare infrastructure which is already inadequate in most developing countries and parts of newly industrializing countries. This undermines a key element of adaptive capacity. Even in industrialized countries, if there is inadequate adaptation (e.g. lack of air-conditioning) heat waves can cause severe health damage. The French government attributes 11,435 additional deaths to the heat wave in summer 2003 (Neue Züricher Zeitung of 30.8.2003).

However, the greatest health damage arises through indirect effects, as in the case of vector-borne infectious diseases (e.g. infections caused by mosquitoes, ticks or flies). The IPCC predicts that by 2080, 260–320 million more people will be exposed to malaria worldwide (IPCC, 2001b). This may be offset by a possible decrease in malaria exposure in other regions as a result of climate change. However, these effects cannot be compared directly with each other. When malaria enters new regions, this can cause very severe epidemics, as the population is immunologically unprotected. The contrasting health gain provided by a decline of malaria in previously exposed regions is comparatively small (Trape and Rogier, 1996). Dengue fever or tick-transmitted meningitis are also vector-borne infectious diseases that can be influenced by climate change. Quantifying climate impacts on infectious diseases poses a research challenge.

In regions where food security or water supply are already at risk today, it must be expected that combined effects (of e.g. a regional rise in temperature, mounting water scarcity, and salination of soils as a result of rising sea levels) will cause harvest failures and – if adaptation is inadequate – malnutrition or amplified water stress among particularly vulnerable population groups, such as children, women and the poor (Section 2.1.3.1; WHO, 2000).

It is plausible to assume that the health effects of malnutrition, drinking water scarcity, the spread of malaria and flood disasters are synergistic. While it is not yet possible to quantify interactions, the temperature sensitivities of the population estimated by Parry et al. (1999) indicate that the additional proportion of the population suffering under water scarcity rises sharply when temperatures rise by values ranging between 1°C and 1.8°C (Section 2.1.3.3).

Water scarcity leaves less scope for personal hygiene, and must therefore be expected to lead to a distinct rise in diarrhoeal illness. This threshold characteristic amplifies the continuous growth of diarrhoeal illness in step with warming. These illnesses are estimated to grow by 3–8% per degree temperature rise (Checkley et al., 2000; Singh et al., 2001; WHO et al., 2003).

2.1.5.2
Tolerance limits for impacts on human health

In summary, the Council concludes as follows:
- The climate impacts on human health are substantial and cumulative.
- The impacts will vary very widely in geographical terms, whereby Africa and south Asia will be most severely affected, i.e. regions with above-average population growth and inadequate adaptive capacity.
- The estimates currently available suggest that the WBGU climate window, with a maximum of 2°C increase of global mean temperature, will tend rather to be too wide, certainly not too narrow.
- However, the knowledge currently available does not permit an exact quantification of the future

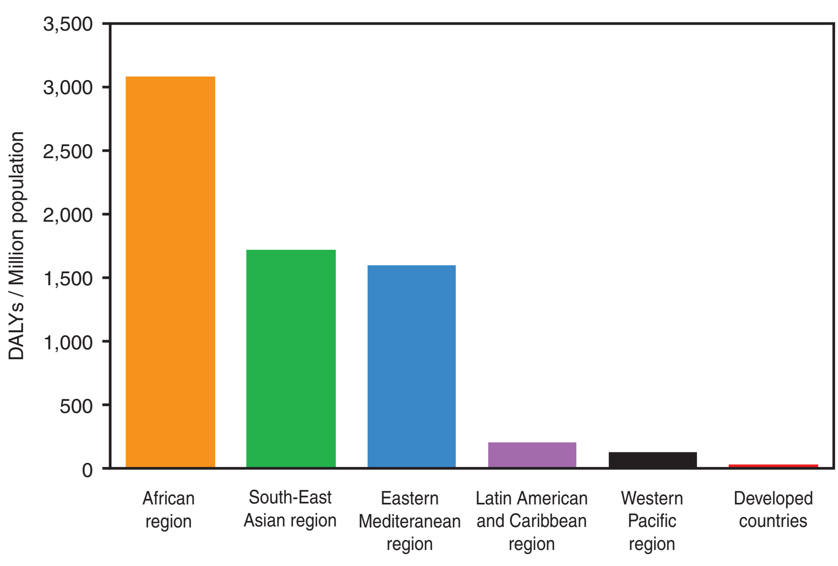


Figure 2.1-2:
Estimated health impact of climate change (1990–2000) by region. Calculated for Malaria, Malnutrition, Diarrhoea and Floods. DALYs are a parameter for the cumulated burden through diseases (see text). Source: Campbell-Lendrum et al., 2003

impacts of climate change upon human health – impacts that are mediated by complex webs of interrelations (WHO et al., 2003).

- The Council specifically points out that intensified research efforts (prospective data series, modelling) will be necessary in order to better understand and quantify the webs of interrelations linking global environmental changes with human health. As a part of such efforts, the Council especially recommends applying the DALY approach (WHO, 2002; WHO et al., 2003) as a cumulative measure of health impact.

2.1.6 Large singular events triggered by climate change

2.1.6.1 Climate change and large singular events

The risk of singular, non-linear events triggered by climate change represent a devastating risk to humankind. Several systemic thresholds are possible in the complex planetary system, beyond which large singular events can be triggered (Schellnhuber, 2002). Model simulations indicate that such system swings lie within the range of temperature changes that are projected for the next few centuries if greenhouse gas concentrations continue to rise (IPCC, 2001a). Crossing these thresholds can lead to unforeseeable and irreversible changes. The WBGU terms as irreversible a process that is irreversible within human time horizons (millennia), such as the melting of glaciers or climate-related sea-level rise. It is in general very difficult to predict when these thresholds would be reached, but it is important to note that the likelihood of many singular events can be expected to increase with the rate of change of forcing. However, it is not yet possible to predict the onset, timing and scale of large-scale events. Some uncertainties will always be associated with projections of singular climate changes, due to increased unpredictability exhibited near climate thresholds (Alley et al., 2003).

Even if some of the effects could happen in a very distant future, the impacts could still be so abrupt and severe that damages would be very high and adaptation almost impossible (IPCC, 2001b). Therefore, the Council states that the following large-scale abrupt changes should be prevented in any event.

Thermohaline circulation shutdown

The thermohaline circulation (THC) brings warm tropical water to the North Atlantic, thus warming Northern and Western Europe by several ºC, and increasing precipitation throughout the region. Knowledge from past climate change and model simulations suggests that there are multiple equilibria for the THC in the North Atlantic. Switching between the equilibria can occur as a result of temperature or freshwater forcing. Complex general circulation models suggest that future climate change could cause a slowdown or even collapse in the THC.

Some model studies suggest that the threat of a complete shutdown increases beyond a global mean warming of 4–5ºC, but this is still very uncertain (IPCC, 2001b). Stocker and Schmittner (1997) have shown that the THC is sensitive not only to the final level of warming, but also to the warming rate. These and other simulations (e.g. Rahmsdorf and Ganopolski, 1999) suggest that global warming could lead to a breakdown of the THC centuries later, which would irrevocably lead to intolerable burdens on future generations, as well as severe consequences for marine ecosystems and fisheries, and also for carbon uptake by the ocean.

Runaway greenhouse effect

Climate change could reduce the efficiency of current oceanic and biospheric carbon sinks. Under certain conditions, the biosphere could even become a source for greenhouse gases, e.g. if marine reservoirs of methane hydrates are destabilized, releasing large amounts of methane to the atmosphere. These processes could generate a positive feedback, accelerating the global warming. Methane released from the vast reserves of natural gas hydrates in oceanic, deep lake and polar sediments and the free gas trapped beneath hydrate deposits could explain the – on a geological time scale – abrupt global warming about 55 million years ago, when temperatures in some areas rose by up to 8ºC within a few thousand years (Schiermeier, 2003). Recent model studies show that it could be explained by a switch in the thermohaline circulation, with a resultant destabilization of large quantities of methane hydrates (Bice and Marotzke, 2002; NRC, 2002). The switch was caused by a slow increase in the atmospheric water cycle, as expected under increasing temperatures. Large methane releases may also have played a major role in the sudden events terminating glaciation at the end of the last ice age. There are large remaining hydrate reservoirs in the Arctic and in shelf sediments globally, and there is substantial risk of further emissions (Nisbet, 2002).

Transformation of continental monsoons

The Asian summer monsoon is a large-scale circulation pattern driven by the disparate warming and cooling of land and ocean. Each year the predominant winds switch direction, e.g. over India from northeasterlies in winter to southwesterlies in summer. The latter lead to abundant rainfall, as they bring much moisture from the Indian Ocean. Monsoon rains provide 75–90% of the annual rainfall over India. Thus, the monsoon rainfalls play a crucial role for agricultural and industrial production throughout South and East Asia. The monsoon is related to the migration of the Intertropical Convergence Zone (ITCZ), a region of low surface pressure where the trade winds converge. The location of the ITCZ in summer switches between two preferred latitudes, one associated with abundant rainfall over India (active monsoon), the other with less rainfall over land (break monsoon). Palaeoclimatic evidence and the nonlinear nature of the Asian monsoon reveal the potential for abrupt system changes in the future (Zickfeld, 2003).

The very close correlation of Indian food production with the quantity of monsoon rainfall over recent decades underscores the great importance of the summer monsoon for the population of India, counting around one thousand million people. For instance, some 600,000 people died of starvation in northern India during the period 1790–1796 as a result of limited monsoon rainfall and low soil moisture. Very weak summer monsoons are not an unknown occurrence in the region over the past 600 years. Although the impact of drought on agriculture can be mitigated by irrigation, this is only the case if water reserves, primarily groundwater, are available. Such buffers of groundwater will most certainly not be able to offset the next collapse of the monsoon in northern India (Alverson et al., 2003). Although India has succeeded since its independence in preventing drought disasters by means of country-wide food distribution, a systemic change of the summer monsoons poses an existential threat to its population.

Increased greenhouse gas concentrations could intensify the Asian summer monsoon (IPCC, 2001b). This effect is partially compensated by regionally elevated anthropogenic air turbidity, above all by sulphate aerosol particles, through which the land warms up less. Intensification of the monsoon could be accompanied by an increase in precipitation variability. This could lead to the occurrence of periods of reduced monsoon rainfall as well as to periods of intensified precipitation. Changes in timing and intensity and increased variability within seasons could lead to severe impacts on food production and flood and drought occurrences in Asia. The state of science concerning the Asian monsoon differs from that concerning the THC: No well-defined thresholds have yet been identified.

DISINTEGRATION OF THE WEST ANTARCTIC ICE SHEET

Marine-grounded ice sheets are inherently unstable. In the past 1.3 million years, the West Antarctic Ice Sheet has collapsed at least once. Temperatures then may not have been more than 2°C above today's (Oppenheimer, 1998). Global warming projected for the 21st century could set in motion an irreversible melting of the West Antarctic Ice Sheet, implying sea-level rise by 4–6 m and most severe damage (IPCC, 2001b). There is large uncertainty with regard to the time scale of the possible disintegration. Estimates figure 400–500 years and 1600–2400 years, leading to a contribution to sea-level rise of 10–15 mm or, respectively, 2.5 mm per year (IPCC, 2001b). The former would cause sea levels to rise by 1–1.5 m within a century. This is well outside human experience and would widely exceed the adaptive capacity of most coastal structures and ecosystems (IPCC, 2001b).

GREENLAND ICE UNDER THREAT

The melting of the Greenland ice would cause the mean sea level to rise by several metres over many millennia (IPCC, 2001a). Model computations indicate that for this to happen the critical (local) warming over Greenland is around 3°C. Local warming over Greenland, however, is higher than global warming by a factor of 1.3–3.1 (IPCC, 2001a). If an amplification factor of 2 was assumed, then a global warming by only approx. 1.5°C could already lead to an irreversible melting of the Greenland ice in its entirety.

2.1.6.2
Tolerance limits for large-scale singular events

Due to the large uncertainties with regard to any quantitative assessment of thresholds in the climate system, and the inherent unpredictability exhibited by the system near these thresholds, the precautionary approach becomes the main guiding principle in setting a quantitative guard rail. Adaptation in the face of these singular climate changes is almost impossible, and the impacts upon large regions or even worldwide are potentially devastating. The risk of crossing any of the thresholds described above rises with increased warming as well as with an increased rate of warming. Therefore, the Council considers that a limit of 2ºC for global warming relative to pre-industrial levels, as well as a limit of 0.2ºC per decade for the rate of global warming, should not be exceeded. This is necessary to avoid an unacceptable risk of large singular events (WBGU, 2004).

Even within these limits, the risk of triggering irreversible large-scale events is not negligible.

2.1.7 Conclusion: The WBGU global mean warming guard rail

Having discussed the climate impacts of global mean temperature rise as the prime parameter, the Council finds its view set out in previous reports confirmed that, globally aggregated, danger begins at 2°C global mean temperature rise relative to pre-industrial levels (WBGU, 1995, 1997). Secondly, the long-term average rate of global warming should not exceed 0.2ºC per decade.

Even if this tolerable climate window can be maintained many adverse consequences, particularly in developing countries, would still occur. Moreover, separate evaluation of the individual criteria cannot produce any statement on how these criteria are linked to each other and how they interact with other factors of global environmental change (such as soil degradation). Warming may therefore already be dangerous at lower levels of global mean temperature rise.

2.1.8 Recommendations for research

In view of the severe consequences of climate change, there is a need to devote further study to the conditions under which such change might occur. To further reduce the uncertainties of assessments, there is a need for intensified research on the impacts of climatic changes upon ecosystems, food production, water supply, human health and economic development. Particular consideration must be given to the increase of extreme weather events. In such efforts, regional impact studies should be aligned more closely to the standards and be related more systematically to the scenarios developed by the IPCC (2000). International cooperation should ensure that all relevant regions are studied. In particular, there is a need to gain an improved understanding of the causal chains linking global mean temperature with local climatic factors.

There is also a need for research on the potential and risks of adaptation of farming to climate impacts by using genetically modified organisms. Adaptation to climate change should be made a priority of international agricultural research.

To provide support in defining tolerable limits of global mean temperature for ecosystems, a worldwide effort should be launched to compare, in the various regions and ecosystems, the interannual variability of climate parameters with the anticipated shift of these parameters as a consequence of climate change. This would make it possible to identify, for each level of global warming, the percentage of worldwide ecosystem area that would probably be damaged. An excessive shift would convert weather events that were previously extreme into common events, and would thus jeopardize the survival of the ecosystem in question. This approach could help to improve the scientific basis for defining tolerable limits of climate change.

Finally, integrated impact research should study more closely the interactions among climate change and socio-economic factors, as well as the interactions among climate change impacts upon different sectors. In particular, this should involve further development of the approach of determining the number of people affected ('millions at risk'; Parry et al., 2001). Such research should address, for instance, the question of the effects of water scarcity upon socio-economic systems, and the opportunities and limits of adaptation measures. To quantify the health impacts of climate change, the DALY approach should be used and further developed.

2.2 From temperature limits to emission pathways

After defining the maximum limit of the global mean temperature (Section 2.1.7), the Council analyses in the following different CO_2 concentration levels and corresponding cost-minimizing emission pathways compatible with the WBGU climate window (Chapter 3). The determination of global CO_2 emission profiles compatible with the climate window involves two steps: First, CO_2 concentration targets compatible with the climate window will be determined. This involves some assumptions with regard to uncertainty factors (Section 2.2.1). Second, determination of CO_2 emission pathways leading to these concentration levels involves questions with regard to the best timing of emission reductions (Section 2.2.2).

2.2.1 From temperature limits to carbon dioxide stabilization targets

There is a wide range of uncertainty associated with the stabilization level of CO_2 concentration required to stay within the WBGU temperature limit described in Section 2.1. The required level depends on the emissions of other greenhouse gases and on the climate sensitivity, as well as on the strength of the carbon cycle feedback and other uncertainties with regard to the climate system. These parameters and uncertainties will be described in the following sections.

Emissions from other greenhouse gases and aerosol particles

Energy- and industry-related CO_2 emissions contribute most to climate change and their relative role is expected to increase in the future without any climate policies (IPCC, 2000). These emissions can be measured and projected with much higher accuracy than emissions from land-use change and emissions of other greenhouse gases controlled by the Kyoto Protocol (methane, nitrous oxide, HFCs, PFCs, SF_6) or by the Montreal Protocol (CFCs and HCFCs). In contrast to the effect of these long-lived greenhouse gases, the climate effect of aerosol particles (e.g. anthropogenic sulphates are cooling) and soot (warming) as well as the indirect effect of the precursors of tropospheric ozone (CO, NO_X, VOCs) are regional. Uncertainty is particularly high for the radiative forcing of aerosol particles.

The uncertainty with regard to current land-use emissions is high. Most changes in land use are induced by the demand for cropland and grassland. Different assumptions about economic and demographic development as well as technology development lead to different scenarios of CO_2 emissions from land use and land-use change (IPCC, 2000). In general, emissions increase initially because of continuing deforestation in developing countries and subsequently decrease due to reduced population growth and increase in agricultural productivity.

The climate impact of non-CO_2 greenhouse gases (methane, nitrous oxide, halocarbons) over the past century is roughly equivalent to that of CO_2 (Reilly et al., 2003). The emissions arise from a variety of sectors and applications and are therefore more uncertain than CO_2 emissions (IPCC, 2000).

Climate sensitivity

Climate sensitivity refers to the change in global mean surface temperature following a doubling of the atmospheric CO_2 concentration. It is by far the most important uncertainty factor when forecasting climate change and its impacts (Caldeira et al., 2003). The IPCC (2001a) assumes between 1.7 and 4.2°C warming due to doubling of pre-industrial CO_2 concentration, which is the range of values resulting from seven coupled atmosphere-ocean general circulation models. The median of this range is 2.6°C. However, IPCC does not make any assumption on a best-guess value for climate sensitivity. There have been several studies trying to estimate probability distribution functions of climate sensitivity. Some show a high likelihood for climate sensitivity being even higher than 4.2°C (Andronova and Schlesinger, 2001; Forest et al., 2002; Knutti et al., 2002). One difficulty in estimating climate sensitivity is the uncertainty with regard to the strength of the cooling effect of anthropogenic aerosol particles. If this effect is stronger than assumed hitherto – and empirical evidence seems to point in that direction (Anderson et al., 2003) – then it could mean that climate sensitivity, namely the response of the climate system without the cooling effect of aerosol particles, is higher than previously estimated. This would mean that warming rates in the 21st century, when aerosol emissions are expected to decline (IPCC, 2000), would be much higher than previously estimated (IPCC, 2001a). This effect is even enhanced if carbon cycle feedback is taken into account, because aerosol particles suppress the rate of warming due to greenhouse gases, and thereby increase carbon accumulation at present. The carbon cycle feedback effect is thus delayed, but then stronger because of the additional release of carbon accumulated in the soils. Negative impacts of climate change on the carbon cycle are thus shifted into the future (Jones et al., 2003).

Carbon cycle feedback

Simulations with general circulation models with interactive land and ocean carbon cycle components show a positive feedback, i.e., both CO_2 concentrations and climate change at the end of the 21st century are higher than without the carbon cycle feedback (IPCC, 2001a). This feedback effect can be explained by the reduced uptake of CO_2 by oceans and by the terrestrial biosphere: Warming reduces the solubility of CO_2 and therefore reduces uptake of CO_2 by the ocean. In addition, warming is likely to lead to increased vertical stratification of the ocean, which would lead to reduced ocean CO_2 uptake.

Warming also reduces terrestrial uptake by increasing the rate by which living organisms convert organic matter to CO_2. The long-term effect is not yet clear. The net terrestrial carbon uptake observed at present will also decline as re-growing forests in the Northern Hemisphere mature and the effects of CO_2 fertilization and nitrogen deposition saturate. Moreover, climate change is likely to increase disturbance and mineralisation rates, leading to a reduced terrestrial uptake (IPCC, 2001d; WBGU, 1998).

Several vegetation models project that the recent global net terrestrial carbon uptake will peak, then level off or decrease (Cramer et al., 2001). The peak could be passed within the 21st century according to several model projections. Climate change, in particular shifts in precipitation patterns, can lead to large changes in vegetation distribution and structure (Section 2.1.2). The models show large forest dieback caused by droughts in Africa, America and Southeast Asia (Cramer et al., 2001). This leads to a significant loss of carbon, as forests are replaced by grasslands. Jones et al. (2003) calculate the effect of climate change and changed concentration of greenhouse gases on the terrestrial biosphere, coupling a global climate model with a dynamic vegetation model, taking into account i.a. the effect of aerosol particles. The effect of increased respiration of plants and Amazon dieback causes the terrestrial biosphere to turn into a net source in about 2040 (Jones et al., 2003). According to these model results, the land carbon source reaches 7 Tg C per year by 2100, thus even exceeding the ocean carbon sink by about 2080. The transitional character of the contemporary terrestrial carbon sink has important consequences for the adequate way of dealing with the terrestrial biosphere within the accounting framework of the Kyoto Protocol (Chapter 4): The reduction of emissions from fossil fuel burning implies permanent storage of carbon in safe fossil deposits. In contrast, measures to enlarge carbon stocks in the biosphere come with an increased risk of later release of the additionally stored carbon into the atmosphere, e.g. through changes in land use, climate change or fire.

2.2.2 From stabilization targets to time paths of emissions

The same stabilization level for CO_2 concentration can be reached by different emission pathways, even if the same target year is chosen. If higher emissions are allowed in earlier decades, steeper reductions are necessary in later decades. Such delays in emission reductions lead to more rapid warming in the first decades. Whether higher reductions in the near-term or deferral of response measures lead to lower overall cost estimates for a given concentration target depends on assumed discount rates as well as on how technological learning is factored in. While some studies state that delay of response measures leads to lower costs (Wigley et al., 1996; Manne and Richels, 1997), others show that early action can stimulate more rapid deployment of existing low-emission technologies and thus help reduce costs (technological learning-by-doing) and avoid risks of lock-in to carbon-intensive technologies (Grübler and Messner, 1998; van Vuuren and de Vries, 2001).

A decision on a long-term concentration target might not be possible or even recommendable due to the large uncertainties with regard to the tolerable concentration level (Section 2.2.1). Therefore, decision frameworks dealing with this uncertainty have been developed (IPCC, 2001d). The implications of the inertia of the energy system have to be taken into account: If, for example, a 550 ppm target is regarded as tolerable, but some decades later new scientific knowledge arises leading to the conclusion that a lower target should be aimed at, then emissions would have to be reduced sharply. Due to premature retirement of capital, this could lead to higher costs than if a lower level had been targeted from the beginning. Once investments in long-term infrastructure have been done, it is costly to change the pathway of energy system development (lock-in effects).

Ha-Duong et al. (1997) show that the economic risks associated with deferring abatement justify starting to limit CO_2 emissions from energy systems immediately, if there is a significant probability of having to maintain greenhouse gas concentrations below about double those of the pre-industrial era (this corresponds to about 450 ppm CO_2 concentration). This conclusion holds even without taking into account technological 'learning-by-doing', which would favour early action even more. The mounting climate change damage due to a delayed abatement must also be taken into account. The crucial factor is the uncertainty with regard to the definition of a 'tolerable' concentration level, combined with the inertia of energy systems: Costs of acting too late (and having to shift to more stringent targets later on the basis of new scientific evidence) then dominate costs of early action (Hourcade et al., 2001). This conclusion is even stronger if induced technological change and 'learning-by-doing' is factored in, as then the costs are minimized all the more strongly, the earlier abatement takes place.

Uncertainty with regard to the definition of 'tolerable' concentration levels thus points to hedging strategies as appropriate decision frameworks (IPCC, 2001c). Even if, for example, a CO_2 stabilization level of 450 ppm is regarded as a best guess for a safe level, it is more cost effective to follow a lower emissions path than the one leading to stabilization of 450 ppm, as long as the tolerable stabilization level is uncertain, in other words, as long as there is a considerable likelihood that this might turn out to be a too dangerous target.

2.2.3 Conclusions

Based on the analysis of uncertainties with regard to the global mean warming that follows from specific CO_2 concentration levels, the WBGU has decided to analyse two different CO_2 concentration levels (400 and 450 ppm), which are compatible with the WBGU climate window under certain assumptions with regard to climate sensitivity and other emissions (e.g.

deforestation, agriculture) and other uncertainty factors (Section 2.1.1). Due to the large uncertainties related to the climate system, the definition of a specific concentration level as tolerable would be premature. The Council recommends a hedging strategy, leading to the recommendation to pursue lower concentration level targets (below 450 ppm) initially, rather than having to correct a higher target later on.

The uncertainty with regard to the role of the terrestrial biosphere in the carbon cycle and the transitional character of the present-day terrestrial carbon sink make it highly risky to offset fossil fuel reduction commitments against terrestrial sinks (Chapter 4).

As concerns research efforts, in order to operationalize Article 2 UNFCCC, there is a particular need to pursue integrated modelling approaches that take into consideration many actors with disparate interests and diverse uncertainties, based upon the Tolerable Windows Approach (Section 2.1.1). This creates a methodological separation between the normative setting of guard rails and identification of global climate change impacts on the one hand, and the determination of tolerable emissions paths and optimal strategies on the other. To this end, the reduction potentials and associated costs of other greenhouse gases besides CO_2 need to be integrated within corresponding modelling studies. This can identify least-cost strategies by which to remain within the WBGU climate window, that embrace all radiatively active gases. There is also a need for further analysis and research on action under uncertainty (e.g. approaches with heterogeneous agents with potentially defective behaviour).

Finally, to study abatement strategies and their economic and other impacts, a broad range of stabilization scenarios should be analysed. Thereby the entire spectrum of possible futures can be taken into consideration – such as are presented by the SRES scenarios (IPCC, 2000) – in order to thus be able to appraise the costs. This must include study of target carbon dioxide concentrations below 450 ppm.

2.3 Seeking compliance with given emissions profiles

2.3.1 Principles for the allocation of emission rights

Proceeding from a global target path for emissions that prevents 'dangerous' climate change, it is possible and essential to determine at country and regional level target paths for emissions in such a way that compliance with the global emission path can be ensured. This means that country-specific emission rights must be allocated in such a way that the global emission boundaries are not transgressed. By comparing such desired emission paths with those that are to be expected if no counteracting measures are taken (emissions in the reference scenarios), we can also calculate a time profile for the requisite emissions reductions.

Various different regionalized emission paths are compatible with the global emission path. The question thus arises of which criteria are to be applied to allocate the emission rights and the reduction commitments that result from these rights. A number of different approaches are under debate. These do justice to differing degrees to the principles established by the UNFCCC concerning an equitable assumption of climate change mitigation commitments (Art. 3(1)). One is the principle of common but differentiated responsibilities. This implies that countries assume reduction commitments essentially according to their historical and present contribution to global warming. A further is the principle that countries contribute to climate protection in accordance with their capabilities, particularly in accordance with their economic and technological capacities. The criterion of needs is also under debate (Berk and den Elzen, 2001; Höhne et al., 2003); this can be derived indirectly from the Convention (Art. 3(2)) and its preamble. Taking as a basic precept that every person or every country is entitled to a certain level of welfare, it follows from the principle of needs that justice must be done to the right to development and the resultant different development needs, as well as to, for instance, geographically or climatically determined differences in emissions needs. The needs principle cannot be concretized directly from the Convention, so that it would appear that the principle can only be operationalized to a limited degree. However, the Council sees a potential for concretization in the egalitarian principle, which can be derived from the human right to equal treatment and, in relations among contracting parties, from the principle of equity (Art. 3(1) UNFCCC; Kokott, 1999). In addition, the Council postulates the principle of constancy, according to which abrupt measures leading to drastic effects should be avoided in socio-economic systems, as these may have severe consequences affecting the economies of all regions.

2.3.2 Contraction and convergence

The model of 'contraction and convergence' (C&C; Meyer, 2000) is based upon a fundamentally equal right of all individuals to emit. This can be derived from the human right to equal treatment, and corresponds to the principle of equity under the UNFCCC (Art. 3(1)), and thus corresponds to the egalitarian principle postulated by the Council.

Under this approach, the global emissions budget resulting at each point in time from the target path for global emissions is broken down such that the per-capita emission rights of all countries or regions converge and are equal from a set convergence year onwards. This process can be linear or non-linear, at a rate that must also be set. Thus, for pragmatic reasons (principle of constancy), realization of the right to equal per-capita emissions is aimed at with a time lag of several decades (roughly up to the year 2050 or 2100). The approach does justice to the principle of economic capability by the circumstance that industrialized countries would be subject on average to substantially higher reduction commitments than the developing countries. There are contradictions, however, between taking the C&C approach or the capability principle as a basis for allocating emission rights – these conflicts become particularly clear if, instead of comparing the 'industrialized country' and 'developing country' groups, individual countries are compared. The principle of differentiated responsibilities is complied with to the extent that the per-capita reduction burden of countries is greater the higher their current per-capita share in greenhouse gas emissions is. However, differences in historical responsibilities are largely not taken into account.

In terms of the CO_2 emissions path, the C&C approach is highly targeted, as emission budgets are fixed over the long term and are not subject to any fluctuation.

2.3.3 Three-sector approach ('Triptych')

An approach giving explicit consideration to structural differences is the 'Triptych' approach (Berk and den Elzen, 2001; den Elzen, 2003). Under this approach, country-specific emission budgets are calculated for three different sectors – the energy, industrial and household sectors (Michaelowa et al., 2003). The budgets are based upon assumptions on future economic and technological developments in the sectors. The approach further assumes convergence of household emissions. This provides the basis on which to assess the reduction commitments of individual countries. Due to its dependence upon assumptions on the development of individual sectors in member states, the Triptych approach is hard to operationalize. Moreover, it can contradict the principle of differentiated responsibilities. The emission situation created in the past may have a strong effect if the past high emissions of a country with a large emissions-intensive sector entail high emissions budgets in the future. This would entail an unjustifiable advantage for historically emissions-intensive countries.

2.3.4 Multi-sector convergence

The multi-sector convergence approach (Jansen et al., 2001) takes structural differences between countries or country groups into consideration in a manner similar to the Triptych approach. Based upon a fixed convergence year, converging per-capita targets are determined for seven sectors. Country-specific emission budgets are then determined in binding form on this basis.

This approach shares the problems of the Triptych approach – difficulties in operationalization, and a certain tendency to favour countries with historically emissions-intensive sectors. A further problem of all sector-specific approaches lies in the high requirements that they place upon country-specific data. The data required to calculate sector-specific emissions budgets are frequently not available, and can be manipulated easily.

2.3.5 Brazilian proposal

An approach that stresses historical responsibility is based on a proposal made by Brazil for the allocation of the commitments of Annex-I states under the Kyoto Protocol. The proposal suggests that states must contribute all the more to emissions reduction the more they have contributed in the past to the climate problem. Historical responsibilities are to be measured by the contribution to global warming. With this approach it would be necessary to determine a reference point in time at which the international community must already have been aware of the problem of climate change, e.g. 1990 when the IPCC published its first assessment report. Otherwise the approach could amount to a 'liability' for behaviour which, while harmful, could not be recognized as such at the time. Many industrialized and transition countries fear that the Brazilian proposal might entail a drastic ad-hoc transformation that would exceed their economic capabilities.

2.3.6 Multistage approach

In contrast to the approaches towards allocating emission rights and reduction commitments set out above, the multistage approach is concerned less with determining the allocation standard, and more with a possible procedure by which to integrate individual countries or groups of countries into the regime in a step-wise process. Thus, while under the contraction and convergence approach and under the Brazilian proposal it is generally assumed that all participating countries are integrated immediately into the reduction system, the multistage approach (Berk and den Elzen, 2001; den Elzen, 2003) assumes gradual entry into the reduction system. Different country groups engage in different stages of reduction commitment. Stages range from, for instance, the complete absence of a reduction commitment through to a commitment oriented to economic growth, or an absolute reduction target. This approach is flexible in terms of the choice of criteria for involving states in the various stages, in terms of the types of reduction targets (absolute reduction targets, intensity targets, sustainable development policies and measures, etc.) and in terms of criteria for differentiating the reduction commitments of states at any given stage (Berk and den Elzen, 2001). Depending upon the way reduction commitments are defined specifically in a stage, different weight attaches to the individual equity principles within the multistage approach.

In terms of negotiation dynamics, the flexibility of the multistage approach is an advantage. However, this flexibility poses risks with respect to ambitious reduction commitments. Moreover, most relative emission reduction targets discussed for interim stages (intensity targets, sustainable development policies and measures, etc.) present major problems of implementation, measurement and monitoring. Ultimately, the multistage approach is more a forecast of potential negotiation processes, and less an autonomous, scientific criterion for allocating reduction commitments.

2.3.7 Conclusions

Particularly with regard to targetedness in terms of CO_2 emissions, in consideration of the fundamentally equal right of all individuals to emissions, and further considering the principle of constancy, the WBGU has decided to base its in-depth analysis of the implications of emissions allocation on the contraction and convergence model. This analysis compares the differences between scenarios converging by 2050, and by 2100. In both cases, linear convergence is assumed for the sake of simplicity. No base year for population development is assumed, as this would intervene severely in the policies of countries with high population growth rates (Section 3.2).

It is important for the concrete practical implementation of such a long-term C&C approach to clarify by which short- and medium-term measures long-term convergence can be achieved. This must include a deliberation of how the approach would need to be modified if not all countries are able to fully accept this regime from the start. It may be useful in this context to make use of the procedure proposed by the multistage approach, which explicitly envisages that individual countries join the system successively. This aspect is discussed in more detail in Chapter 5.

Stabilization scenarios 3

3.1
Climate policy and sustainable energy systems

3.1.1
Guard rails for sustainable energy policy

In its report titled 'Towards Sustainable Energy Systems' (WBGU, 2004), the German Advisory Council on Global Change (WBGU) elaborated an exemplary path for the transformation of the global energy system. This path is characterized by ambitious climate change mitigation, strong economic growth as well as global convergence. That report succeeded in demonstrating that a sustainable transformation of the global energy system is indeed possible in a way that is also in line with the guard rails for sustainable energy policy developed by the Council (WBGU, 2004).

Proceeding from these guard rails, the Council has analysed the realizable sustainable potential of the energy sources available for this transformation process. In many instances, this sustainable potential is far lower than the technological potential of the specific energy source, not to mention the theoretical potential. The sustainable potential of fossil energy sources is determined essentially by the requisite stabilization of atmospheric CO_2 concentrations (Section 2.2). This requirement produces restrictions for a number of renewable forms of energy, too, resulting in the following potentials: biomass 100 EJ per year, wind 140 EJ per year, hydropower 12 EJ per year over the medium term and 15 EJ per year over the long term. The solar energy potential is the only one that can be considered quasi-unlimited in relation to anthropogenic energy consumption. The use of nuclear fission is associated with unacceptable risks, so that the WBGU recommends shutting down existing nuclear power plants when their current operating permits expire, and not building any further ones. Despite path dependencies, a global phase-out of nuclear energy use by the year 2050 is deemed acceptable and feasible. The potential hazards of fusion power plants also appear substantial. As fusion power plants will be available in the second half of the present century at the earliest – if at all – the Council recommends that such plants should not be considered as a part of a transformation of energy systems.

The WBGU views CO_2 capture from the exhausts of energy conversion systems, with subsequent CO_2 storage in geological formations, as a bridging technology, and assesses its sustainable potential, with particular consideration to the safety of the repositories, at a cumulative volume of about 300 Gt C (WBGU, 2004). Storage in oceans is considered non-sustainable (WBGU, 2004). As, overall, carbon storage can only have a transitional function, the Council recommends its phase-out by the year 2100.

Moreover energy consumption reductions brought about by major yearly improvements of energy intensity are just as important as the reconfiguration of the supply side.

It further needs to be kept in mind that technological CO_2 stabilization can be jeopardized by emissions from natural reservoirs (Chapter 4). It is therefore essential to protect these reservoirs, e.g. through appropriate land-use activities.

3.1.2
Global climate change mitigation scenarios

3.1.2.1
Development of the IPCC mitigation scenarios

The potential development paths of the global energy system under certain CO_2 stabilization levels vary widely, depending upon demographic, economic and technological boundary conditions (IPCC, 2000; WBGU, 2004). To address this issue, the WBGU already analysed in previous reports a series of different potential developments with regard to their compliance with the WBGU guard rails (SRES and post-SRES scenarios: IPCC, 2001c). The above-mentioned exemplary path for the transformation of the global energy system which modified IIASA's post-SRES scenario A1T-450, was developed upon the basis of these analyses.

To pursue this approach in further depth and, moreover, to attain regionally disaggregated information within the various future paths, the Council commissioned IIASA to continue the corresponding scenario development process (Nakicenovic and Riahi, 2003 a,b). In this work, the scenarios were created with an energy system model (MESSAGE), which was coupled and iterated with a macroeconomic model (MACRO). This permits endogenous determination within the model of, inter alia, energy demand and costs, whereby macroeconomic optimization is assumed. Thus, while the above-mentioned exemplary path defined by the WBGU is based upon consistent quantification, the IIASA models used here are optimization algorithms with endogenous parameters. The scenarios described in the following were based upon the SRES families B1, B2 and A1T, with the properties set out in Table 3.1-1. The Council takes the view that the assumptions on which the SRES A2 world is based (heterogeneous world, no emphasis on sustainability, slow technology development, low levels of efficiency improvement and decarbonization) make achievability of climate protection goals extremely improbable. Hence no A2 scenario was included in the present study.

Building upon B1, B2 and A1T, various calibrations were updated. Carbon capture at biomass-utilizing installations was included as an additional CO_2 sink in the underlying technology portfolios. Furthermore, the sustainability conditions of the Council (Section 3.1.1) were implemented as boundary conditions in two of these scenario families (A1T, B1), while B2 was not made subject to the WBGU boundary conditions. The resulting reference scenarios are termed in the following A1T*, B1* and B2 (* = created under the boundary conditions of sustainable energy systems set out in Section 3.1.1; Fig. 3.1-1). Subsequently, building upon these reference scenarios, challenging CO_2 stabilization targets were implemented (B1* and B2: 400 ppm, A1T*: 450 ppm; Section 2.2). The corresponding mitigation scenarios are termed in the following A1T*-450, B1*-400 and B2-400 (Fig. 3.1-1).

The results for scenario A1T*-450 follow on from the development of the exemplary path in the Council's 'Towards Sustainable Energy Systems' report. Consequently, in order to permit comparability, a CO_2 stabilization concentration of 450 ppm was selected for scenario development in the present report. The A1 world has a high level of energy consumption due to strong economic growth. At the same time, the modified scenario restricts a number of carbon-free energy sources due to higher-level sustainability considerations (biomass, hydro, wind, nuclear; Section 3.1.1). Hence the scenario assumptions had to be further adjusted in a number of points compared to the original A1T-450 post-SRES scenario. In particular, due to quantitative restrictions upon bio fuels, it proved difficult to realize a low-carbon transport sector in A1T*-450. As a result, the relevant maximum rate of dissemination of hydrogen technologies had to be increased in the model compared to the SRES assumptions. In addition, battery-driven electric vehicles establish themselves. Furthermore, it was assumed that the global energy system has an enhanced capacity to respond to higher energy prices with reduced demand. This improved global energy intensity in both A1T* and A1T*-450 by up to 2% annually. Nonetheless, it was not possible within the IIASA models (with endogenous determination of key parameters) to achieve phase-out of geological carbon storage by the year 2100 in the CO_2-stabilizing scenario A1T*-450.

A lower stabilization concentration – of 400 ppm – was selected for the CO_2-stabilizing scenarios in the

Table 3.1-1
Characteristics of selected SRES storylines.
Source: IPCC, 2000

SRES world storyline	
A1	Very rapid economic growth, market and technology emphasis, globalization, increasing mobility, convergence among the world's regions, reduction of energy intensity beyond historical rates (1.3%/a), low population growth (9 thousand million in 2050, 7 thousand million in 2100). *A1T*: rapid development of non-fossil energy sources, broad-scale deployment of hydrogen technology.
B1	Rapid economic growth, dynamic technology development, globalization, convergence among the world's regions, strong emphasis on environmental and social sustainability, dematerialization, transition to a less materialistic lifestyle, low population growth, reduction of energy intensity beyond historical rates (2%/a).
B2	Locally and regionally specific development paths, moderate economic and technological development (projections in line with historical trends, business-as-usual), intermediate population growth (10 thousand million in 2100), reduction of energy intensity at historical rate (1%/a).

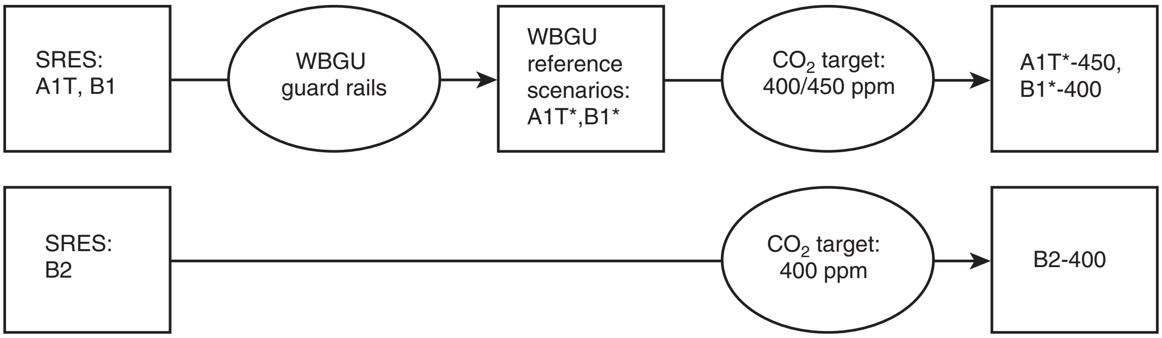


Figure 3.1-1
Scenario naming: The scenario development described in the text was based upon the SRES families A1T, B1 and B2. In two of these scenario families (A1T, B1), the sustainability demands of the WBGU were implemented as constraints, and the resulting reference scenarios termed A1T* and B1*. Challenging CO_2 stabilization targets were implemented in the reference scenarios (A1T: 450 ppm, B1* and B2: 400 ppm). The resulting mitigation scenarios are termed A1T*-450, B1*-400 and B2-40.
(* compliant with the WBGU guard rails for sustainable energy systems)
Source: WBGU

B1 and B2 families, in order to reduce the uncertainties regarding climate development that must be tolerated (Section 2.2). While the B2 family marks a business-as-usual world, the B1 family corresponds more to a global sustainability world (low population growth, rapid economic growth, rapid global convergence, strong emphasis on sustainability goals, etc.). This is expanded upon in the current B1* scenario to include sustainability criteria within the energy system. Comparison between B2-400 as a reference world without sustainability requirements and B1*-400 thus permits conclusions regarding the combination of climate protection policy with policy approaches towards general sustainable development.

Emission rights allocation impacts upon financial resource flows and thus also upon regional development paths. All CO_2-stabilizing scenarios take as allocation mechanism a linear contraction and convergence approach (Section 2.3.2). Two variants were calculated for each of the CO_2-stabilizing scenarios: one with a per-capita emissions convergence year of 2050, and one with a convergence year of 2100.

3.1.2.2
Results: Global energy systems of the IIASA-WBGU scenarios

Figure 3.1-2 shows the global primary energy portfolios of the resulting reference scenarios A1T*, B1* and B2, as well as of the CO_2-stabilizing scenarios A1T*-450, B1*-400 and B2-400. Figure 3.1-3 displays the corresponding global development paths as trajectories in a triangle between the corner points of coal, oil/gas and renewables/nuclear. It is obvious that, with the exception of the B2 reference scenario, all scenarios studied exhibit a clear development towards carbon-free energy systems. The commonalities and differences between the scenarios are set out in more detail in the following.

CO_2-STABILIZING WORLDS:
ELECTRICITY/HYDROGEN ECONOMY

Despite the fundamental differences in the underlying assumptions, the CO_2-stabilizing scenarios display basic commonalities: While today not only the primary energy sector but also the final energy sector is still dominated by fossil energy carriers, in the CO_2-stabilizing scenarios a dominance of electricity and hydrogen emerges in the final energy sector – a 'electricity/hydrogen economy'. In the technologically optimistic scenarios (A1T*-450 and B1*-400), a large part of the electricity is generated through hydrogen produced at low cost in the IIASA models, while in contrast the WBGU considers a direct final energy use of solar-generated electricity within the context of a globally connected network (global link) to be more probable. In all CO_2-stabilizing scenarios the launch of the electricity/hydrogen economy starts initially on the basis of fossil resources (e.g. steam reformation of natural gas), whereby carbon capture at centralized energy conversion facilities makes an important contribution to climate change mitigation. The conversion technologies required to produce electricity and hydrogen from fossil sources are already available today on an industrial scale. This facilitates the inception of this structural change. Restructuring the emissions-intensive transport sector in time is an important element: Here the development of battery- and hydrogen-driven vehicles must be accelerated. To this end, a swift – if initially fossil-based – establishment of the corresponding elements of an electricity/hydrogen economy is

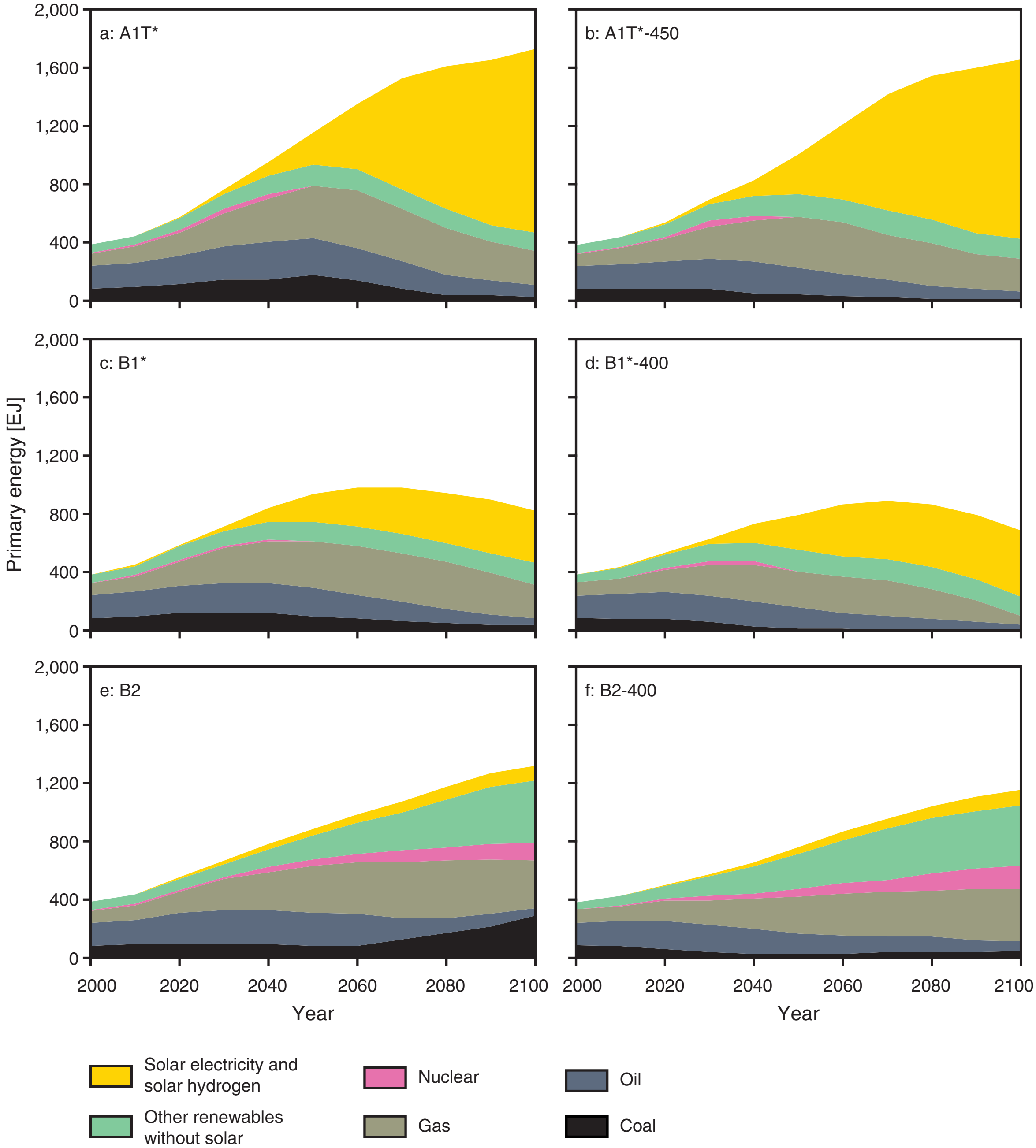


Figure 3.1-2
Primary energy use in the IIASA-WBGU scenarios. The figure shows the development over time of the global primary energy portfolio in the reference scenarios (a: A1T*, c: B1*, e: B2) and in the corresponding CO_2-stabilizing scenarios (b:A1T*-450, d: B1*-400, f: B2-400). The figure shows that carbon intensity in the fossil sector is reduced through intensified use of gas, at the expense of oil and coal. Coal use, in particular, almost expires in all CO_2-stabilizing scenarios by the middle of the century (A1T*-450, B1*-400) or at least drops to a very low level (B2-400). By the end of the century, energy supply is based essentially on solar electricity and solar hydrogen, particularly in A1T*/A1T*-450 and B1*/B1*-400. Comparison of the reference scenarios (a, c, e) with the CO_2-stabilizing scenarios (b, d, f) shows that the A1T and B1 storylines support the technology portfolios required for committed climate change mitigation. The same can be said for emissions (Fig. 3.1-4) and costs (Fig. 3.1-7). The category 'Other renewables without solar' comprises biomass, wind, hydro, solar thermal (only heat), geothermal and further renewables.
Source: Nakicenovic and Riahi, 2003b

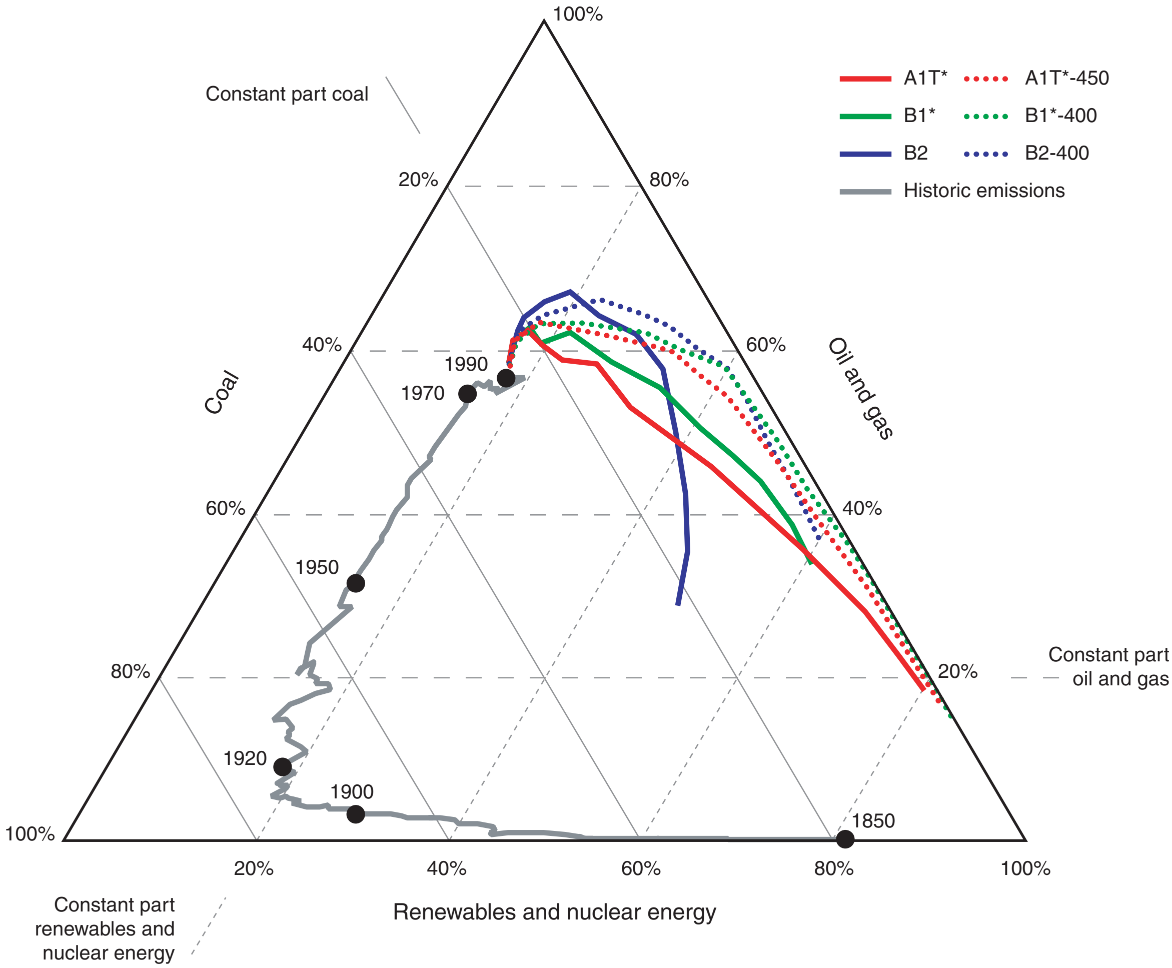


Figure 3.1-3
Evolution of the shares of energy sources in global primary energy consumption, as trajectories until 2100 in a triangle between the corner points of coal, oil/gas and renewable/nuclear. Until 1990, the figure shows the historical development. From then onwards, trajectories split according to the development paths of the six scenarios (A1T*, A1T*-450, B1*, B1*-400, B2, B2-400; Fig. 3.1-1). With the exception of the B2 reference scenario, all scenarios show a clear development towards carbon-free energy systems.
Source: Nakicenovic and Riahi, 2003a

essential. Over the long term, even more far-reaching changes in energy supply are anticipated in the electricity/hydrogen economy of the scenarios: While in the technologically more conservative B2-400 world only biomass gasification emerges as an additional hydrogen source and the intensified use of nuclear power as an electricity source, in the technologically highly dynamic A1T*-450 and B1*-400 scenarios solar energy provides the greater proportion of electricity and hydrogen supply. The corresponding developments of the technology portfolios over time are determined strongly by the WBGU guard rails for sustainable energy policy (Section 3.1.1).

Commonalities and differences in primary energy supply

A more detailed analysis of the development over time of the volume of individual primary energy carriers evidences long-term commonalities among the technologically optimistic A1T*-450 and B1*-400 scenarios. At the same time, the fundamental differences to scenario B2-400 become clear: In B2-400, nuclear power adopts a dominant role, while in A1T*-450 and B1*-400 it is phased out over the medium term for sustainability reasons (Section 3.1.1). Similarly, biomass use grows over the long term to an extreme level of more than 300 EJ per year in B2-400, while in the sustainable energy systems of A1T*-450 and B1*-400 it remains below the maximum limit of sustainable use (100 EJ per year).

In A1T*-450 and B1*-400, solar energy provides over the long term by far the greatest proportion of energy supply in the electricity/hydrogen economy, while in B2-400 it plays a subordinate role, even over the longer term. It is only in the sphere of fossil energy carriers that the trends are similar in all three CO_2-stabilizing scenarios: The necessary reduction of carbon intensity is provided by an intensified use of gas, at the expense of oil and coal. In all CO_2-stabilizing scenarios, coal use is practically phased out by the middle of the century (A1T*-450, B1*-400) or at least falls to only a fraction of its previous levels (B2-400). This is attributable mainly to two economic reasons: Firstly, hydrogen can be produced at lower cost from natural gas than from coal. Secondly, even if geological carbon storage were permitted without limit, the higher specific CO_2 arisings of coal compared to gas lead to economic disadvantages, both in storage and in the emission (entailing debits) of the remaining quantities of exhaust that cannot be captured for technological reasons. Only in regions of the world where there are major coal reserves that can be extracted at low cost (e.g. China) do the scenarios anticipate a further growth of coal use for a transitional period of several decades.

3.1.2.3 Results: Emissions and resulting climate change

Figure 3.1-4 shows the emission paths of all three CO_2-stabilizing scenarios compared to the corresponding reference scenarios.

As in the IIASA models only the energy-related and industrial greenhouse gases were subject to endogenous macroeconomic optimization when developing the CO_2-stabilizing scenarios, the emission profiles of anthropogenic greenhouse gases not covered endogenously were predetermined exogenously upon the basis of equivalent stabilization scenarios.

Figure 3.1-4 breaks down the emissions prevented in the CO_2-stabilizing scenarios compared to the reference scenarios into three categories: demand reductions following higher prices, structural changes (notably the greater use of renewable energy sources and of low-carbon conventional energy carriers) and, third, geological carbon storage. Energy efficiency improvements are a part of the first two categories. The emissions reductions shown in the figure relate exclusively to energy-related and industrial CO_2 emissions. The contribution of demand reduction is comparatively small in all scenarios, because the mitigation-induced energy costs additional to the reference scenarios are moderate (Fig. 3.1-1). The contribution of carbon storage, in contrast, is major and remains large at the end of the century, unless it is restricted exogenously as in B1*-400. Nonetheless, in all three scenarios total carbon storage by 2100 remains below the maximum of 300 Gt C deemed tolerable by the WBGU. The model outcomes for carbon storage remain problematic in A1T*-450 and B2-400, however, as rates of carbon storage continue to be significant at the end of the century, threatening to transgress the tolerable maximum limit of safe geological storage in the course of the following century. These results follow from the economic assumptions of the underlying models. The WBGU takes the view that policy measures should steer CO_2 production and storage in such a manner that CO_2 storage is terminated worldwide in 2100. Therefore the carbon storage contained in the scenarios must not be a measure locking development trajectories into a fossil path. One reason why it appears comparatively large in Figure 3.1-4 is that a considerable proportion of structural change measures (renewables, efficiency improvement, etc.) is already contained in the reference scenarios (Fig. 3.1-1). Carbon storage in the sustainable CO_2-stabilizing scenarios is associated largely with the use of natural gas and biomass, and not with coal-based technologies.

It is common to all three CO_2-stabilizing scenarios that at the end of the period considered annual CO_2 emissions are still falling. To ensure long-term stabilization pursuant to Article 2 UNFCCC, emissions must continue to be reduced after 2100. Over the long term (a period of several centuries) they must be returned to such a low level that they can be absorbed by persistent natural sinks. These are assumed to be very small (0.2 Gt C per year) (IPCC, 2001a).

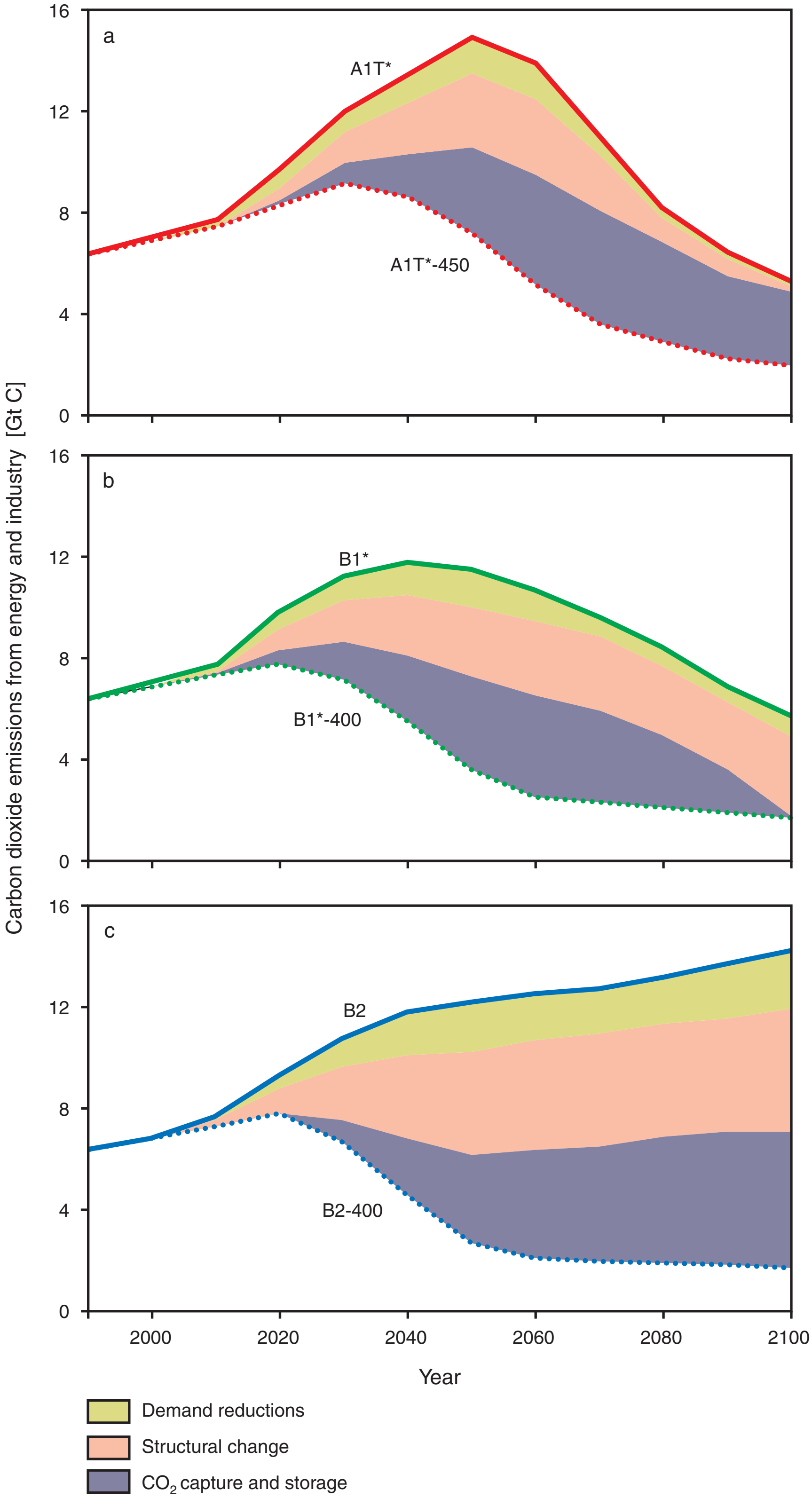
Assumptions on other sources and greenhouse gases

For the calculations of the climate impacts of the CO_2-stabilizing scenarios, the following assumptions were made concerning CO_2 emissions from land-use change and on the other greenhouse gases:

- Emissions from land-use change (primarily deforestation in developing countries) were adopted unchanged from the respective reference paths.
- The emissions of other greenhouse gases were adopted from other comparable CO_2-stabilizing scenarios. Emissions of methane, nitrous oxide and ozone precursor substances (NO_X, VOCs, CO) correspond to the scenario developed by Swart et al. (2002). Emissions of PFCs, HFCs and SF_6 were adopted from Rao and Riahi (2003).

Figure 3.1-5 shows the assumptions on CO_2 emissions from land-use change and on anthropogenic methane emissions for the individual scenarios (IPCC, 2000; Swart et al., 2002).

Figure 3.1-4
Emissions in the reference scenarios and in the CO_2-stabilizing scenarios (a: A1T storyline; b: B1 storyline; c: B2 storyline). Avoided emissions are seperated into three categories: demand reductions, structural change and CO_2 capture and storage. Nomenclature of scenarios as in Fig. 3.1-1. Source: Nakicenovic and Riahi, 2003b



Land-use changes lead to emissions (such as in the case of deforestation, mainly in the tropics), but also to the uptake of carbon dioxide (such as in the case of afforestation). The figure shows the global net effect of all land-use changes. For B1 and B2 this is already negative from about 2030 onwards, for A1T from about 2050 onwards, i.e. from then onwards the uptake of CO_2 by afforestation exceeds emissions from deforestation.

Half of anthropogenic methane emissions comes from agriculture, and a quarter comes from the extraction, transportation and distribution of fossil fuels. A further important source is waste treatment. Appraisals of future methane emissions depend on the one hand upon assumptions about the future use of fossil fuels, and on the other hand upon assumptions about population and economic development and agricultural practices as well as dietary habits (IPCC, 2000).

Figure 3.1-6 shows the temperature development, calculated with the simple climate model MAGICC, that follows from all emitted greenhouse gases relative to pre-industrial levels (underlying climate sensitivity: 2.5°C) and sea-level rise relative to the year 2000. It also indicates the uncertainty ranges of the models, taking into consideration a climate sensitivity range of 1.5°C to 4.5°C.

The circumstance that the temperature develops differently between B1*-400 and B2-400 despite identical CO_2 stabilization level is attributable mainly to different energy-related SO_x emissions.

The degree of safety compared to the projected climate changes can be expressed by the climate sensitivity value that would lead in the scenarios to a long-term temperature increase of not more than

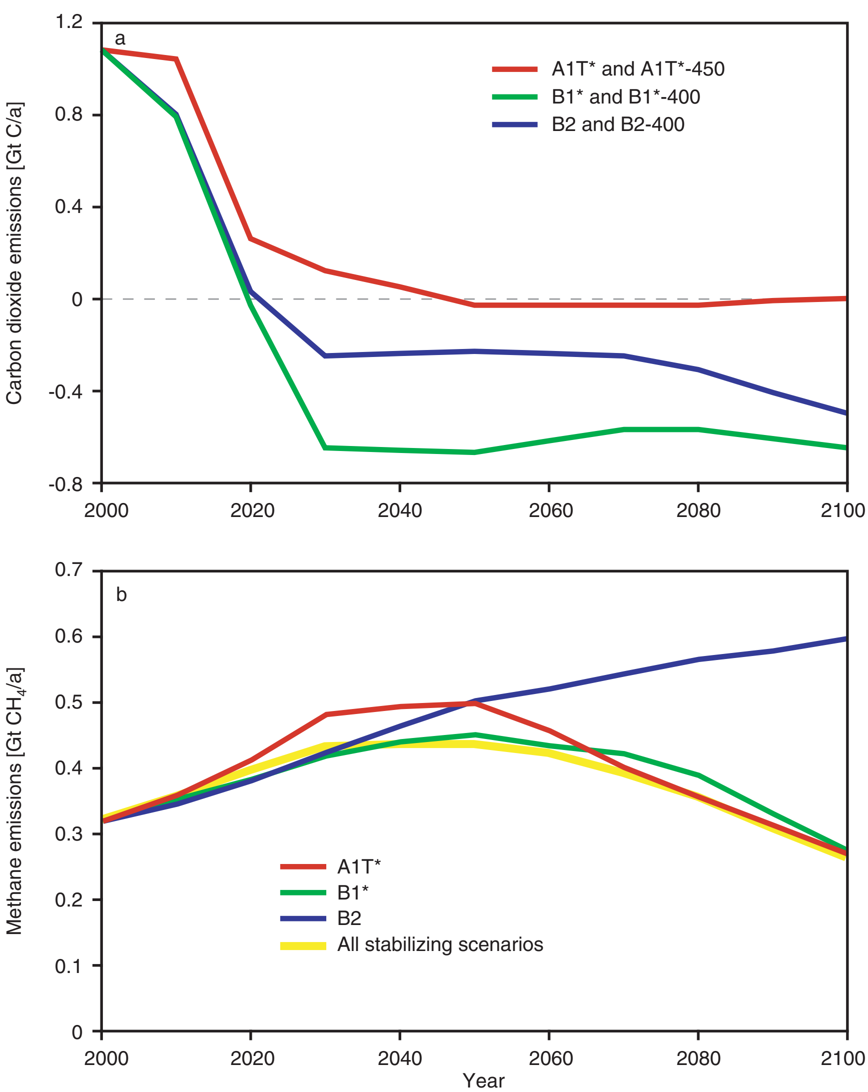


Figure 3.1-5
a) CO_2 emissions from land-use change in the reference scenarios and in the CO_2-stabilizing scenarios. It was assumed that CO_2 emissions from land-use change in the CO_2-stabilizing scenarios do not differ from the reference scenarios. Land-use changes (e.g. deforestation, mainly in the tropics) lead to emissions or to the uptake of CO_2 (e.g. through afforestation). The figure shows the global net effect of all land-use changes. b) Anthropogenic methane emissions from all sources (energy, industry, agriculture) in the reference scenarios and in the CO_2-stabilizing scenarios. For methane and other greenhouse gases, uniform emissions reduction paths were assumed for all CO_2-stabilizing scenarios.
Source: Nakicenovic and Riahi, 2003b

2°C relative to the pre-industrial era: The higher the value, the safer the scenario. The values generated by the model computations are 2.0°C for A1T*-450, 2.4°C for B1*-400 and 2.9°C for B2-400, assuming stabilized CO_2 emissions and constant emissions of other greenhouse gases after 2100.

If the scenarios had taken unaltered from the reference runs the non-energy-related non-industrial emissions predetermined exogenously on the basis of equivalent stabilization scenarios (i.e. mitigation exclusively in the energy sector), then a significant additional warming would arise for 2100. Assuming a climate sensitivity of 2.5°C, this additional warming would amount to 0.2°C (A1T*-450), 0.04°C (B1*-400) or 0.2°C (B2-400). The low value of the B1*-400 scenario is due to the circumstance that in the reference scenario the emissions of relevant greenhouse gases are already very low. Overall, these findings illustrate that non-energy-related emissions of CO_2, methane and nitrous oxide from both technological and biological sources must also become a focus of mitigation efforts.

3.1.2.4
Results: Mitigation costs

The regional distribution of mitigation costs is treated in detail in Section 3.2 below. The present section provides a preliminary outline of overall global costs. Relative global GDP losses were taken as the parameter to be analysed – i.e. the GDP of the three CO_2-stabilizing scenarios as a fraction of the GDP of the respective reference scenarios. Figure 3.1-7 illustrates the results.

These effects reflect the macroeconomic consequences of the energy system costs elevated by climate change mitigation activities (discounted invest-

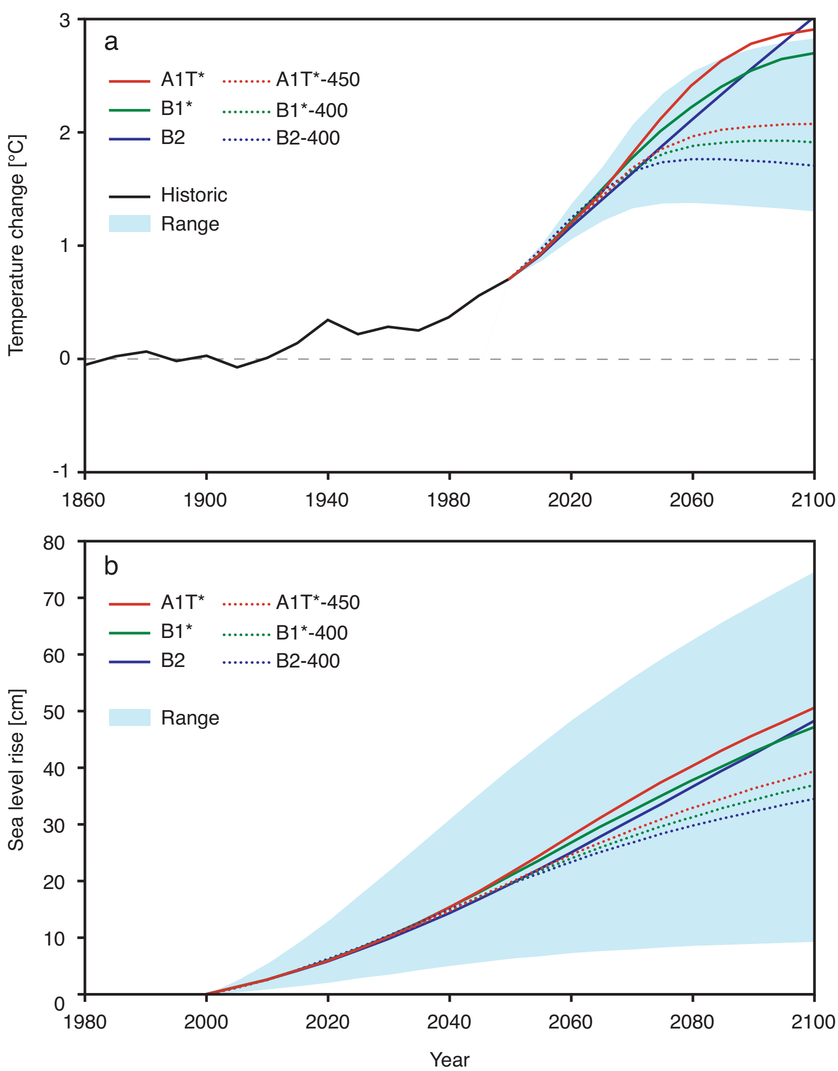


Figure 3.1-6
a) Temperature change relative to the pre-industrial mean.
b) Resulting sea-level rise relative to the year 2000 assuming a climate sensitivity of 2.5°C. The blue shaded area expresses the uncertainties for the CO_2-stabilizing scenarios. The main factor for this uncertainty is the climate sensitivity ranging from 1.5°C to 4.5°C. The temperature change of all CO_2-stabilizing scenarios shows a slight violation of the upper limit of 0.2°C per decade defined by the WBGU climate window
Source: Nakicenovic and Riahi, 2003b

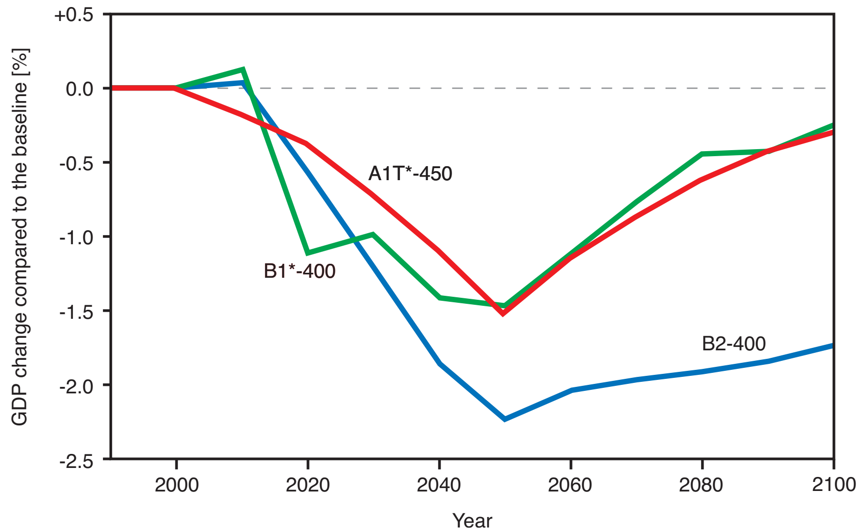


Figure 3.1-7
Relative losses of global gross domestic product (GDP) as a consequence of climate change mitigation measures (GDP of CO_2-stabilizing scenarios in relation to GDP of the reference scenarios). The A1T* and B1* storylines prove advantageous from a cost perspective, too. The same applies to emissions (Fig. 3.1-4) and primary energy use (Fig. 3.1-2). Source: Nakicenovic and Riahi, 2003b

ment plus current operating costs). When assessing these findings, it needs to be taken into consideration that the technology portfolios of the reference scenarios A1T* and B1* are already very close to those of the CO_2-stabilizing scenarios. Interpretation of the GDP losses shown must keep in mind that the CO_2-stabilizing scenarios prevent a large proportion of the external costs of climate change (climate damage and adaptation costs) which are not contained in the reference scenarios. Over the long term the costs of CO_2 stabilization appear to be lower than the adaptation and damage costs (Sections 2.1 and 3.3). Moreover, other types of damage are also prevented, such as air pollution and disease.

GDP losses peak in 2050 in all CO_2-stabilizing scenarios, but remain well below 3% of global GDP (Fig. 3.1-7). For both A1T*-450 and B1*-400, GDP losses are below 1.5%, averaging less than 0.7%. After 2050, relative GDP losses drop almost to zero by the end of the century in A1T*-450 and B1*-400, while they remain at a significant level in B2-400.

Comparison of the costs associated with the CO_2-stabilizing scenarios with those associated with the respective reference scenarios shows overall that mitigation is easier to realize in the A1T* and B1* worlds than in B2. This is due to developments that follow from the underlying storylines and already come to bear in the reference scenarios. This may be viewed as a call upon the policy arena to base mitigation efforts upon, among other things, the key elements of the A1T* and B1* storylines. These include technology transfer to developing countries, strengthening international cooperation, providing major support to research on energy sources and efficiency, and undertaking investment in technology development and applications.

A further finding of the scenarios studied is that both the regional structures of the energy system and the overall global costs are independent of the convergence year (2050 or 2100), as long as an emissions trading system ensures the minimization of global costs. Without emissions trading, it can be expected that the structural development of energy systems will be significantly different in certain regions.

3.2 Analysis: Contraction and convergence in selected scenarios

The following section analyses the implications of an allocation of rights to shares in the global CO_2 emission budget among individual countries or regions according to the contraction and convergence (C&C) approach (Section 2.3). This analysis is based on the results of scenarios computed by IIASA (Nakicenovic and Riahi, 2003a, b; on scenario nomenclature see Fig. 3.1-1), based upon two different convergence years – 2050 and 2100. The calculations are broken down to the level of 11 aggregated world regions shown in Fig. 3.2-1. At a next higher level of aggregation, these regions form four macroregions. Linear convergence was assumed, and no base year was set for population development (Section 2.3). It was assumed for the calculation of emissions that the USA does not participate in the first commitment period, but adopts proportionate reduction commitments from 2012 onwards.

3.2.1 Regional allocation of emission rights

Allocation of emission rights according to the contraction and convergence approach leads to convergence of per-capita emission rights in all countries or regions. Convergence is more or less rapid, depending upon the convergence year selected (Fig. 3.2-2).

The greatest difference between scenarios with different convergence years (2050 or 2100) is that, compared to 2050, the slower convergence by 2100 lessens the reduction commitments of industrialized and transition countries. As a result, less emission rights are allocated to the developing countries, giving many scarcely any leeway for a rise in per-capita emissions. If, in contrast, reduction scenarios converge by 2050, then this means higher emission rights particularly for sub-Saharan Africa and South Asia including India, which is particularly apparent in the middle of the century. Conversely, industrialized and transition countries then have comparatively less emission rights from the onset of the convergence process.

This effect is also apparent in the analysis of cumulative regional emission rights from 2000 to 2100 and of average regional per-capita emission rights over the period up to 2100 (Fig. 3.2-3). Particularly the average per-capita emission rights over the period up to 2100 (Fig. 3.2-3 b, d, f) illustrate the simultaneous consideration of the egalitarian principle and the principle of constancy (Section 2.3). The outcome of

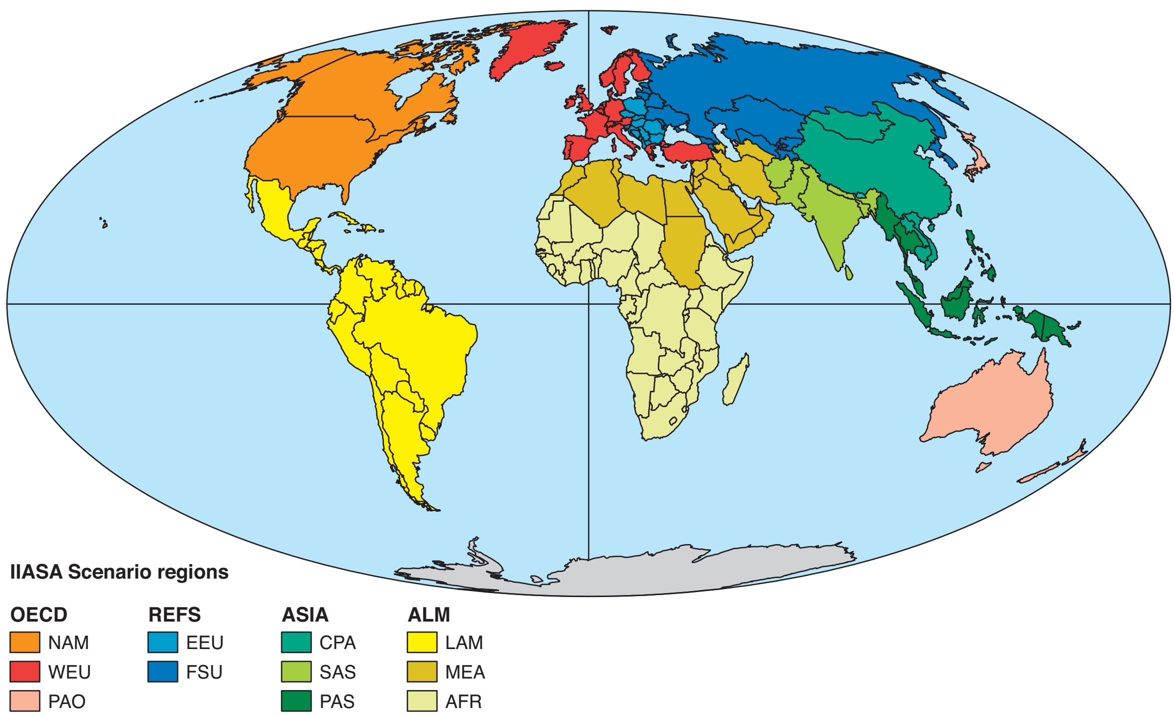
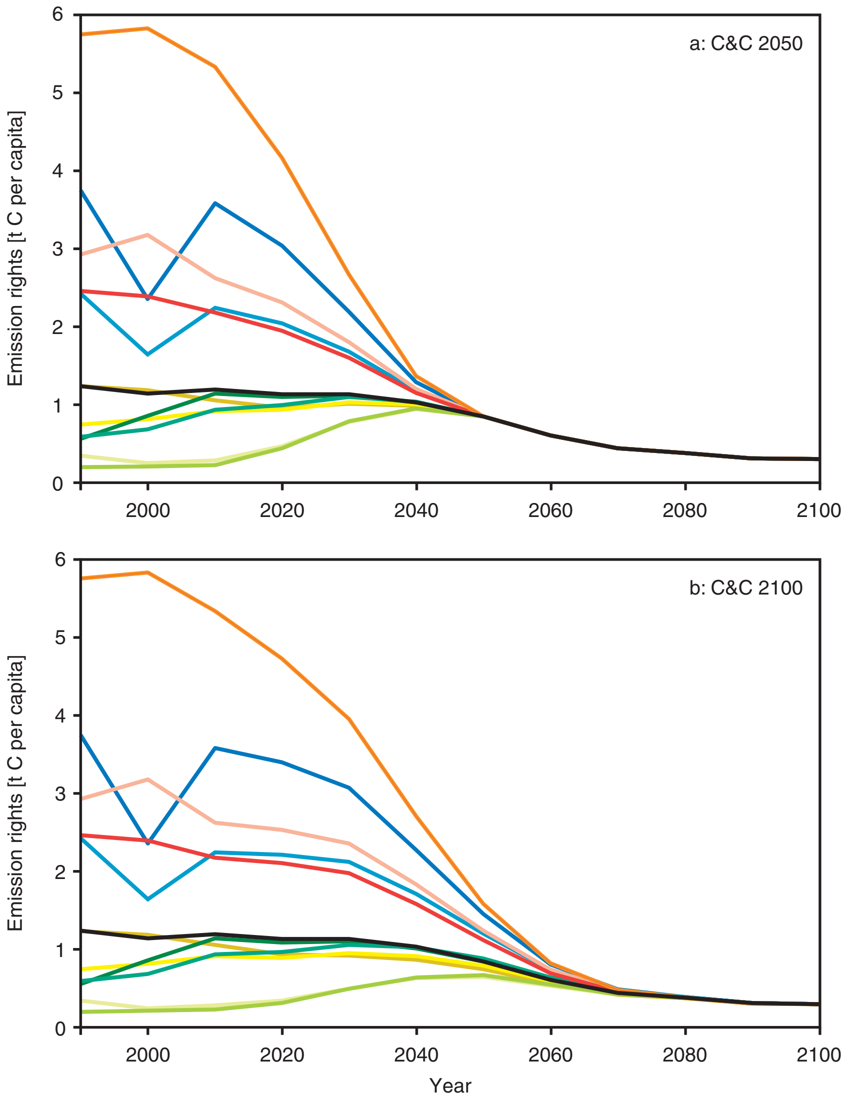


Figure 3.2-1
IIASA world regions used in the scenarios.
OECD:
NAM – North America (USA, Canada)
WEU – Western Europe (incl. Turkey)
PAO – Pacific OECD (Japan, NZ, Australia)
REFS:
EEU – Central and Eastern Europe
FSU – Newly independent states of the former Soviet Union
ASIA:
CPA – Centrally planned Asia and China
SAS – South Asia (incl. India)
PAS – Other Pacific Asia
ALM (Africa, Latin America, Middle East):
LAM – Latin America and the Carribean
AFR – Sub-Saharan Africa
MEA – Middle East and North Africa
Source: Nakicenovic et al., 1998



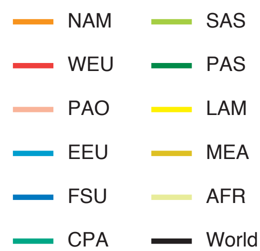


Figure 3.2-2
Development of per-capita emission rights under contraction and convergence in scenario A1T*-450 with years of convergence 2050 (a: C&C 2050) and 2100 (b: C&C 2100). The figures for B1*-400 and B1-400 are very similar but on a slightly lower level. The values until 2010 result from the commitments to the first commitment period of the Kyoto Protocol.
Source: Nakicenovic and Riahi, 2003b

slower convergence is that industrialized and transition countries, due to their high initial emissions levels, receive on average more per-capita emission rights than developing countries.

Figure 3.2-4 illustrates the development of emission rights for selected regions within the reference paths and for the reduction scenarios of A1T*, B1* and B2, for the two cases of 2050 and 2100 as convergence year. This shows that the curves of industrialized, transition and developing countries deviate greatly from each other, but that curves are similar within the group of industrialized countries on the one hand and the group of developing countries on the other.

The high emissions of the B2 scenario's reference path are striking. This is attributable to the low technological dynamics of the storyline and the correspondingly low levels of energy productivity improvement. Only Western Europe and North America do not show a similar development. The former Soviet Union region only commands over 'surplus' emission rights (rights for larger quantities of CO_2 emissions than arose in the reference scenario) until 2020. It is subsequently confronted in all reduction scenarios with strikingly high reduction commitments. For centrally planned Asia and China there are similarly large differences in the A1T*-450 scenarios. The development of emission rights for this region in the reduction scenarios is relatively independent of the convergence year. However, this is an effect that cannot be found for any other region (Figs. 3.2-3 and 3.2-4). South-East Asia including India and sub-Saharan Africa, in particular, have surplus emission rights up to the middle of the century, the volume depending upon the baseline scenario and the convergence year. For sub-Saharan Africa

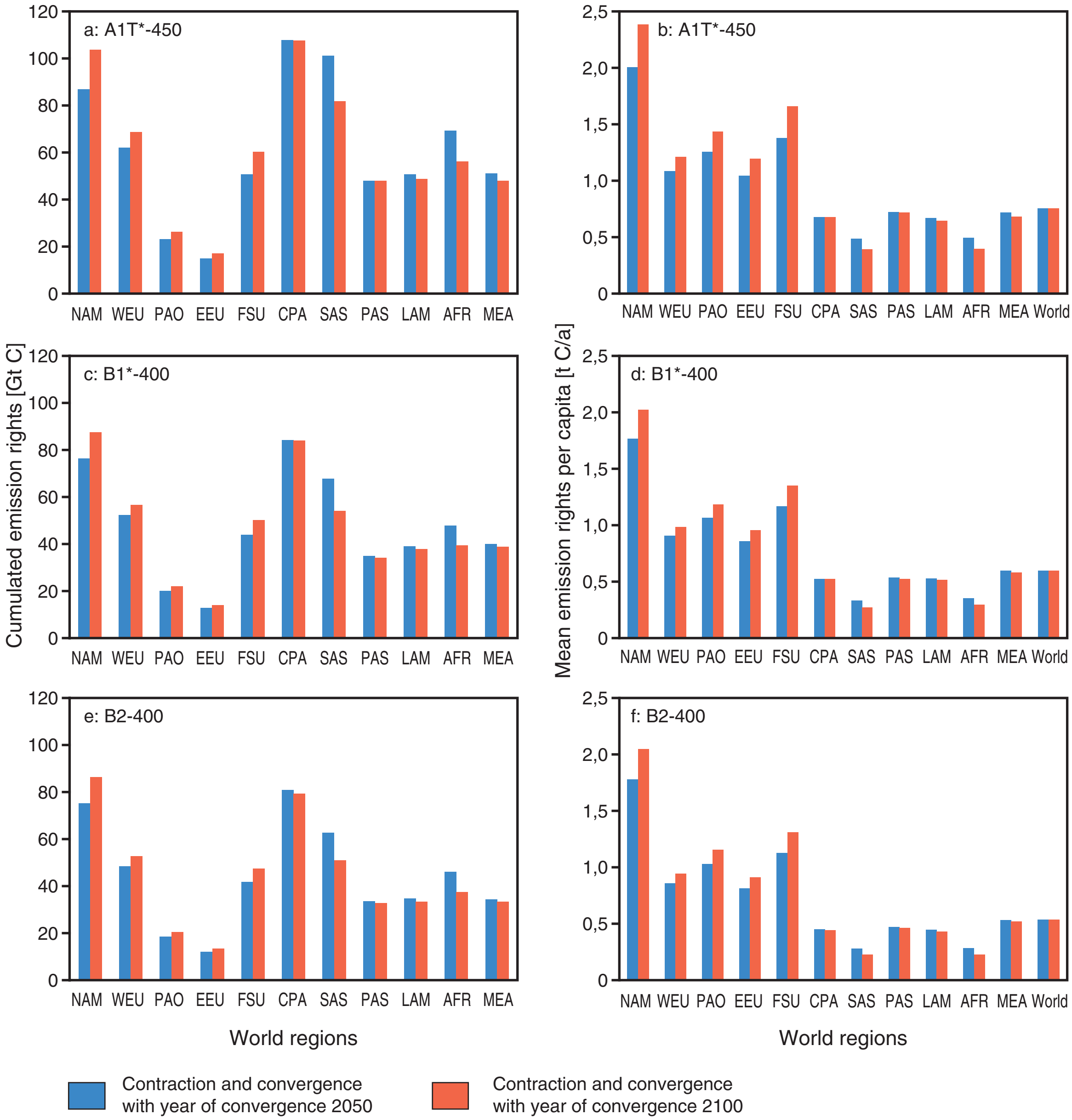


Figure 3.2-3
Emission rights cumulated from 2000 to 2100 (a,c,e) and mean per-capita emission rights from 2000 to 2100. Shown are the values for contraction and convergence in 2050 (blue) and 2100 (red). Nomenclature of scenarios as in Fig 3.1-1, regions as in Fig 3.2-1.
Source: Nakicenovic and Riahi, 2003b

this surplus ends somewhat earlier in scenarios A1T*-450 and B1*-400, especially with a convergence year of 2100 (up to four decades in B1*-400-2100).

3.2.2
Overview of anticipated emissions trading

To achieve contraction and convergence without intolerable economic consequences, it is indispensable to establish a system of worldwide trading in assigned emission rights (Chapter 5). Such a system will benefit developing countries by the middle of the century (Section 3.2.3).

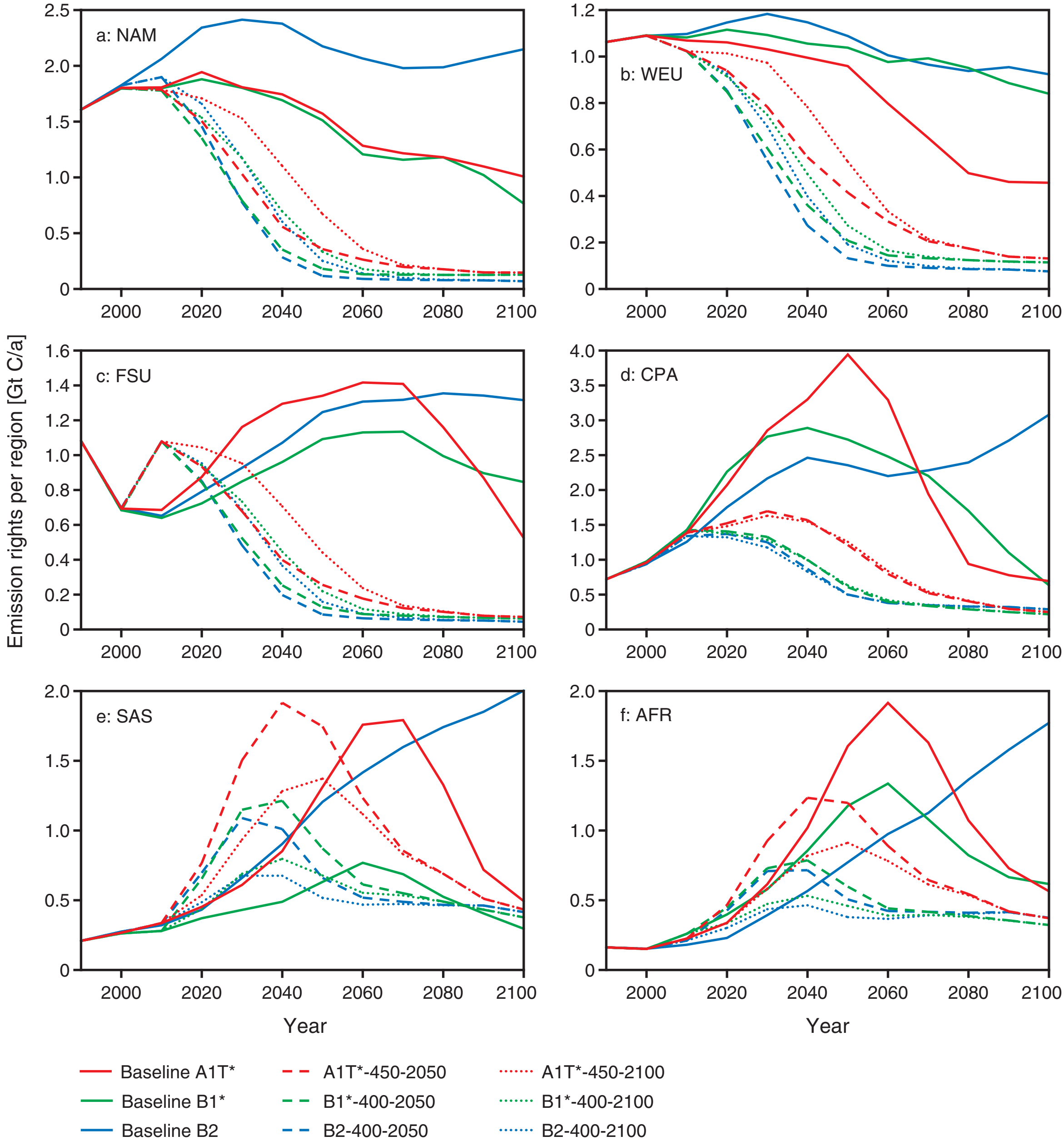


Figure 3.2-4
Development of the emission rights for selected regions and all scenarios with both years of convergence 2050 and 2100. Nomenclature of scenarios as in Fig 3.1-1, regions as in Fig 3.2-1.
Source: Nakicenovic and Riahi, 2003b

For one thing, most developing countries have a low starting level of emissions in their reference scenarios. For another, Latin America, sub-Saharan Africa and South Asia in particular command over major potentials to expand solar energies and biomass. Through the intensified deployment of solar hydrogen and emissions reducing technologies such as carbon capture at biomass-using facilities, which are partly paid for by the revenues from emissions trading in the stabilization scenarios, these regions can stay far below the quantities of emission certificates assigned to them. Particularly in the reduction scenarios that converge by 2050, these regions (Asia, Africa and Latin America) have the opportunity to sell large quantities of emission certificates to the OECD countries (Fig. 3.2-5).

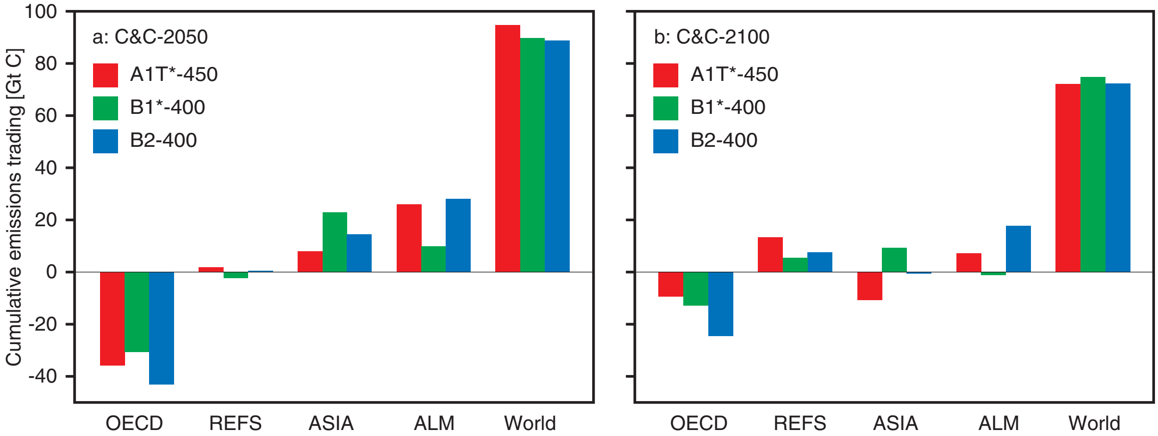


Figure 3.2-5
Cumulative emissions trading in the stabilizing scenarios until 2100. a) Contraction and convergence 2050, b) Contraction and convergence 2100. Nomenclature of scenarios as in Fig 3.1-1, regions as in Fig 3.2-1.
Source: Nakicenovic and Riahi, 2003a

A shift of the convergence year from 2050 to 2100 leads to an allocation of larger quantities of emission rights to OECD countries, and correspondingly smaller quantities to the developing countries. This leads to a decline of the global volume of emission certificates traded.

In an inter-temporal perspective, there are major trade flow differences among all scenarios. Imports to OECD countries peak between 2020 and 2050, particularly in the middle of the century, when particularly strong changes are required in the process of transforming energy systems and the marginal costs in the model rise steeply due to the rapid phase-out of specific technologies (Nakicenovic and Riahi, 2003a). As technologies compliant with the WBGU guard rails are not yet available in sufficient volume at economic prices during this period, demand rises and the price of emission certificates rises steeply (Fig. 3.2-8), up to US$ 600 per tonne carbon in scenario B1*-400 and 400 US$ per tonne carbon in scenario A1T*-450 (Nakicenovic and Riahi, 2003a). This effect does not arise in scenario B2-400, for which the WBGU sustainability guard rails were not integrated.

Trade flows among developing countries are also considerable. The model calculations suggest that in the second half of the century China and the Near East will be the main importers of emission rights from South Asia and sub-Saharan Africa (Nakicenovic and Riahi, 2003a).

Figure 3.2-6 presents a comparison, for the four macroregions, of all nine scenarios analysed (three baseline scenarios and six stabilization scenarios) – showing historical emissions (1800-2000) and cumulative emissions and emission rights from 2000 up to 2100. For the stabilization scenarios, the black horizontal bar shows the level of emission rights. Realized emissions rising above the bar thus indicate the corresponding purchase of emission rights, while if realized emissions remain below it this indicates the sale of a corresponding volume of emission rights, assuming that there is sufficient demand. The difference between the emissions of a baseline scenario and the emissions of the associated stabilization scenarios illustrates the emissions reductions achieved. The figure shows that the contribution of emissions trading is relatively small compared to the volume of emissions reductions. The fears that introduction of a global emissions trading system would lead to only a small part of emissions being reduced and the larger part being purchased with 'hot air' thus proves groundless, at least for the scenarios analysed here.

Figure 3.2-7 illustrates the potential heterogeneity of individual regions within a macroregion, as exemplified by the very different regions South Asia and centrally planned Asia and China. For the above reasons, the realized emissions in South Asia remain far below the emission rights assigned to this region, particularly up to the middle of the century. Centrally planned Asia and China, in contrast, will need to purchase emission rights from 2020 onwards – proceeding from its baseline path, it will be confronted with substantial emissions reductions. This is due to cheap coal, which is used to a greater extent for energy production in the reference scenario, particularly in the first half of the century. In the stabilization scenario, this must be replaced by renewables. Due to the limited potential of some regions for this transformation, centrally planned Asia and China must buy in corresponding quantities of emission rights, which leads to CO_2 trading among developing countries within the same region.

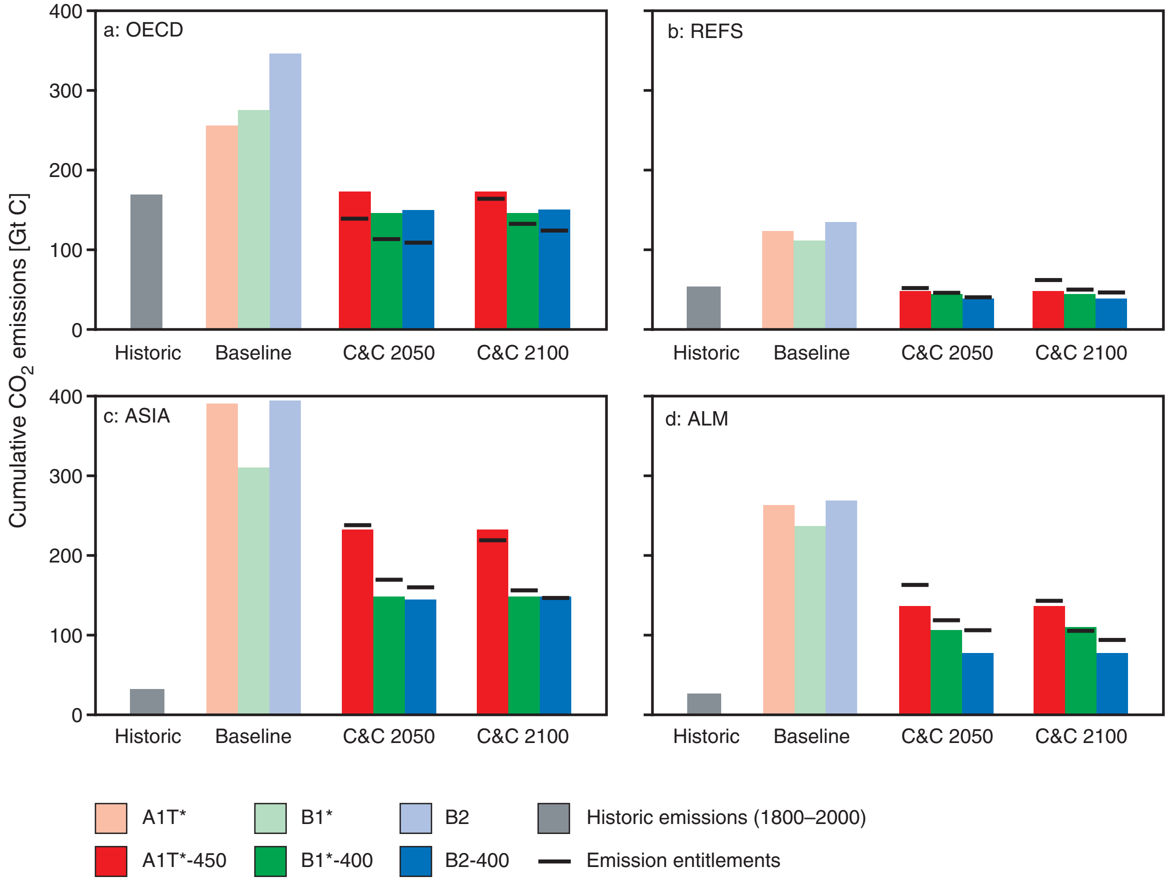


Figure 3.2-6
Cumulative energy system related and industrial CO_2 emissions. Compared are the historic (1800–2000) and future (2000–2100) emissions as well as the emissions for the reference and the stabilizing scenarios. Nomenclature of scenarios as in Fig 3.1-1, regions as in Fig 3.2-1.
Source: Nakicenovic and Riahi, 2003a

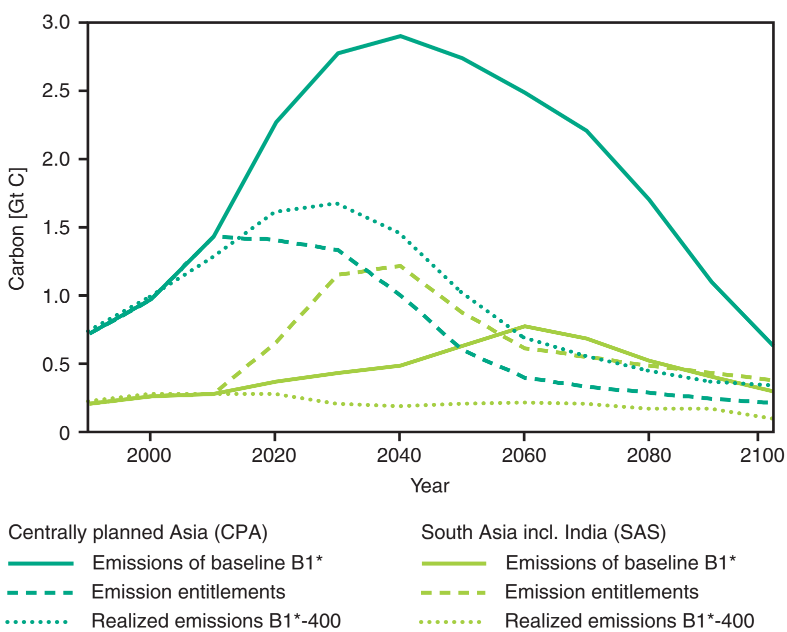


Figure 3.2-7
Comparison of the emissions in the reference scenario B1* as well as the emission rights and the realized emissions in the stabilizing scenario B1*-400. Shown are the values for contraction and convergence in 2050 in the regions CPA and SAS. Nomenclature of scenarios as in Fig 3.1-1, regions as in Fig 3.2-1.
Source: Nakicenovic and Riahi, 2003b

Figure 3.2-8 compares the development of the price of emission certificates for the stabilization scenarios, and illustrates the differences that result from the two selected convergence years. The figure shows clearly that the price is determined primarily by the underlying reference scenario. Variation of the convergence year produces scarcely any differences. The certificate price develops relatively similarly in all scenarios up to 2040. In the period from 2040 to 2060, a differentiation occurs, above all between the B2-400 scenarios on the one hand, which are subject to no WBGU sustainability guard rails whatsoever and are thus more favourable until then, and the A1T*-450 and B1*-400 scenarios on the other. This is because the phase-out of non-sustainable technologies by 2050 produces peak marginal costs in A1T*-450 and B1*-400, and thus high certificate prices. After 2060, the situation is reversed: The price of emission rights in scenarios A1T*-450 and B1*-400, whose storylines have greater dynamics in the development of new technologies, drops, while it continues to rise in scenario B2-400. The steep price increase in B1*-400 after 2090 is due to the phase-out of sequestration by 2100, a guard rail set for neither scenario B2-400 nor for A1T*-450. Without this guard rail, the price of emission certificates in scenario B1*-400 would be – despite the lower targeted CO_2 concentration level – approximately in the region of the price in scenario A1T*-450. This can be taken as an indication that in a sustainable scenario stabilization costs develop more favourably (Sections 3.1 and 3.2.3).

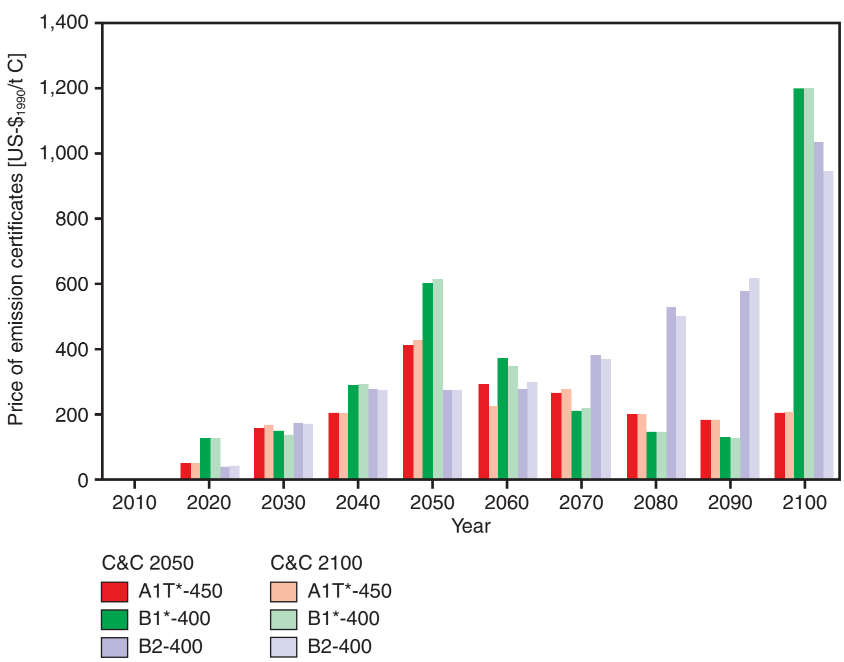
3.2.3
Overview of anticipated economic effects

To calculate the effects of reduced emissions and convergent per-capita emission rights upon the gross domestic product of regions, the following analysis examined the revenues and expenditures resulting from emissions trading, and the energy system costs derived from MESSAGE and MACRO iterations (Section 3.1). This did not take into account the external costs of climate damage and adaptation measures prevented by climate change mitigation, nor the external benefits of mitigation, e.g. in the form of prevented air pollution.

The expectation is frequently voiced that an allocation of emission rights according to a contraction and convergence (C&C) approach will lead to high financial transfers from industrialized to developing countries. While such transfers do indeed take place through emissions trading, this effect is only distinct if the convergence year is 2050 and if stabilization scenario B2 is used (Fig. 3.2-9).

In all C&C-2050 scenarios, the transition countries experience net losses. Russia, for instance, is able to sell 'hot air', particularly in the first decades of the century. This is a period characterized by relatively low prices for emission certificates. However, due to a lack of technological adaptation towards low-emission or zero-emission energy sources as assumed in the models – possible until then due to the use of large domestic gas reservoirs – certificates will need

Figure 3.2-8
Development of prices of emission certificates in the stabilizing scenarios for contraction and convergence in 2050 and 2100.
Nomenclature of scenarios as in Fig 3.1-1.
Source: Nakicenovic and Riahi, 2003b



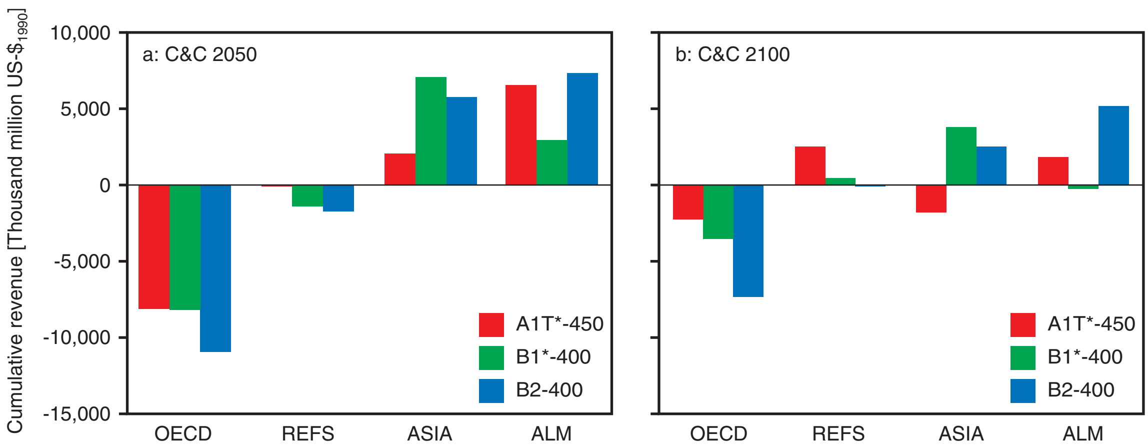


Figure 3.2-9
Cumulative revenue from emissions trading in the stabilizing scenarios shown for the macro regions and the stabilizing scenarios. Nomenclature of scenarios as in Fig 3.1-1, regions as in Fig 3.2-1.
Source: Nakicenovic and Riahi, 2003a

to be purchased in a period in which the price rises steeply.

In total, emissions trading leads by 2100 to a transfer from OECD and transition countries towards developing countries amounting to some US$ 8,000–13,000 thousand million. This corresponds – with major temporal fluctuations – to US$ 84–128 thousand million per year (Nakicenovic and Riahi, 2003a). By way of comparison, official development assistance in 2000 amounted globally to US$ 53 thousand million.

The analysis, however, reveals that the financial transfers resulting from emissions trading do not cover the reduction costs with which the developing countries are confronted. Nor do they cover the losses suffered by regions rich in resources (coal and oil), due to the lack of exports. As these regions must abstain from their readily available energy sources, they are increasingly dependent on the additional purchase of energy carriers such as liquefied petroleum gas or bioalcohol.

Figure 3.2-10 shows the effects on GDP for the years 2020, 2050 and 2100 for all six reduction scenarios. This confirms the high costs in the middle of the century and the finding that the level of economic effects is determined primarily by the baseline scenario – such as the economic implications of the steeply rising marginal costs from 2050 as a result of the rapid phase-out of non-sustainable technologies in the B1* and A1T* scenarios, or the high burden in the B2 scenarios as a result of the low technological dynamics of the storyline. Similarly, the previously noted influence of the convergence year is apparent in the slightly less negative values for developing countries if convergence is by 2050 and for industrialized and transition countries if convergence is by 2100 – whereby these differences are slight compared to the above-mentioned differences determined by the baseline scenario.

The gains of South Asia are striking, which are very high in 2020, particularly in the A1T*-450-C&C-2050 and B1*-400-C&C-2050 scenarios (approx. +5% and, respectively, +4% compared to the baseline scenarios). In 2050, these gains amount to more than 4% in scenario B1*-400-C&C-2050 and more than 2% in scenario B1*-400-C&C-2100. This can be explained by the high quantity of emission certificates available for sale (Section 3.2.2).

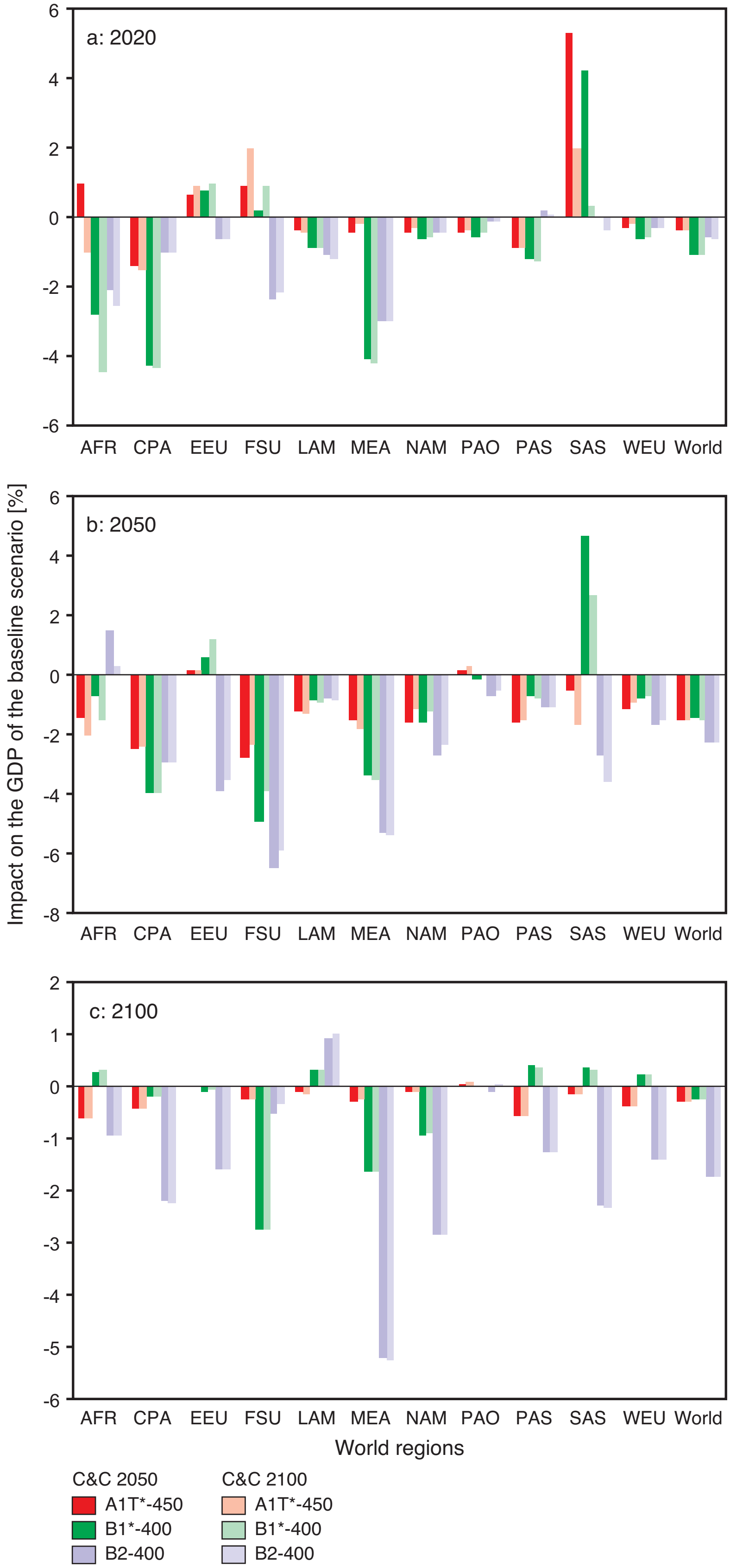
By 2100, negative economic effects drop to very low values in the stabilization scenarios A1T*-450 and B1*-400 for almost all regions. This is due above all to dynamic learning processes that follow massive investment in renewables. Solar electricity production and solar hydrogen generation play a key role in this context (Section 3.1.2.2). Only the resource-rich former Soviet Union (natural gas) and Middle East and North Africa (mineral oil) regions suffer losses amounting to almost 3% and, respectively, just under 2%. This is due to their foregone revenues from resource exports.

3.3 Conclusions

Comparative analysis of the model findings reported above (Nakicenovic and Riahi, 2003a, b) leads to the following conclusions:

The CO_2 emissions prevented compared to a world without climate change mitigation can be grouped in three categories: Demand reduction due to higher prices, structural change (particularly the

Figure 3.2-10
Effects on GDP stabilization in the years 2020 (a), 2050 (b) and 2100 (c) for the IIASA world regions in the stabilizing scenarios. Shown are the deviations from the expected GDP of the reference scenario. Remarkable are the high costs in B2-400. Nomenclature of scenarios as in Fig 3.1-1, regions as in Fig 3.2-1.
Source: Nakicenovic and Riahi, 2003a



intensified deployment of renewable energy forms and of low-carbon conventional technologies) and CO_2 sequestration. Energy efficiency improvements fall into the first two categories.

Mitigation-related energy price increases have only a relatively weak demand-reducing effect in all CO_2 stabilization scenarios. The contribution of carbon sequestration remains at a high level at the end of the century if it is not restricted exogenously (as in B1*-400). Structural changes are very similar in all worlds studied. Figure 3.1-3 illustrates their characteristic features: With the exception of the B2 baseline scenario, the energy systems of all worlds studied move far towards carbon-free systems by the end of the 21st century. Structural change towards carbon-free systems takes the following course:

- The reduction of carbon intensity in the fossil sector is achieved through intensified use of gas, at the expense of oil and coal. Coal use, in particular, practically expires by the middle of the century in all CO_2 stabilization scenarios (A1T*-450, B1*-400) or at least drops to very low levels (B2-400). This implies that if ambitious mitigation targets are set over longer time scales, even the most technologically advanced coal-fired power plants are not a sustainable technology.
- In all mitigation scenarios studied, an electricity/hydrogen economy emerges in the final energy sector. This is particularly pronounced in A1T*-450 and B1*-400. The launch of the electricity/hydrogen economy is in all cases initially based upon hydrogen from fossil sources. The technologies to produce this are already available today on an industrial scale. This is the only way by which to restructure the final energy sector in time. Over the long term, electricity and hydrogen supply becomes largely based on solar technologies in A1T*-450 and B1*-400, while in B2-400 hydrogen production based on carbon feedstocks remains important.
- In A1T*-450 and B1*-400, in particular, energy supply is based essentially on solar electricity and solar-produced hydrogen by the end of the century. This supply-side dominance implies major dependency upon the corresponding technological processes – processes which are still at the beginning of their development trajectory today. It is therefore essential to expand considerably global research efforts in this field in order to underpin this path.

If the global emissions budget is distributed among individual countries or regions according to the contraction and convergence approach, the selected convergence year (the years 2050 and 2100 have been examined in the present study as representative examples) modifies emission rights endowments and economic implications significantly at the regional level.

If per-capita emission rights converge only by 2100, then this reduces the reduction commitments of industrialized and transition countries. Conversely, if convergence is delayed until that date, the developing countries receive correspondingly less emission rights and are subjected to higher economic burdens than they would be if per-capita emission rights were to converge by 2050.

To prevent dangerous climate change, the WBGU thus recommends to urge for an allocation of emission rights following the contraction and convergence model, with per-capita emission rights converging by 2050 in the second commitment period of the Kyoto protocol. In addition to focussing clearly on the target of reducing CO_2 emissions, this approach also embraces the attempt to implement, to the largest degree possible, the fundamentally equal right of all individuals to emissions.

Promoting global technological and economic convergence, as well as sustainable development, and securing a viable emissions trading system are the key points of departure in order to attain this goal at least cost.

4.1 The global carbon balance

The surface of the Earth (land and ocean) has been a net carbon sink of 2 to 4 Gt C per year between 1990 and 2000 (Schimel et al., 2001). This sink reacts sensible to climate events and human activities. Its size ranges from years in which almost all the fossil fuel emissions are reabsorbed (Fig. 4.1-1a) to other years in which the sink capacity of the earth surface is almost zero (Prentice et al., 2001). A large fraction of these oscillations has been associated with El-Niño and major biomass-burning events. Presently we are in a period of a strong but declining net surface sink (Rödenbeck et al., 2003).

Despite all changes, the global surface sink, on average, has increased proportionally to fossil fuel emissions and the carbon fraction remaining in the atmosphere has been surprisingly constant at 40% over the last 40 years, apart from El Niño and fire-dependent short-term variability (Fig. 4.1-1b). This means

- that the global net surface sink has continued to increase with fossil fuel emission and atmospheric CO_2 concentration, and
- that the global surface has not been saturated with CO_2, and it is uncertain at present if and when this will happen.

The partitioning of the earth surface CO_2 flux into oceanic uptake and land surface uptake has been subject to long debates. Schimel et al. (2001) conclude that in the 1990s the flux into the ocean has been fairly constant (1.7 to 1.9 ± 0.5 Gt C per year), while the net flux from the atmosphere into terrestrial systems has been much more variable (0.2 to 1.4 ± 0.7 Gt C per year).

The global carbon balance as summarized in Table 4.1-1 contains the regional variation in fossil fuel emissions as well as in biospheric uptake of CO_2. The emissions, originating in large part from the USA and Europe, lead to an increase of the atmospheric CO_2 mass by 3.2 ± 0.1 Gt C per year. The oceans and the

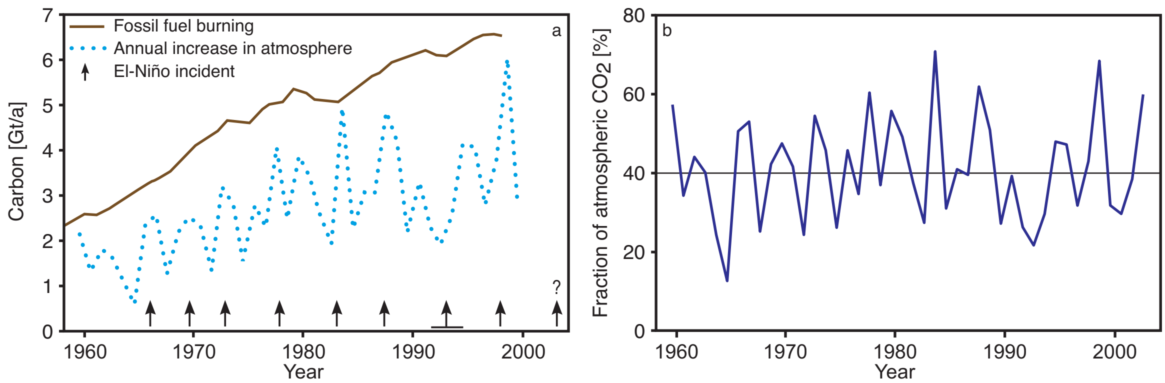


Figure 4.1-1
a) Fossil fuel emissions and increase of CO_2 concentration in the atmosphere. Arrows on the x-axis indicate El-Niño incidents. A high rate of CO_2 increase indicates a low surface assimilation. The difference between the fossil fuel emissions curve and the atmospheric increase depicts the global surface sink.
b) Fraction of fossil fuel emissions measured as increase in atmospheric CO_2 concentration from 1960 to 2002.
Source: a) after Prentice et al., 2001 b) Heimann, personal communication

Table 4.1-1
The global carbon balance for the period 1990 to 2000. Source: after Schimel et al., 2001

	[Gt C a^{-1}]	[%]
Fossil fuel emissions	6.3 ± 0.4	
USA	1.6	25
EU-15	1.1	17
Russia	0.8	13
Germany	0.3	4.8
Atmospheric CO_2 increase	3.2 ± 0.1	
Net uptake of the oceans	1.7 ± 0.5	
Net uptake of the continents	1.4 ± 0.7	
Emissions due to land-use change	1.6 ± 0.8	
Assimilation by vegetation	3.0	
USA	0.8	27
Europe	0.4	13
Siberia	1.3	43
Tropics	0.5	17

continents absorbed 1.7 ± 0.5 Gt per year and 1.4 Gt ± 0.7 Gt per year respectively. The contribution of the continents is a net balance between the assimilation by the present terrestrial systems (3.0 Gt C per year) and emissions from land use change (1.6 Gt C per year). It is important to recognize that the CO_2 assimilation of the land surface is not constant and exhibits substantial regional variations. Siberia, consisting mainly of natural unmanaged forest, contributes most (43%) to the net global terrestrial assimilation. From Table 4.1-1several conclusions can be drawn:

- The land surface of the USA re-assimilates about half of the US emissions.
- The land surface of Europe re-assimilates a good third of the European emissions.
- The surface of Europe and Russia jointly re-assimilate 89% of the emissions from these territories, mainly in the pristine boreal forests. This emphasizes the global importance of unmanaged primary forests.
- Given the fact that the allocation of carbon emission between atmosphere and global surface is constant, we conclude that the boreal forest and its soil is not carbon saturated.
- The emissions from land-use change originate mainly from utilizing primary forest, adding 25 ± 12% to the global emissions. Thus the effect of land-use change is 5 times larger than defined in the Kyoto Protocol, and it will continue to be a source for the foreseeable future.

Current scientific knowledge of the global carbon cycle reinforces the need to take land use and the terrestrial carbon balance into consideration for management of the global carbon budget.

Fig. 4.1-2 describes the different component fluxes involved in the terrestrial carbon balance. The net biome production (NBP) would be the appropriate parameter to consider when calculating the sink strength of a region or country. The atmosphere does not 'see' net primary production (NPP) nor net ecosystem production (NEP), but only NBP.

Ciais et al. (2003) compared NPP and NBP for the Amazonian, the Siberian and the European forests (Fig. 4.1-3). NPP is about 10 times larger than NBP. While NPP of the Amazon is twice that of Europe and exceeds NPP of Siberia by a factor 3, the rate of NBP of the Amazon is even lower than that of Europe and Siberia.

While in the Amazon region NPP and NBP can be explained by the observed increase in CO_2, this is not the case in Siberia. Here they are most likely related to increasing temperature. In Europe, the situation is mixed. In contrast to models and inventories, case studies indicate a strong CO_2 effect. The effect is probably due to nitrogen deposition from the atmosphere. Hence: The global carbon sink is much larger than the 'Kyoto sink' because the Kyoto Protocol refers to small parts of the land surface only. Regions behave differently. High CO_2 concentration can explain NPP in the tropics but not in Siberia. In Europe, the sink is influenced by direct and indirect human interventions.

4.2 The terrestrial carbon flux balance

The global carbon cycle is characterized by large fluxes towards the Earth surface and away from it, connecting huge terrestrial and oceanic carbon stocks with relatively small atmospheric carbon stocks (Fig. 4.2-1). The net fluxes are the difference between these large directional fluxes. Thus, the system is highly sensitive because small changes in the directional fluxes may cause large disturbances in the net flux.

In the context of the Kyoto Protocol, we would like to point to the very large carbon stocks in the terrestrial biosphere. The carbon pool in plant biomass

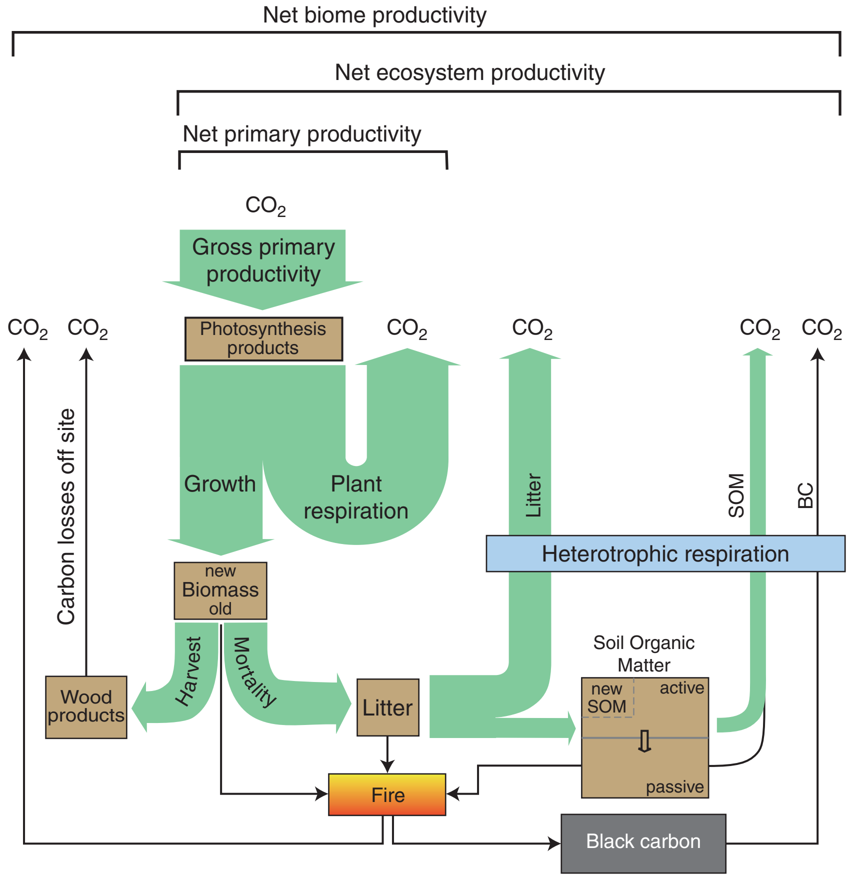


Figure 4.1-2
Carbon fluxes of ecosystems and definitions to describe the component fluxes.
Source: after Schulze et al., 2000

(560 Gt C) is almost as large as the atmospheric one (750 Gt C). Plant biomass mainly consists of wood, and the greatest part of this is stored in unmanaged primary forests (IGBP, 1998). The emissions caused by land-use change (Table 4.1-1) refer mainly to the destruction of this resource. Soils contain twice as much carbon as the atmosphere, and land-use change may release up to 50% of the soil carbon stocks (e.g. through ploughing of natural grasslands). Carbon stocks have been influenced in the past above all by land-use changes, which have had a greater impact than climatic effects. This problem is not limited to the less developed part of the world but also involves industrialized nations. The building of infrastructure (e.g. surface sealing by road construction) in industrialized nations consumed large amounts of soil carbon, which were not equilibrated by afforestation over areas of equivalent size.

Depletion and recovery of ecosystem carbon stocks are highly asymmetric. While depletion can be nearly instantaneous, e.g. by fire (clearing of land in the tropics), recovery may take centuries. Effects of land-use change on soil carbon stocks in Germany can be detected even after centuries (Wirth et al., 2003; Fig. 4.2-2).

The natural carbon accumulation in soils is very slow, ranging from about 0.5 t C per ha and year during recovery from previous agricultural use for approx. 100 years (Jenkinson et al., 1992) to about 0.05 t C per ha and year during forest recovery within one rotation period in managed forests (Mund and Schulze, 2003). Areas under continuous observation in England – the famous Rothamsted Experiment – show that even more than 100 years after conversion from arable land to grassland, carbon accumulation does not reach saturation, and disturbances introduced experimentally 100 years ago are still detectable today in the soil carbon stocks.

The effects of fire are even more complicated. Ground fires lead to a growth depression of the remaining stand which is followed by increased growth due to improved cation supply. Soil carbon may initially increase due to the production of charcoal. However, a subsequent fire could consume this charcoal layer again. Thus the total amount of charcoal appears to be constant, unless the charcoal is cut off from atmospheric oxygen through erosion processes (Czimczik et al., 2003).

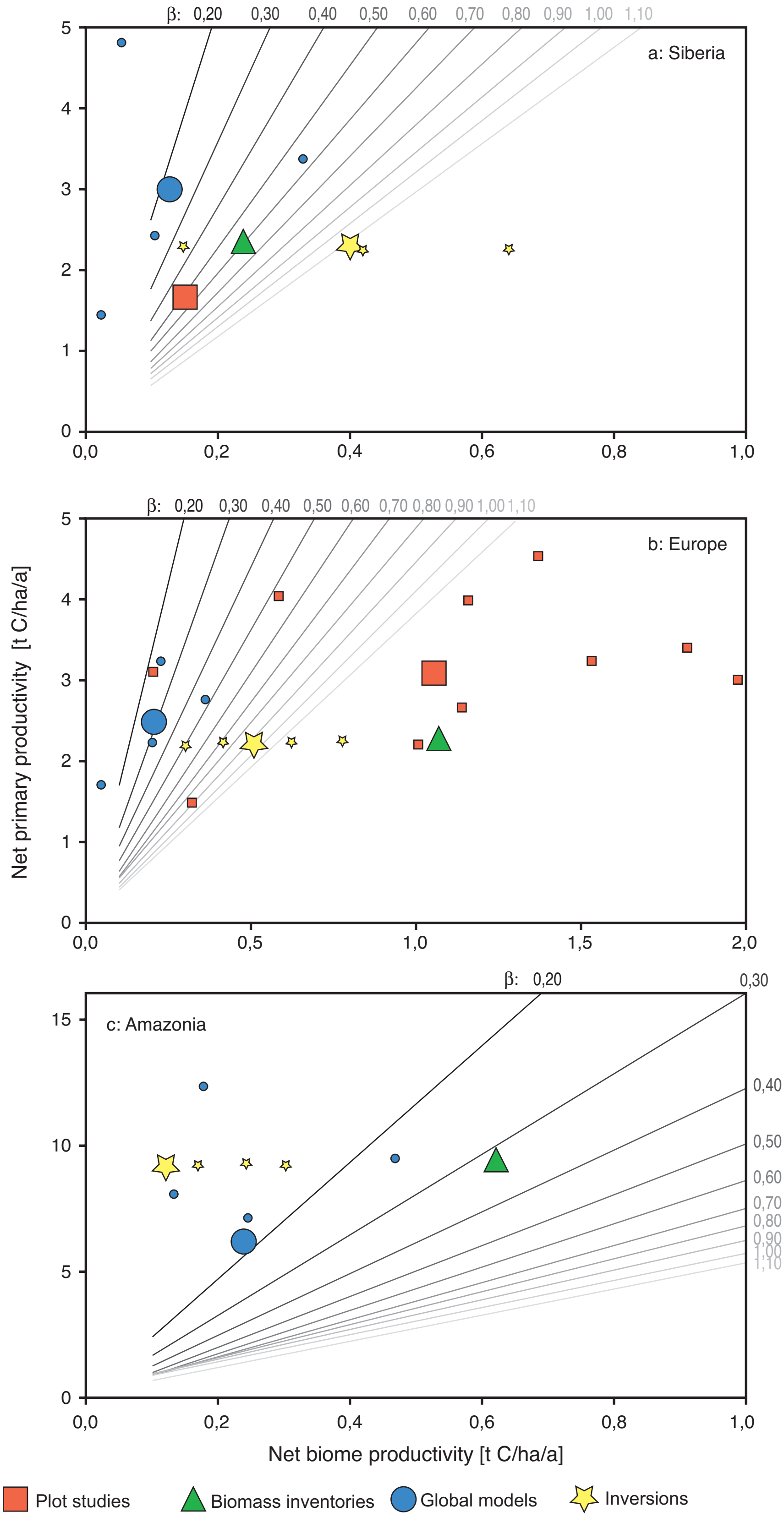
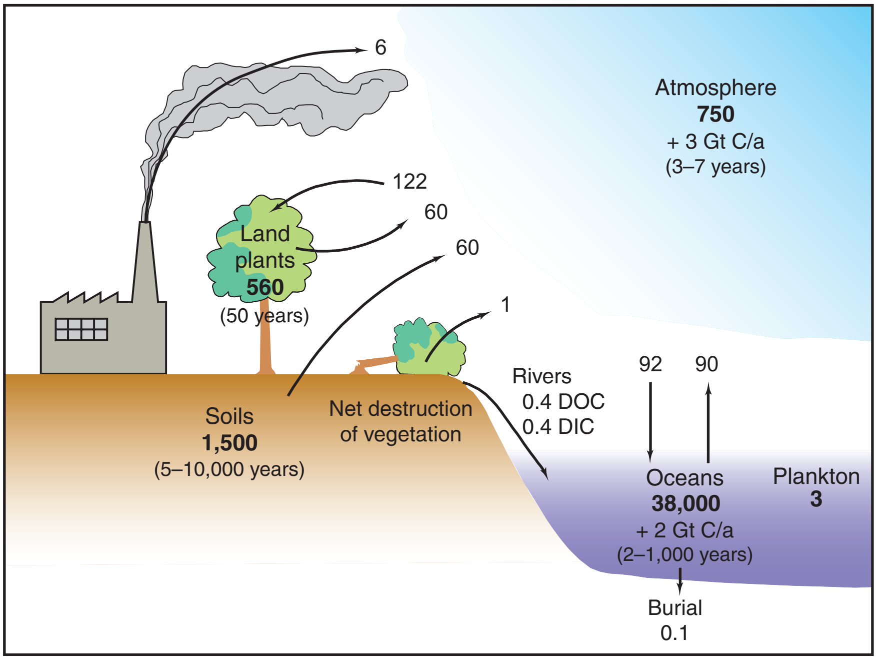


Figure 4.1-3
Comparison of net primary productivity (NPP) and net biome productivity (NBP) in Siberia, Europe and Amazonia, based on plot studies, large-scale biomass inventories, global models and inversion calculations based on CO_2 measurements in the troposphere.
The gradients show the changes in NPP and NBP that follow from a doubling of CO_2 concentration (350 to 700 ppm), the so called fertilization factor β. Experiments show that a doubling of CO_2 concentration leads to an increase of NPP by 20–40%. The position of points below or above the 0.2-β-line indicates whether the NPP can be explained by the change in CO_2 concentration.
Source: Ciais et al., 2003

Figure 4.2-1
The global carbon cycle with carbon stocks and fluxes. Stocks are shown bold in Gt C, fluxes in Gt C per year and printed in normal. Numbers in paranthesis are mean residence times. The flux into the soil is estimated at 1.5 Gt/a. *DOC* dissolved organic carbon, *DIC* dissolved inorganic carbon. Source: after Schlesinger, 1997



4.3 Regional carbon balance assessments

Only few regional carbon balances are presently available. The European carbon balance is presented as an example. Janssens et al. (2003a) conclude that the European biosphere absorbs 7 to 12% of European anthropogenic CO_2 emissions. This estimate is considerably lower than the 36% (Table 4.1-1) given by Schimel et al. (2001). Above all the emissions from agricultural soils have been underestimated in the past. This means that the figures presented by the IPCC (2001a) must be revised.

A share of 7 to 12% may not appear large at first glance, but this is 3 to 4 times as much as the fossil fuel emissions presently avoided by using hydropower. Thus the European biosphere is very efficient, but the sink is only partially accountable under the Kyoto Protocol. Based on current land-based measurements, the forest sector in Europe is estimated to be a sink of about 380 Mt C per year (flux from the atmosphere to the ground) whereas agriculture is considered to be a source of 200 Mt C per year (flux from the ground to the atmosphere). The figure for agriculture refers to stock changes in soils. It does not contain the emissions from animal farming and manure, nor the emissions of other greenhouse gases (CH_4 and N_2O) from animal farming, pastureland and cropland. Thus the overall agricultural greenhouse gas emissions are even higher.

Europe consists of a mosaic of different land-uses. An accurate assessment of land-use data as well as information on agricultural and forest management strategies is crucial in estimating reliably the net carbon balance of this region. The regulations concerning the accounting of sources and sinks from forestry and agriculture according to the Bonn Agreements negociated at COP 6 to UNFCCC are sector-specific and do not help to assess such a net carbon balance. In forestry the change in woody biomass in the commitment period is accountable if the change was initiated by human induced activity after 1990 (gross-net approach). Only 15% of the gross change is accountable in order to exclude indirect effects of global change (increased CO_2 and N deposition). In contrast, in agriculture the net change in 1990, which could be an emission, is compared with the net change in the commitment period, which could again be an emission, and if the emissions rate has improved in comparison with the 1990 figure, the difference is accountable (net-net approach). Therefore, although ground-based estimates including land-use data are currently submitted to the UNFCCC data base via National Reports, and carbon sources are in principle to be included in these reports, only few countries have done this so far. Thus for agriculture, the net-net approach pursuant to Article 3.4 may create a false impression since a reduction of the source will be accounted as a sink, although in fact the system remains a source. There is no mandatory emission reduction commitment in agriculture. There are also no incentives to avoid carbon emissions in the forestry sector, e.g. the increased use of small trees produced during short rotation periods causes a substantial emission by the forestry

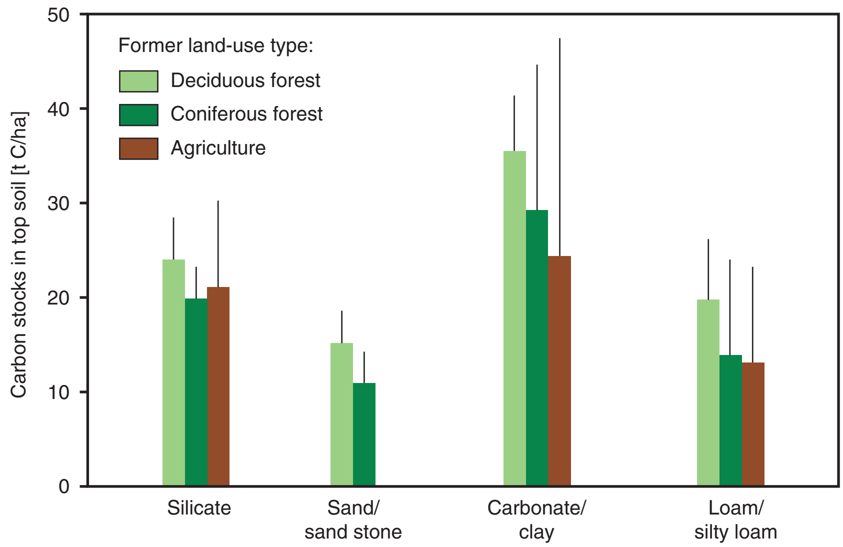


Figure 4.2-2
Carbon stocks in topsoil (0–10 cm) under forest as a function of different land uses in the past with standard deviation. Data for Germany.
Source: after Wirth et al., 2003

sector, but may appear to be an increased sink in the commitment period.

It emerges that European countries differ greatly in the comparative balance they achieve between forest sink and agricultural source. The 'winners' are countries like Austria, Slovenia and Slovakia due to their extensive forest areas (Fig. 4.3-1). In contrast, small countries with a high population density, little forest but large areas of arable land or countries with significant amounts of disturbance or use of wetlands appear as net carbon emitters. Trade of food and wood products increases carbon emissions in many countries.

4.4 Verification issues

The worry that forest sinks may not be verifiable has lead to some of the decisions in the Bonn Agreements (Schulze et al., 2002). In the meantime, verification mechanisms have been developed; however, these are still scale dependent. For small-scale (plot size) assessments, sound statistical approaches have been developed to verify even minimal changes in biomass. The verification of changes in soil carbon remains a difficult issue. This is important, because compartments which do not appear to be sources need not be reported under the UNFCCC regime. If an inappropriate statistical approach is used, changes can go un-reported, even if the soil has become a source. However, similar approaches for verification of soils are currently under development. The same approaches as for plot scale can be used at regional scale.

For regional, national and continental scale assessments, the EU has initiated tall tower observations across Europe and regular flights to sample tropospheric air above the continent. Given the very large footprint of these towers (500 km diameter) and the high precision of trace gas measurements, they could become the backbone of a future monitoring network which would scrutinize by independent assessment the chemical status of the atmosphere. The tall towers primarily measure concentrations and not fluxes. The concentration of greenhouse gases in the atmosphere – the target of climate protection efforts – is the outcome of the sum of fluxes resulting from burning fossil fuels, land use and forestry. Concentrations are thus the ultimate parameter indicating whether measures initiated under the Kyoto Protocol are effective. Moreover, various attributes (isotopes, correlating trace gases) can be used to deduce changes in sources.

In its 6th Framework Programme, the EU has initiated research in Europe that will measure carbon changes at plot and at regional scale with 10% accuracy by combining ground-based and atmosphere-based measurements.

4.5 Assessment of the present Kyoto Protocol with regard to carbon sinks

4.5.1 Problems arising from the history of the Kyoto Protocol

The Bonn Agreements (COP 6) and the Marrakesh Accords (COP 7) have been critically assessed by Schulze et al. (2002). One critical point originates from the history of the Kyoto Protocol. While some

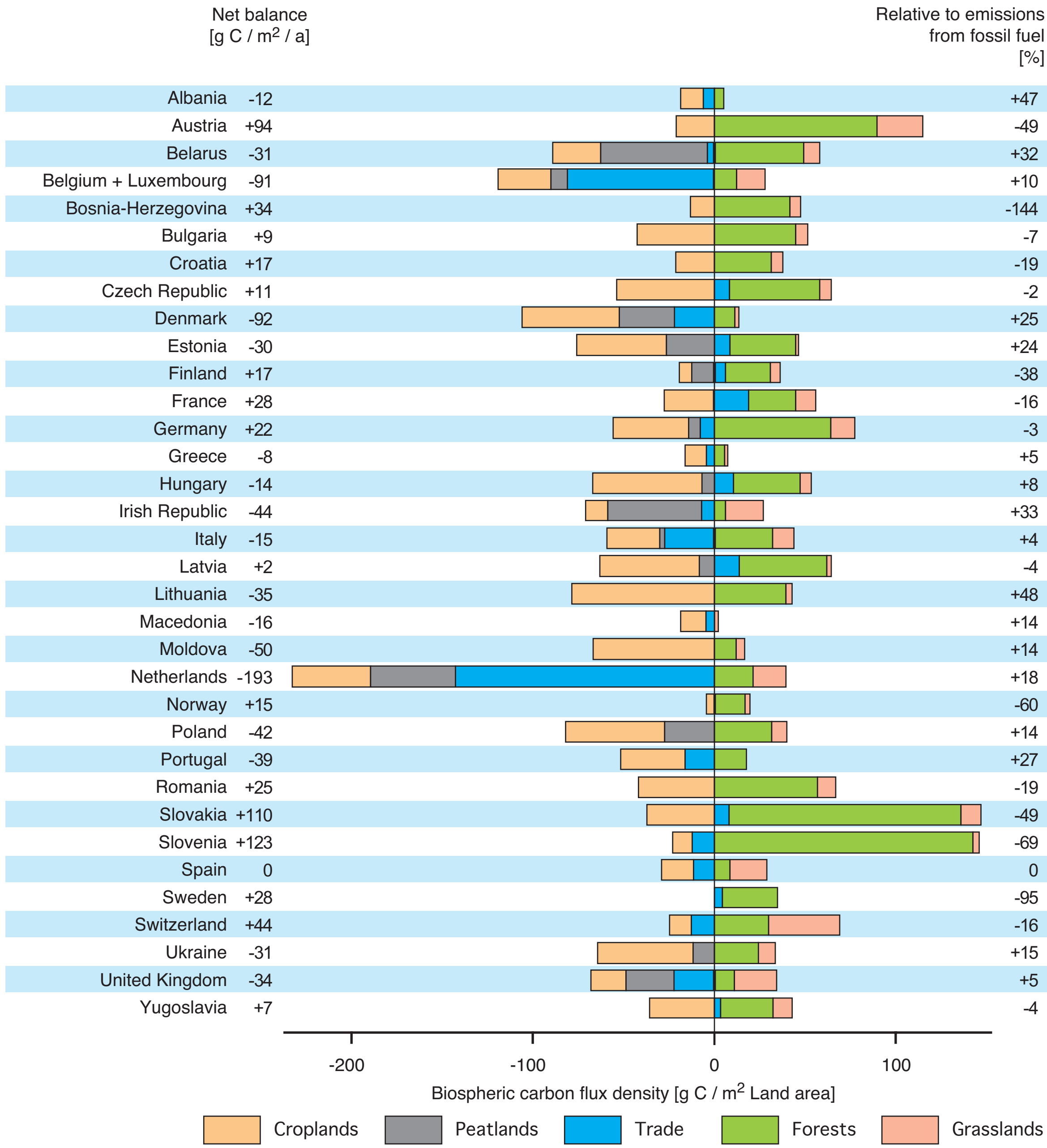


Figure 4.3-1
The carbon balance of the terrestrial biosphere for different European countries. The total net balance is presented both in absolute numbers as well as relative to fossil fuel emissions. The net balance results from a source of carbon mainly from agriculture and a sink mainly provided by forests and grasslands. Trade includes nunmbers for food and wood products derived from national statistics. Positive numbers indicate a sink.
Source: Janssens et al., 2003b

nations voted for the option to include sinks arising from agricultural or forest management as well as afforestation and reforestation, others aimed at restricting these options to a very limited amount of the total emission reductions in order not to soften the reduction commitments for fossil fuel emissions. It was thus decided that 'the mere presence of carbon stocks be not accountable.' Once intended to restrict measures other than direct emission reductions, this sentence from the preamble of the Bonn Agreements leads to substantial problems related to reducing emissions to the atmosphere. The carbon stocks in the carbon cycle, which are mainly located in pristine forests but also in temperate, sustainably managed forests (where they may change following economic impacts) are not acknowledged. Therefore no incentives exist to prevent these stocks from being lost if forests or peatlands are converted into arable land or plantations. The problem of accounting in Annex-I and in non-Annex-I nations is presently being evaluated by the IPCC in a Good Practice Guidance report. The following examples provide some insights into the developments and risks of the Kyoto agreement in its present form:

- The inclusion of afforestation and reforestation bears the danger of losing pristine forests or peatlands to forest plantations containing and assimilating much smaller amounts of carbon than the natural ecosystems. Afforestation of peatland (Cannell et al., 1993) is likely to reduce soil carbon stocks while increasing less permanent carbon stocks in biomass and litter. Moreover, biodiversity of the concerned ecosystems might be threatened seriously.
- Reforestation of grasslands and croplands may lead to either an increase or decrease in soil carbon stocks, depending on climatic factors, the land-use preceding afforestation and the initial soil carbon stocks (Vesterdal et al., 2002; Paul et al., 2002). For instance, Jackson et al. (2002) reported soil carbon changes ranging from -61 t C per ha to +13 t C per ha within the first 30 to 100 years after afforestation of grassland – in most regions losses prevailed but gains were reported from dry regions.
- Balancing deforestation and reforestation for a certain region often results in negative carbon stock changes because stocks lost due to forest destruction are usually greater than gains in newly forested areas, especially if old-growth forests are replaced by short-rotation plantations. Germany serves as an example: 1,080 ha were deforested from 1991 until 1999 for highway building projects in the new Länder. At the same time, 2,850 ha were afforested. Superficially, this would be a positive forest balance. However, taking the average aboveground carbon stock (82 t C per ha) and the average soil carbon stock (107 t C per ha) as the basis, the carbon loss despite reforestation totalled 146 Kt C, assuming 50% loss from soils upon deforestation as well as carbon loss from soil after afforestation. It will take more than 500 years until changes in soil carbon are balanced. Literature values for losses upon cultivation of previous forests range from 24% in a review by Murty et al. (2002) to 63% over 90 years in a study of US agroecosystems (Kucharik et al., 2001). These examples illustrate the problem of defining a baseline, particularly as deforestation and afforestation activities take place on different land, and at different times.
- ARD (Afforestation, Reforestation and Deforestation) in CDM countries: Schulze et al. (2003) showed that reforestations which were carried out in tropical regions after previous deforestation had a negative net carbon balance. Large areas in the tropics are covered with *Imperata cylindrica*, a very invasive grass species of little feed value. Its aboveground biomass amounts to 8.5 t C per ha, which is periodically released to the atmosphere when grasslands are burned to improve food quality for livestock. Is reforestation of these vast areas an option to increase carbon stocks, or is it better to use *Imperata* which, as a C4 grass, has a higher NPP than that of a forest? This is what is currently being done with the grass *Stipa tenesissima* in Algeria.
- The human induced carbon storage component was restricted for forestry to 15%, which was the result of negotiations assuming that only 15% of the forestry sink related to human activities since 1990 be accountable. The actual carbon sequestration in forestry due to management decisions since 1990 actually exceeds this fraction (Wirth et al., 2003).

Fig. 4.3-1 already shows that there is a large potential for management to enhance the European net carbon sink. However, it remains debatable what the right tools are:

- *Agriculture:* It has been suggested to use low tillage as tool for reducing carbon emissions. This practice, however, will either require greater use of herbicides together with genetically modified cultivars that are herbicide resistant, residue burning or a crop rotation that requires deep ploughing periodically. In many areas of Europe, sugar beet, potato or other tuberous crops are rotated with grain crops, and this requires ploughing that will release the carbon saved by low tillage. Rotation of agriculture and pasture, especially using lucerne, may offset losses, which however increase if other greenhouse gas emissions are added. Options to increase carbon storage must also be evaluated with a view to the contribution of agriculture to the energy sector.
- *Forestry:* Many options have been considered to increase the forest sink. At this stage, it remains unknown if there is an upper limitation in the potential sink of forest soils. Wirth et al. (2003) ran models across the following options for biomass, which generally show that it is difficult to increase the biomass in German forests, since the stocking rate is high already, and sustainable management has been a primary goal for some time. The following options are discussed:

Changes in the length of the rotation period

Increasing forest age in a rotation forest will increase the forest sink in the short term. This leads to an uneven age structure transitionally, which will cause oscillations and a change from a sink to a source in the long term. However, it also leads to an increase in the volume of wood products, a part of which replace fossil fuels. Moreover, current trends in the forest industry point to the opposite development. Especially in the case of heartwood trees, small trees with a high proportion of sapwood (easy to treat with chemicals) have come to make up a high market share. The management aim for pine is early harvesting of immature stands. This change in management will result in a major loss of carbon stocks, including in soil. It could substantially accelerate climate change due to emissions from logging of old stands.

Change from rotation forest to uneven-aged forest

Selection cutting does not necessarily result in higher biomass (Wirth et al., 2003). This management system was developed to achieve a few high quality stems, not to achieve a high biomass per area. Therefore, the average biomass can be higher under rotation forestry than in age-structured forests.

From coniferous to broad-leafed forest

This could potentially increase the carbon stocks in the long term, despite an initial carbon loss (Fischer et al., 2002b). Modelling the change from coniferous to broad leafed forest, Wirth et al. (2003) conclude that the accountable carbon gain is about 0.1 t C per ha and year because the change takes place over a long period of time (about 200 years).

Increasing the dead wood carbon stocks

Managed forests of Europe have a very low stock of dead wood. Whole tree harvesting contributes to this. Nevertheless, increasing the dead wood carbon stocks is a promising option for climate mitigation in the long term, because the mean residence time of dead wood is significantly longer that that of forest products (Wirth et al., 2003), not taking into account their use for energy purposes. This has consequences for accounting of wind throw events.

Avoiding forest harvest and creating protected areas

Avoiding harvest leads to a higher carbon sink. Both protected and primary forests reach an upper limit of biomass which is higher than in managed forests (Mund and Schulze, 2003). Obviously additional processes exist that make unmanaged forests distinct from managed forests. Carbon stocks in dead wood and soil are higher in unmanaged forests. The large proportion of alpine protection forest in Austria, Slovenia and Slovakia probably explains the superior effectiveness of the forest sink in these countries (Fig. 4.3-1).

4.5.2 Problems related to sink determination

Carbon sinks are calculated by different methods in agriculture, forestry and in the CDM. This makes calculations scarcely reproducible and comparisons difficult. The only common feature of all three methodologies is that nations can select projects in which carbon gains occur while situations where carbon is emitted are neglected. If the net changes reverse from positive to negative and countries turn out to be emitters between 1990 and 2008, they will not choose (by 2005) to use Article 3.4 or focus on the gain in 1990 as compared to the commitment period 2008 to 2012. In forestry, losses between 1990 and 2007 are reported in the national reports to the UNFCCC, but are not accounted under the Kyoto Protocol because they took place before the commitment period 2008 to 2012. In CDM, the change from a baseline is accountable, and the result depends on the selection of the baseline. If the carbon stocks prior to deforestation would be the baseline, none of the reforestation CDM projects would be a sink. Houghton et al. (1999) presented the carbon balance of the USA and showed that the past deforestation is the basis for that country's present carbon sink. The Annex-I nations must decide in 2005 if they want to allow accounting of management-related sinks according to Art 3.4.

4.6 Evaluation of the Bonn Agreements and considerations for future commitment periods

The above assessment shows that the present Art. 3.3 and 3.4 of the Kyoto Protocol and the text of the Bonn Agreements are not suitable for the purpose of climate change mitigation:

- The present text does not stimulate broad-scale carbon sequestration.

- The Kyoto Protocol does not provide any mechanism to protect the high carbon stocks of pristine and old-growth forests.
- The accumulation of biomass in managed forests can only buy time, because these forests will be harvested at a later stage. Thus in the Kyoto sense these sinks are not permanent, even though the forest continues to serve a climate change mitigation function and the forest products may serve to replace fossil fuel. It must be kept in mind when considering the 'permanence' of biological sinks in forestry that the rotation period (the period of growth until a harvestable tree size) is between 80 and 300 years in Europe. This sequestration thus takes place over a longer period than that considered in the present report. The modern forest practice of creating uneven-aged stands could equilibrate oscillations of carbon stocks, but this would prevent them from being accountable because such uneven-aged stands would not exhibit net changes in biomass even if sustainable harvesting were practised.

Given the shortcomings of the present Kyoto Protocol in the accounting of terrestrial carbon sources and sinks, it seems appropriate to consider changes for future commitment periods. These changes are:

- *Full carbon accounting:* The EU research cluster CarboEurope already recommended during the Bonn negotiations at COP 6 to amalgamate Art. 3.3 and 3.4 and base the assessment on full carbon accounting. The atmosphere does not distinguish the human-induced management components of forestry, but feels the impact of total changes in carbon stocks at regional scale along with the total emissions from agriculture into the atmosphere. The present problems of verification mainly result from the notion of separating direct and indirect human factors, not from any absence of measuring techniques to detect changes. The verification of total (not selective parts of) carbon emissions and sinks is possible at all scales, and can be checked across scales despite their natural geographic and inter-annual variability. It is the net balance of all fluxes (fossil plus land surface), rather than the effect of partial fluxes, which affects the atmosphere and thus induces climate change. A full carbon accounting system would avoid debatable classifications into direct and indirect human effects, and it would use different spatial scales as part of the verification system (upscaling of terrestrial observations must match downscaling from atmospheric observations). This cannot be done with the Kyoto accounting system.
- *Conservation of carbon stocks:* In view of the emissions from land use and land-use change, the conservation of existing carbon stocks appears more important than the enhancement of sinks. The present accounting system is not suitable for managed systems, or leads to situations in which only sinks but not emissions are reported.

The present form of the Kyoto Protocol is not suited for management in forestry: (1) the selected minimum area for projects is too small and does not do justice to management options; (2) the permanent designation of an area as 'Kyoto forest' or 'non-Kyoto forest' creates a conflict of interest between climate change mitigation and management options; (3) the focus on 'human induced' actions is in conflict with the multi-functionality of forests; (4) the fact that previously unmanaged (pristine) forest is not included in the accounting scheme or in the baselines fails to prevent emissions from primary exploitation of these forest areas; (5) different accounting schemes for agriculture, forestry and CDM detract greatly from the transparency of the whole process and enable nations to account for sinks without reporting land-use sources.

The problem of forest management is that we are dealing with very large carbon stocks that can be released in a very short time but re-established only by relatively small fluxes over very long periods of time. The time constants for destruction and regeneration differ by several orders of magnitude, and this applies to soils as much as to forests. It may take only 5 minutes to cut a tree, but it takes 50 million minutes to grow a tree to a harvestable size. The present Kyoto Protocol does not consider the asymmetry of destruction and regeneration, because it explicitly excludes the accounting of carbon stocks ('the mere presence of carbon stocks be not accountable').

Institutional design of the future climate protection regime 5

5.1 Full accounting of greenhouse gas emissions and stocks (full carbon accounting)

To ensure effective climate change mitigation, all greenhouse gas emissions must be covered, i.e. beside CO_2 also methane, nitrous oxide and other climate active substances. To standardize monitoring, gases should be converted into equivalent CO_2 emissions ('greenhouse gas basket') as envisaged in the Kyoto Protocol.

Institutional separation of emission reductions and conservation of carbon stocks

For greenhouse gas emissions from fossil fuel use and the allocation of reduction commitments, the Council recommends the 'contraction and convergence' (C&C) approach. Greenhouse gas stocks in the terrestrial ecosphere should be treated separately. Consequently the Council argues in favour of a separate 'stocks protocol'. This could complement the Kyoto Protocol, as a parallel agreement, in fleshing out the details of the Framework Convention on Climate Change. It should regulate, among other aspects, the accountability of afforestation and reforestation projects. In the following Sections 5.2 to 5.4, the Council first examines the possible shape of the Kyoto Protocol in order to limit greenhouse gas emissions from the use of fossil fuels. Section 5.5 then presents the basic idea of a separate protocol on carbon stocks and sinks, whereas Sections 5.6 to 5.8 treat incentive and compliance measures, financing instruments and instruments of global energy policy.

Reliable inventories as a basis for decisions

The preconditions for an effective international climate protection regime include reliable and detailed greenhouse gas inventories. This involves both regular, reliable reports on changes in stocks, and detailed information on the volumes and sectoral origins of greenhouse gas emissions (IPCC et al., 1996; IPCC, 2001e). Correct information on greenhouse gas emissions from fossil fuel use is a key prerequisite for contraction and convergence (C&C), as all countries/regions directly receive absolute emission limits and can participate in emissions trading. If developing countries are to be integrated fully into trading, there is a need not only for data on CO_2 emissions, but also for more differentiated inventories of other emissions that are comparatively important in this group of countries, such as methane or nitrous oxide.

Moreover, much higher requirements upon inventories are to be expected if full carbon accounting for the sources and sinks of the terrestrial biosphere (Chapter 4) is introduced, as this would necessitate complete coverage of all stocks and fluxes for both natural and managed ecosystems.

5.2 The 'contraction and convergence' (C&C) regime

For a second commitment period, the Council recommends applying the C&C approach, with linear convergence of emissions shares towards equal per-capita emission rights by the year 2050 (Chapter 3). Ideally, all states would then adopt absolute emission limits. This would remove the current distinction made by the Kyoto Protocol between Annex-I states and non-Annex-I states. The flexible mechanisms of emissions trading, Joint Fulfillment ('bubbles', e.g. burden sharing within the EU in accordance with Art. 4 UNFCCC) and Joint Implementation would then be basically available to all states. In order to promote willingness to adopt emission limits, the other instruments – particularly access to the climate funds (Section 5.6.1) – should be made conditional upon participation in C&C.

If it should emerge that various developing states are not able or not willing to accept absolute emission limits from the outset, the Council considers a special clause tolerable for countries that have less economic capability and relatively low emissions (an 'opt-out clause'). Modelled on a reduced form of the multistage approach (Chapter 3), under this modified C&C regime states would only then need to accept absolute emission limits if they transgress a certain threshold value oriented to per-capita emissions or per-capita income. Countries below this threshold are allowed, upon prior approval, to make use of the opt-out clause and must not, for the time being, comply with absolute emission limits. To remain within the tolerable climate window despite an opt-out clause, the countries participating in the C&C regime would have to commit themselves to share the remaining reduction burdens. The threshold would thus need to be set such that the additional burdens are bearable for the participating countries. It also needs to be set such that at least all economically advanced developing countries and the transition countries are integrated within the commitments. As developing countries without absolute emission limits cannot participate in emissions trading, but should nonetheless be integrated into international climate protection efforts, it is recommendable within this modified approach to retain the CDM. A further aspect is that the countries participating in the C&C regime could reduce their burdens by using CDM credits in emissions trading.

The Council is aware of the danger that individual states could entirely refuse to adopt emission limits and could thus assume a free rider position. To cope with this, the London based Global Commons Institute, which originally developed the C&C model, has proposed a 'Global Climate Community': A group of core states (EU, some Umbrella Group states, developing countries) adopts emissions reductions according to the C&C principle. The Council similarly recommends to the coalition of voluntary participants that it retains the basic idea of the C&C allocation approach despite the absence of important countries. On the other hand, the Council expressly warns that in such a situation the climate change mitigation goal would most probably not be attained – this will be all the more so the more large-scale emitters refuse to join the regime. The goal of coalition members must therefore be to expand the group of participants as swiftly and comprehensively as possible. Positive incentives alone will probably not have sufficient effect. The resources required to 'buy' the participation of all free riders could not be mustered. Therefore the coalition members should agree that they will impose political and economic sanctions against free rider states when the need arises.

5.3 Improving greenhouse gas inventories

The Convention commits all states parties, i.e. also the developing countries, to compile inventories for all greenhouse gases not controlled by the Montreal Protocol (Arts. 4.1 and 12 UNFCCC). However, requirements regarding the completeness, accuracy and frequency of information are currently higher for Annex-I states. The least developed countries (LDCs) are free to determine their reporting schedule.

Introduction of C&C would necessitate the same requirements for all countries that are currently placed upon Annex-I states. Annex-I states must report their inventories annually; they are also reviewed annually by international experts. Further commitments arise from the Kyoto Protocol. However, not all Annex-I states have met all requirements as yet (Herold, 2003).

Until now, numerous states have failed to produce reliable inventories. One cause is that many developing countries lack the requisite technical, financial and/or institutional capacities for compiling regular and complete inventories. To reduce such barriers, there is a need for additional technical cooperation activities. These activities should not be financed from already constrained development cooperation budgets, but rather through additional GEF replenishment (Section 5.7). A review procedure as prescribed for Annex-I states would also doubtlessly greatly increase the quality of inventories (Herold, 2003).

The main issue at present is that of the political reservations to compiling and updating reliable inventories (IEA, 2001). Such resistance can presumably be overcome if the adoption of emission limits is made as attractive as possible in economic terms from the outset and, at the same time, developing countries, too, are only permitted to participate in emissions trading if inventories meet high quality demands. Attractiveness thus depends upon the modalities for allocating emission rights, and upon the way the emissions trading system is shaped. The higher the anticipated revenue from emissions trading is, the bigger will be the incentive to participate and thus also the willingness and ability to compile inventories. The C&C approach favoured by the Council performs this incentive function above all with regard to the poorer developing countries, who will be net sellers of emission rights. The incentives are weaker, in contrast, for developing countries which, due to relatively high per-capita emissions, will need to curb their overall emissions in the near future.

However, the opportunity to participate in emissions trading does not suffice as a sole incentive to compile inventories if, through an opt-out clause, various countries have the option not to commit themselves for the time being to any maximum emission limits. Such countries then cannot participate in emissions trading in any case. The CDM would then serve as such an incentive instead: Using the CDM is also conditional upon certain, albeit less demanding inventory requirements. Here the willingness to compile inventories should be a more important criterion than their quality. For the CDM to perform this incentive function, it would need to be ensured that the willingness of these countries to compile reliable inventories is an actual condition for the accountability of credits generated by CDM projects in these countries.

5.4 Further development of the flexible mechanisms

5.4.1 Clean Development Mechanism

Future relevance of the CDM

The Clean Development Mechanism (CDM) is viewed as the key instrument of the Kyoto Protocol by which to engage states without binding reduction targets for the first commitment period in international climate protection activities. The Marrakesh Accords provide that CDM credits are fungible in emissions trading. Estimates suggest a market volume for the CDM of between 0.2 and 2.6 thousand million t CO_2 equivalents in the year 2010; total payments are estimated at US$ 10–50 thousand million (KfW, 2001). These estimates include the USA, which is anticipated to be the largest net buyer of emission rights. More recent estimates of the financial transfer generated by the CDM excluding the USA indicate a cumulative transfer of only US$ 1.5 to 10.7 thousand million for the first commitment period 2008–2012 (Michaelowa et al., 2003).

Even if C&C is introduced, which would expand the group of states with emission limitation targets, the CDM would initially retain its key integrative function, as it can be assumed that not all states will be integrated fully into emissions trading from the outset – be it because not all meet inventory compilation requirements, or because the modified C&C approach permits a temporary opt-out of certain countries (tolerance clause). Finally, the possibility needs to be considered in connection with questions of institutional restructuring that the states parties do not agree upon C&C involving all countries, but rather agree upon a modified continuation of the Kyoto Protocol regime (a possibility that scarcely points in the right direction in the opinion of the Council). For these reasons, the Council discusses the further development of the CDM in detail in the following.

Strengthening the integrative function of the CDM

In the view of the Council, the core objectives of the CDM should be to promote technical mitigation projects in developing countries, and to move these countries to adopt absolute maximum emission targets or to engage in emissions trading. It follows that as many of those countries that are not fully integrated in the reduction system should be involved in the CDM as possible. Past experience with the CDM within the AIJ (Activities Implemented Jointly) project phase, however, make it seem probable that projects will mostly be carried out in those developing countries to which the bulk of foreign direct investment flows (Michaelowa et al., 2003). In order that CDM projects increasingly take place in other, economically less attractive locations, it would be helpful if more international resources were deployed to create the fundamental infrastructural and institutional preconditions for CDM projects, possibly using the Least Developed Countries Fund (Section 5.7). Specific incentives to carry out CDM projects in previously neglected countries or in LDCs would also be conceivable – e.g. in the form of higher CDM credits. This, however, could produce distortions to the detriment of the other countries, and/or could reduce the ecological effectiveness of the global climate protection regime.

Reducing free rider effects and preventing 'perverse' incentives

The precursors of CDM projects have frequently been ecologically dubious or have been characterized by free rider effects, i.e. credits have been applied for projects that would have been carried out in any case – even without the Kyoto Protocol and its flexible mechanisms. For sinks projects, in particular, the current accountability criteria create additional 'perverse' incentives – the CDM effectively promotes the destruction of carbon stocks such as primary forests (Chapter 4). This presents a need for stricter registration criteria. The crucial aspect is the definition of additionality in relation to the baseline. International climate policy distinguishes between additionality criteria for sink-related projects, and other CDM projects. The following discussion is concerned only with non-sink CDM projects, as the Council takes the view that sinks should be taken out of the CDM entirely from the second commitment period onwards (Chapter 4 and Section 5.5).

Investment additionality approach

In Marrakesh, three alternative approaches were agreed for non-sink projects by which project developers can claim credit for greenhouse gas emissions saved, i.e. the emissions that would have arisen without CDM (the baseline case). Two of the approaches proceed from the status quo as baseline, and thus provide only limited information on the volume of emissions that would actually have been released without the CDM activity. The third approach – 'investment additionality' – comes closer to providing such information. Here the baseline is the quantity of emissions that would result if the investor were to deploy the technology 'appropriate' from a micro-economic perspective to meet a certain demand, e.g. for energy, in the specific location. An investor who deploys a technology that, while micro-economically less favourable, is associated with lower greenhouse gas emissions, receives CDM credits to the amount of the difference in emissions.

One weakness of this theoretically elegant approach is that its standardization is exceedingly difficult. For one thing, there are disparate methods of cost, output and investment calculation. For another, subjective criteria play an essential role when determining the crucial parameters. Moreover, due to the complex calculations required and their review, the approach increases the costs of CDM projects. If the approach were made binding this would impede the uptake of CDM activities and would reduce the economic efficiency of climate mitigation efforts. The WBGU thus does not consider it purposeful to reintroduce into the negotiations the investment additionality approach as a mandatory method for all CDM projects. Instead, the investment additionality approach is only made mandatory for large-scale projects. Both project costs and the volume of CDM credits applied for could be taken as criteria.

Positive or negative lists of project types

The danger that CDM credits are granted to non-sustainable projects could be reduced by means of positive or negative lists of project types. Compared to a positive list, the exclusion of certain project types through a negative list would have the advantage that formulation of this list requires less prospective information, gives actors more flexibility and thus generally has a less restrictive effect upon the uptake of CDM activities. On the other hand, a negative list is less focussed. Furthermore, it can appear, at least subjectively, to be more discriminatory than a positive list, which can make it even more difficult to find agreement on fundamentally non-eligible project types.

The idea of a positive list has already been rejected by the parties – the WBGU recommends not taking it up again for the time being. Instead, the approach of a priority list should be pursued, which establishes facilitated application and review procedures for certain project types (WWF, 2000). A further approach worth considering is to approve credits for projects which, due to their type, are not classified as priority, with less than 100% in emissions trading. Finally, building upon its negative assessment of nuclear energy (WBGU, 2004), the Council urges that the soft formulation established by the states parties regarding nuclear projects is amended such that these are non-eligible ('one-item negative list').

CDM projects should not be impeded by a charge

The intention of the states parties to finance the Adaptation Fund by means of a charge amounting to 2% of the value of emission credits generated by CDM projects represents a general disadvantage of CDM credits compared to other flexible mechanisms. The charge must be expected to reduce the CDM volume and would thus impair its important integrative function. A further point is that at least a part of the charge will presumably be passed through to the developing countries. This would not only reduce the incentive to participate in CDM projects, but would also be questionable from a distributional perspective.

Charges should be levied not only on the CDM – a mechanism that will be superseded over the long term in any case if the C&C approach is adopted. If at all, charges should be paid for all transactions within the context of flexible mechanisms. Ideally the level of charges should not depend upon the requirements of the climate change funds, but should reflect only the administrative costs generated by the use of flexible instruments. To finance the funds, other approaches should be aimed at that conform more closely to the principles of equitable and reliable financing (Section 5.7).

5.4.2
Joint Implementation

Within the AIJ pilot phase, project-based cooperation between two Annex-I countries has played only a subordinate role. The integration of JI (Joint Implementation) emission credits into emissions trading, in particular, may be expected to make the relevance of JI decline further in the course of the first commitment period.

A complete integration of JI within emissions trading is therefore worth considering. One argument in favour of this is that it would simplify the environmental policy toolbox. On the other hand, continuance of JI could prove purposeful in order to continue ongoing CDM projects – but not sinks projects – by converting them into JI projects. Moreover, the joint implementation approach could prove helpful for projects that are entirely or partly excluded from emissions trading.

Thus the Council argues in favour of conducting a review of the functioning of JI towards the end of the first commitment period, with the option of integrating the mechanism into emissions trading, or merging it with the CDM if the CDM should continue to exist. An advantage of this is that JI projects which have currently been agreed between Annex-I states who not meet their inventory compilation commitments ('Second Track Joint Implementation') could be carried forward into a modified CDM.

5.4.3 Emissions trading

Safeguarding market liquidity

Various studies on the shape of a future emissions trading regime have expressed fears that there may be surplus supply of emission certificates (caused e.g. by the failure of large-scale emitters such as the USA to meet commitments or join the regime), but also supply bottlenecks caused by unexpectedly high emissions reduction costs or strategic hoarding of emission certificates (Michaelowa et al., 2003). This would lead to certificate prices that do not reflect scarcity and are very low or very high, and to extreme price fluctuation. The functioning of the price mechanism and the stability of a market depend upon, among other factors, the liquidity and number of participants. This presents a further reason for a regime for the allocation of reduction commitments that sets absolute emission caps for as large a number of countries as possible. The C&C approach holds out great potential in this regard, too.

In contrast, the Council rejects at the present time the idea of involving the private sector directly in international emissions trading. Negotiations on this point complicate the process of finding climate policy consensus, and implementation increases administrative effort. Moreover, the participation of the private sector would not necessarily reduce price volatility, and may in fact increase it.

Establishing a Climate Central Bank to smooth price spikes

The scenario outcomes indicate that the present Annex-I states and a growing number of other countries will need to buy emission certificates, over the medium term at the latest. This requires that, firstly, the total permissible quantity of emissions is reduced to the level required to prevent dangerous climate change (Chapter 2) and, secondly, an allocation mechanism for emission rights is implemented pursuant to a C&C-2050 approach. The economic model on which the calculation of certificate prices was based in the various scenarios can be used to derive statements on anticipated long-term price trends along market equilibria. In practice, however, the price formation process can be expected to lead to outcomes that deviate over the medium and short term. There is thus uncertainty concerning the development of certificate prices, for instance due to unpredictable economic, political and technological developments, as well as the exceedingly heterogeneous group of participants in trading (Baumert et al., 2003). Furthermore, there is a danger of sharp price surges (volatility) caused by, for instance, strategic behaviour of market participants or cyclical fluctuations in national economies.

The Council finds the establishment of a Climate Central Bank (CCB) worth considering in order to smooth disproportionately strong price spikes. This can limit the uncertainty regarding the future costs of climate change mitigation, which increases planning certainty for companies and private households, who ultimately bear the costs. CCB interventions could proceed in a manner similar to that of the 'safety valve' mechanism discussed in the literature (Jacoby and Ellermann, 2002; IEA, 2002; Philibert and Criqui, 2003). However, in contrast to a rigid price cap, the CCB intervention does not nullify the market mechanism, but primarily has an attenuating function: When the market comes close to generating upward price fluctuations that exceed a previously determined margin, the CCB could reduce scarcity by issuing against payment the amount of additional emission rights needed to ensure that the price spike does not cross the set threshold.

Economic arguments speak in principle for such an intervention. However, in order not to perturb regular trading activities, such an intervention should only proceed if upward price jumps are very high. The prospect that jumps will be smoothed may also make it politically easier for some countries to adopt reduction targets. However, if the CCB were to intervene too rapidly because of a narrow volatility range, this would seriously jeopardize attainment of the long-term global emission budget and thus the environmental effectiveness of the climate regime. This is a fear that has also been voiced with regard to the safety valve approach (Müller et al., 2001). It is therefore essential to establish a mechanism by which certificates created additionally by the CCB can be saved again in later periods. This can be done in phases of dropping prices, for instance, in which the CCB re-absorbs the additionally issued emission rights from the market. In the event that – for instance within a period of 6–8 years – this does not succeed, the parties would need to establish a modality for allocating the emissions savings. Moreover, in order that the volatility margin presented here does not degenerate to an inflexible price cap, it needs to be ensured that, once it has been transgressed, the price considered 'normal' is raised, for instance by a certain percentage. There is also a need for a regulatory mechanism that ensures that persistent multiannual transgressions of the permissible volatility margin lead to a correction of the price trend considered 'normal', i.e. that after such transgression the permissible volatility margin for a set period is automatically extended, e.g. doubled. In other words, the CCB should smooth extreme upward price surges, but should not decouple the market price for emission rights from the development of reduction costs.

Performance of the Climate Central Bank function does not necessitate any new international organization, but could be provided by an already existing institution, such as the UNFCCC Secretariat. That institution could also provide coordination between the CCB and the Conference of the Parties, the latter being responsible for ensuring compliance and reviewing national greenhouse gas inventories (through the Enforcement and the Facilitative Branche), which in turn is key to the environmental effectiveness of emissions trading.

Exploring the concept of a flexible bottom price

The Council further suggests examining, within the context of the establishment of the CCB, the introduction of a bottom intervention price for certificates or a margin for downward price fluctuations. If the market price threatens to drop below a politically set limit, the CCB could support the price by purchasing certificates. Several reasons speak in favour of such an approach: Very low prices indicate that the costs of emissions reduction are unexpectedly low or that too much 'hot air' is on the market. This justifies a tightening of emission rights supply, which amounts to more ambitious emissions reduction targets. Furthermore, bottom price limits would provide the suppliers of emission rights with a certain degree of planning certainty, as they would then be protected against a complete collapse of prices. However, the bottom intervention price would have to be set very low or the margin for downward price fluctuations very wide in order that the market mechanism can fulfil its functions as smoothly as possible. Moreover, if the bottom price limit is too high, this could appreciably detract from the willingness to adopt more ambitious maximum emission targets or emissions reduction targets, among surplus and deficit countries alike. A further point is that, in contrast to the approach of a volatility margin or of a safety valve, which has the potential to generate revenues for the international climate regime, the issue of financing would need to be clarified. In the view of the Council there is a need for further research to clarify the question whether these problems can also be solved by rule-based mechanisms.

Expiry date for emission rights

Two reasons speak in favour of limiting the validity of emission certificates over time, and thus limiting not only 'borrowing' (the advance use of future emission rights), but also 'banking' (use of accumulated emission rights assigned in previous periods but not required then). First, unlimited banking could, at least hypothetically, lead to a situation in which numerous countries initially keep their emissions low, but then, more or less arbitrarily, release simultaneously several times more than the normal average. This could lead to an accelerated climate change in the mid term, which would infringe one of the Council's goals, the general restriction of the average global warming rate to a tolerable level. Second, the expiry of emission rights would make strategic hoarding less attractive, and would thus reduce price uncertainty in emissions trading. How exactly such a limitation of banking is implemented – e.g. through a one-off or successive devaluation of emission certificates, or through a percentage cap on banking – is secondary.

Reaffirming national-level mitigation efforts

The Council recommends that the German federal government underscores the priority of national-level mitigation efforts in a second commitment period, too. Reasons of innovation policy, above all, speak in favour of this. Consequently the demand should be raised again in the negotiations to limit the use of flexible mechanisms to meet national reduction targets.

Integrating emissions of international aviation and shipping

The emissions generated by international aviation and shipping must at last be integrated within emissions trading. Basically this would require their itemization in the individual national emission budgets. As this would involve major attribution difficulties, special budgets for these sectors are worth considering instead. Alternatively, or as a transitional step, user charges should be levied at the global level, or at least at the European level (WBGU, 2002).

5.5 Adoption of a protocol on the conservation of carbon stocks

Besides reducing worldwide greenhouse gas emissions from the use of fossil fuels, conservation of the carbon stocks of terrestrial ecosystems should be made a prime objective for the further development of the Kyoto Protocol. As set out in Chapter 4, the Council accords the same priority to preserving existing stocks in terrestrial ecosystems as to creating sinks.

The distinction envisaged at present in the Kyoto Protocol between sources and sinks produced by direct human intervention from those attributable to indirect or natural factors causes major problems (Chapter 4). It is thus essential to ensure that there is in future a full accounting of all carbon fluxes (full carbon accounting).

In principle, this could be done by integrating into emissions trading or into the CDM activities to protect existing carbon stocks – e.g. primary forests, wetlands, grasslands – as well as the creation of sinks. The idea of temporary certified emission reduction units (TCER) provides a starting point for this. Such units would then be issued not only for sinks, but also for abstaining from the degrading utilization of, for instance, primary forests.

However, the Council advises against offsetting the carbon stocks of terrestrial ecosystems against commitments to reduce emissions from the use of fossil fuels. One main reason speaking against this is that conceiving and agreeing upon a comprehensive system is much more time-consuming than negotiating maximum emission limits for the use of fossil fuels. While for these emissions at least first steps have been taken in the right direction with the Kyoto Protocol, negotiations on the conservation of carbon stocks would have to start practically from scratch. Moreover, among other things, verification problems would need to be solved, and responsibilities clarified for disturbances to the biological sequestration of carbon that are caused externally or beyond national boundaries. This is compounded by differences in the planability of emissions from fossil fuel use and the variability of natural fluxes.

It must be noted that the distributional effects of a C&C regime that integrates additionally the conservation of carbon stocks will differ from those of a C&C regime without this added element. Furthermore, it would have to be expected that negotiations for such an expansion of the C&C regime would take a great deal of time. In view of the urgent need to take climate policy action, long periods of 'inaction' are intolerable. The reduction of emissions from fossil fuel use should thus press ahead without delay. Indeed, if the contentious issue of the accountability of terrestrial biological sinks and sources is completely excluded, this may even facilitate negotiations on maximum limits to emissions from fossil fuel use, insofar as parallel negotiations commence on the conservation of terrestrial biological carbon stocks. Despite the probably difficult negociations there is an urgent need for action concerning biological stocks and emissions since the amount of CO_2 set free by land use activites is many times higher than from the use of fossil fuels.

The negotiations should aim at an additional protocol establishing, on the one hand, commitments to preserve stocks and providing, on the other hand, economic incentives to forego degrading land uses. The Council argues in favour of integrating these commitments within the UNFCCC regime – for instance as a 'Protocol on the Conservation of Carbon Stocks of Terrestrial Ecosystems'. One advantage would be that states that are not yet participating in the Kyoto protocol could be integrated into the UNFCCC process more closely. As a first step in this direction, the Council recommends committing all states to compiling inventories of the biological terrestrial carbon stocks in their territories.

In a second step, a global target would need to be set and quantified, possibly differentiated according to agricultural and forestry areas, pastureland and primary forests. The 'Stocks Protocol' would not, as does the Kyoto Protocol until now, distinguish between direct human intervention, indirect human intervention (such as the CO_2 fertilization effect) and natural factors (such as natural climate variability). A carbon balance of the terrestrial ecosphere compiled by means of full carbon accounting can be taken as the basis for global targets.

In a third step, the mechanism would need to be agreed according to which the burdens are shared by states. The simplest procedure would be to commit each country to largely stabilize its own carbon stocks, possibly differentiated according to types of areas. However, this would mean that the burden is borne above all by those states which (still) host large natural sinks. This could be viewed as inequitable. Above all, the resource-rich states will scarcely be willing to follow such an approach. Conservation of the natural ecosphere with its carbon stocks thus requires a system that distributes the costs of conservation among all countries while at the same time creating incentives for states to protect their ecosystems – ecosystems that are valuable not only from a climate perspective. This applies all the more as it is particularly the natural ecosystems that represent key carbon stocks (such as primary forests, wetlands, grasslands; Chapter 4; WBGU, 1998). Furthermore, they have the character of global commons or goods of global value to a much greater degree than managed ecosystems (WBGU, 2002). Thus not only the benefits of their conservation, but also the costs of protecting these stocks should be shared among the entire international community.

One option by which to institutionally implement this mechanism would be to establish a worldwide system of non-utilization obligations similar to that already proposed by the Council for global biodiversity policy (WBGU, 2002). A system of tradable non-utilization commitment certificates would share the costs of foregoing the degrading use of carbon stocks among all states. Thus countries that (no longer) host sufficiently intact ecosystems would have to buy non-utilization commitments from other, resource-rich countries. This would lead to the emergence of an international system of market-regulated payments providing compensation to resource-rich countries for their foregone returns from the degrading use of natural carbon stocks. A further effect of this trading would be that carbon stocks are protected against degradation in the locations where the opportunity costs of non-degradation are lowest. The flexibility and economic efficiency of the system is thus higher than if each country would have to preserve a fixed proportion of its own carbon stocks.

In order that tradable non-utilization units can be created, the resource in question must ideally be homogenous. In a system of tradable non-utilization commitment certificates under the protocol to the UNFCCC proposed here, in contrast to, for instance, global biodiversity policy (Kulessa and Ringel, 2003), the ecosphere would need to be valued solely upon the basis of carbon content in order to ensure homogeneity to the greatest possible extent. The approach of temporary certified emission reduction units (TCER) set out above provides a starting point for the technical design of non-utilization units.

Tradable non-utilization commitment certificates are of little assistance if carbon loss is not caused by a degrading use (e.g. forest clearance). For instance, if major carbon losses are triggered solely by anthropogenic climate change then non-utilization commitments are not a sufficient response. From a climate protection perspective it will then be necessary to offset the impacts of such carbon losses upon the global carbon balance. This needs to be taken into account by the international community, be it within the context of a 'Stocks Protocol' or through more far-reaching reduction commitments relating to emissions from the use of fossil fuels.

In the Council's view this is not the only option for combining the protocol on the conservation of carbon stocks of terrestrial ecosystems with the protocol for other emissions, for instance the C&C-2050 regime. It would be purposeful after the end of the second commitment period to compare the prices for emission certificates with those for non-utilization commitment units. This would provide information on the differences between the respective marginal costs of mitigation activities under the two regimes. If the differences are substantial, it would be recommendable to loosen the targets under the sub-regime with the higher prices, while at the same time tightening targets under the other sub-regime.

Overall, the WBGU sees a need for further research on the concrete technical and institutional design of a separate protocol on the conservation of carbon stocks of terrestrial ecosystems. Above all, however, there is a need for research on the question of how the two protocols could be purposefully linked. This includes the question of the conditions under which it is expedient to introduce greater fungibility in trading between the two systems.

5.6 Incentive and compliance mechanism

It will be impossible to ensure the long-term viability of a climate regime seeking the participation of all states without an effective compliance mechanism. The purpose of an effective compliance and incentive regime is to move parties to adopt and adhere to their commitments and to substantially reduce the risk of free rider behaviour.

5.6.1 Existing sanctions mechanisms

Following several rounds of negotiations, COP 7 in 2001 adopted a compliance system as a component of the Marrakesh Accords. Under this system, parties that fail to achieve their emissions reduction targets must subtract their extra emissions from their budget of emission rights for the second commitment period, with a 'reparation rate' of 1.3. Moreover, they must submit a compliance plan, and are not permitted to sell emission certificates. Furthermore, a country is excluded from the flexible mechanisms if it does not meet its reporting obligations.

The decision whether these sanctions are imposed on a country is taken by the 'Enforcement Branch' of the Compliance Committee. Implementation problems that are not a matter of non-compliance are addressed by a 'Facilitative Branch', which has an advisory and supportive function, performing a form of early warning system function to prevent non-compliance from arising.

The final decision on whether the compliance system will be enshrined in legally binding form in the protocol will only be taken after entry into force of the protocol. Nonetheless, it can already be said today that no other environmental agreement commands over comparably far-reaching means to exert political pressure.

5.6.2 Options for future development

MEASURES IN THE EVENT OF INFRINGEMENT OF AGREED MAXIMUM EMISSION LIMITS

The sanction mechanisms existing for the first commitment period appear fundamentally appropriate to counter infringements of maximum emission limits. A point of criticism is, however, that the envisaged sanctions mechanism does not make provisions by which to differentiate sanctions according to the causes of non-compliance. A problematic aspect in this connection is the uncertainty as to whether states that will not achieve their emission reduction targets can purchase sufficient quantities of certificates. In order to prevent a situation in which sanctions are imposed on states despite these being essentially willing to meet their commitments, the establishment of a compliance fund is under debate (Wiser and Goldberg, 1999): If a state party is unable to buy emission rights in the 'true-up period', additionally created certificates are made available to that state for a payment. The payment would comprise the certificate price plus an extra charge paid in addition to the issue price. The financial resources of the compliance fund could be deployed for mitigation projects. No agreement has yet been achieved in the negotiations on such a fund.

The proposal to set up such a compliance fund would not need to be further pursued if the states parties were to agree to establish a Climate Central Bank (Section 5.4.3).

As yet, no possibilities to impose sanctions outside of the climate regime have been created for the event that a country fails to meet its commitments. Conceivable options include trade or investment restrictions imposed on these countries. However, the developing countries, in particular, are vehemently opposed to linking environmental protection issues with protectionist measures. The Council advises against overburdening the willingness of these countries to cooperate by making any proposal concerning trade sanctions.

In general, the threat of sanctions is all the more credible the less leverage the parties involved have upon the actual implementation of sanctions. In view of the discretion open to decision-makers, the possibility cannot be excluded that attempts to influence decision-makers are successful. However, before making any concrete recommendations on, for instance, the introduction of automatic procedures and of firm stages within the sanctions procedure, in the opinion of the WBGU first the experience gained with the existing compliance mechanisms needs to be evaluated.

Ultimately, a reform of the compliance regime will depend crucially upon whether and how all countries can be involved in the C&C commitment system.

INCENTIVES TO ADOPT MAXIMUM EMISSION LIMITS

If it does not prove possible for all states to agree on a C&C regime in which all countries accept maximum emission limits from the outset – i.e. certain countries with lower levels of economic capacity have an opt-out clause – incentives should be established to move these countries to opt into the allocation regime as early as possible. An essential part of this is that only countries with a maximum emission limit can participate in emissions trading. Moreover, it should be examined to what extent access to the climate funds should be made conditional upon willingness to accept maximum emission limits.

MEASURES TO PREVENT FREE RIDER BEHAVIOUR

As yet, there are no ways of sanctioning a country if it opts out of the international climate regime after, for instance, it has developed from a net seller of certificates to a net buyer, or in the event that a country does not participate at all. States that reject participation should be excluded from use of the flexible mechanisms, i.e. specifically also from the CDM. This is already envisaged for the compliance regime of the first commitment period. Moreover, free rider states should not gain access to the climate funds (Section 5.2). However, over the long term such exclusion from flexible mechanisms and funds will not be a sufficiently effective sanction. Stricter forms of sanctions thus need to be considered, although their deployment may lead to goal conflicts with other agreements under international law, such as the General Agreement on Tariffs and Trade or the World Trade Organization (Kulessa and Ringel, 2003). States participating 'voluntarily' should make it clear that they would indeed be willing to adopt various political and economic sanctions, such as trade restrictions, upon free rider states.

5.7 Financing instruments

Three climate change funds have been established until now under the GEF umbrella. The Adaptation

Fund supports measures for adaptation to climate change in particularly affected developing countries. The fund will be financed from a charge levied on CDM projects. However, according to recent estimates, demand for CDM certificates may be so low in the first commitment period (Jotzo and Michaelowa, 2001) that a serious under-financing of the fund is to be feared. This is in marked contrast to the importance of adaptation measures, which is set to grow in the future.

The same applies to the Least Developed Country Fund (LDC Fund), which shall support the poorest developing countries in preparing national climate action programmes, and to the Special Climate Change Fund (SCCF) which supports, complementary to GEF funding, technology transfer, adaptation measures and mitigation programmes. Both funds are financed by voluntary contributions. Some industrialized countries have already committed funding, but the overall sum appears too low to finance the measures required to integrate developing countries more firmly. This applies all the more as numerous states are proving very reticent in making financing commitments now that the USA has decided not to ratify the Kyoto Protocol.

Besides financing adaptation measures and supporting mitigation activities in developing countries, the Council considers it appropriate in a second commitment period to make provision for an additional Compensation Fund from which payments for the compensation of climate damage can be financed. A more far-reaching regime, such as one involving strict liability, appears problematic for various reasons. Above all, such an approach would be difficult to enforce, as it would involve unforeseeable financial consequences for the affected states. In addition, a liability regime would have to resolve an array of highly complex problems of causation and proof and would further need to assess damage. A fund-based approach under the GEF umbrella could avoid these difficulties.

As, by all appearances, the financial resources available to the funds will not suffice to integrate states more closely into climate policy activities, nor to bear adaptation and compensation costs, there is a need to swiftly restructure the funds and their financing. This process needs to be put on track now.

Binding funding commitments are preferable to voluntary ad-hoc contributions. For the Compensation and Adaptation Fund, the financing contributions of individual states should be based essentially on the principle of causation, i.e. oriented to the cumulated CO_2 emissions of a country. In this connection, the polluter pays principle should be applied retroactively, starting in the year 1990. Earlier emissions also contribute to the damage and to the need for adaptation measures, but their consideration in the assessment of contributions would be incommensurate insofar as decision-makers were only necessarily aware of the harmfulness of the emissions when the First Assessment Report of the IPCC was published in 1990. The assessment of eligibility to claim funds should further take into consideration the ability-to-pay principle, and thus should prefer above all countries with low per-capita incomes. User charges levied on international aviation and shipping could provide a further source of revenue (WBGU, 2002). At all events the Adaptation Fund should not be financed by charges raised on CDM projects alone (Section 5.4.1). As a last resort, a charge on *all* flexible mechanisms could come into consideration, i.e. levied essentially on emissions trading.

Furthermore the question needs to be addressed whether and to what extent the efficiency of funding deployment could be enhanced by a clearer distribution of responsibilities among the funds. E.g. the relationship between the GEF and the Special Climate Change Fund should be clarified, as well as the adaptation financing removed from the latter.

5.8 Instruments of global energy policy

Climate protection measures are – at least as regards greenhouse gas emissions reduction – closely linked to global energy policy measures. Emissions reduction can only be achieved worldwide without curtailment of energy supply for all people if reduction activities are accompanied by incentives to modify energy technologies involving e.g. improved energy productivity or the expansion of renewable energy sources (WBGU, 2004).

At a global level, major importance attaches above all to energy policy instruments such as international (tradable) quotas for renewables and a swift liberalization of trade in goods and services relating to renewables and energy efficiency. There is also a need for a Multilateral Energy Subsidization Agreement (MESA) that militates towards a gradual removal of subsidies for fossil and nuclear energy, and comprises rules governing the subsidization of renewables and efficiency technologies. A global transformation of energy systems that – as recommended by the WBGU – calls for more sustainability makes a key contribution to mitigating climate change. It is essential to establish close linkages between global climate protection measures, global energy policy and global structural policy (for instance through consistent sectoral policies or strategic alliances between industrialized and developing countries).

Recommendations 6

6.1
Action is urgently needed to avert dangerous impacts of climate change

Comply with the 'WBGU climate window' and reduce emissions

In its recommendations on climate change mitigation, the German Advisory Council on Global Change (WBGU) proceeds from 'moderate anthropocentrism' (WBGU, 2000b, 2001) and the precautionary principle (Principle 15 of the Rio Declaration; UNCED 1992; Art. 2.2 UNFCCC). Moderate anthropocentrism bases humankind's obligation to preserve nature for today's and coming generations on nature's life-maintaining and life-enhancing importance to humanity. It is a matter not only of nature's utilitarian value as a natural life-support system and resource, but also of its aesthetic and cultural function. The precautionary principle posits that the lack of scientific certainty cannot be a reason to postpone action to avert a possible threat. Security requirements increase with the degree and irreversibility of the potential damage.

From these two principles, the WBGU derives its recommendation to the German federal government to commit itself to the target of keeping global warming within the 'WBGU climate window': Within this window, the rise in global mean temperature should not exceed 2°C relative to pre-industrial levels and the maximum rate of global warming should not exceed 0.2°C per decade. This rate relates to the change in mean global temperature averaged over several decades. As global mean temperature has already risen by 0.6°C since the onset of industrialization, only a further warming of 1.4°C is still tolerable.

The German federal government should work within the climate regime negotiations towards adoption of this target, thereby fleshing out the provisions of Article 2 UNFCCC. In view of the uncertainties in assessing the response of the climate system to anthropogenic emissions, the WBGU recommends that negotiations should not at present seek to establish, for the long term, a fixed CO_2 concentration level as a 'safe' level within the meaning of Article 2.

The WBGU therefore advises a 'hedging' strategy: Initially, CO_2 targets below 450 ppm should be aimed at, for otherwise, if climate sensitivities exceed 2°C (the IPCC assumes sensitivities between 1.5°C and 4.5°C), the climate window can no longer be complied with. Global energy- and industry-related CO_2 emissions must therefore be reduced by about 45–60% by the year 2050, taking 1990 as base year. Industrialized countries must reduce their greenhouse gas emissions by at least 20% by 2020. They have currently committed themselves to reduce emissions by 5% by the year 2012 relative to 1990 (Annex-I states).

Full carbon accounting

From the principle of 'moderate anthropocentrism' and the precautionary principle, the Council derives the recommendation to give greater consideration in climate policy to terrestrial biological carbon stocks and sinks. All carbon fluxes and stocks should be accounted fully ('full carbon accounting'). However, at the present time the Council advises against seeking to regulate the conservation of biological terrestrial carbon stocks within the same system, with the same allocation procedure and with the same instruments as reduction commitments for fossil carbon stocks. Such an approach could cause an unacceptable delay of the entire climate protection process.

Taking account of the role of the biosphere through a special agreement

Consequently, the WBGU recommends agreeing a special intergovernmental commitment to preserve the carbon stocks of terrestrial ecosystems. Such an agreement could be implemented as a 'protocol for the conservation of carbon stocks' to the UNFCCC. This approach should not distinguish, as the Kyoto Protocol has done until now, between direct and indirect human impacts (such as CO_2 fertilization or climate change) or natural factors (such as natural climate variability). Rather, it should involve measurement and accounting of the full carbon balance of all areas (full carbon accounting). One advantage of a new protocol could be that countries which have not yet joined the Kyoto Protocol could be integrated more strongly within the UNFCCC process.

The first step on the path towards such a protocol would be a commitment for all countries to compile inventories. The second step would be the definition of a global goal and its quantification, possibly differentiated according to types of area (e.g. agricultural or forestry areas, pastureland, primary forest). In a third step, a mechanism would need to be found by which to share burdens equitably among states. This would need to give resource-rich states incentives to participate.

Especially for the conservation of natural ecosystems, which represent major carbon reservoirs (e.g. primary forests, wetlands or grasslands), an international system of tradable non-utilization commitments could be set up, similar to that already presented by the Council in a previous report for global biodiversity policy (WBGU, 2002). This would distribute among the international community of states not only the benefits arising from the conservation of carbon stocks, but also the costs of their conservation. Such an approach would create an international system of market-regulated compensation payments providing resource-rich countries compensation for their foregone yields from the degrading use of natural carbon stocks. The concept of temporary certified emission reduction units (TCER; UNFCCC, 2002) provides a starting point for the technical design of a system of tradable non-utilization units.

Reducing uncertainties through research

Clearly, there is a continuing need for research in order to limit uncertainties relating to the type and strength of climate system responses to greenhouse gas emissions, and the behaviour of biogeochemical cycles. In view of the potentially catastrophic consequences of very fast climatic changes, the conditions under which such events may occur must be studied in more detail. More intensive research is also needed on climate change impacts upon ecosystems, food production, water supply, human health and economic development, in order to reduce prevailing assessment uncertainties. Particular consideration needs to be given to the occurrence of extreme weather events and their altered frequency. In this connection, regional impact studies should be based more firmly on the standards developed by the IPCC and should relate more systematically to its scenarios. There is a need for international cooperation to ensure that all relevant regions are studied. In particular, a better understanding is needed of the causal chains linking global mean temperature with local climatic factors.

To operationalize Article 2 UNFCCC, research activities need to pursue integrated modelling approaches based upon the Tolerable Windows Approach. This approach establishes a methodological separation of the normative setting of guard rails and determination of the consequences of global climate change on the one hand, from the determination of permissible emission pathways and optimal strategies on the other. This involves, in particular, integrating the reduction potentials (and associated costs) of other greenhouse gases, besides CO_2, in corresponding modelling studies. This approach produces least-cost strategies by which to comply with the WBGU climate window, integrating all radiative forcing gases. Similarly, there is a need for further analysis and research on action under uncertainty.

Finally, a range of stabilization scenarios needs to be analysed in order to study mitigation strategies and their economic and other effects. This makes it possible to reflect the entire range of possible futures, as modelled, for example, by the SRES scenarios (IPCC, 2000). Target carbon dioxide concentrations below 450 ppm also need to be examined in this context.

6.2 Shaping commitments equitably

Aiming towards equal emission rights

The WBGU bases its arguments additionally on the egalitarian principle, which can be derived from the human right to equal treatment. In terms of relations among the parties to the Convention or Protocol, this corresponds to the principle of 'equity' (Art. 3(1) UNFCCC). It follows that ultimately, only an allocation of emission rights according to equal per-capita shares can be considered just.

Implementing contraction and convergence

At the long-term global emissions must be reduced significantly (contraction). In addition, the WBGU postulates the principle of constancy, according to which abrupt measures leading to drastic effects should be avoided in socio-economic systems. A sudden switch to a per-capita allocation of tradable emission certificates is therefore not recommended: The resulting high transfer payments from industrialized to developing countries could have severe effects that would impact on the economies of all regions. For these reasons, the Council argues in favour of moving in a continuous process from the present allocation of shares, which entails very great imbalance in per-capita emissions, towards allocation according to equal per-capita shares (convergence). Building upon the review of scenario computations set out in Chapter 3, the WBGU recommends this 'contraction and convergence' (C&C) approach with a linear convergence of emissions shares towards equal per-capita emission rights by the year 2050. This should embrace the emissions of CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 (the 'Kyoto basket' of greenhouse gases) from energy, industry, agriculture and waste management. The emissions of other greenhouse gases would be accounted for as CO_2-equivalent values according to their global warming potential, as already provided for in the Kyoto Protocol.

If developing countries are unable or unwilling to accept national-level emission caps in accordance with the C&C approach from the outset, the WBGU recommends an opt-out clause for countries with relatively low economic capacities, i.e. relatively low per-capita emissions and per-capita income. This means that states would need to agree on a threshold allowing to make use of the opt-out clause. For instance, per-capita income and per-capita emissions could be combined in one indicator. When states exceed this threshold, they would be obliged to participate in the global C&C regime. The reduction burden of developing countries which make use of the opt-out clause would be spread across the participating countries. This would ensure attainment of the stabilization target and thus compliance with the climate window. In this context, CDM projects in non-participating countries could have the function of reducing burdens and integrating non-participants into the system. It needs to be noted that such a gradual transition from the present structure of the Kyoto Protocol (with its distinction between Annex-I and non-Annex-I states) towards a global C&C regime can only succeed if opt-out criteria are tight enough for the participating countries to be able to cope with the additional emissions reduction burdens.

Examine sanctions against free riders

The WBGU is aware of the risk that individual states could completely refuse to accept emission caps and adopt a free rider behaviour. But even then the Council recommends to the coalition of voluntary participants that it stands by the basic idea of the C&C allocation principle. The WBGU warns expressly that the climate protection objective is highly unlikely to be attained if many large-scale emitters refuse to join the regime. The goal of first mover countries must consequently be to expand the group of participants as swiftly and comprehensively as possible. Moreover, they should therefore agree that, at the appropriate time, they will impose political and economic sanctions upon free rider states.

6.3 Reviewing and enhanceing instruments

Utilizing the opportunities of emissions trading and minimizing risks

The WBGU recommends establishing an international Climate Central Bank in support of the emissions trading system in order to safeguard stable emissions trading and limit uncertainties regarding the future costs of climate mitigation activities. One task of this institution would be to smoothen disproportionately strong upward price fluctuations. In addition, the introduction of a flexible bottom price limit for certificates should be examined, with the aim of protecting certificate suppliers against a collapse of prices. Before any introduction of such instruments, there is still a need to research the way in which a Climate Central Bank may operate, and the issues surrounding the concept of a bottom price limit. Also the introduction of an expiry date for emission rights should be examined.

The Council recommends to the German federal government that it argues for limitations to the use of flexible mechanisms to comply with national reduction targets in the second commitment period, too (WBGU, 1997).

The WBGU further considers that it is now urgent to integrate the emissions of international aviation and shipping into the emissions trading regime. Alternatively, emissions-based user charges could be levied on international aviation and on international shipping at a global or at least European level (WBGU, 2002).

Ensuring regime integrity through reliable inventories

To ensure the integrity of the climate protection regime, the Council recommends that eligibility to participate in emissions trading be made conditional upon a high quality of carbon inventories. Countries that do not possess the requisite economic and institutional capacities must receive support to a greater degree than in the past, within the context of development cooperation activities. Less stringent inventory criteria could be applied to developing countries for their participation at the CDM. This would make it possible to integrate these countries through CDM projects in the climate regime even if they do not yet meet the requirements for participating in emissions trading, or reject the adoption of reduction targets or are not yet obliged to adopt such targets.

Utilizing the Clean Development Mechanism as a transitional solution

In order to strengthen the function of the CDM as a tool by which to integrate, within the climate regime, developing countries that do not (yet) participate in the C&C system, the WBGU urges that targeted support be provided to building the infrastructural and institutional preconditions in the poorer developing countries. Additionally, special incentives should be created for CDM projects in the least developed countries. Sinks projects should be excluded from the CDM because the WBGU proposes a separate regime for carbon stocks in the biosphere.

To prevent free rider effects in connection with CDM projects, the WBGU recommends making the 'investment additionality' approach mandatory for large-scale projects. It would need to be demonstrated explicitly that large-scale projects would not be realized if they were not planned as CDM projects.

Furthermore, CDM projects should not be placed at a disadvantage compared to the other flexible mechanisms by the circumstance that only they are burdened with a charge. Instead, the Council argues for a moderate levy on all transactions in connection with flexible mechanisms. The revenue should be used solely to meet the administrative costs of deploying the flexible instruments concerned. The WBGU argues for a review of the instrument of Joint Implementation towards the end of the first commitment period. Here it would need to be considered whether JI should be fully subsumed under emissions trading, or whether it is merged with the CDM.

6.4 Equitable financing of adaptation measures

Apportioning contributions for adaptation to climate change equitably

From the principle of responsibilities (Art. 3.1 UNFCCC) and the polluter pays principle, the WBGU derives the recommendation that the contributions of states to finance compensation for climate damage and adaptation to climate change be oriented to each state's contribution to global warming. Although climate change can be contained so as to remain within the WBGU climate window, a need for such adaptation measures will remain. However, only emissions from 1990 onwards should be taken into consideration when assessing funding contributions. This was when the IPCC published its first assessment report, and is thus roughly the point at which the international community recognized the climate problem and the severity of its consequences (IPCC, 1990). Specifically, the WBGU calls for a greater volume of the funds established by the Marrakesh Accords in order to facilitate the efforts by developing countries to adapt to climate change. Furthermore, the WBGU recommends the establishment of a Compensation Fund to enable particularly affected states to compensate for climate damage. Annual contributions should be based on the various contributions of states to emissions, assessed retrospectively until 1990.

Reviewing sanctions mechanisms

For the time being, the WBGU sees no urgent need to reform the sanctions mechanisms envisaged vis-à-vis countries that do not meet their commitments. Negotiations on this issue should be postponed to the end of the first commitment period, when experience with the existing compliance mechanisms can be evaluated. Nonetheless, it may be expedient to raise early on in negotiations the issue of which political and economic incentives and sanctions are to be applied to those countries that fundamentally refuse to adopt commitments, such as the USA and Australia at present.

6.5 Linking climate protection consistently with global governance

Supporting convergence between industrialised and developing countries

To do justice to the vision of sustainable development, social and economic exigencies must be taken into account besides the climate protection goal. So that the climate protection goal can be attained over the long term at low costs, climate policy needs to be linked consistently with global governance and development policy. The aim must be to promote social and economic convergence between industrialized and developing countries, and to facilitate technology transfer. In addition to development cooperation activities focussed more firmly upon sustainability, a first step towards convergence can be to open markets to the products of developing countries. So that in the course of the globalization process, worldwide economic and social convergence can occur under circumstances characterized by declining rates of population growth over the long term (from 2050 onwards), development cooperation needs to be further intensified. In order to avoid an increase of the global population beyond the year 2050, education and health programmes for women in developing countries need to be promoted, as does the introduction of systems of social security.

Turning energy systems towards sustainability

The Council stresses that without a fundamentally new orientation of energy systems towards sustainability, it will not be possible to protect the world's climate. The energy policy measures proposed by the Council which are essential to turn global energy systems towards sustainability should be implemented as swiftly as possible (WBGU, 2004). These include, for example, internationally tradable renewable energy quotas, as well as swift liberalization of trade in goods and services in the fields of renewable energy and energy efficiency. Moreover, a Multilateral Energy Subsidization Agreement (MESA) should be concluded, providing for a gradual removal of subsidies for fossil and nuclear energies and setting rules for the subsidization of renewable energies and efficient energy technologies.

Dovetailing efforts to reduce greenhouse gases through a C&C regime with a system of global energy policy measures makes it possible to protect the global climate without incurring energy supply losses for anyone. Such dovetailing creates incentives on both the supply and demand sides to enhance energy productivity and substantially expand renewables. Emissions reductions can thus be achieved in a way that not only ensures there is no deterioration in worldwide energy supply, but even secures an improvement in supply. Finally, it is important to note that linking global climate protection measures or global energy policy with global governance (such as consistent sectoral policies or strategic alliances between industrialized and developing countries) is indispensable. The Council calls for specific agreements in order to achieve minimum quotas for renewable energy carriers (WBGU, 2004) and develop infrastructures for a global solar electricity/hydrogen economy. In this connection, long-term coal use is not compatible with the WBGU climate window, even when the most modern coal-fired power plants are used. By means of such measures that complement – and make feasible – emissions reductions within a C&C regime, the policy arena creates the preconditions for cost-effective climate protection.

A necessary requirement for the transformation of energy systems is a clear increase in investment in research on and the development of sustainable technologies. To broadly underpin the development path towards a solar electricity/hydrogen economy, relevant research efforts need to be intensified. The Council has presented detailed recommendations for such research in its energy report (WBGU, 2004).

Key strategic decisions lie ahead

In the coming years, the international community will need to take key strategic decisions in international climate policy, if dangerous climate change is to be prevented. The UNFCCC provides an indispensable framework for upcoming negotiations. With every further delay of consistent climate protection policy, the scope for action narrows. The present report shows strategies and instruments to meet this challenge.

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