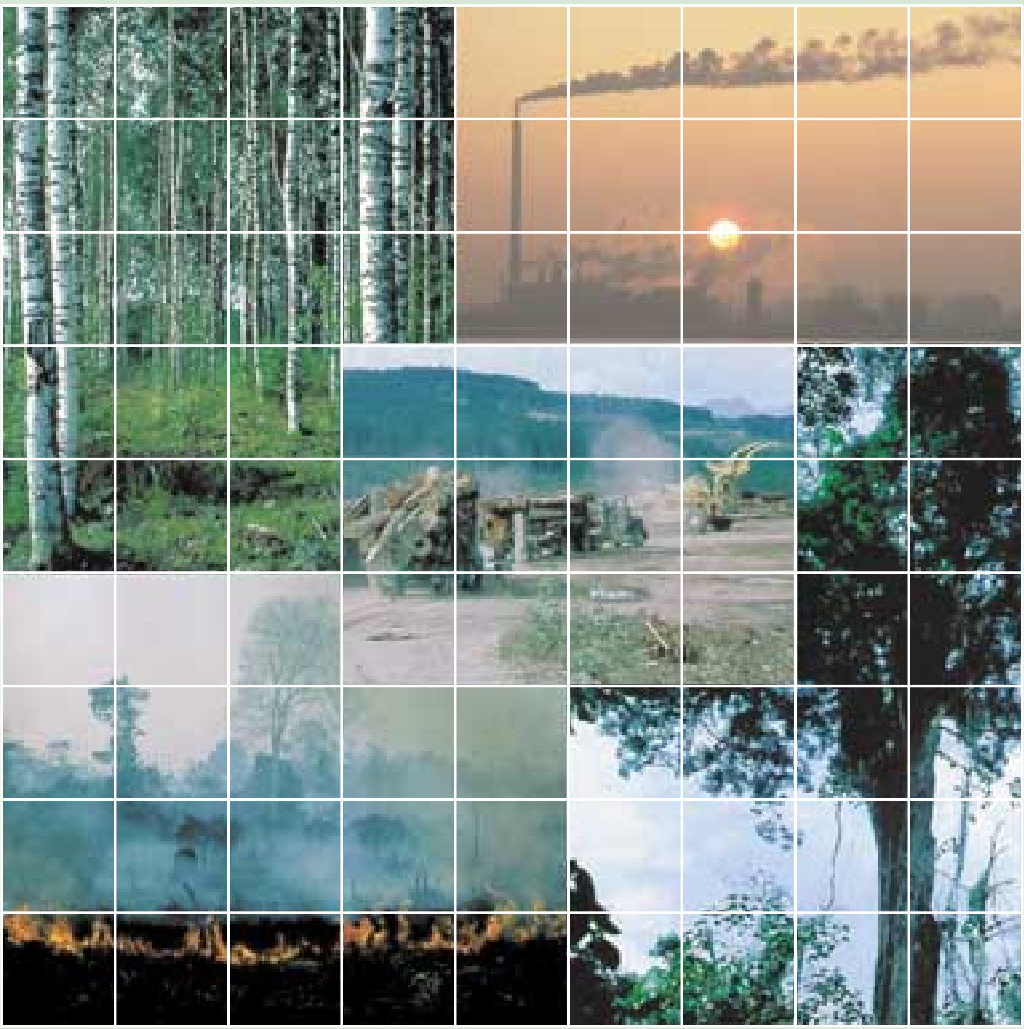
The Accounting of Biological Sinks and Sources Under the Kyoto Protocol:

A Step Forwards or Backwards for Global Environmental Protection?

German Advisory Council on Global Change (WBGU)

Special Report 1998



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Preface

The German Advisory Council on Global Change (WBGU) has prepared this Special Report at the request of the Federal Minister for the Environment, Nature Conservation and Reactor Safety, Dr. Angela Merkel, as a part of the follow-up to the third session of the Conference of the Parties to the UN Framework Convention on Climate Change (COP 3). This conference, held in December 1997 in Kyoto, adopted a Protocol to the Convention (the "Kyoto Protocol") that gives an unexpected degree of consideration to the function of biological systems as sources or sinks of greenhouse gases. The remit of the Advisory Council was therefore to collate available knowledge on this issue, to assess the pertinent provisions of the Kyoto Protocol in this light and to formulate proposals for the environmental policy stance to be taken by the Federal Government in the upcoming negotiations.

The report presented here has been prepared and adopted in its entirety by the Advisory Council, as is the regular procedure of the Council. In its preparation, the Council's secretariat and the scientific assistants of the individual Council members (see page 75) have provided invaluable substantive, logistic and technical support. Particular thanks go to Dipl.-Geogr. Gerald Busch, Dipl.-Phys. Ursula Fuentes Hutfilter and Dipl.-Biol. Martina Mund for their expert input in conceiving and carrying out this study.

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Summary

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) contains, for the first time, quantified, legally binding commitments to limit or reduce greenhouse gas emissions. Under the Protocol, the industrialized countries must reduce their emissions by at least 5% below 1990 levels within the commitment period 2008–2012. Article 3 para 3 of the Protocol provides that biological sources and sinks shall also be used to meet commitments in the commitment period 2008–2012, but limits these sources and sinks as yet to such “afforestation, reforestation and deforestation” that took place since 1990. Article 3 para 4 further provides for the possibility of using additional “land-use change and forestry” activities to meet reduction commitments.

In the study presented here, the German Advisory Council on Global Change (WBGU) assesses the Kyoto Protocol with respect to the accounting of biological sources and sinks. In principle, the Council supports the idea of linking climate protection and the conservation of sinks. However, the Council considers the form in which “land-use change and forestry” activities are accounted under the Kyoto Protocol to be inadequate and in need of improvement if the objectives of climate protection and biodiversity conservation are both to be served. The present accounting approach can lead to incentives with negative impacts upon climate protection, biodiversity conservation and soil protection. Furthermore, the accounting of terrestrial sources and sinks in the form of changes in carbon stocks over a 5-year commitment period fails to do justice to the differing dynamics over time of carbon stocks and fluxes.

In addition, many uncertainties and imponderables attach to the reduction in net emissions that is achievable by means of terrestrial sinks. Terrestrial sinks are by no means constant. Even slight climate changes can lead to sinks becoming sources. Over the long run, fossil fuel emissions can not be compensated for by the terrestrial biosphere.

Because of the uncertainties attached to the estimation of carbon stocks, accounting of sinks reduces the transparency of reduction commitments, and thus hampers verification.

The following points of criticism are explained and reasoned in the present study:

Article 3

- The accounting approach only considers sinks within the commitment period 2008–2012, but does not consider them for the calculation of the 1990 baseline emissions. In addition, Article 3 para 7 permits those countries for whom “land-use change and forestry” constituted a net source of greenhouse gas emissions in 1990 to include in their 1990 emissions base the sources from land-use change. This diminishes the commitment to reduce energy-related emissions.
- The accountable activities – “afforestation, reforestation and deforestation” – are not adequately defined. In particular, it is unclear how reforestation is distinguished from other forest management practices. Depending upon the definition, the span of accountable sinks can be substantially constrained or significantly expanded.
- Article 3 para 3 does not define precisely which carbon stocks or changes in stocks should be included in the calculation of sinks.
- The conversion of primary forests to secondary forests could be indirectly promoted if accountable activities are defined accordingly.
- The use of forests (harvesting or clear-cutting without conversion to other forms of land use) is not taken into consideration, although it can form a significant source of greenhouse gas emissions.
- The possibility of offsetting emissions against reforestation without recording the emissions associated with clear-cutting amounts to an incentive to clear-cut primary forests.
- As opposed to deforestation, the degradation of forests is not recorded, although it leads to emissions of a similar magnitude.
- The protection of primary forests, wetlands and soils as natural carbon reservoirs and sinks is not positively promoted.

- An accounting of changes in carbon stocks during the 5-year commitment periods could create an incentive to establish rapidly growing plantations without sustained carbon sequestration, unless it is guaranteed without doubt that commitment periods follow upon each other without interruption.
- The inclusion of additional land-use change and forestry activities (Article 3 para 4) would further exacerbate the difficulties involved in accounting, and would thus further diminish the verifiability of reduction commitments.

Article 5

- The present IPCC Guidelines for National Greenhouse Gas Inventories are not suited to form a legal basis for the accounting of biological sources and sinks, as they do not place adequate minimum requirements upon the recording of all relevant processes.

Article 6 and Article 17

- Article 6, which regulates the joint implementation of measures among industrialized countries, could make it possible to offset emissions against sinks in other industrialized countries that would be prohibited domestically by Article 3 para 3. This would significantly exacerbate the risks and imponderables associated with the accounting of biological sources and sinks. The same risks and imponderables could also result from emissions trading (Article 17).

Article 12

- Industrialized countries may possibly claim credit against domestic emissions for afforestation projects carried out in developing countries (Article 12). This would give an incentive to clear-cut primary forests, insofar as the emissions caused by clear-cutting are not accounted to either country.

The Kyoto Protocol and the associated further rules leave a certain degree of leeway in the interpretation, concretization and refinement of principles, modalities, rules and guidelines. It is urgently necessary to expand and supplement the IPCC Guidelines. Moreover, the Council recommends using the guidelines yet to be adopted under Article 7 para 4 to combat and minimize the impending undermining of climate protection and impairment of terrestrial ecosystems. At the same time, the opportunities given to conserve sinks should be safeguarded and expanded, whereby care must be taken that the reduction targets are watered down as little as possible by the accounting approach. Specifically, the Council recommends the following:

- No additional sinks should be accounted according to the provisions of Article 3 para 4, because this exacerbates the uncertainties in verification and further diminishes the reduction commitment for emissions from fossil fuels.
- Joint implementation of measures in other industrialized countries (Article 6) should not permit an accounting of sinks that would be domestically prohibited under Article 3 para 3.
- Commitment periods must follow each other without interruption, in order that no incentives are given to clear-cut forests.
- If biological sources and sinks are accounted, then so too must be the destruction of important biological reservoirs (primary forests, wetlands).
- In order that no incentives are given for clear-cutting, emissions should only be offset against reforestation if this takes place on areas that had no forest cover in 1990.
- Emissions should only be offset against afforestation or reforestation if it is ensured that these forests are maintained over the long term.
- Emissions resulting from the conversion of primary to secondary forests must be accounted.
- An accounting of deforestation should also include forest degradation.
- The calculation of carbon stocks of terrestrial ecosystems must, in addition to above-ground biomass, also include the carbon stocks in soils (organic layer) and underground biomass.
- The offsetting of commitments of industrialized countries against projects aimed at enhancing sinks in developing countries (Article 12) should be abstained from for at least as long as the developing countries have not assumed emission limitation or reduction commitments, and as long as the existing uncertainties concerning verification of the impacts of sinks upon developing countries have not been clarified.

Introduction 2

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) (Kyoto Protocol, 1997) was adopted at the third session of the Conference of the Parties to the Convention (COP 3). It contains, for the first time, quantified, legally binding commitments to limit or reduce greenhouse gas emissions. The countries listed in Annex I to the UNFCCC (industrialized countries) must, if they ratify the Protocol, reduce their aggregate emissions of a basket of six greenhouse gases by at least 5% below 1990 levels within the period 2008–2012.

The German Advisory Council on Global Change (WBGU) views the adoption of the Kyoto Protocol as a decisive step forward on the path towards globally reducing greenhouse gas emissions. Moreover, the Council considers the Protocol to offer, in the spirit of solidarity, a starting point for global climate protection in the sense of "good global governance". The success of the Protocol can be measured less by the level of reductions agreed upon for the coming commitment period, than rather by the fundamental recognition by the Parties to it that global CO_2 emissions need to be cut. Agreement of all countries to the Protocol was secured by establishing that biological sinks created during the calculation period can in parts be included in the calculation of the amounts of emissions assigned to each country. While this approach is as such proper and to be welcomed, it harbours some danger, because the accounting methodologies and the difficulties associated with verifying the sinks lead to the possibility of abuse. In order that the necessary purpose of the UNFCCC – the reduction of CO_2 emissions from fossil fuels – is not sidestepped, the Council presents in this study an analysis of the accountability of biological sinks, and derives from this recommendations for political action.

Under Article 3 para 1 of the Kyoto Protocol, emissions must be reduced from the sectors listed in Annex A to the Protocol, namely "energy" (including transport), "industrial processes", "agriculture" and "waste". The land-use change and forestry sector is not included in Annex A, despite the fact that it can contain both sources (for instance as a consequence of clearing forests or draining wetlands) and sinks (for instance the afforestation of degraded areas) for carbon dioxide and other greenhouse gases. However, under Article 3 para 3, net changes in the emissions of a country that result from afforestation, reforestation and deforestation activities are used to meet commitments. Such an accounting of sources and sinks in land-use change and forestry is limited for the present to these three activities. However, the Parties to the Protocol shall further adopt the accounting of additional activities in the agricultural soils and the land-use change and forestry categories (Article 3 para 4).

Offsetting emission reduction commitments against the sources and sinks of terrestrial ecosystems was a very contentious issue throughout the negotiations for the Kyoto Protocol, not least because sources and sinks created or modified by human-induced activities in terrestrial ecosystems (land-use changes, agriculture and forestry) can only be estimated with major uncertainties.

The Council first analyses the provisions of the Kyoto Protocol concerning the net accounting of human-induced activities in land-use change, agriculture and forestry. Subsequently, the state of knowledge on the source and sink potentials of terrestrial ecosystems and on the existing uncertainties and unresolved issues is presented. This forms the basis for an assessment of the provisions of the Protocol. From the assessment are derived recommendations for the interpretation and concrete application of these provisions, and for the follow-up negotiations.

3 Analysis of the Kyoto Protocol

Under Article 3 para 1 of the Kyoto Protocol (the official text is reproduced as Annex 2 to the present report) the industrialized countries have a commitment to ensure that their emissions of the six greenhouse gases listed in Annex A to the Protocol from the sectors and source categories also listed there (Greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6); Sectors/ source categories: energy, industrial processes, solvent and other product use, agriculture and waste) do not exceed the amount assigned to them. This “assigned amount” is calculated in the first commitment period (2008–2012) as a percentage of the total anthropogenic emissions of a particular country in the year 1990, multiplied by five (as the commitment period comprises five years; cf. Article 3 para 7). Different percentages have been agreed for the individual countries (for instance 92% for the European Union). These percentages are listed in Annex B to the Protocol.

Two provisions of the Kyoto Protocol are of particular relevance to using sinks and sources in the “land-use change and forestry” categories of activities to meet the commitments of the industrialized countries:

- Under Article 3 para 3, sources and sinks resulting from land-use change and forestry activities are accounted if they result (since 1990) from the explicitly stated direct human-induced activities of “afforestation, reforestation and deforestation”.
- Furthermore, under Article 3 para 4, the Conference of the Parties serving as the meeting of the Parties to the Protocol (COPsmoP) can decide to include additional human-induced activities related to “agricultural soils” and “land-use change and forestry” in the accounting of assigned amounts.

The calculation procedure for the accounting of sources and sinks in the various sectors follows from Article 3 para 7. Moreover, the following articles are relevant:

- Article 5 paras 1 and 2 concerns the methodologies for estimating emissions by sources and removals by sinks. The article refers in particular to the Guidelines for National Greenhouse Gas Inventories prepared by the Intergovernmental Panel on Climate Change (IPCC).
- Article 7 para 4 charges COPsmoP with adopting guidelines for the preparation of the information required by reporting obligations, and to decide upon modalities for the accounting of assigned amounts.
- The joint implementation of measures among industrialized countries that is permitted under Article 6 expressly also concerns projects aimed at enhancing sinks. In contrast, it is not yet clear whether sinks can also be included in the emissions trading agreed upon in principle in Article 17, or in the joint implementation of projects among industrialized and developing countries (Article 12).

3.1 Calculation procedure

The 1990 *baseline emissions* for calculating the assigned amounts in the commitment period 2008–2012 is defined in Article 3 para 7 in conjunction with Annex A as the aggregate of all emissions of the six greenhouse gases stated in Annex A from the sectors listed there (energy, industrial processes, agriculture and waste). These are gross emissions, as only sources are included, but not sinks. In particular, neither sources nor sinks in the land-use change and forestry categories are considered, as these are not listed in Annex A. An exception applies to those countries for which sources and sinks in these categories add up to a net source in the year 1990. According to the national communications submitted by the industrialized countries (UNFCCC, 1997a) (Annex Table 1), this applies to Australia and to a small extent also to the United Kingdom. These countries add emissions by sources and subtract removals by sinks in the land-use change category to or from the baseline emissions (Fig. 1, case 1). For Australia, this exception raises the baseline emissions by some 30%.

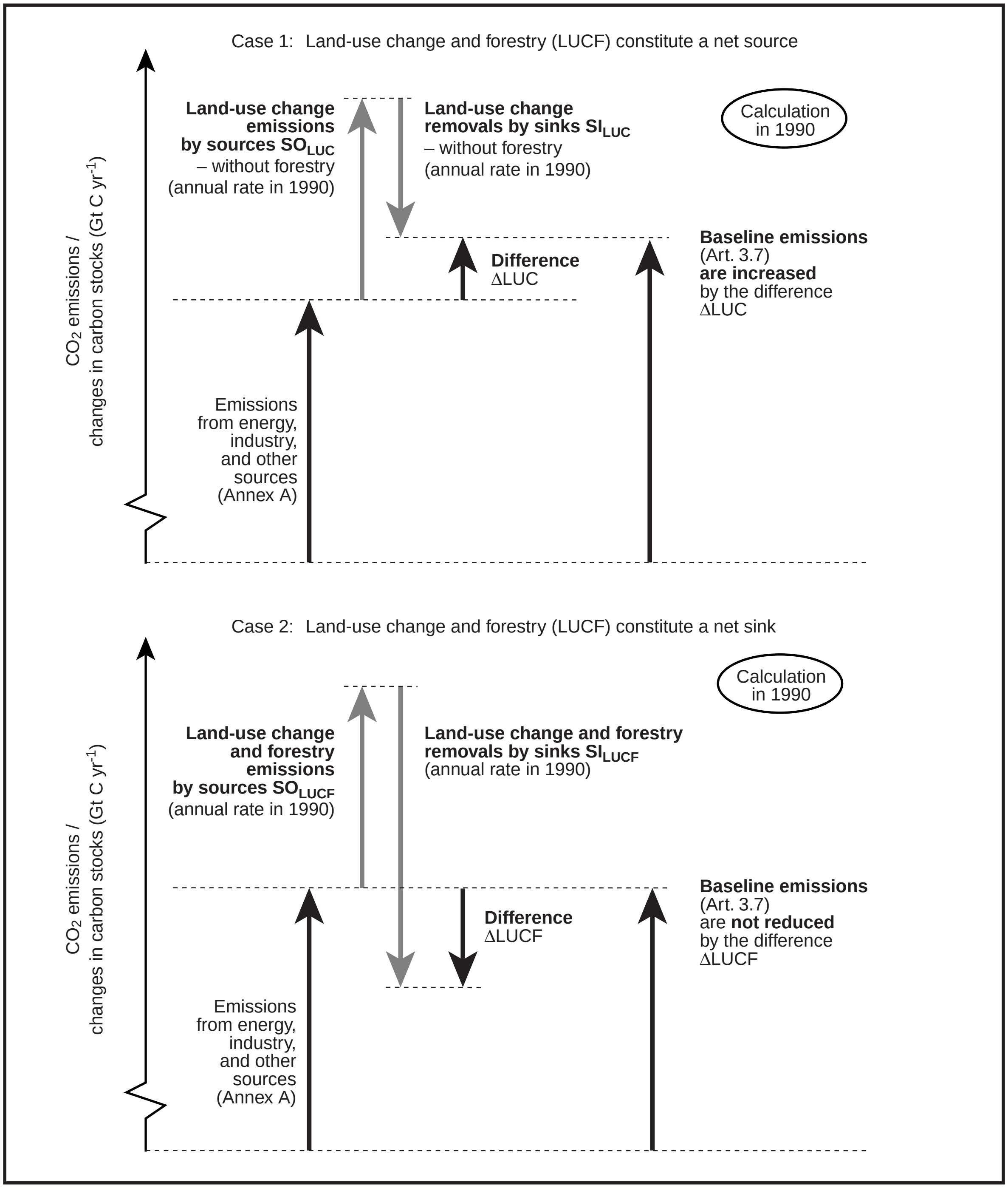

Figure 1
Calculation of the 1990 baseline emissions: The Figure shows the approach for calculating the baseline emissions for the reduction commitments of industrialized countries (Article 3 para 7 of the Kyoto Protocol). Case 1: If "land-use change and forestry" activities represent a net source for an industrialized country (this applies to Australia and to a lesser extent to the United Kingdom), then the baseline emissions is calculated as the aggregate of all emissions from the sectors listed in Annex A to the Protocol ("energy", "industrial processes", "agriculture" and "waste") plus the difference between sources and sinks in the "land-use change" category. It must be noted that forestry is disregarded here. Within the land-use change category, deforestation is the most important source. Case 2: For other countries for which "land-use change and forestry" activities represent a net sink (this applies to most of the industrialized countries), the baseline emissions is not reduced by this difference.
Source: WBGU

The permitted or *"assigned" amount* of emissions is calculated as a *percentage of this baseline emissions*. It follows that the higher the baseline emissions is, the more a country can emit with a given percentage (pursuant to Annex B).

Article 3 further contains a series of provisions under which the amounts assigned to an industrialized country – i.e. the permitted quantity of gross emissions – is altered by accounting certain emissions due to biological sources, withdrawal processes due to biological sinks, and reductions achieved in other industrialized countries or in developing countries.

Under Article 3 para 3, sources and sinks in the "land-use change and forestry" category, limited to "afforestation, reforestation and deforestation" activities since 1990 (so-called "Kyoto Forest", cf. Glossary), are accounted to an industrialized country insofar as they are measurable as changes in carbon stocks in the commitment period 2008–2012. If afforestation, reforestation and deforestation in an industrialized country lead to more equivalent carbon dioxide being withdrawn than emitted, then the biological sources and sinks accounted under Article 3 para 3 add up to a net sink (Fig. 2). This net sink (measured as change in carbon stocks in the commitment period 2008–2012) raises the amount of permitted gross emissions (the "assigned amount"). If, conversely, a net source results, the permitted gross emissions are reduced (Fig. 3). This interpretation of Article 3 para 3 has been confirmed by a decision of the Subsidiary Body for Scientific and Technological Advice, SBSTA (UNFCCC, 1998). This decision also determines that "since 1990" includes activities from 1.1.1990 onwards. This is regrettable as it means that the absorptive capacity in 1990 of sinks created in that year are accounted in the commitment period without being included in the calculation of the baseline emissions. A corresponding net sink in the year 1990 is not taken into consideration in the calculation of the baseline emissions (Fig. 1b).

The calculation procedure thus in effect amounts to a comparison between net emissions in the commitment period 2008–2012 and gross emissions in the 1990 base year. In the event of a net sink, this increases the quantity of permitted emissions (Fuentes et al., 1998).

If we follow the national reports submitted by the Annex I Parties, then the ratio of all sinks created by human-induced activities to national emissions (in 1990) ranges between only 1% (e.g. the Netherlands) and 81% (New Zealand) (UNFCCC, 1997a) (Annex Table 1). For Germany, the ratio figures only 3%. It is uncertain which proportion of this will be accounted under Article 3 paras 3 and 4. The more activities to create sinks are accounted under Article 3 para 4 in the future, the larger the permitted amount of emissions becomes. This calculation procedure disadvan-

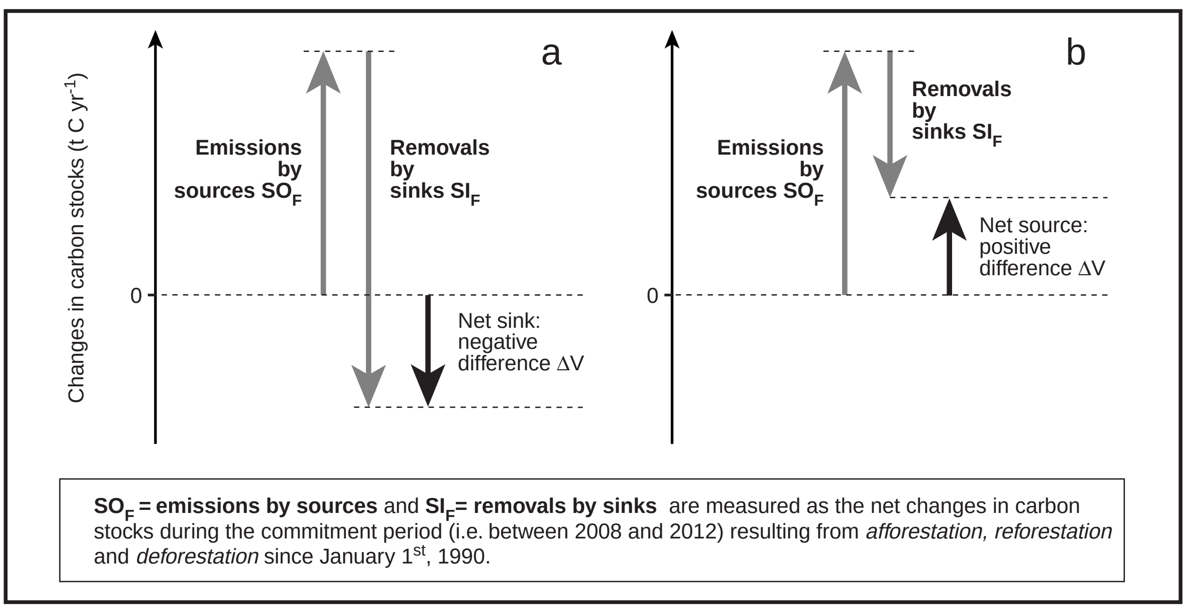

Figure 2
Net accounting of biological sources and sinks under Article 3 para 3: (a) The difference between the emissions by sources and the removals by sinks resulting from afforestation, reforestation and deforestation results in a net sink in the commitment period 2008–2012. (b) If emissions due to deforestation have predominated since 1990, then this results in a net source. The difference leads to a change in carbon stocks in the commitment period 2008–2012 (see Fig. 3).
Source: WBGU

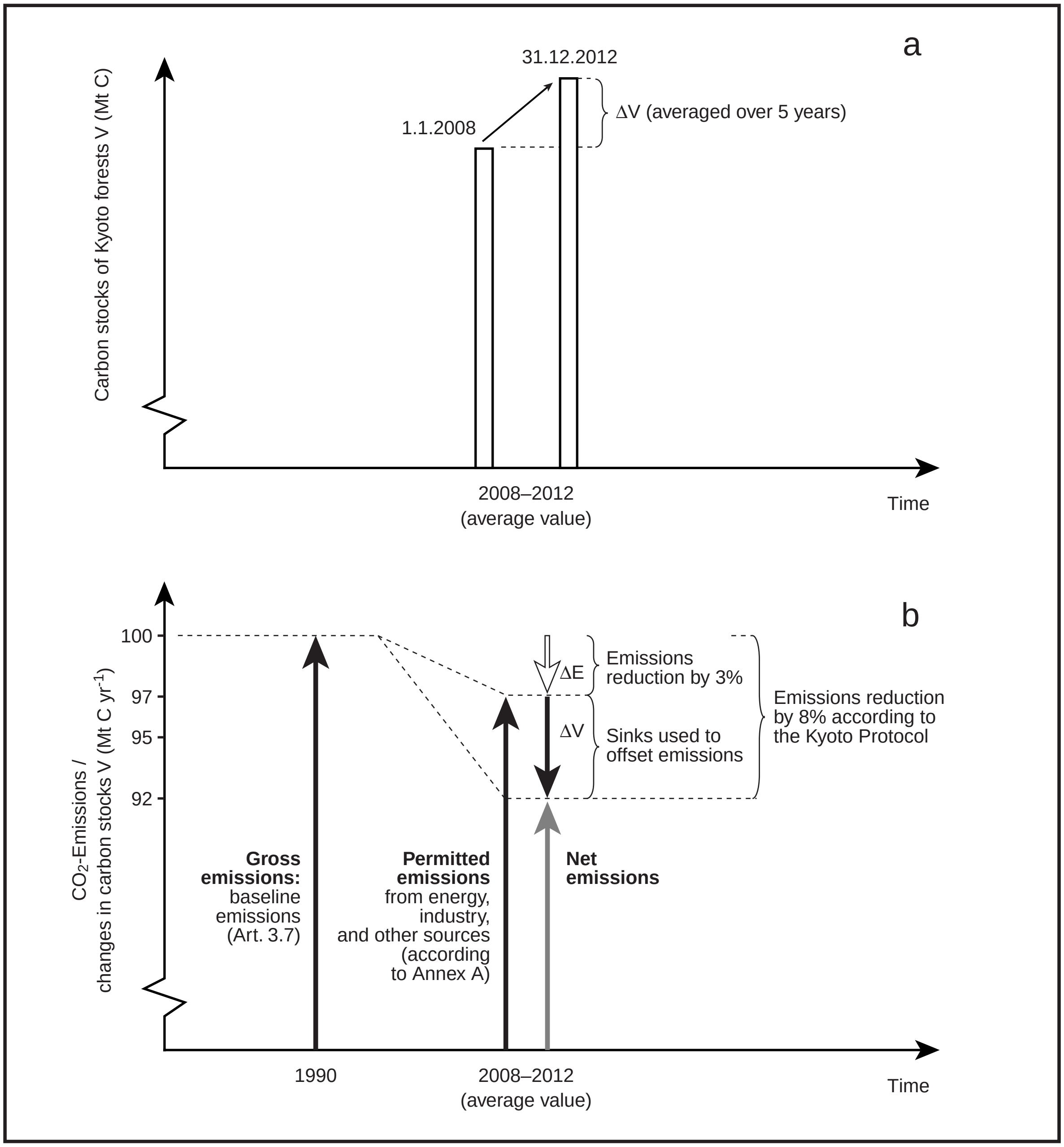

Figure 3
Accounting of biological sources and sinks under the Kyoto Protocol: The Figure illustrates the approach for offsetting the reduction commitments of the industrialized countries against biological sources and sinks (Article 3 para 3 of the Protocol) for the example of an imaginary country. (a) It is assumed that, averaged over the five years of the commitment period (2008–2012), carbon stocks rise annually by the amount ΔV due to the afforestation, reforestation and deforestation that took place since 1990. (b) It is further assumed that under the Kyoto Protocol the country must reduce its emissions by 8% of the gross emissions of 1990. In the commitment period 2008–2012, the growth in carbon stocks due to the afforestation, reforestation and deforestation that took place since 1990 is credited to the country pursuant to Article 3 para 3. This means that the permitted gross emissions in the commitment period are raised by ΔV annually – the reduction commitment is thus reduced by 5%. The calculation approach results in a gross emission reduction commitment of only 3%.
Source: WBGU

tages those countries for whom the proportion of accountable sinks is low vis-à-vis other countries.

Finally, the assigned amount of gross emissions can be supplemented or reduced by emission reduction units (Article 3 paras 10 and 11) or parts of an assigned amount that a Party acquires or transfers by means of joint implementation of measures in another industrialized country (pursuant to Article 6) or by means of emissions trading (Article 17). Certified emission reductions obtainable in developing countries pursuant to Article 12 are also added to the assigned amount. These options are examined in more detail below.

3.1.1 Future commitment periods

The commitment of industrialized countries to reduce overall emissions by at least 5% from 1990 levels only refers to the first commitment period 2008–2012. The calculation procedure set out in Article 3 para 7 also only applies to this first commitment period. Article 3 para 9 regulates the establishment of commitments for subsequent periods. These must be established by amending Annex B to the Protocol, which lists the reduction quota for the individual industrialized countries. It is unclear whether this presumes that the calculation procedure set out in Article 3 para 7 also applies to subsequent commitment periods. Article 3 para 3, which regulates the accounting of sources and sinks in the "land-use change and forestry" category, refers to "each commitment period".

The commitment periods must follow on from each other without interruption. This is an essential precondition to the verifiability and effectiveness of reduction measures.

The Parties must initiate the consideration of commitments for subsequent periods at least seven years before the end of the first commitment period, i.e. by 2005 at the latest.

Under Article 3 para 13, the Parties can add that proportion of emission reductions that they have achieved in a commitment period in excess of their commitment to the assigned amount for subsequent commitment periods. This permits so-called "banking", i.e. the possibility of meeting commitments for future periods in advance. By contrast, the opposite, i.e. postponing reduction obligations to future periods ("borrowing") is not permitted.

3.2 Accounting afforestation, reforestation and deforestation (Article 3 para 3)

As explained above, Article 3 para 3 regulates the accounting of biological sources and sinks to the commitments of the industrialized countries. However, only the impacts of those "afforestation, reforestation and deforestation" activities carried out since 1990 can be accounted to the emissions in the years 2008–2012. These impacts are measured as verifiable changes in carbon stocks in each commitment period. This means that in the years 2008–2012 records must be kept on the proportion of changes in carbon stocks that is attributable to the growth of forests planted since 1990 (afforestation and reforestation) and to deforestation that has taken place since 1990. Impacts of deforestation or afforestation that took place prior to 1990 – even if existing and measurable – shall not be included in the accounting. Changes in carbon stocks shall thus only be accounted for those areas on which afforestation, reforestation or deforestation took place since 1990 ("Kyoto forest").

The formulation of Article 3 para 3 begs a series of questions:

- Which changes in carbon stocks are *verifiable*? Should only above-ground biomass stocks be considered, or should carbon stocks in soils also be included?
- How should changes in carbon stocks be *measured* or calculated during the commitment period in order to arrive at comparable figures? Are practicable accounting procedures available that could be applied to all Parties (i.e. also different climate zones, soil types and vegetation types)?
- How are the *"afforestation"*, *"reforestation"* and *"deforestation"* activities defined? In particular, how is reforestation distinguished from logging and replanting in the course of regular forestry activities? Is the conversion of primary forests to plantations taken into consideration?
- How can the impact of *direct human-induced activities* in "land-use change and forestry" be distinguished from natural impacts and factors, such as forest fires?
- How exactly shall net changes in greenhouse gas emissions and removals brought about by the stated activities be *used to meet* commitments? Can prevailing uncertainties and the role of differing time scales be taken into consideration by introducing certain discounting procedures or by limiting the total accountable change resulting from these activities to a maximum level?
- Should real changes in carbon stocks be used in the commitment period, or should the mean

stocks – averaged over the rotation of the respective forest ecosystems – be considered?

- Should the calculation of carbon stocks also consider the service life and utilization of harvested products (firewood, paper production, building timbers, furniture)?

Article 3 para 3 in conjunction with Article 7 delivers indications for the answers to these questions: Emissions by sources and removals by sinks resulting from the above activities shall be reported in a "transparent and verifiable manner" and reviewed in accordance with Articles 7 and 8. Article 7 regulates the preparation of national communications by the Annex I Parties, which shall, among other things, contain annual inventories of greenhouse gas emissions and removals. Article 8 regulates the review of the national communications by expert review teams.

3.2.1 National reports and greenhouse gas inventories (Articles 7 and 5)

The Parties to the Convention must prepare national inventories of emissions by sources and removals by sinks (Article 4 para 1 UNFCCC) and must submit national reports at certain intervals (Article 12 UNFCCC). According to Article 7 of the Kyoto Protocol, Annex I Parties must incorporate in their national communications and inventories the necessary supplementary information for the purposes of ensuring or demonstrating their compliance with the Kyoto Protocol (Article 7 paras 1 and 2). Article 7 para 4 stipulates that the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol (COPsmoP) shall adopt at its first session guidelines for the preparation of this information. Furthermore, COPsmoP shall, prior to the first commitment period, decide upon modalities for the accounting of assigned amounts. These guidelines and modalities, which are yet to be adopted, can be used to concretize the accounting of afforestation, reforestation and deforestation measures pursuant to Article 3 para 3.

In addition, Article 5 of the Protocol states that the Annex I Parties shall have in place no later than 2007 a national system for the estimation of anthropogenic emissions by sources and removals by sinks. The first session of COPsmoP shall decide upon the guidelines for such national systems. According to Article 5 para 2, this estimation shall use the methodologies accepted by the IPCC and agreed upon by COP 3 (1997). These are the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1997; UNFCCC, 1997b) as revised in 1996. These methodologies and their adjustments are to be regularly reviewed by COPsmoP and revised as appropriate. However, any revision can only be used for commitment periods adopted subsequent to that revision (Article 5 para 2, fourth sentence). It is thus not possible to utilize a revision for the already adopted first commitment period 2008–2012.

3.2.2 The IPCC Guidelines

The IPCC Guidelines for National Greenhouse Gas Inventories serve the Parties to the UNFCCC as instructions for the inventories of their anthropogenic emissions by sources and removals by sinks which they are obliged to prepare under Article 4 para 1 UNFCCC. In particular, the Guidelines are to make available comparable methodologies and reporting systems. Work on these Guidelines has been carried out since 1991 by the IPCC in cooperation with the Organization for Economic Cooperation and Development (OECD) and the International Energy Agency (IEA), with participation of experts from numerous countries. The revised 1996 version of the Guidelines (IPCC, 1997), which already formed the basis for the second national communications of Annex I Parties, shall now also serve as the basis for the calculation of accountable sinks (Article 5 para 2 Kyoto Protocol).

The IPCC Guidelines stipulate minimum requirements upon calculation procedures, their underlying assumptions and the level of detail. However, it is repeatedly pointed out that wherever possible improved methods, data and assumptions should be used. Particularly in the sphere of land-use change and forestry, the Guidelines stress that the minimum requirements by no means permit a realistic estimation of actual sources and sinks, because, for instance, many processes (such as those in the soil) are not adequately considered. This is borne out by a comparison of national communications on the land-use change and forestry categories carried out by the Convention secretariat (UNFCCC, 1997a), which shows that these are scarcely comparable because they are based on very disparate calculation methodologies and data sources. Attention is also repeatedly drawn in the Guidelines to considerable uncertainties and sources of error.

In their present form, the IPCC Guidelines for the land-use change and forestry sector were not originally formulated as a basis for the implementation and review of legally binding commitments (Bolin, 1998). Thus the preface to the revised 1996 Guidelines expressly points out that work is needed to refine methods in this sector (IPCC, 1997). The question then arises to what extent they are suited in their present form to deliver methodologies pursuant to Article 5 of the Kyoto Protocol for assessing compliance with commitments (Fuentes et al. 1998).

In the land-use change and forestry sector, the IPCC Guidelines only establish inventories for carbon dioxide, other greenhouse gases are not considered. The Guidelines contain the following definitions and procedures that are relevant to Article 3 para 3 of the Kyoto Protocol:

The glossary to the IPCC Guidelines defines *afforestation* as "planting of new forests on lands which, historically, have not contained forest". *Reforestation* is defined as "planting forests on areas which have, historically, previously contained forest but which have been converted to some other use". The distinction between afforestation and reforestation is defined more precisely elsewhere (in connection with the definition of plantations): Here it is stated that afforestation is when soils have not borne any forests for more than 50 years. Reafforestation, by contrast, means "planting on lands that have supported forests within the last 50 years" (IPCC, 1997). Both activities are categorized as forestry measures ("changes in forest and other woody biomass stocks"), where only changes in above-ground biomass are inventorized (calculated as annual growth minus harvested biomass). The IPCC reference approach does not consider changes in carbon stocks in the soil, neither before nor after afforestation. If the IPCC Guidelines are applied to implement the commitments under the Kyoto Protocol, it would be necessary to record separately the annual growth of forests planted after 1990 and of forests that already existed prior to this date.

It is unclear whether the natural regeneration of forests (see Glossary) can be accounted as a sink. The Guidelines give no definition or explicit instructions on this. As natural regeneration is not an active measure aimed at creating sinks and according to the wording of the IPCC Guidelines reforestation means *planting* forests, an accounting of natural regeneration is presumably not intended.

Deforestation means, according to the IPCC Guidelines, the conversion of forests to other uses (pasture, arable farming and others). The Guidelines provide for taking delayed effects of deforestation into consideration, such as those on carbon stocks in soil. In addition to net changes of carbon sequestered in above-ground biomass measured or calculated in the inventory year, the following changes in carbon stocks are considered in the calculation of the impacts of deforestation in a previous year upon the carbon flow in the inventory year (such as a commitment year):

- The biomass burnt or extracted in the first year is inventorized in this year as an emission (this part is generally by far the largest).
- It is assumed that a part of the burnt biomass is sequestered over the long term in the form of charcoal.
- It is assumed that the biomass remaining on the area decays over a period of ten years. The annual inventories of the ten years following deforestation thus record one tenth each of the decomposed biomass as an emission.
- It is assumed that the decomposition processes in the soil leading to a reduction of soil stocks after deforestation or burning persist for twenty years. Accordingly, the inventories of the twenty years subsequent to deforestation assess one twentieth of the assumed soil loss as annual emission.

Emissions in an inventory year (this can be a year within the commitment period) thus include time-delayed effects of deforestation of the past ten years (decomposition of above-ground biomass and in the soil) and of the past twenty years (decomposition in soil).

It is unclear how to treat clearing that is immediately followed by establishing a forest plantation. The definition of "reforestation" in the Glossary attached to the IPCC Guidelines states that a certain period during which the area has been used differently elapses between logging and reforestation ("historically, previously contained forests, but which have been converted to some other use"). Reforestation directly after harvest would thus presumably not be accounted. By contrast, the FAO definition (reforestation: "establishment of a tree crop on forest land"), which corresponds more closely to common usage, could include this process, and could thus consider the resultant annual increment in the annual inventories (Schlamadinger and Marland, 1998). Neither of the two definitions suggest accounting the emissions caused by the previous clearing.

According to the IPCC Guidelines, undisturbed natural forests need not be considered in the inventories, as it is assumed that these are in a state of equilibrium and represent neither a source nor a sink. However, the Guidelines state that the loss of above-ground biomass caused by logging a natural forest and subsequent use as plantation *should* indeed be inventorized under the category of conversion from forest to other uses. No reference is made to the losses in soil associated with this.

The IPCC Guidelines do not define the distinction between reforestation and other forest management practices, as they provide for inventorization of all forestry measures in any case. It follows that the IPCC Guidelines make no provision for the differentiation between reforestation and other measures that is required by the Kyoto Protocol.

3.3 Accounting additional activities? (Article 3 para 4)

According to Article 3 para 4, each Annex I Party shall provide data prior to the first session of COPsmoP that enables its carbon stocks in the year 1990 and in the subsequent years to be calculated. At its first session, COPsmoP shall then decide upon *modalities, rules and guidelines as to how, and which, additional human-induced activities* related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be accounted. This decision shall in principle only apply in the subsequent commitment periods, but Parties may choose to already apply such a decision in the first commitment period.

COPsmoP can only adopt decisions on the accounting of additional activities when the Kyoto Protocol has entered into force. This will certainly not take place before the year 2000. Nonetheless, such decisions may already impact upon the first commitment period (2008–2012). This is why COP 3 resolved in its decision on the adoption of the Kyoto Protocol (UNFCCC, 1997c) to request the subsidiary bodies to already prepare consideration by COP 4 (scheduled for November 1998) of the issues addressed by Article 3 para 4. The SBSTA, for its part, has requested the Parties to submit information on Article 3 para 4 to the Convention secretariat.

The development of the negotiations in Kyoto showed that numerous Parties are most interested in including further activities (such as other forest management practices, or the use of agricultural soils) in the list of accountable sinks.

The wording of Article 3 para 4 states that COPsmoP shall decide upon how, and which, "additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties included in Annex I". The "assigned amount" is the permitted amount of gross emissions in the 2008–2012 period. The decision must take into account uncertainties, transparency in reporting and verifiability.

Article 3 para 4 has no effect upon the baseline emissions defined in Article 3 para 7. This means that every further accounted sink increases the permitted amount of emissions from fossil energy sources.

3.4 Flexible implementation of measures in industrialized countries (Articles 6 and 17)

Article 6 permits the joint implementation of projects by several industrialized countries. Annex I Parties can use such projects to acquire emission reduction units in other industrialized countries. These projects can also aim expressly at enhancing the removal of carbon dioxide by sinks. Under Article 6, the accounting of sinks is not restricted to the activities stated in Article 3 para 3, nor to the additionally accountable activities under Article 3 para 4. This may mean that the definition of projects under Article 6 permits an accounting of measures (such as forest management) in other industrialized countries that would not be domestically eligible for acounting.

As opposed to accounting under Article 3 para 3, projects under Article 6 must provide a reduction in emissions or an enhancement of removals by sinks that is "additional to any that would otherwise occur". Furthermore, Article 6 para 2 charges COPsmoP with elaborating guidelines for the implementation of Article 6. These guidelines must also cover verification and reporting. Here again COP 3 has requested COP 4 (1998) to prepare this decision.

Article 17 permits trading with emission permits ("emissions trading"). Annex I Parties can use these tradable permits to meet a part of their commitments under Article 3. However, it is unclear whether these permits are also to be issued for the creation or enhancement of sinks. Principles, modalities, rules and guidelines for emissions trading must be adopted by the Conference of the Parties.

3.5 Measures in developing countries (Article 12)

It is possible that the provisions of the Kyoto Protocol on reducing or limiting greenhouse gas emissions and on accounting of land-use change and forestry activities will not only concern the Annex I Parties. This follows from the clean development mechanism (CDM) agreed upon in Article 12. This mechanism factually allows the agreement of jointly implemented emission reduction measures between Annex I Parties and developing countries. Article 12 para 3 states: "Parties included in Annex I may use certified emission reductions accruing from such project activities to contribute to compliance with part of their quantified emission limitation and reduction commitments under Article 3". Annex I Parties can already begin with this in the year 2000, whereby certified emission reductions obtained in the period from 2000 to 2008 (i.e. prior to the first commitment period) can be used to meet commitments in the first period (Article 12 para 10).

Article 12 – including its paragraph 5, which stipulates the requirements for certification – only states "emission reductions" throughout. In contrast, Article 6 para 1 refers to "emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks". Thus Article 12, which regulates the joint implementation of projects among industrialized and developing countries, does not state sinks, while Article 6, which regulates the joint implementation of measures among industrialized countries, does state them. Conversely, this can lead to the interpretation that Article 12 does not cover sinks. Nonetheless, some Parties will wish to interpret Article 12 such that it refers to net emissions, i.e. covers both energy-related emissions and sources and sinks in the land-use change and forestry categories. This could be reasoned by referring to the commitments under Article 3, which do indeed include sinks. The question would then arise of whether projects in developing countries must also be restricted to the activities stated in Article 3 para 3, or whether they are subject to no restriction at all (apart from the conditions under para 5).

In addition to the immediate impacts of the agreed clean development mechanism, it must be kept in mind that it is highly probable that developing countries will be included in the commitments for further commitment periods.

The present report therefore examines the sources and sinks of terrestrial ecosystems and the human-induced impacts upon them worldwide – not only in Annex I Parties.

Table 1
Overview of the accounting approach under the Kyoto Protocol.
AE: Aggregate emissions (energy, industry, agriculture, waste, no land-use change and forestry sources and sinks, Annex A Kyoto Protocol)
NE_{LUFC}: Net emissions from land-use change and forestry
NE_{LUC}: Net emissions from land-use change (without forestry)
$\Delta V_{LUFC\ (1990–2012)}$ (2008–2012): Change in carbon stocks during the commitment period that are accounted for under Article 3 paras 3 and 4
ER_{CDM}: Certified emission reductions accruing from projects in developing countries (pursuant to Article 12, CDM). May possibly contain sink projects, such as reforestation.
$ER_{Art.\ 6}$: Acquired emission reduction units from projects in other industrialized countries, minus transferred units (pursuant to Article 6). Sink projects are contained.
$EC_{Art.\ 17}$: Emission certificates purchased minus certificates sold
X%: Reduction rate (see Annex B Kyoto Protocol, e.g. European Community 8%)
Source: WBGU

	Annex I countries	**Developing countries**
1990	Baseline emissions = AE (1990) (base year) (without land-use change and forestry) Exception: if NE_{LUFC} (1990) >0: (e.g. Australia) Baseline emissions = AE(1990)+NE_{LUC}(1990)	No commitment. Deforestation is not accounted to any state
from 1990 on	Activities: afforestation, reforestation and deforestation (Art. 3.3) (impacts during 2008–2012) – Soil is neglected in reforestation/afforestation – Management is not accounted – Conservation of primary forests is not accounted – Distinction management/reforestation? – Conversion primary forest to secondary forest? – Accounting of organic layer? – Additional activities? (Art. 3.4)	
from 2000 on	Partial accounting of projects in developing countries (Article 12, CDM)	Financing of CDM projects Deforestation is not accounted to any state
2008–2012 (commit-ment-period)	Changes in carbon stocks are accounted Projects in other industrialized countries (Article 6) Emissions trading (Article 17) Accounting of afforestation projects in developing countries? (CDM, Article 12) Permitted emissions (2008–2012) = (X% of baseline emissions)*5 (Art. 3 para 7) + $\Delta V_{LUFC(1990–2012)}$(2008–2012) (Art. 3 para 3, Art. 3 para 4?) + ER_{CDM}(2000–2012) (Art. 12) + $ER_{Art.\ 6}$(2008–2012) (Art. 6) + $EC_{Art.\ 17}$(2008–2012) (Art. 17)	Deforestation is not accounted to any state

4 Carbon source and sink potentials of terrestrial ecosystems

This Section presents the current state of knowledge on the carbon source and sink potentials of terrestrial ecosystems. To start with, the terms used to describe the carbon cycle will be defined.

- In keeping with the definition used in the United Nations Framework Convention on Climate Change (UNFCCC, Article 1 para 9), a *source* of a greenhouse gas (such as carbon dioxide) is understood to mean any process or activity which releases a greenhouse gas into the atmosphere.
- Correspondingly, a *sink*, according to Article 1 para 8 UNFCCC, is a process, activity or mechanism which removes a greenhouse gas from the atmosphere. Thus, an ecosystem represents a sink for carbon dioxide if its assimilation of carbon (through photosynthesis) exceeds its loss of carbon through respiration and extraction (harvest). In this way the carbon stocks of the vegetation or soil (organic layer, mineral soil) increase. Conversely, an ecosystem represents a source of carbon dioxide if its carbon assimilation is smaller than its carbon loss through respiration plus extraction. In this case the carbon stocks of the vegetation or soil decrease over time.
- Following Article 1 UNFCCC, a *carbon reservoir* is defined as a component (such as a land area or vegetation zone) of the climate system where carbon is stored.
- *Carbon stocks* or *pools* are understood to mean the mass of carbon stored in a carbon reservoir (such as a vegetation zone, a country, or a land area).
- *Carbon concentration* gives the amount of carbon per gram dry matter.
- *Carbon flux* denotes the mass of carbon per unit time that is absorbed by a vegetation zone, a land area or country (negative sign), or that is released into the atmosphere (positive sign). In the case of a negative sign the vegetation zone or land area or country represents a sink, while a positive sign identifies it as a source.
- *Carbon flux density* is understood to mean carbon flux per unit area and time.
- *Carbon balance* denotes the net carbon flux, which is the sum out of all carbon fluxes and changes in stocks (including extraction through harvest).

4.1 Carbon stocks in the biosphere and pedosphere

The carbon stocks of terrestrial ecosystems are distributed above- and belowground, in the vegetation, organic layer and mineral soil (soil organic carbon, SOC) (see Fig. 4). Vegetation biomass divides into above- and belowground biomass (roots, for example). The organic layer consists of litter and a part of the humus layer. Bogs and fens additionally bear a peat layer. Some of the carbon contained in the mineral soil (SOC) exists in dissolved form (dissolved organic carbon, DOC). Only a quarter of terrestrial carbon is stored in the vegetation, the remaining three quarters being contained in the soil and its organic layer (Heimann et al., 1997; Annex Table 2). Any attempt to assess the management of global carbon sources and sinks must therefore give particular consideration to changes in the soil.

The Earth's carbon stocks are by no means evenly distributed over its land area, as storage of carbon in soil occurs above all in cooler climates (Annex Table 2). While the Annex I countries together account for only around a third of the terrestrial land surface, this area contains approximately 50% of terrestrial carbon, mainly in the soil. Thus, the Annex I Parties bear a special responsibility for the protection of soil carbon.

4.2 Comparison of vegetation types

Forests contain approximately 46%, and already forest soils, including their organic layer, store 39% of total terrestrial carbon (Annex Table 2). Half of global forest carbon is distributed over the boreal forests of Russia, Canada, and Alaska, while the tropical forests together account for 37%. *As far as the*

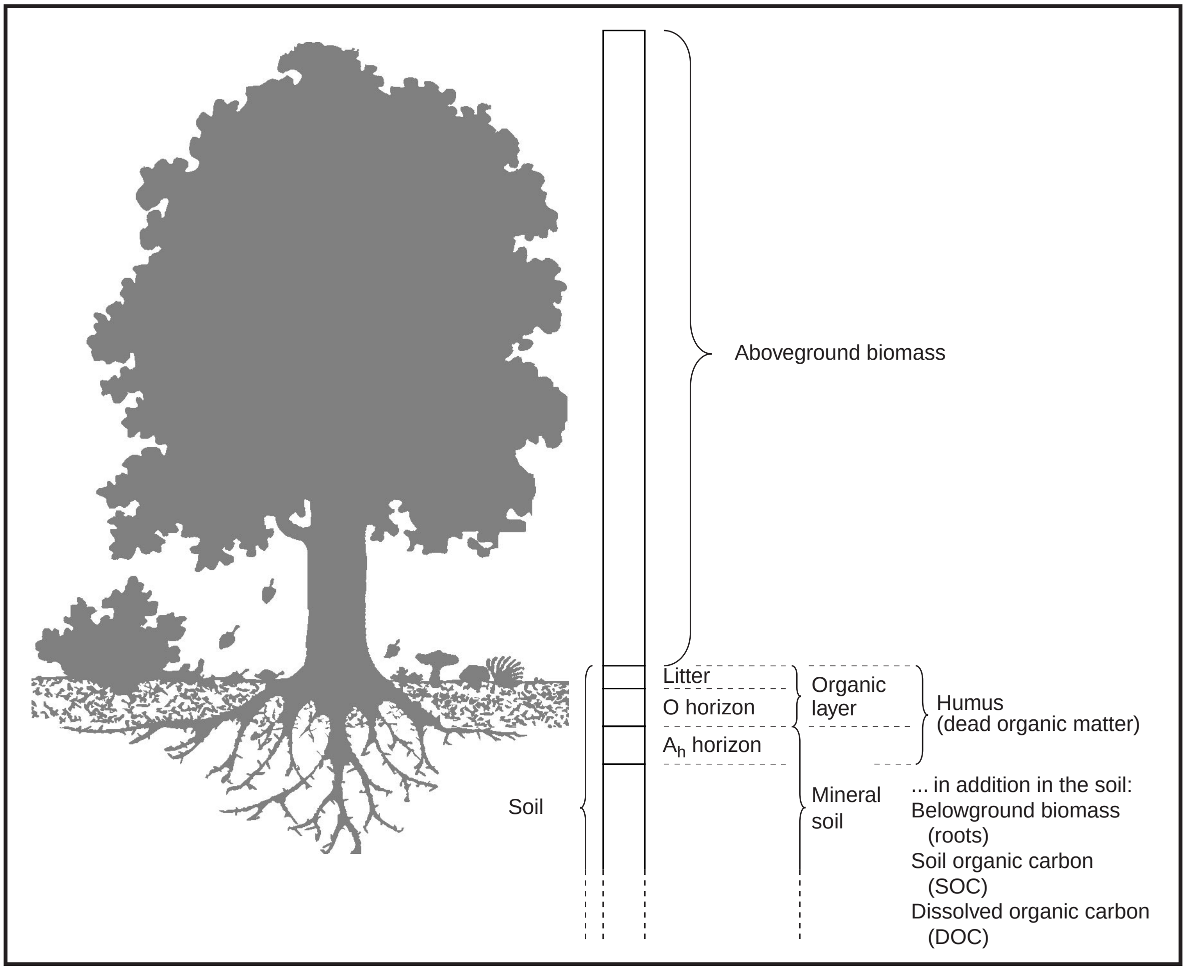

Figure 4
Schematic of the carbon compartments of a terrestrial ecosystem. The terms are explained in the glossary in Section 9.
Source: WBGU

global carbon regime is concerned, the protection of the boreal forests is therefore at least as important as that of the tropical forests. One difference between tropical and boreal forests is that in boreal forests 84% of the carbon is stored in the soil (organic layer, peat, and soil organic carbon), whereas in the tropics this figure is only 50%. Boreal forest management should therefore be geared to conserving soil carbon. European forest soils have conspicuously small carbon stocks, even when referred to units of area. It cannot be excluded that this is due to the influence on the soil carbon balance of intense forest management, including the centuries-old practice of litter utilization.

Temperate grasslands and savannas cover approximately 23% of the land surface and contain some 26% of the Earth's terrestrial carbon stocks, mainly in their soils. The soil carbon pool per unit of area is two to four times greater in temperate grasslands (chernozem) than it is in the savannas (Atjay et al., 1979; Houghton, 1995). The large-scale conversion in the past of temperate grassland to cropland has resulted in a loss of some 50% of this carbon at a soil depth of 0–20 cm (Matson et al., 1997). Secondary grasslands (e.g. genus *Imperata*) such as develop in the tropics after fire cultivation store very little carbon, depending on fire frequency. However, pasture soils in the Amazon region may be equal or even richer in their total carbon content than the soils of intact rainforests (Annex Table 6). It is foreseeable that many seasonal and moist tropical forests will be converted to grassland in the future. To what extent this has an effect on the global carbon regime will depend on whether the forest is succeeded by degraded land (e.g., *Imperata* grassland) or managed pasture. This in turn depends in large part on soil quality and anthropogenic fire cycles.

Table 2
Global terrestrial carbon stocks and net primary productivity of vegetation types, and their proportion in Annex I countries.
Source: IGBP, 1998

	Area [mill. km²]		Carbon stock [Gt]		Net primary productivity [Gt C year⁻¹]	
	Global	Annex I countries	Global	Annex I countries	Global	Annex I countries
Forests and woodlands	41.8	19.3	987	526	25	9
Crops, arable and permanent pasture	48.1	14.9	385	119	25	8
Peat	4.8	4.5	430	401	0.2	0.2
Other lands	54.3	11.5	388	69	11	2
Total	149	50.2	2,190	1,115	61	19
Atmosphere			750			
Coal deposits			9,000			
Projected net increase under CO_2 increase, climate change and vegetation redistribution			290			

The global cropland area amounts to 1.4 billion ha, which is 11% of the Earth's ice-free land surface. This area accounts for less than 1% of the carbon contained in the aboveground biomass of terrestrial ecosystems and 8–10% of global soil carbon stocks. At present some 80% of potential cropland is actually cultivated (Cole et al., 1993). Bouwman and Leemans (1995) estimate the annual rate of conversion of forest to cropland during the 1990s as 12 million ha and that to grassland as 2.5 million. The expansion of total cropland area to today's 1.4 billion ha has led to a loss of 93 Gt C in aboveground biomass (Lal et al., 1998). The conversion of natural ecosystems to cropland is associated with a ca. 25% to 30% decrease in carbon content of the uppermost meter of the soil profile. This loss can vary widely depending on the farming method, initial climatic situation and the condition of the soil (Detwiler, 1986; Mann, 1986; Batjes and Sombroek, 1997). Altogether the conversion of natural ecosystems to cropland has led to a decrease in soil carbon stocks of 38 Gt C. According to IPCC estimates (1996b), improved management, if maintained over a period of 50–100 years, would create a sink potential for the sequestration of 20–40 Gt C.

Low carbon stocks are the result of regular harvesting and soil tillage. In many regions the net primary productivity (NPP) of farmland is very low compared with the NPP of native vegetation. Only in a few industrialized countries does the NPP of farmland approach or exceed that of the native vegetation. In developing countries, NPP of crops is only 10–20% of that of the native vegetation (Esser, 1994). Diminished NPP means reduced plant biomass. This reduction leads to a decrease in crop residues and thus to a diminished carbon input to the crop residue / humus subsystem.

Although w*etlands* only cover 3–6% of the Earth's surface, depending on how they are defined, they contain 10–30% of global terrestrial carbon, again depending on the definitions employed (Lugo et al., 1990; IPCC, 1996b; Mitsch and Wu, 1995) (Annex Table 2). In relation to unit area, they store three times as much carbon as forests (Mitsch and Wu, 1995). According to Zoltai and Martikainen (1996), peatlands hold soil carbon stocks of 541 Gt, which accounts for 34.6% of total terrestrial soil carbon. Adding biomass to this pool leads to an insignificant increase to 566.7 Gt C. This is equivalent to 20% of the entire carbon pool of terrestrial ecosystems. Inventories (Annex Table 2) may contain double counts, e.g. in the case of forested peatlands. The share of tropical wetlands in global wetland area is estimated between 30% and 50% if rice growing areas are included. Excluding rice farmland, the proportion of tropical wetlands ranges between 10% and 30%. Despite their small share in total wetland area, the carbon stocks of tropical wetlands are of a magnitude similar to those of the wetlands of the northern hemisphere. This is because their stocks per unit area are several times larger, both in the biomass and the soil compartment (Matthews and Fung, 1987; Aselmann and Crutzen, 1989; Maltby and Turner, 1983; IPCC, 1996b). The carbon stocks of tropical wetlands are seriously endangered, especially by land-use changes (rice cultivation).

The arctic carbon stocks are at risk of being released through climate change, as this could alter the water regime of wetlands and render the carbon stocks of permafrost soils prone to mineralization. Despite all remaining uncertainties, the cited estimates demonstrate the immense significance and urgent need of protection of these habitats, including those in the temperate zone (e.g. wetlands in Germany).

5 Carbon fluxes

5.1 The concept of net biome productivity

This Section will examine how durable the currently assumed sequestration of carbon by the Earth's surface is. This requires an understanding of all processes relevant to the carbon cycle in terrestrial ecosystems (Fig. 5).

Approximately half of the carbon assimilated through photosynthesis (*gross primary productivity*, GPP) is consumed again by the plant's energy metabolism (autotrophic respiration) (Waring et al., 1998). The other half is invested in the growth of the plant (*net primary productivity*, NPP). A large proportion of this NPP is returned to the soil as litter and is subsequently mineralized by soil organisms (heterotrophic respiration). This results in the release of roughly another 45% of the original GPP, and the mineral nutrients contained in this fraction thus becomes available again for the growth of the plant. The remaining 5% of GPP (*net ecosystem productivity*, NEP) forms the fraction of slowly decomposable organic material known as humus. Humans use a part of NPP as a food and energy source and as building and fiber material. Beside this some organic matter is reconverted to carbon dioxide through natural or anthropogenic fire. It is estimated that this leaves only 0.5% of GPP in the ecosystem in the form of long-lived carbon (charcoal, stable humus) (*net biome productivity*, NBP; Schulze and Heimann, 1998).

The schematic in Fig. 5 integrates *net carbon fluxes* over various temporal and spatial scales. It does not show the *carbon stocks* that are stored intermediately at different scales of time and space during the individual stages of the process. Moreover, it gives no indication of the dependence of fluxes on various environmental factors. For example, assimilation is

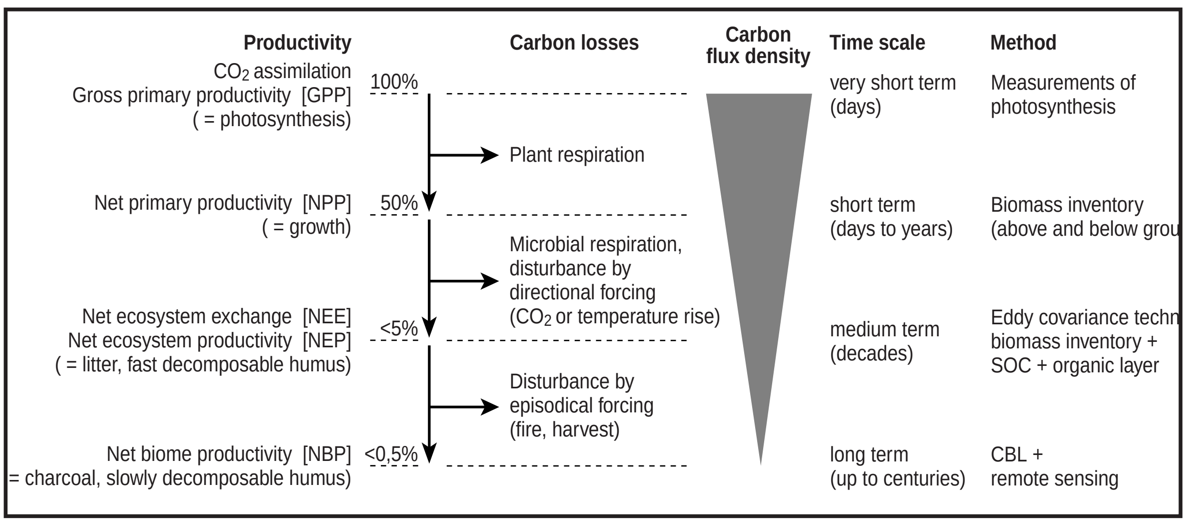

Figure 5
Model of the fate of carbon after its assimilation by an ecosystem. The diagram shows the different levels of carbon productivity and loss; carbon flux density; time scales of the different productivity levels; and the measuring methods by which productivity can be quantified. CBL = balance for the Convective Boundary Layer of the atmosphere.
Source: adapted from Schulze and Heimann, 1998

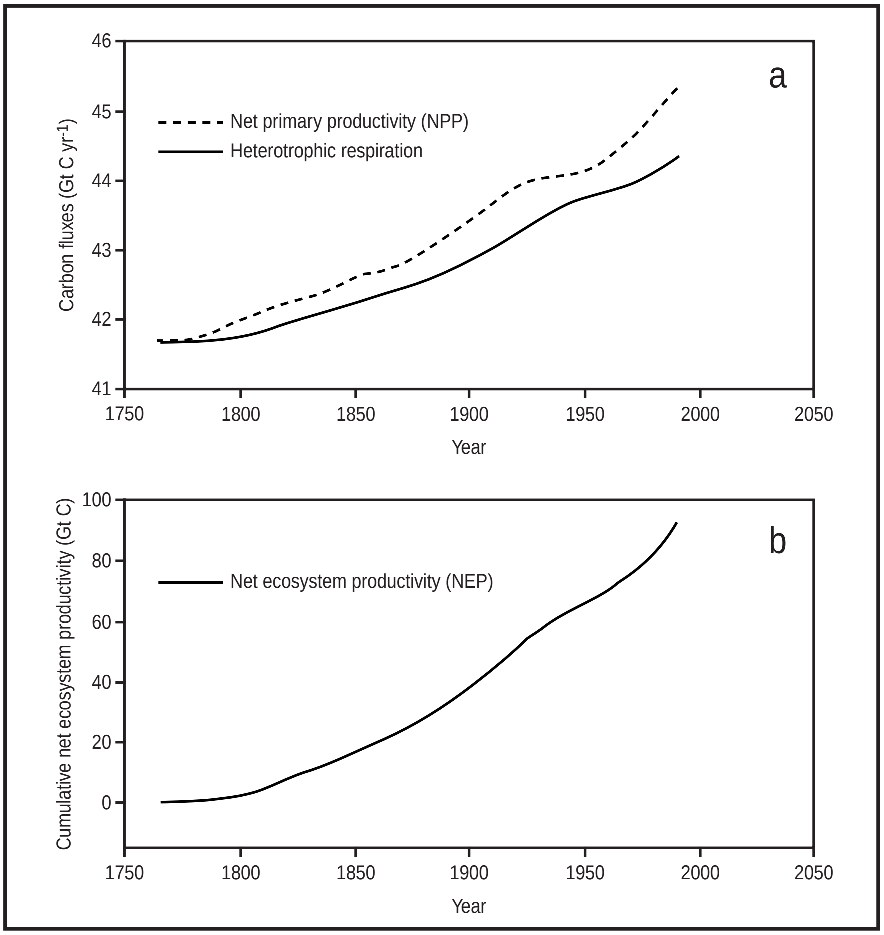

Figure 6
Development of the carbon sink potential of the terrestrial biosphere, simulated by means of the Terrestrial Ecosystem Model (TEM). Net primary productivity increases with growing atmospheric carbon concentration.
(a) Simulated net primary productivity (NPP) and heterotrophic respiration since 1750.
(b) Cumulative net ecosystem productivity (NEP) since 1750.
Source: IPCC, 1996a

chiefly controlled by light, carbon dioxide concentration, and nutritive availability, while respiration is largely a function of temperature (Scholes et al., 1998). Seen over the period of a year autotrophic respiration occurs simultaneously with assimilation. At this time scale heterotrophic respiration occurs with a delay, extending over a period of up to 20 years depending on the plant material (for some of the humus fraction it can even last several centuries in cold climates, but this is quantitatively irrelevant in the present context). If the assimilation rate continues to increase as a result of human activity (in particular through carbon dioxide and nitrogen deposition), then this will be reflected in heterotrophic respiration with a time lag of about 30 years (IPCC, 1996a) (Fig. 6).

The flux of carbon to an intermediate storage is susceptible to human influence: on the one hand via the harvest of biomass, and on the other hand through fire. Fire transfers carbon partly into the atmosphere and partly into the very stable storage form of charcoal.

It is foreseeable that NPP will not continue to increase at the same rate as in the past (Walker et al., 1998). At the same time, however, respiration will increase exponentially as a result of rising temperatures (climate change) (Fig. 7).

This means that the lead of NPP will diminish in the course of the 21st century and will probably even be reversed in favor of respiration. *As a result, terrestrial ecosystems which are now sinks for carbon dioxide will at some point in the future transform into sources of this greenhouse gas.* It is difficult to estimate to what degree humans are accelerating this process (through fire, harvesting, and other disturbances).

The following Section makes an estimate of the fluxes represented by NPP, NEP and NBP and extrapolates a global carbon balance.

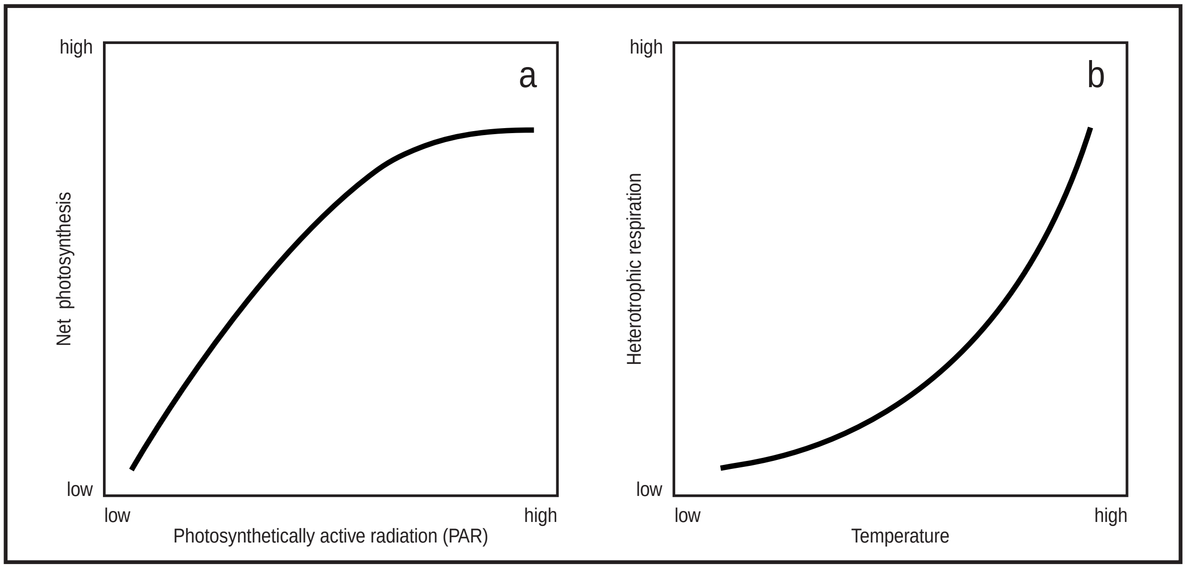

Figure 7
Model of the dependence of photosynthesis and heterotrophic respiration on abiotic factors. (a) Dependence of photosynthesis on light. (b) Dependence of heterotrophic respiration on temperature.
Sources: adapted from Larcher, 1994; Lloyd and Taylor, 1994

5.2 Net primary productivity (NPP), net ecosystem productivity (NEP), and net biome productivity (NBP)

The available data base for estimating NEP is inadequate for calculating sinks pursuant to the Kyoto Protocol. It only contains data on individual stands or species. Only some of the data sets contain measurements for a whole year. Unfortunately, NEP data that cover only a few months are insufficient because carbon fluxes depend on the weather and vegetation period and can also fluctuate strongly between net assimilation and dissimilation.

The data collected until now (Annex Table 4) indicate that *per unit area the temperate forests are at present probably the strongest terrestrial sink* (NEP ranging from -1.4 to -15.5 t C ha^{-1} $year^{-1}$ (median -3,7 t C ha^{-1} $year^{-1}$)). The NEP of the boreal and tropical forests is also negative, though to a far smaller degree than the temperate forests (+0.7 to -1.3 t C ha^{-1} $year^{-1}$ and -1 t C ha^{-1} $year^{-1}$, respectively). Old stands also exhibit substantial negative NEP (Buchmann and Schulze, 1998).

Pasture land in the temperate zones can pose an unexpectedly large carbon source, while natural grasslands can represent substantial sinks (Annex Table 4). There are no or at best very few data available on wetlands, grasslands, and tropical forests. The first complete all-year data sets are now forthcoming from the international research projects EUROFLUX, AMERIFLUX, EUROSIBIRIEN and CARBONFLUX. There have recently been some results published from the BOREAS project (Journal of Geophysical Research, 1998, Vol. 102). As yet NBP can only be estimated for individual stands. Schlesinger (1990) reckons with an accumulation of soil organic carbon (SOC) in the order of 0.024 t C ha^{-1} $year^{-1}$ in soils between 3,000 and 10,000 years of age.

5.3 Estimate of the global carbon balance

To draw up a global carbon balance, an integration over the various carbon fluxes has to be carried out (Fig. 8). In the 1980s land-use changes in the tropics (destruction of rainforests) accounted for carbon dioxide emissions of around 1.6 Gt C $year^{-1}$, this amounting to 25% of the total anthropogenic release in that period (Schimel, 1995). On the other hand the terrestrial vegetation assimilated approximately 1.8 Gt C $year^{-1}$ during the same period (IPCC, 1996a). Reforestation in the middle latitudes and fertilization and climatic effects are thought to have played an important role in this accretion. Fertilization effects are attributed to elevated carbon dioxide emissions and nitrogen deposition (air pollution). In sum, the carbon balance shows that in the 1980s the terrestrial vegetation acted as net carbon sink with a rate of 0.2 Gt C $year^{-1}$. According to the latest measurements, performed by Keeling et al. (1996), the assimilation potential of all land surfaces together com-

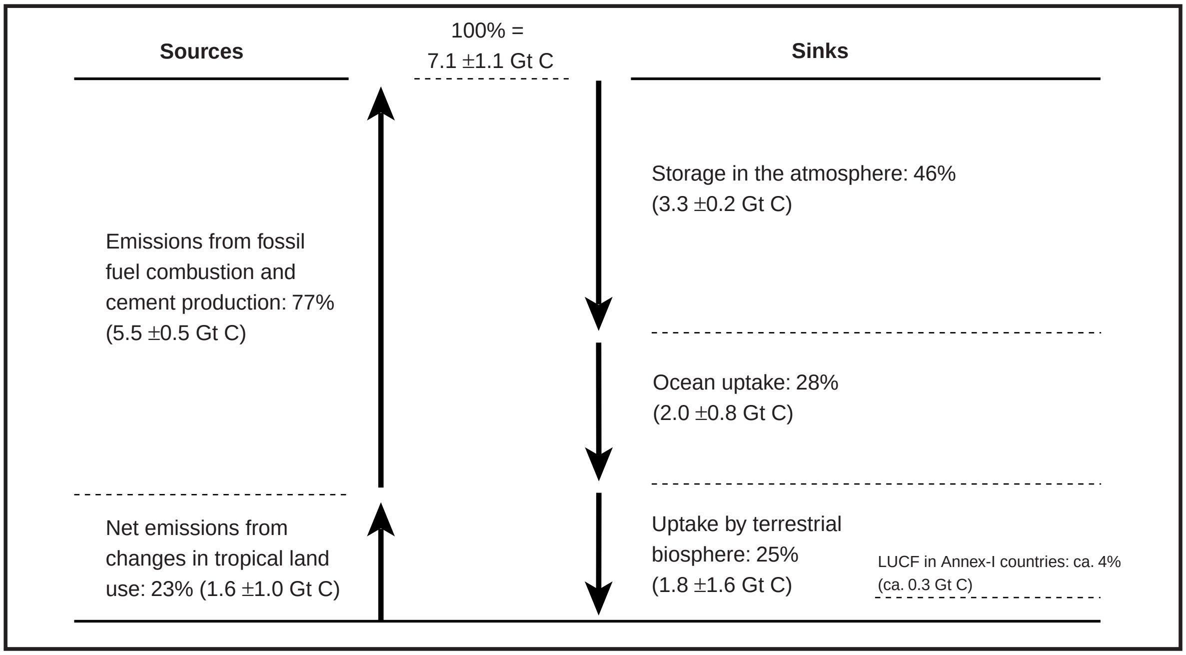

Figure 8
Annual average carbon balance for the period from 1980 to 1989. Carbon fluxes and changes in stocks are given in Gt C year^{-1}. Net anthropogenic carbon assimilation by the industrialized countries in 1990 in the "land-use change and forestry" (LUCF) categories is given for comparison. According to the national reports of these countries this quantity runs to some 0.3 Gt C. This is equivalent to 8% of these countries' total emissions or roughly 4% of global anthropogenic emissions.
Sources: IPCC, 1996a; UNFCCC, 1997a

pensates approximately a third of human-induced carbon dioxide emissions. This has been confirmed by inverse modeling, which deduces sinks and sources on the Earth's surface from measurements of the distribution of atmospheric CO_2 concentrations (Ciais et al., 1995).

5.3.1
Natural variability

Terrestrial carbon fluxes are climate-dependent and vary widely from region to region, from year to year, and from day to day. This makes an estimation of fluxes very difficult. Moreover, it shows that we are dealing with dynamic processes which should not be thought of as "eternal" sinks. The influence of disturbances (in particular fire) has only been examined in a rudimentary manner to date (for example for the boreal forests of Canada: Kurz and Apps, 1996), despite their outstanding significance for the global carbon balance. It could be that the carbon balance of the terrestrial biosphere during the past 60 years has oscillated by more than 1 Gt C between net carbon assimilation and dissimilation solely on account of climate variability. Sinks can even turn into sources as a result of seasonal changes. Annual variability has been around 0.3 Gt C during the past 60 years (Townsend et al., 1996b). The spatial variability of sinks is presumably of about the same order. The present density of monitoring networks would not seem to permit calculating the baseline biological sources and sinks of the year 1990.

5.3.2
Complete carbon balances for nation states

There are few countries to date for which complete carbon balances have been drawn up, among them Switzerland (Paulsen, 1995) and Austria (Körner et al., 1993). There is no such inventory for Germany.

6 Human interventions in sinks and sources

6.1 Land-use change and forestry activities

6.1.1 Conversion of primary forests to secondary forests or managed forests

Although the conversion of primary forests to secondary or managed forests can lead to very high emissions, it is not clear in the IPCC Guidelines (IPCC, 1997) whether such human intervention in terrestrial ecosystems must be accounted for (as deforestation or reforestation) pursuant to Article 3 para 3 of the Kyoto Protocol.

Deforestation is currently taking place above all in the tropics. However, conversion of primary forests to secondary forests or timber plantations is not restricted to the tropics, but is also taking place in boreal coniferous forests and in the Pacific North-West of North America. Most studies have only considered the impact of this on the carbon cycle insofar as it concerns plantation or secondary forest biomass that is utilizable for forestry purposes. Annex Table 5 gives examples of published overall balances.

Old, natural forests store very large quantities of carbon that are prone to release upon forest management or conversion to other uses (Figs. 11 and 12). *Plantations in the tropics hold 20–50% lower biomass carbon stocks than do primary forests there.* Secondary forests and forests subject to unregulated exploitation have 30–80% lower stocks of wood biomass (Fölster, 1989; FAO, 1981). In the temperate zones, production forests are 40–50% poorer in biomass. This is chiefly attributable to the fact that production forests do not reach the same age as primary forests, due to their early harvest, which takes place after 20–50 years in the tropics and 60–120 years (ca. 200 in the case of oaks) in the temperate zones, depending on the species and type and intensity of use. The lower biomass is further attributable to the continual extraction of biomass by thinning. According to Cooper (1983), integration over several rotations of growth and harvest results in a mean carbon pool of intensively used forests that is only 30% of that of undisturbed old stands or primary forests. Intensively used forests are understood in this context to mean plantations and production forests that yield the "maximum sustained yield". In the temperate zone a secondary forest will need some 150–250 years of undisturbed growth in order to accumulate carbon stocks characteristic of primary forests (Harmon et al., 1990). In the tropics it will presumably also need more than 150 years (Walter, 1964; Saldarriaga et al., 1986, quoted by Fearnside, 1996).

Forest management also manifests itself in the quantity of soil organic carbon (SOC). Many studies fail to take account of the organic layer (Cooper, 1983). The organic layer and the soil of temperate and especially of boreal forests are large carbon reservoirs (Annex Tables 2 and 3) which are usually, at least partly, destroyed by fire or intensive harvest.

Frequently it is possible to convert a primary to a secondary, commercially oriented forest without the need for planting. This requires creating soil conditions that allow the desired secondary forest to shoot and grow "naturally". For example, the very species-rich *Thuja* forests of the Pacific North-West of North America are converted by laying the mineral soil bare by mechanical action ("scalping") and burning the organic layer, thus allowing the desired commercial tree species *Pinus contorta* to shoot. This practice is then termed natural regeneration. It seems unlikely that it should be permissible to account natural regeneration in the form practised for many commercial tree species of the temperate and boreal forests (pine and Douglas fir, for example) under the definition of reforestation provided by the IPCC Guidelines (Section 3.2.2 above). Beside this, natural regeneration is not an active measure for creating sinks. However, when it is carried out on small areas in the context of a sustainable management system (e.g. shelterwood systems) there is much in favor of natural regeneration from the ecological viewpoint. It remains to be clarified how ecologically beneficial natural regeneration measures can be kept distinct from those that are preceded by large scale clearcutting and the destruction of carbon pools.

As young stands usually show very high growth rates, the clearing of a primary forest or old-growth stand is usually followed by the rapid recovery of aboveground biomass. However, the temperature and water conditions that prevail after clearcutting can promote soil respiration to such a degree that it exceeds the young trees' assimilation for many years. In this case it can take 20–50 years before substantial carbon quantities are sequestered again (Heimann et al., 1997; Cohen et al., 1996). Soil carbon stocks (including the organic layer) reach a minimum some 10–20 years after forest harvest (Black and Harden, 1995; Covington, 1981). There have been no studies to date on the long-term development of carbon stocks after several rotations of a timber plantation. There is some evidence to suggest that repeated harvesting does not compromise the constancy of soil carbon stocks (Johnson, 1992).

6.1.2
Forest degradation

Forest degradation does not count as deforestation according to the IPCC Guidelines and to generally accepted forestry definitions. This form of human intervention would therefore not be accounted for under Article 3 para 3 of the Kyoto Protocol, even where forest degradation does de facto lead to deforestation.

The gradual degradation of forests through inappropriate selective timber harvesting, unauthorized cutting and anthropogenic fire is a further process beside deforestation and forest conversion which may well have a momentous impact on the global carbon balance (Brown, 1996). These interventions lead to changes in stand structure, microclimate and soils. Formerly dense, closed forest formations change into open, increasingly fragmented formations rich in bushes or grasses. In the tropics, degradation can ultimately lead to the establishment of *Imperata* grassland.

The possibility of sustainable timber extraction is particularly in doubt in primary forests. *To the knowledge of the Council, most attempts at establishing in the tropics forestry practices that are sustainable in terms of both timber production and the various other ecosystem functions (biodiversity, nutrient regime etc.; as ensured by continuous selection cutting systems in temperate forests) have failed* (e.g. in Guyana, Australia, New Zealand and Indonesia). In addition to the high sensitivity of primary forest ecosystems to disturbances, the size of harvested trees in conjunction with the high density of stands leads to a great destructive potential of timber extraction, even if individual trees are selectively harvested. The full extent of the area affected by gradual degradation of primary forests is unknown. *According to FAO estimates* (1993, cited after Brown, 1996) *the rate of degradation is several times higher than that of deforestation.*

6.1.3
Conversion of forests to grassland

The IPCC Guidelines classify the conversion of forests to grassland as deforestation. A part of the emissions attributable to such a conversion that took place after 01.01.1990 is therefore accounted as deforestation in the meaning of Article 3 para 3 of the Kyoto Protocol – but only that proportion of emissions that takes place in the commitment period (2008–2012). However, the greater part of the emissions caused by logging or burning takes place in the same year in which deforestation occurs. Only a fraction of the emissions then arises over the following 10–20 years through decomposition of biomass and through soil processes. Thus only a fraction of the actual emissions caused by deforestation taking place between 1990 and 2008 is accounted (10 or 20-year "depreciation").

In the tropics, forests are frequently converted to pasture. Grasslands further emerge as a result of forest degradation or when reforestation is not carried out. The main change in the carbon balance is caused by conversion in the form of logging or burning primary forest. While the aboveground biomass of grasslands is small and this part of the carbon pool is lost through conversion from forest to grassland, carbon stocks in the soil can be increased, depending upon the initial conditions, the type of grass community and management (de Moraes et al., 1996; Neill et al., 1997). Nonetheless, in the tropics this increase per unit area can only compensate for about 3–12% of the aboveground biomass of the primary forest (Neill et al., 1997) (Annex Table 6).

6.1.4
Conversion of forests to cropland

According to the IPCC Guidelines, the conversion of forests to cropland is also to be inventorized as deforestation.

Lal et al. (1998) state an area of 750 million ha for forests that have been converted to agriculturally utilized area, from the emergence of arable farming to the present. This corresponds to a share of 45% in total land-use change. Assuming a carbon release of

100% from vegetation and 25% from the soil, the authors calculate a loss of 96.5 Gt C from vegetation and 24.5 Gt C from soils for this period. According to these figures, the mean loss of agriculturally utilized soils is 33 t C ha^{-1} and that of aboveground biomass is 128 t C ha^{-1}. The present process of conversion of forest areas to agriculturally utilized areas is mainly taking place in the tropics. Between 1980 and 1995, some 13 million ha forest area was converted annually in the tropics. Of this, 86–94% was attributable to agricultural areas. About half of these areas (41–48%) was in turn cleared in shifting cultivation for self-provisioning of the local population (BML, 1997a). It is to be assumed that, in the course of conversion, 80–90% of the aboveground biomass is either directly burnt during conversion or is used as firewood. With stocks ranging between 50 t C ha^{-1} (dry forest) and 186 t C ha^{-1} (rainforest), this means a release of 40–167 t C ha^{-1} from the biomass.

When forests are converted to agricultural lands, biomass losses are generally joined by soil carbon losses, which vary as a function of climatic conditions and management methods. The figures reported in the literature on carbon losses resulting from conversion to cropland vary greatly (Annex Table 7), and average 25–30% over 1 m soil depth (Houghton, 1995; Davidson and Ackermann, 1993). The 1996 IPCC Guidelines state them as averaging 25–40% of soil carbon (Detwiler, 1986; Schlesinger, 1986; Mann, 1986). Losses are generally highest in the tillage horizon (0–20 cm). In this horizon, the reduction of soil carbon stocks amounts to some 40% (Davidson and Ackermann, 1993). In addition to reduction percentages, absolute losses are determined by the initial absolute level of carbon stocks in the soil. For instance, conversion on cambisols (relatively recent, slightly weathered soils) leads to losses of 85 t C ha^{-1}, while conversion on rendzic leptosols (soils determined strongly by the parent rock, e.g. limestone, gypsum or anhydrous material) only leads to average losses of 40 t C ha^{-1}. Differentiation according to vegetation zones instead of soil types shows for the tropics that the conversion of rainforest leads to 45 t C ha^{-1} of soil carbon stocks being released, while conversion of dry forest releases 16.5 t C ha^{-1} (Detwiler, 1986). On average, this means for tropical soils a carbon loss of 24.5 t C ha^{-1} (Eswaran et al., 1993). All these examples are based on a loss rate of 25% over 1 m depth.

The reported soil carbon losses differ so greatly because different depths are examined, and findings are reported from different ecological regions and management methods. Global averages are thus not expedient for calculating releases and changes in stocks. Beside the quantity, the quality of the organic material also changes – interventions frequently lead to the bulk density of soils changing, topsoil material is transported to the subsoil, erosion occurs. All of this hampers comparability between forest soils and cultivated soils (Johnson, 1992).

Frequently, figures are only reported for the upper 30–40 cm of the soil. The IPCC Guidelines also only cover the top 30 cm. Recent studies in the tropics suggest that subsoil carbon has been underestimated (Veldkamp, 1998; Brown, 1996) and that this accounts for at least 10% of the total losses from the first meter of the soil profile (van Nordwijk et al., 1997).

The greater part of carbon loss occurs within the first 20 years after conversion, whereby losses decrease exponentially, i.e. the bulk of carbon loss occurs within the first 5 years after conversion. This is particularly so in the tropics. In soils with high carbon stocks and slower release rates due to climatic conditions, decomposition can extend over several decades. On average, a new equilibrium is established at a low level after 20–50 years (Arrouays et al., 1995; Brown and Lugo, 1990; Houghton, 1991; Scholes and Scholes, 1993). Beside climatic conditions, both loss rates and the level of absolute losses depend upon the initial level of carbon stocks in the soil.

Little attention has yet been paid to the accumulation of charcoal. For burning, Klein Goldewijk and Vloedbeld (1995) report a transfer of 2% from trunk wood and 1% from leaves and branches into the slowly decomposable to inert carbon pool represented by charcoal. For the conversion of primary forests in the tropics, this means, assuming initial carbon stocks in the biomass of 120–190 t C, that 3.2–5.1 t C ha^{-1} are sequestered as charcoal.

6.1.5
Conversion of grassland to cropland

Pursuant to Article 3 para 3 of the Kyoto Protocol, the conversion of grassland to cropland does not fall under the human activities accountable as sinks or sources. However, it does indeed lead to considerable losses of stored carbon, that can be of the same magnitude as those caused by deforestation.

The figures reported on changes in soil carbon stocks after conversion to cropland range from slight growths (2.5%) to losses of up to 47% (Bouwman, 1990). Here, too, the results of studies are not directly comparable, because they refer to different depths, were carried out over differing utilization periods and come from different regions. Nonetheless, despite the differences, a global average value of 20–30% losses in soil carbon stocks over 1 m reference depth is stated. Depending upon the original carbon stocks of converted soils, the same percentage losses can be associated with major differences in the absolute values (Annex Table 8). The conversion of a chernozem (humus-rich soil of temperate grasslands), for instance, leads to a reduction of carbon stocks by 80 t C ha^{-1}, while the conversion of a solontchak (saline soil of arid and semi-arid regions) only leads to losses of 30 t C ha^{-1}.

According to Lal et al. (1998) the grassland area already converted worldwide to cropland amounts to 660 million ha. The authors state the original soil carbon stocks to have been 76.5 Gt C. With a loss of 25%, the stock is reduced by 19 Gt C, or 29 t C ha^{-1}. Soil carbon stocks are thus reduced from 116 t C ha^{-1} under grassland to 87 t C ha^{-1} under cropland. For the biomass, losses of 7.7 Gt C are reported. This corresponds to a reduction in stocks by 11.4 t C ha^{-1}.

There are enormous differences in the distribution of carbon stocks between tropical and temperate grasslands. Tropical grasslands have a biomass that is twice as high, but less than a quarter of the soil carbon stock, compared to temperate grasslands. The ratio of soil carbon to biomass carbon stocks figures about 25:1 in temperate grasslands and 3:1 in tropical grasslands. Future land-use changes will take place above all in the tropics, so that losses can be expected to be lower than the global average. With the same percentages of losses, the absolute losses amount to 10.7 t ha^{-1} from soil carbon stocks and 15.5 t C ha^{-1} from biomass. These figures are 36% lower than the global averages stated above.

As concerns development over time, similar conditions arise as in conversion from forest to cropland. The largest losses of soil carbon arise over the first 20 years after conversion. The decrease in losses is exponential, and a new equilibrium at a low level is established over a period of 30–100 years.

6.1.6 Conversion of wetlands

Under Article 3 para 3 of the Kyoto Protocol, the conversion of wetlands to other uses is not – as opposed to deforestation – accounted to the emissions of industrialized countries.

Per unit area, wetlands have the largest carbon stocks in soil worldwide. Due to the anaerobic conditions prevailing and the generally low availability of nutrients, the decomposition of organic material is greatly constrained, so that, despite a low net primary productivity, carbon stocks continuously grow. For instance, undrained histosols (a soil type typically associated with wetlands) store 0.14 Gt C yr^{-1} (Armentano, 1980 after Lugo et al., 1990). In Finland, Silvola (1986) has shown that bogs, with a removal of 0.25 t C ha^{-1} yr^{-1}, are sinks. Gorham (1991) states an annual increase in stocks of 0.29 t C ha^{-1} for the peat-forming wetlands of the northern latitudes. Globally, he estimates these wetlands to be a sink with a carbon flux of –0.1 G t C yr^{-1} (Annex Table 9a).

If peat-forming wetlands are drained and thus converted into utilized areas, the mineralization of carbon stocks that then commences generates high carbon flux densities. Bouwman (1990) reports losses of 10 t C ha^{-1} yr^{-1} in the initial years. In Great Britain, losses resulting from converting bogs to cultivation are estimated at 5 t C ha^{-1} yr^{-1} (Adger, 1994). For Finland, Silvola et al. (1996) report loss rates of approximately 2.5 t C ha^{-1} yr^{-1} after drainage. Maltby and Immirzy (1993) estimate losses through conversion to agricultural lands to figure 0.063–0.085 Gt C yr^{-1} in temperate regions, and 0.053–0.114 Gt C yr^{-1} in the tropics (Annex Tables 9b, c).

To assess the source and sink potentials associated with converting wetlands, the flows of methane (CH_4) and nitrous oxide (N_2O) must be taken into consideration in addition to carbon dioxide flows. Natural peat-forming wetlands store small amounts of CO_2 and emit only small amounts of N_2O, but emit large quantities of CH_4. By contrast, when wetlands are converted and subsequently managed, large quantities of CO_2 and N_2O are released, while methane emissions drop greatly – indeed, a slight methane removal may even occur. As these gases have differing atmospheric residence times and undergo different chemical reactions in the atmosphere, they have different global warming potentials (GWP). Recent studies have shown for Finland, Sweden and the Netherlands that natural wetlands accumulate between 0.16–0.25 t C ha^{-1} yr^{-1}. The methane releases of such wetlands of 0.075–0.15 t C ha^{-1} yr^{-1} mean that, if the GWP of methane (25, 100-year time horizon) is taken into consideration, these wetlands become a source corresponding to CO_2 equivalent emissions of 0.43–1.1 t C ha^{-1} yr^{-1} (Kasimir-Klemedtsson et al., 1997). The same balance for converting wetlands to cropland shows, depending upon land use, a carbon release from the organic material amounting to 1–19 t C ha^{-1} yr^{-1}, while methane emissions cease entirely. However, the increased N_2O emissions raise the source potential of the converted areas as compared to natural wetlands considerably, to aggregate rates of 3.8–19 t C ha^{-1} yr^{-1} (CO_2 equivalent emission).

6.1.7 Conversion of grassland and cropland to forest

A diverse array of estimates of the areas available for afforestation have been made in the literature. These are not readily comparable, as the criteria by which the areas were selected are not uniform. Nowhere has selection yet been carried out on the basis of a combination of ecological and socio-economic criteria. Trexler and Haugen (1995) and Nilsson and Schopfhauser (1995) were the first to consider socio-economic criteria when determining the potential area for afforestation measures. A similar situation prevails with regard to the reported carbon fluxes and stocks. In addition to different methodologies for determining mean carbon stocks, carbon balances differ in the way in which they consider or do not consider root biomass, soil carbon and the storage potential of forest products. The IPCC Guidelines neglect underground biomass and soil stocks. The IPCC standard method for drawing up inventories gives no consideration to forest products (it is assumed that they decompose in the same year in which they were produced).

Earlier estimates that proceeded from very high carbon flux densities (6.2 t C ha^{-1} yr^{-1}; Sedjo and Solomon, 1989) and potential areas (1,200 million ha; Winjum et al., 1992) have had to be corrected very much downwards. The latest study of Nilsson and Schopfhauser (1995) indicates an available potential area of 344.8 million ha and a mean carbon flux density of 3 t C ha^{-1} yr^{-1}. Of this potential area, agroforestry measures make up 69.7 million ha and other afforestation measures 275.1 million ha. In regional terms, 130.2 million ha are in the tropics, 119.5 million ha in the temperate and 95.1 million ha in the boreal regions. The potential growth in carbon stocks for these areas are stated to be 37.7 Gt C by the year 2050 and 104 Gt C by the year 2095. Potentials for high flux densities and thus higher mean carbon stocks over the analysis period are available above all in the tropics and the temperate regions, where they are 4 or 3–8 times higher, respectively, than in boreal regions (Annex Table 10). Degraded areas and areas converted from agricultural use offer a potential area amounting to at least 90 million ha (Fig. 9). Proceeding from the estimates made by Nilsson and Schopfhauser (1995), these form a mean stock of 9 Gt C by the year 2050 or 28 Gt C by the year 2095 (Busch and Mund, 1998).

Different options are available for afforestation measures. These range from fast-growing energy crops or industrial timber plantations at the one extreme, to mixed forests managed to follow natural vegetation patterns at the other. The first variant has high annual increments, but only forms small carbon stocks in the forest stands. An accumulation of carbon in the soil and in the organic layer takes place, but remains at a low level due to the short rotations and the comparatively small volume of biomass in the stand (Fig. 11d). The second variant has significantly lower increments, but stores substantially larger carbon stocks in the forest stand over longer periods (60–200 years). Due to the larger volume of biomass and of litter throw, larger carbon stocks are also formed in the organic layer and in the soil.

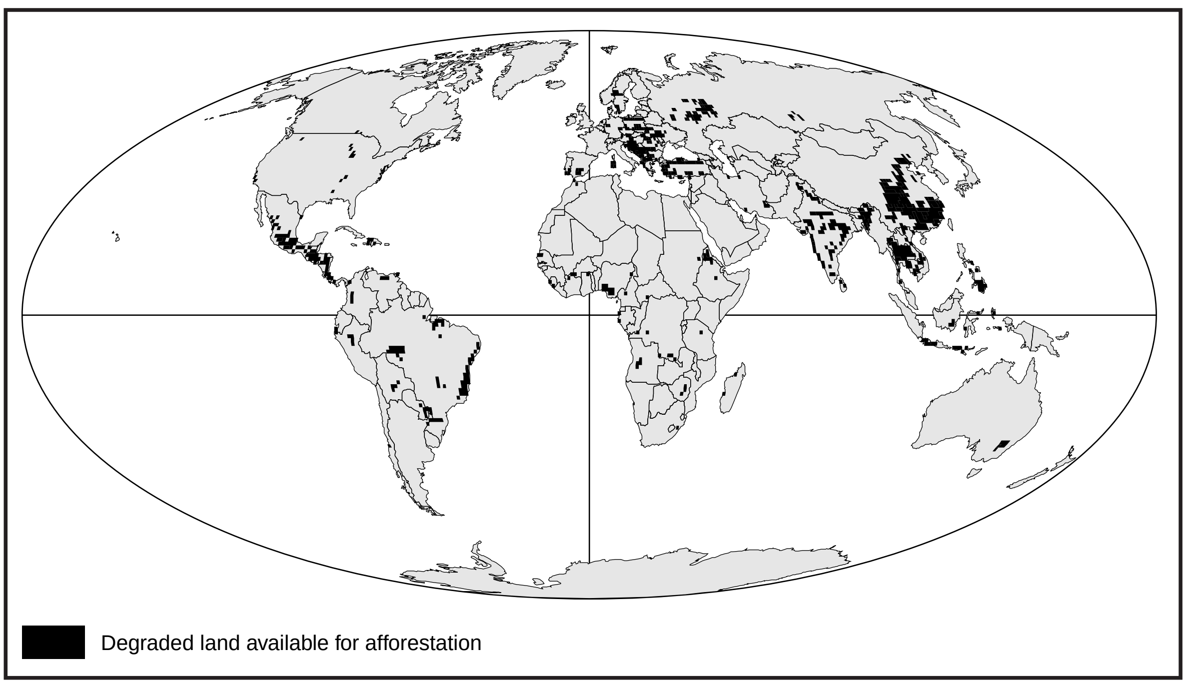

Figure 9
Moderately to severely degraded agricultural soils which, as former forest sites, are suitable for afforestation.
Sources: WBGU with data from Oldeman (1992) and Matthews (1983)

Carbon stock calculations of afforestation measures depend upon timber use and vary depending upon whether the mean carbon stock in the forest stand, accumulative storage by energy substitution and/or the life cycle of the resulting products are taken into consideration. The IPCC Guidelines do not consider carbon storage in wood products.

All in all, the reported figures on stocks and fluxes are subject to major uncertainties – above all as regards soil carbon – because the data density is low, spatial variability is high and methodological deficits frequently render surveys incomparable.

6.1.8 Forest management

Forest management measures, which go beyond afforestation and deforestation, are not accounted for under Article 3 para 3 of the Kyoto Protocol. They can, however, have an influence upon the source and sink characteristics of forests.

In principle, it is indubitable that forestry measures such as low-impact harvesting techniques (tree protection, soil conservation), extending rotations, safeguarding regeneration (against browsing, avalanches, erosion etc.), protection against pests etc. do enhance the sink function of forests. However, the sink potential of such measures is low compared to that of afforestation or reforestation (IPCC, 1996b).

In addition to rotation lengths (Section 6.1.1), harvesting techniques are the main avenue by which to influence the use-related carbon balance of managed forests. The more intensively the organic layer and the soil are disturbed by harvesting, the higher and more sustained are the carbon losses (Burschel et al., 1993; Johnson, 1992; Jurgensen et al., 1997; Mund and Busch, 1998; Pritchett and Fisher, 1979).

A further important factor in the estimation of the sink potential offered by forestry operations is to be found in the carbon stocks stored in durable wood products, and the substitution of fossil fuels by wood. Durable wood products can only then increase the level of carbon storage if demand for and thus the stock of wood products rises, i.e. new wood products more than replace the old ones, and, moreover, the lifetimes of wood products are longer than the rotation of plantations or production forests (Attiwill, 1994; Cannell et al., 1992; Dewar, 1991; Dewar and Cannell, 1992; Harmon et al., 1990; Karjalainen, 1996). *A substitution of fossil fuels by wood is only possible to a limited extent, or at the cost of sink functions and other forest ecosystem functions.* Moreover, such a use of forests must consider in the overall balance the energy inputs required for investments (e. g. road construction, wood processing) and for transporting the timber. *After conserving unmanaged primary forests, the next best option for maximizing carbon sequestration in forests is presumably management by continuous selection cutting, which permits a large biomass in the standing stock (cf. Section 9, Glossary)* (Fischlin, 1996). However, this form of management is not possible at all sites, nor presumably in all climate zones.

Spruce monocultures and mixed deciduous forests do not exhibit fundamentally different carbon stocks. It must however be stressed that a conversion of forests to monocultures has considerable impacts upon biodiversity and soil quality, and thus upon the stand stability and sustainability of these forests. In the light of the long time frame of the management goal (harvest after more than 50 years), this sustainability aspect carries major economic weight.

6.1.9 Options for agricultural carbon sequestration

Agricultural land uses are generally associated with a reduction of soil carbon stocks and of biomass. Newly converted agricultural areas are strong carbon sources. By contrast, agricultural areas that have been used as such for a long time are no longer sources, as here a new, lower carbon balance has established itself. Driven by continuing population growth, the rate of new conversion to agriculture is estimated at 15 million ha annually (Cole et al., 1993).

Carbon stocks in cropland can only be increased by increasing the volume of biomass and constraining carbon decomposition in the soil. Various options are available for this. Their application depends greatly upon regional conditions (e.g. temperature, distribution and level of precipitation, water limitation). An interlocking package of improved or reduced tillage, nutrient and water management and erosion control suggests itself for carbon sequestration in agricultural land uses (Fig. 10).

By means of improved soil management, set-aside and rehabilitation of degraded land, IPCC estimates indicate that 50–75% of the lost soil carbon can be sequestered again. Over the next 50 years, some 23–44 Gt C could thus be stored in agricultural soils. This would correspond to 0.43–0.88 Gt C yr^{-1} or 13–27% of the annual increase in atmospheric CO_2 concentrations during the 1980s.

For the arable soils of the temperate zone, Sauerbeck (1993) states that optimized soil management can increase the carbon stock by 10 t C ha^{-1} over a period of 50–100 years. This would correspond to an increase in soil carbon levels by some 10%, and, given 690 million hectares of arable soil in the temperate

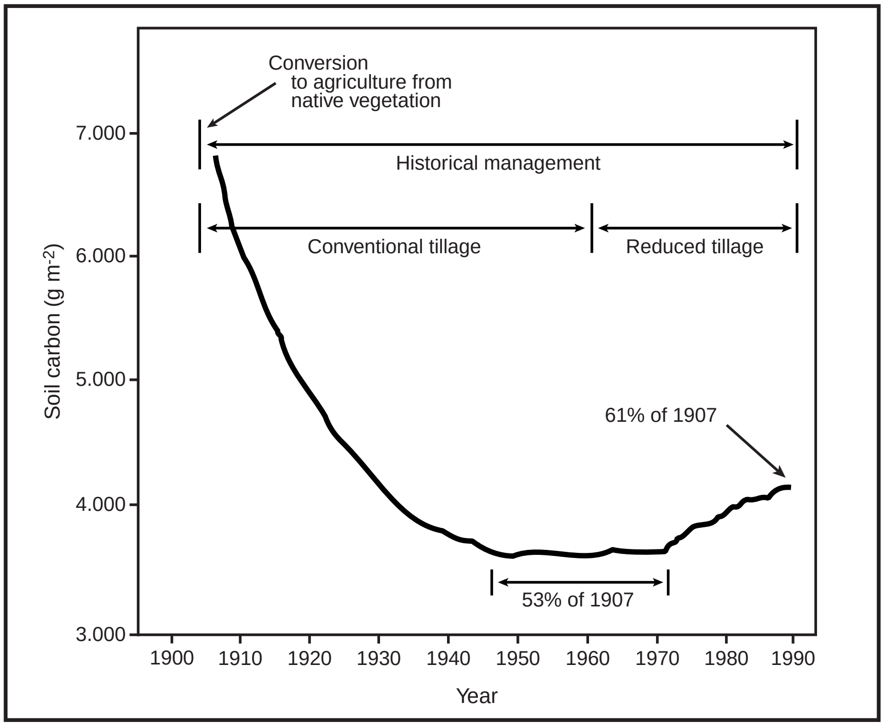

Figure 10
Simulated change in total soil carbon stock (SOC at a depth of 0 to 20 cm) for the central cereal production areas of the USA. The points in time are indicated at which carbon contents reach 53% and 61% of the original level (prior to conversion to cropland in 1907).
Source: Matson et al., 1997

zone, a sequestration of 6.9 Gt C. In other regions, particularly in the tropics, it must be assumed that many soils cannot sequester any noteworthy additional quantities of carbon. An example of this is given by the aridisols, which on average only contain 4.2 t C ha^{-1} and are exposed to severe utilization pressures in the arid zones. One expression of these pressures is that harvest residues cannot be used to support humus levels, because they are needed as fodder and fuels.

The additional sequestration of 0.5 t C ha^{-1} over the next 50 years is stated by various authors as the achievable global target. This would correspond to a stock of 7 Gt C, and is distinctly less than the optimistic scenario of the IPCC.

A different avenue by which agriculture could indirectly sequester carbon is to produce biomass that is used as a substitute for fossil fuels. The area that could potentially be used to cultivate renewable raw materials was estimated in 1993 by Cole to amount to 50–60 million ha for the USA and the European Union. The production of grasses or of rapidly growing trees in plantations as energy crops could deliver major savings of fossil fuels, and is viewed by the IPCC as one of the main management options available to agriculture by which to reduce greenhouse gas emissions. The level of CO_2 savings delivered through substituting fossil fuels by renewable resources depends upon the net energy yield of bioenergy production (energy input during growth, harvesting and processing) and is determined by the global warming potential of emissions occurring during growth. Studies carried out in Germany (Flessa et al., 1998) comparing intensively and extensively managed poplar, rape and potato crops have shown that only the poplar crops contributed to reducing CO_2 emissions. They were found to deliver a maximum carbon storage potential of 4.2 t C ha^{-1} yr^{-1}. At the same time, the poplar stands also delivered the highest net energy yield, figuring 200 GJ ha^{-1} yr^{-1}. The studies showed that the contribution of biomass production to reducing total greenhouse gas emissions depends quite decisively upon the level of N_2O emissions, as in the crops under consideration these are the parameter determining total GWP.

6.2
Indirect human influences

Under Article 3 para 3 of the Kyoto Protocol, emission commitments can only be offset against direct human activities. This excludes a consideration of the indirect effects that impact upon the source and sink characteristics of terrestrial ecosystems through anthropogenic nitrogen deposition, rising carbon dioxide concentrations or climatic changes. Nonetheless, an estimation of these indirect effects is of major relevance to forecasting the future development of the sink potential of terrestrial ecosystems.

6.2.1
Changes in sources and sinks through nitrogen deposition

The carbon and nitrogen cycles are closely linked, e.g. in photosynthesis and in the storage and accumulation of nitrogen in organic compounds. A parallel increase of both atmospheric carbon dioxide concentrations and nitrogen availability could lead, through increased growth, to increased carbon sequestration in the biosphere (fertilization effect). It needs to be clarified whether an extrapolation of this effect as found in physiological experiments is correct.

In Europe, forest stocks have grown considerably since 1950 (Franz et al., 1993; Hofmann et al., 1990; Röhle, 1995; Spiecker et al., 1996). Beside changes in forestry practices (prohibition of forest litter utilization), this is due to the simultaneous rise in nitrogen deposition. *In addition to a limited growth-enhancing effect, nitrogen inputs have an array of negative side-effects* (soil acidification and cation losses to the point of aluminum release, reduced biodiversity and destabilization of ecosystems, impairment of groundwater quality by nitrate, N_2O emissions of nitrogen-saturated forests). Forest decline has meant in particularly damaged areas that self-thinning or forestry measures have lowered stand densities and that the aboveground biomass has not risen in proportion to the growth in carbon stocks (Pretzsch, 1996; Landmann and Bonneau, 1995; Mund, 1996). *The accumulation of humus (Berg and Matzner, 1997) that has taken place as a result of high nitrogen deposition is only a short-term carbon sink.* On the one hand, cations are also stored in the humus, which intensifies nutrient imbalances (leading to yellowing and forest damage). On the other hand, there is a risk that the accumulated litter is very suddenly mineralized in the event of clearcutting, and large amounts of nitrate and carbon dioxide are released.

But even if the deleterious effects of high nitrogen deposition levels are disregarded, high growths in carbon stocks are not equivalent to long-term storage. Under forest management, the forests are harvested when a certain target volume is reached, i.e. large increments shorten the rotation lengths, and may increase carbon turnover, but not carbon stocks (Fig. 11).

Although a global rise in nitrogen deposition is expected for the future, the growth-enhancing effect observed in Europe cannot be globally extrapolated (Annex Table 11). Here further site factors (and growth-limiting conditions) and land-use changes need to be taken into consideration. In tropical lowlands, for instance, phosphate is the limiting factor, not nitrogen (Vitousek, 1984; Tanner et al., 1998).

6.2.2
Changes in sources and sinks through higher atmospheric carbon dioxide concentrations (carbon dioxide fertilization)

The effects of increased carbon dioxide concentrations upon growth and upon soil carbon stocks have been the subject of intensive research efforts in recent years. In respect of the carbon balance, the following findings have been made:

- Insofar as all other factors are optimal, net primary productivity (NPP) in agricultural crops rises in proportion to carbon dioxide concentrations. *Nonetheless, the increased NPP is not a global carbon sink,* as the products are directly harvested and converted back to carbon dioxide, and because carbon dioxide releases take place through soil respiration in the same ecosystem.
- *In native vegetation, a doubling of CO_2 concentration presumably only leads to a 5% increase of NPP* (Mooney et al., 1998). This assessment already takes into consideration the influences of increased carbon dioxide levels upon photosynthesis (down-regulation, nutrition and water balance).
- *The slight increase in NPP brought about by raised carbon dioxide levels will presumably already be compensated over the next 30 years by a temperature-related increase in respiration* (see below; Scholes et al., 1998) (Fig. 7).

6.2.3
Changes in sources and sinks through climatic changes

As photosynthesis, following a saturation function, is primarily controlled by incident light and increasing cloud cover and aerosol concentrations in the atmosphere must be expected to lead rather to a decrease than an increase in photosynthesis capacity, the global carbon balance will in future be determined primarily by the temperature-driven, exponential increase in respiration (Fig. 7). It is expected that respiration will exceed present assimilation at some point within the next 30–50 years. Various models (e.g. CENTURY) have predicted that *the present carbon sinks will then become sources, even if land use does not change* (Scholes et al., 1998; Mooney et al., 1998). In boreal coniferous forests, annual weather variability has already now been found to lead to an oscillation between net carbon emissions and assimilations at the same site.

6.2.4 Sources through fires and other episodical disturbances

For many types of vegetation (Mediterranean vegetation, boreal forest), fire is a necessary factor in the development of plant species. The natural frequency of fires depends upon the climatic conditions. In Siberian coniferous forests, for example, fires occur every 30–50 years. This frequency has risen significantly through human action in the vicinity of settlements (Korovin, 1996). A remarkable point is that fires can release less carbon than complete forest clearances (Harmon et al., 1990). In the tropics, fire has become a new vegetation-determining factor. Here fire leads to forest degradation to the point of invasion by fire-adapted grass species. The annual fire cycle established by the grasses suppresses forest regeneration over many years (Asner et al., 1997). The large areas (15 million ha) of *Imperata* grasslands in East Asia bear testimony to this.

Annual losses of timber volume due to insects and diseases have figured 102.8 million m^3 in Canada between 1982 and 1987. By comparison, fire destroyed 36 million m^3, and 160 million m^3 were harvested (Volney, 1996).

Beside the undesired effect of CO_2 release, fire also has a positive effect upon the global carbon balance through the formation of charcoal. About 3% of the burnt biomass is converted to charcoal (Houghton, 1991; Klein Goldewijk and Vloedbeld, 1995). For the tropics, Crutzen and Andreae (1990) estimate a carbon flux to charcoal of 0.2–0.6 Gt C yr^{-1}. In Siberian coniferous forests, the proportion of charcoal in the humus and mineral soil figures about 25%. The global rate of charcoal formation is variously estimated at 0.07–0.24 Gt C yr^{-1} (Kuhlbusch, 1994 after Heimann et al., 1997) or 0.044 Gt C yr^{-1} (Heimann et al., 1997).

Assessment

The German Advisory Council on Global Change views both climate protection and biodiversity conservation as essential objectives of global environmental policy (WBGU, 1996). The Council has repeatedly stressed the urgency of soil conservation (WBGU, 1995). The Council therefore basically welcomes the idea of linking the protection of the global climate and the protection of greenhouse gas sinks, as would appear conceivable by offsetting climate protection commitments against sink protection activities. Various options for action are available that could serve to both conserve biodiversity and protect or create carbon sinks. These include the conservation of wetlands and primary forests, which, as the present study shows, represent large and still stable global carbon reservoirs in terrestrial ecosystems. The promotion of afforestation measures on degraded areas that no longer permit agricultural uses can also serve to protect the climate and conserve soils and biodiversity.

Using terrestrial sinks to meet emission reduction commitments is expedient in principle. However, this requires a dynamic analysis of all geological and ecological carbon stocks and fluxes at the continental, national or regional level. Net accounting is only purposeful if the differing time constants are taken into consideration.

No individual category of measures offers by itself a significant regulative effect upon the global carbon balance. The present study shows that terrestrial ecosystems can only be used to a limited extent as carbon sinks. It would not appear possible to increase, over the long term and durably, the sink potential of ecosystems used for agricultural and forestry purposes to an extent that considerably exceeds the sink potential of natural potential vegetation. Any approach towards offsetting emission reduction commitments against terrestrial sources and sinks must therefore carefully balance the opportunities and risks.

This study shows that many uncertainties and imponderables attach to the de facto reduction of net emissions that is achievable through terrestrial sinks. Terrestrial sinks are by no means constant. Even slight climate change can make sinks become sources, even where net primary productivity is high. Moreover, due to their complex non-linear dynamics, the time scales associated with terrestrial ecosystems differ greatly from those of energy-related processes, which are the largest sources of anthropogenic global warming.

The Council therefore welcomes the decision of the Subsidiary Body for Scientific and Technological Advice (SBSTA) (UNFCCC, 1998) to request the IPCC to prepare a Special Report examining the methodological, scientific and technical implications of the pertinent provisions of the Kyoto Protocol relating to accounting biological sources and sinks, in particular the organic matter in soils.

Against the background of the findings concerning the sink potential of terrestrial ecosystems reviewed in this study, the Council considers the form in which "land-use change and forestry" activities are accounted under the Kyoto Protocol inadequate to serve both the objectives of "climate protection" and "conservation of biological diversity". In particular, the approach under the Protocol fails to do justice to the above-mentioned uncertainties and differing time scales. Moreover, the form in which individual forestry-related measures are accounted can lead to a series of negative incentives in terms of both climate protection and biodiversity conservation.

It becomes apparent here that a lack of coordination prevails among the various objectives of the instruments aimed at providing protection against global environmental change. For instance, it has not been examined whether the Kyoto Protocol creates incentives that could run counter to the objectives of the other Rio conventions (Biodiversity Convention, Desertification Convention), nor have other negotiation processes (e.g. the Intergovernmental Forum on Forests, IFF) been taken into consideration. Here, a fundamental deficiency of global environmental policy is evident (WBGU, 1996; WBGU, in print). In this context, the Council welcomes the decision of the SBSTA (UNFCCC, 1998) to request the IPCC to examine the implications of carbon sequestration strategies for water, soils and biodiversity. It is also urgently necessary to request the FCCC secretariat to improve the flow of information among the secretariats of the various conventions (biodiversity, desertification) and organizations (IFF, FAO).

These appraisals are substantiated in the following in detail. We first present the fundamental difficulties of offsetting energy-related emissions against terrestrial sinks. Subsequently, we address the specific problems associated with the approach established by the Kyoto Protocol for accounting individual human activities (initially restricted to afforestation, reforestation and deforestation since 1990).

7.1 Risks and problems associated with the accounting of biological sinks

7.1.1 Risks for the long-term stabilization of greenhouse gas concentrations

The ultimate objective of the climate protection regime is to stabilize greenhouse gas concentrations in the atmosphere over the long term at a level that would prevent climate change dangerous to humans and the environment (Article 2 FCCC, cf. WBGU, in print). Ultimately, it are the net emissions of climate-relevant gases that determine the concentration of greenhouse gases in the atmosphere, i.e. the sum of all emissions from sources and fluxes to sinks. However, to stabilize this concentration over the long term, the dynamics over time of sources and sinks and of the processes taking place in the atmosphere need to be taken into consideration. Offsetting carbon dioxide sources against sinks is only then justified if the lifetime of the sinks corresponds roughly to the residence time of carbon dioxide in the atmosphere. However, as the present study shows, this cannot be guaranteed.

In addition, the following needs to be considered: If energy-related emissions are offset against biological sinks, then measures aimed at reducing the combustion of fossil fuels, which would thus be withdrawn (over geological periods) from the carbon dioxide cycle, are equated with the creation of sinks, whose lifetime can generally scarcely be guaranteed over several centuries. If higher emissions from the combustion of fossil fuels are permitted, this means risking that the carbon stored in the sinks is released again after only a few decades or centuries. One could raise the objection that the total deposits of fossil fuels identified today or in the future will be burnt sooner or later in any case. However, the climate models and the calculations of the carbon cycle show that it is not the finiteness of resources that limits the combustion of fossil fuels, but rather the necessary stabilization of greenhouse gas concentrations at a harmless level.

7.1.2 Time dynamics of stocks and fluxes

The accounting of terrestrial sources and sinks in the form of changes in stocks over a 5-year commitment period fails to take into consideration the differing dynamics over time of carbon stocks and fluxes. Only an integration over long periods permits an estimation of the mean sink or source potentials of ecosystems.

The growth increment of forests is initially very large when the trees are young, but quite soon, depending upon climate and management system, reaches a maximum, on average after about 20–50 years, and then drops again. By contrast, the carbon stocks of aboveground biomass grow comparatively slowly and only gradually reach a maximum at a high age (more than 200 years) (Figs. 11a, 12). Carbon can continue to accumulate in the top organic layer or in the soil (assuming no disturbances). This explains why in young forest stands, high rates of carbon assimilation occur in conjunction with low carbon stocks, while old stands have low rates of annual growth but large stocks and the carbon pool of the ecosystem continues to rise. Due to the periodical disturbances by harvesting, the total carbon pool of managed forests is lower than that of primary forests (Figs. 11b, c, d). In management systems with continuous selection cutting, human impacts are relatively slight (Fig. 11b). Carbon stocks are generally reduced in the same degree that the intensity of management rises and the rotation lengths of forest stands are shortened.

The following example (Fig. 12) illustrates the importance that these dynamics over time can have for the accounting of sinks and sources under the Kyoto Protocol.

If *deforestation* takes place in the period between 1990 and 2007, then the IPCC Guidelines provide for a linear accounting of carbon emissions over 10 years for the biomass and over 20 years for the soil carbon. However, the greater part of carbon emissions occurs, depending upon the form of clearing and the use of the logged timber, already directly (in the case of fire clearing) or within a few years after deforestation and is thus not accounted in the commitment period (Fig. 12c). An incentive thus arises to carry out any clearing before the year 2008 in order to avoid a full accounting of carbon emissions.

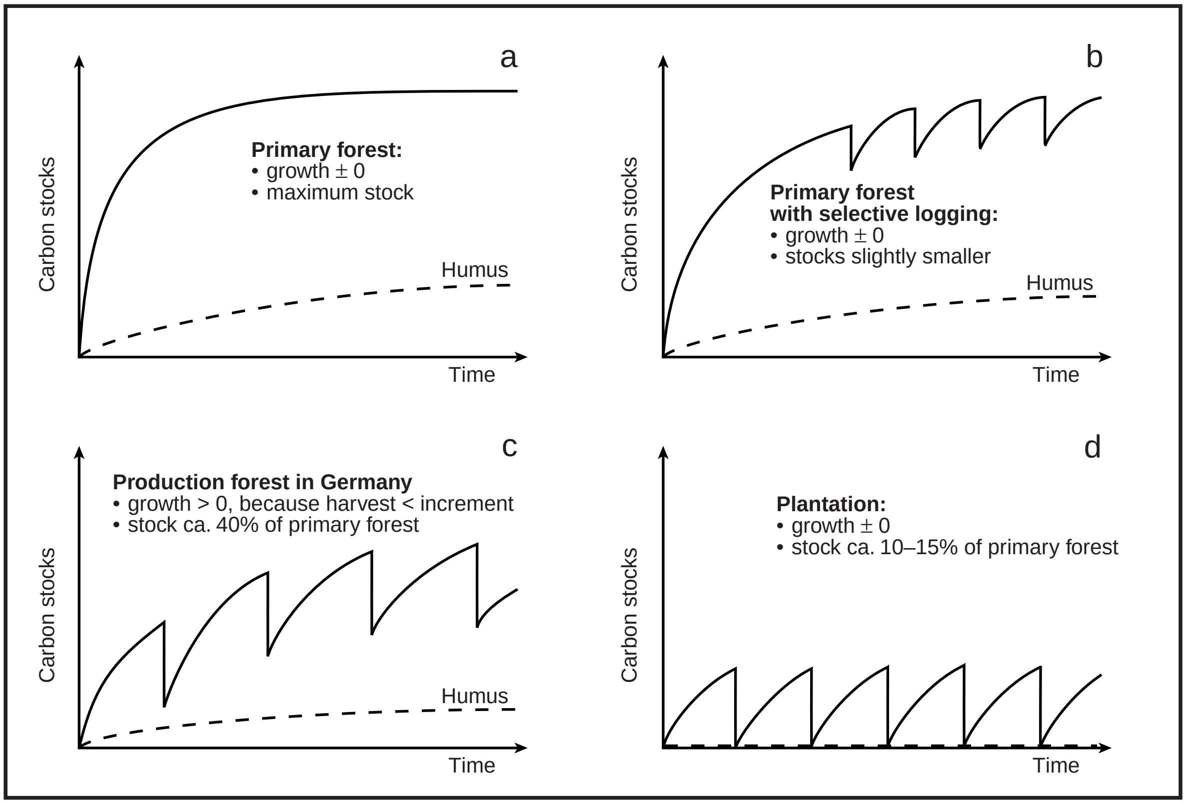

Figure 11
Schematic of carbon stocks in the aboveground biomass and humus of production forests, secondary forests and plantations. It should be kept in mind that the time scales differ (see text) and that the curves do not represent real increment curves.
Source: WBGU

A situation highly deleterious to climate protection, soil conservation and biodiversity conservation would arise if *reforestation* of areas cleared after 1990 could also be accounted. It would then be a lucrative proposition for a country to clear-cut old, mature forests (primary forests), to skim off the timber yields, and to reforest the areas as soon as possible in order to claim this activity as a sink during the commitment period. Due to the fast growth of the young stands, the accountable sink potentials would be relatively large (Fig. 12b), although the carbon stocks would be very small compared to the primary forest (Fig. 12a). Furthermore, the clear-cut area may represent a net source of carbon (Fig. 12c) because of the accelerated decomposition of the organic layer and of harvest residues (the IPCC Guidelines do not explicitly provide for a linear depreciation, as would be the case for a deforestation activity). Fig. 12 also illustrates the implications of accounting for soil carbon during the commitment period. If only the aboveground biomass of the growing stand is accounted for, then the young stand is a carbon sink with high net primary productivity. However, the balance is different if soil respiration is included in the calculation. The disturbance of the soil by harvesting leads to the overall ecosystem becoming a source of carbon. It must be expected to take about 20–30 years for the ecosystem to become a sink. At the ecosystem level, a "Kyoto forest" can thus even become a carbon source during the commitment period. It follows that only the ecosystem approach – including the soil – can provide a scientific basis for adequate climate protection measures.

In the interests of climate protection, the carbon losses caused by harvesting primary forests must be taken into consideration. In particular, it needs to be ensured that the design of the clean development mechanism and of joint implementation does not permit the following scenario of abuse: The carbon losses caused by clearcutting a primary forest are not accounted for, regardless of whether the wood is burnt on site, goes to paper production or is processed to long-lived products. A state could capitalize on this twice over: First by economically exploiting the primary forest, and secondly by claiming credit for reforestation as a carbon sink. The carbon releases from clearing and harvesting would not be debited to any state. Climate protection, soil conservation

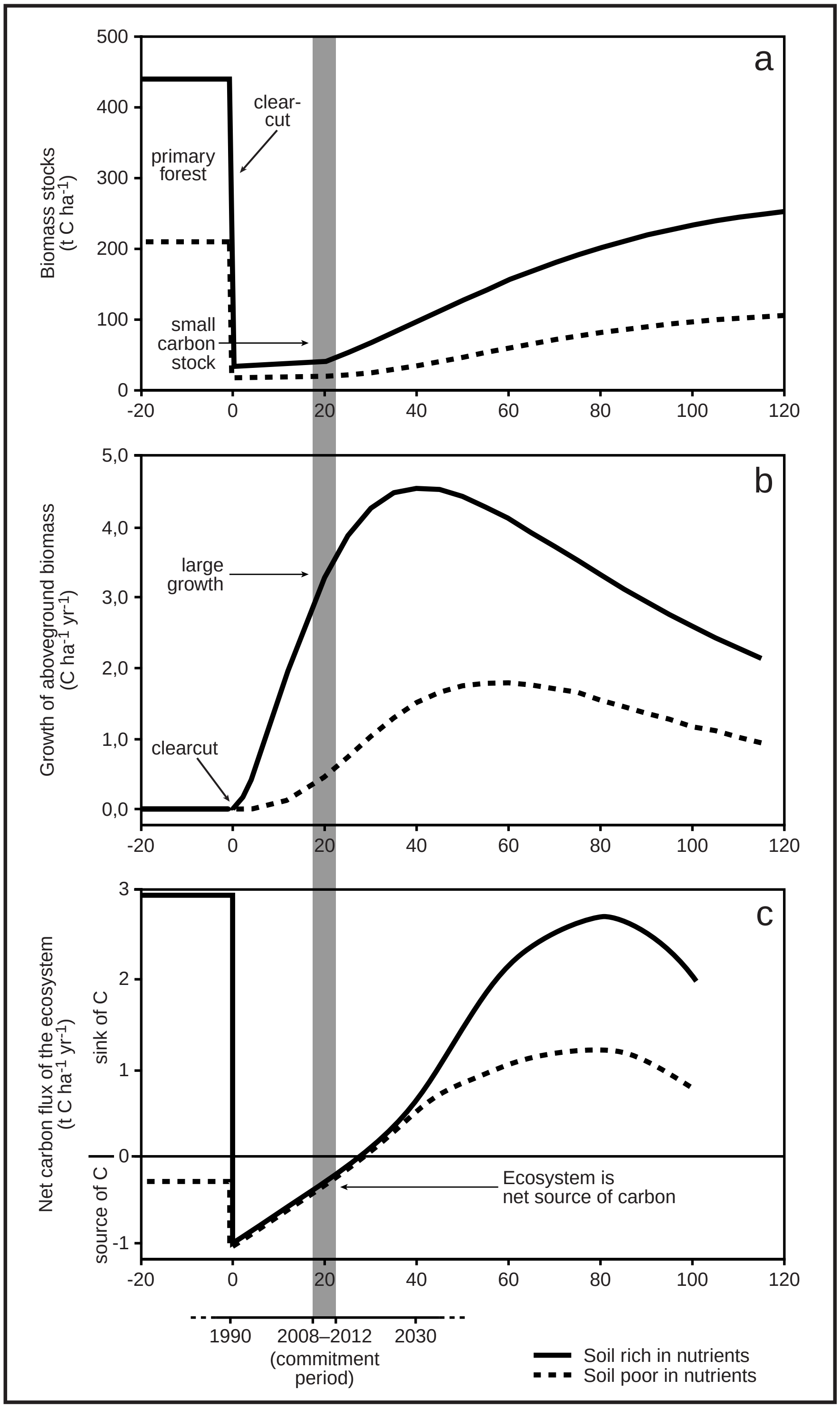

Figure 12
Clearcutting and reforestation – schematic of impact upon carbon stocks and fluxes. The Figure shows the development of carbon stocks and fluxes of coniferous forests in temperate zones after clearcutting and reforestation. The various scenarios of accounting for reforestation under the Kyoto Protocol (the commitment period is indicated by the gray bar) and their climate protection implications are explained in the text. The two curves illustrate the range of possible developments as a function of soil quality.
(a) Development of carbon stocks in aboveground biomass and the organic layer.
(b) Carbon sequestration by the growth of the trees.
(c) Generalized trend of the net carbon flux of the ecosystem.
Source: WBGU

and biodiversity conservation would be turned into their opposites, if in the tropics a brief, very intensive use of an area were to take place between clearcutting and reforestation. Primary forests may then be cleared with the specific aim of such a brief, intensive use followed by an accounting of reforestation. Soils would be degraded within a few years by the intensive cropping systems (e.g. rice). Subsequently, the reforestation of the destroyed areas could be financed via the clean development mechanism.

If future commitment periods do not follow immediately upon each other, then, in the interim periods, the opportunity will repeatedly be given to carry out activities leading to high carbon emissions, without these activities being accounted for.

7.1.3 Major uncertainties inherent in estimations

In a study commissioned by the German Federal Ministry of Education, Science, Research, and Technology, the available data basis relating to the carbon balance of terrestrial ecosystems has been presented and assessed in detail (Heimann et al., 1997; see Sections 6.1–6.4 above). That assessment comes to the conclusion that, for many types of vegetation, the data basis for global extrapolations is exceedingly patchy. The present study, too, has identified major inadequacies for a comparative evaluation of data records.

- Complete carbon inventories only exist for a few countries, ecosystems or forms of land use. There is no such inventory for Germany. Tropical and subtropical areas, economically non-productive ecosystems (e.g. bogs, riparian forests, natural grasslands) but also productive grasslands are greatly under-represented in terms of data availability, which is not commensurate with their importance to the carbon cycle. The assessment of different forms and intensities of land use suffers under the patchiness of data records.
- Most publications on carbon fluxes have omitted the carbon stocks in the organic layer, the underground biomass (roots) and the associate flora. According to the IPCC Guidelines, the inventory of a conversion of forests to cropland or pasture need only consider the top 30 cm of the mineral soil. For most vegetation types, this is inadequate, e.g. in the case of erosion or deeper roots.
- For soils, frequently, only carbon concentrations are stated but not the carbon quantities per unit area. Often, changes in bulk density are not considered. Only a complete and defined record of the soil which takes the bulk density and the depths of horizons in the initial and final state into consideration can deliver a reliable estimation of changes in soil carbon stocks. Very little data is available on the carbon stocks of deeper soil horizons (>100 cm), although plant roots can reach much deeper (on average more than 4 m; Jackson et al., 1996). Moreover, there is a lack of data that differentiates soil carbon fractions (including the dissolved organic carbon) according to their different decomposition rates. The stability of the various humus fractions ranges from a few months and years (e.g. the leaves and needles of the litter) through to several thousand years (stable humic acids in mineral soils or in boggy soils).
- There is as yet an absence of systematic surveys of the carbon dynamics of ecosystems as a function of their intensity and form of use.
- Many studies have pursued issues and purposes that were not those of preparing a complete carbon balance (Paulsen, 1995). This has meant that there is often an absence of information on forest stand age, growth and structure, or water and nutrient availability. This underscores the need for research oriented directly to carbon dynamics.
- Even the reported figures on different vegetation types and land-use forms vary greatly and the level of spatial disaggregation of land-use forms is generally inadequate. Similarly, there is an absence of data on the distribution of areas according to different management intensities (e.g. natural forest vs. extensive production forest vs. plantation).
- A determination of aboveground biomass and its changes does not suffice to quantify terrestrial carbon sources and sinks. Three methods are presently available to draw up carbon assimilation and respiration balances:
  1. through long-term, periodical inventories on a statistical basis, covering both the carbon of the above- and belowground biomass, and the carbon of the organic layer, peat and mineral soil;
  2. through micrometeorological measurements of individual stands (eddy covariance method integrating over km^2),
  3. through inventorizing the convective boundary layer of the atmosphere (CBL integration over $50x50\ km^2$).

Full inventories are exceedingly resource-intensive and time-consuming. The meteorological methods have the disadvantage that they cannot image sudden events that remove carbon from the ecosystem (harvesting or fire). Moreover, the micrometeorological methods may possibly also be distorted by anthropogenic sources. For the future, only a combination and mutual verification of the above methods can promise a realistic estimation of terrestrial sources and sinks.

Due to these fundamental and major uncertainties, a net accounting with the (relatively readily estimable) energy-related emissions leads to a significant reduction in the transparency of commitments. This diminishes the verifiability and the implementability of the legally binding commitments.

7.2 Problematic accounting under the Kyoto Protocol

Above, we have set out fundamental arguments against accounting terrestrial sources with energy-related and industrial sources of greenhouse gases. These show that any attempt to integrate sink protection through offsetting emissions against sinks (the "net approach") is problematic. In the following, we assess the concrete accounting-related provisions of the Kyoto Protocol, in conjunction with the IPCC Guidelines for estimation of source and sink impacts to which the Protocol refers, against the background of the science presented in Sections 4 to 6 above.

7.2.1 Calculation approach

One critical point of the net approach established by the Kyoto Protocol is that sources and sinks relating to land-use change and forestry are not included in the definition of the 1990 baseline emissions, on which the calculation of permitted emissions is based. Accounting is presently restricted under Article 3 para 3 to afforestation, reforestation and deforestation activities since 1990, so that the increase in permitted emissions that results from this approach is well below the increase that would have resulted if all sinks in the sphere of land-use change and forestry were accounted (as originally proposed by some Parties). However, the permitted emissions will rise if additional activities are accounted in the commitment period pursuant to Article 3 para 4. Furthermore, under Article 3 para 7, permitted emissions are increased for those countries in which land-use change and forestry constituted a net sink in 1990. These countries can add the net emissions from land-use change in that year to their 1990 baseline emissions. For Australia, this increases the baseline emissions by some 30%.

7.2.2 Gap before the commitment period

In the period between 1990 and the beginning of the first commitment period in 2008, no emissions by sources or removals by sinks are taken into consideration, as only changes in stocks during the period 2008–2012 are accounted. Due to the non-linear time dynamics of biological sources and sinks (see Section 7.1.2 above), this arrangement creates an incentive to clear-cut forests between 1990 and 2008.

It is therefore essential to insist that the commitment periods follow immediately upon each other. This would preclude a repetition of the accounting difficulties of the initial phase.

7.2.3 Problematic accounting of projects in developing countries

Industrialized countries may possibly use the clean development mechanism (Article 12) to claim credit for providing funding for afforestation projects in developing countries. The Council sees a danger that this possibility is abused by projects involving previous clear-cutting of primary and secondary forests. This would severely infringe the purpose of the Convention. It must, therefore, be ensured that such clearcutting is accounted to the industrialized countries as emissions as long as the developing countries need not yet meet any commitments themselves. An afforestation of thus created degraded areas can then be financed by industrialized countries and credit claimed for this against domestic emissions.

This incentive to clear-cut must at all events be prevented. The Council submits proposals concerning this in Section 8 below.

Without a full carbon inventory having been drawn up for the developing country, an accounting of forest conservation projects may lead merely to a spatial shifting of emissions, if deforestation elsewhere in the country is not taken into consideration. Moreover, it is doubtful whether continued forest conservation can be guaranteed after a project has already been accounted for and has thus led to a lower emission reduction commitment of an industrialized country.

7.3 Selection and definition of accountable activities

By limiting the sinks directly accountable to the reduction commitments of the industrialized countries to afforestation, reforestation and deforestation since 1990, the attempt was made to avoid some of the problems set out above. Furthermore, at least the changes in the aboveground biomass associated with the stated forestry-related activities can be verified more easily than those associated with other forestry measures (forest management). However, a close look at the accounting approach agreed upon under the Kyoto Protocol reveals that unclear definitions of accountable activities and the temporal structure of this approach's implications for net emissions lead to several serious problems.

7.3.1
Unclear definitions

The activities explicitly stated in Article 3 para 3, to which accounting is presently restricted, are not defined in detail in the Kyoto Protocol. The definitions of the IPCC Guidelines are inadequate. It is not clear how reforestation can be distinguished from forestry management practices under which forests are clear-cut and immediately or later replanted. Without such a definition, an unequivocal estimation of the implications of Article 3 para 3, in particular of the undesired incentives created thereby, is not possible. Moreover, imprecise or inappropriate definitions of terms may lead to important processes or ecosystems being neglected (see below). For instance, it is unclear whether the conversion of primary forests to secondary or managed forests or the gradual degradation of forests, which can give rise to considerable emissions, are covered by the three stated activities. The technical feasibility of verification is also unclear. The IPCC Guidelines allow for a series of different methodologies, all with equal standing, although these deliver different results. Finally, it is unclear how the influence of direct human-induced activities is to be held distinct from natural factors.

7.3.2
Possible negative incentives

If we proceed from the application of the present version of the IPCC Guidelines (IPCC, 1997), then the accounting of afforestation, reforestation and deforestation under Article 3 para 3 gives rise to various negative incentives. The incentives for developing countries have already been noted above.

If not accounted for, then the conversion of primary forests to secondary forests could be indirectly promoted, because carbon sequestration in secondary forests or plantations is considered, but the clearcutting of primary forests is not.

In principle, an incentive is created to establish fast-growing plantations. Sustainability aspects, and implications for biodiversity, itself an object of protection, are in danger of being neglected. In particular, the non-consideration of the period until 2008 would create an incentive to carry out reforestation specifically optimized for the commitment period (clearcutting before the commitment period, subsequent reforestation with rapid growth during the commitment period) (Fig. 12).

7.3.3
Neglect of important sources and sinks

The present version of the IPCC Guidelines does not sufficiently consider the conversion of primary to secondary forests, although this process is one of the most important sources of emissions from terrestrial ecosystems (beside deforestation and forest degradation). In contrast to deforestation, forest degradation is not considered, although this leads to emissions of the same magnitude.

No incentives are created that positively promote the conservation of important and stable natural carbon reservoirs, such as above all primary forests and wetlands.

7.3.4
Joint implementation (Article 6) and emissions trading (Article 17)

It is not clear which types of projects aimed at enhancing sinks can be used by industrialized countries to acquire emission reduction units in other industrialized countries. Article 6 does not limit these to the activities stated in Article 3 para 3. This could mean that a joint implementation of projects by two industrialized countries would allow a mutual crediting of sinks that would not be permitted domestically by Article 3 para 3. This may greatly increase the risks and imponderables associated with the accounting of biological sources and sinks.

However, Article 6 does limit accounting insofar as projects must provide an enhancement of removals by sinks "that is additional to any that would otherwise occur" (Article 6 para 1 (b)).

The implications of emissions trading, which is established in principle by Article 17, are not yet estimable either, as the modalities, rules and guidelines for implementing such trading yet need to be adopted.

8 Recommendations

As the assessment given above in Section 7 explains, the form in which the accounting of sinks is regulated under the Kyoto Protocol is by no means suited to effectively uniting the objectives of climate protection and biodiversity conservation. For one thing, the transparency of reduction commitments is greatly reduced because verification is scarcely possible. Moreover, the approach harbours considerable risks with respect to the long-term objective of stabilizing greenhouse gas concentrations. Finally, incentives are given for measures in agriculture and forestry that run counter to the conservation of biodiversity and the conservation of ecosystem functions. The Council views this as a major hazard and one of the most critical points of the Kyoto Protocol. The accounting of sinks fails to give due regard to the objectives of other international conventions, such as "conserving biodiversity" and "combating desertification".

Deleting or reformulating Article 3 paras 3 and 4 – and thus reopening the negotiations on the inclusion of sinks – would therefore be desirable. However, this is not a politically realistic option and harbours the danger that some of the Parties withdraw from the Protocol. Efforts should therefore be directed towards ensuring that Article 3 of the Kyoto Protocol is interpreted and applied in good faith, in a manner that does justice to the Convention's objective of climate protection. Measures that are detrimental over the long term to climate protection should not be accounted to reduction commitments, even where they are formally covered by Article 3 para 3. Furthermore, no decisions should be taken on the accounting of sinks and defining terms in the relevant provisions of the Kyoto Protocol before the Special Report of the IPCC on land-use change and forestry (see UNFCCC, 1998) has made available an in-depth scientific study of all methodological, ecological and socio-economic implications of accounting biological sources and sinks.

As explained in Section 3 above, the Kyoto Protocol and the further provisions proceeding from this allow a certain leeway in the interpretation, concretization and refinement of rules. The Council thus recommends using this leeway to combat and minimize the impending undermining of climate protection and the simultaneously impending impairment of terrestrial ecosystems. At the same time, existing opportunities to conserve sinks should be safeguarded and expanded, while taking care that the accounting procedure waters down the reduction targets as little as possible.

As few sinks as possible should be permitted for accounting, as each credited sink considerably hampers the verifiability of the reduction commitments. In particular, care must be taken that Article 3 para 4 of the Kyoto Protocol is not used in the period until 2012 to credit additional human-induced activities related to removals by sinks in the land-use change and forestry categories.

At the most, the accounting of activities representing relevant sources of greenhouse gases (such as the destruction of natural reservoirs) should be deliberated. This differentiated approach for sources on the one side and sinks on the other is justified because the accounting of sinks is associated with risks to climate protection, but not the accounting of sources.

In the following, we identify options for limiting possible damage and utilizing opportunities for conserving sinks without having to amend the Kyoto Protocol.

The interpretation of Article 3 para 3 in conjunction with Article 5 (on the use and revision of the IPCC Guidelines for National Greenhouse Gas Inventories) and in conjunction with Article 7 (on the modalities yet to be adopted for the accounting of assigned amounts) leaves a certain leeway for defining accountable activities and quantities. The regulation of the clean development mechanism under Article 12 is also in urgent need of clarification. It is essential to prevent the dangerous incentives for deforestation in developing countries that may result from the crediting of projects in developing countries to the commitments of industrialized countries that will already be possible in the year 2000. On this issue, the decision adopted by COP 3 explicitly requests the subsidiary bodies to the UNFCCC to examine the impacts of this early accounting.

8.1 IPCC Special Report on biological sources and sinks

The Council supports the decision of the SBSTA (UNFCCC, 1998), to request the IPCC to prepare a Special Report on land use, land-use change and forestry.

The Special Report should examine the role of the terrestrial biosphere in the carbon cycle as comprehensively as possible, in particular the direct and indirect impacts of human-induced land use, land-use change and forestry upon the concentration of greenhouse gases in the atmosphere, but also upon the hydrosphere, soil organic matter, biological diversity and social and economic conditions. In particular, it is to be clarified to what extent the objective of "long-term stabilization of greenhouse gas concentrations at a level that is not dangerous" could be compromised by an accounting of biological sources and sinks. Here for instance questions as to the constancy of biological sinks under climate change impacts need to be clarified.

For carbon reservoirs and flows in the terrestrial biosphere, other time scales are relevant than the five-year commitment periods under the Kyoto Protocol. It needs to be asked in this connection to what extent existing measuring methods lead to erroneous estimates if they are not integrated over lengthier periods.

Concrete questions concerning the definition of terms and methodologies in connection with Article 3 paras 3 and 4 have already been discussed in Section 3 above. The IPCC should take up these issues and examine the impacts of different definitions and accounting approaches. This examination should also contribute to the improvement of the IPCC Guidelines (see Section 8.2.1). In particular, it should be examined how disregarding important carbon stocks (such as in soils) could impact upon climate protection, biodiversity conservation, soil protection and water resources protection. Can complete carbon inventories be drawn up? Which verification methods are available? How large are the uncertainties associated with these? Over which periods must the findings be integrated in order to arrive at reliable results?

Without a thorough examination of all these questions, the impact of the accounting of biological sources and sinks upon carbon reservoirs and flows and the secondary effects upon water, soils and biodiversity cannot be estimated in concrete terms. Therefore it is essential that no premature decisions are taken on, for instance, the further accounting of sinks under Article 3 para 3 or under Article 12 (projects in developing countries).

8.2 The accounting of afforestation, reforestation and deforestation in industrialized countries

The principal problems associated with the present provisions of Article 3 para 3, in conjunction with the presently applicable IPCC Guidelines, have been discussed in Section 7.2 above. The following need for action results from this:

First of all, efforts should be made to ensure that accounting is only then possible when satisfactory guidelines and methodologies for a transparent and verifiable comparison of compliance by all industrialized countries are adopted. These should be structured keeping in mind that in future the developing countries, too, will assume emission limitation or reduction commitments.

The Council therefore recommends requesting the IPCC to examine all issues relating to uncertainty in the recording and verifiability of sink conservation measures, including secondary effects (such as upon biodiversity or soils) and including the long-term impacts upon the stabilization of greenhouse gases, and to publish its results in a Special Report.

The Council further stresses the importance of revising the IPCC Guidelines. The German federal government should take this into consideration when appointing members of the bodies concerned with the Guidelines. The whole spectrum of natural sciences should be represented, not just forestry. In the following, a number of proposals are made for the revision of the Guidelines.

8.2.1 Proposals concerning the IPCC Guidelines

The IPCC Guidelines (IPCC, 1997) are in urgent need of expansion in order to make them suitable for the review of legally binding commitments. The following aspects especially need to be considered:

- The methodologies applied must lead to comparable inventories. This can only succeed if the requirements upon countries are uniform and at the same time give consideration to the real carbon flows in a sufficiently realistic manner.
- In particular, carbon stocks in organic litter and the O-horizon and in forest soils must be included for all activities.
- The terms "deforestation", "afforestation" and "reforestation" need to be clearly defined. The definition must be such that it does not deliver any

incentive to destroy reservoirs or to impair biodiversity. Furthermore, the definition should lead to an accounting of sinks that is as restrictive as possible, in order to mitigate the gross-net discrepancy and the problems associated with the uncertainties and imponderables of offsetting. The Council suggests defining reforestation by following the definition in the Glossary of the IPCC Guidelines, as plantings on areas that historically (i.e. at some time during the past 50 years, as set out elsewhere in the Guidelines) had forest cover but have been used otherwise in the meantime. This would preclude the accounting of forest management practices involving a harvesting by clear-cutting with subsequent restocking.

- It is essential that the conversion of primary to secondary forest is accounted as an emission, whereby all effects (including soil processes) must be taken into consideration. This should be implemented by means of an appropriate definition of deforestation and reforestation.
- Forest degradation must be accounted in a manner similar to deforestation. Degradation should therefore preferably be included in the definition of deforestation.
- In order to record sources and sinks reasonably completely, the application of micrometeorological methods does not suffice. These methods integrate over larger temporal and spatial scales, permitting a comparatively rapid and accurate determination of actual carbon flows (NEP) between an ecosystem and the atmosphere. However, sudden events such as fire or harvesting, which withdraw carbon from the ecosystem, are not registered. The sudden release of carbon associated with fires may conceivably be determined by means of measurements in the convective boundary layer (CBL) of the atmosphere. However, this first needs further research. Due to the spatial integration of methods, in densely populated regions such as Europe the carbon flows of ecosystems are overlaid by industrial carbon flows. A differentiated measurement of these sources or sinks is only possible with these methods if the stable isotopes are measured at the same time. Micrometeorological methods need to be complemented by monitoring of natural physical-geographical units with due regard to different land-use types, and by inventories of both above-ground and underground biomass. The inventories must also include the organic layer and soil carbon.

8.2.2
Modalities for the accounting of sinks (Article 7 para 4)

Revised IPCC Guidelines can only be applied to commitments for future commitment periods, but not to the 2008–2012 period. This is why – in addition to the urgently necessary expansion and supplementing of the IPCC Guidelines – suitable guidelines need to be decided upon pursuant to Article 7 para 4 for the preparation of the information that is to ensure under Article 7 paras 1 and 2 that commitments under Article 3 are met.

- Thus the largely unavoidable uncertainty as to the verifiability of the impacts of sinks can be contained by ruling that sinks can only be used to offset a certain maximum percentage (e.g. 20%) of gross emissions. Moreover, accounting should be as conservative as possible
- In order to prevent creating an incentive for deforestation prior to the first commitment period, reforestation should only then be accounted if it takes place on areas that were not covered by forest in 1990.
- The accounting of reforestation measures should be linked to a series of conditions in order to ensure their sustainability and prevent undesired side-effects. In particular, an incentive to set up quick-growing species plantations and sensitive monocultures (as opposed to sustainable mixed forests) should be prevented. To this end, the Council suggests that when afforestation or reforestation measures are carried out the mean change in stocks averaged over the rotation period should be accounted, not the change measured in the commitment period.

8.2.3
Should additional activities under Article 3 para 4 be accounted?

Any accounting of additional activities that represent a sink in the land-use change and forestry category leads to increased permitted emissions from fossil fuels. Moreover, the uncertainties associated with all additional activities are far greater than those associated with the activities already included. The Council therefore urgently advises against including further sinks.

At most, important sources not covered by Article 3 para 3 should be accounted using the option offered by Article 3 para 4, if it should not be possible to consider them through appropriate definitions in the IPCC Guidelines and in the guidelines pursuant to Article 7 para 4.

In particular, the degradation of forests, whose inclusion in the definition of deforestation would contradict conventional definitions, could be accounted in this way as a source of emissions. Justice could thus be done to the importance of this source (which, as explained in Section 5 of the present study, is of the same order as deforestation). The draining of wetlands, which can lead to a release of substantial amounts of carbon, could also be accounted by this avenue. If an appropriate accounting of the conversion of primary to secondary or managed forests can not be achieved through the definition of terms in the IPCC Guidelines and in the guidelines pursuant to Article 7 para 4, then accounting as an additional source under Article 3 para 4 could be a way of doing this, too.

8.2.4 Future commitment periods

It is essential to ensure that commitment periods follow upon each other without interruption. Under Article 3 para 9, the Parties must initiate negotiations on this at least 7 years beforehand, i.e. for the second commitment period at the latest in the year 2005. Such continuity can prevent an incentive arising to clear-cut in an interim period. Moreover, the formulation of commitments for future commitment periods should define the baseline emissions such that no discrepancy remains between net emissions in commitment periods and gross emissions in the base year. Finally, it much be insisted that commitment periods are not longer than five years, in order to prevent reduction commitments from being watered down.

8.3 "Joint implementation" of measures among industrialized countries

The recommendations set out above indicate that the accounting of sinks by offsetting emissions against projects in other industrialized countries, which is possible under Article 6, must be restricted. In particular, Article 6 must not provide the possibility of mutual accounting of activities that would be precluded domestically.

8.4 Measures in developing countries

The Council wishes to stress that it certainly supports incentives for the conservation of sinks in developing countries, too. However, the present wording of Article 12 could lead to dangerous incentives if this Article is interpreted as not applying solely to emissions, but also to sinks. As explained in Section 7 above, there is a danger that accounting of reforestation projects within the scope of the clean development mechanism (Article 12) creates an incentive to clear-cut in developing countries, if reforestation measures are financed without previous deforestation being accounted. This must definitely be prevented. One way of removing this incentive is to interpret Article 12 such that it only refers to emissions, but not to sinks. If this interpretation is not enforceable, then the offsetting of commitments of industrialized countries against projects aimed at enhancing sinks should be excluded for at least as long as the developing countries have not assumed emission limitation or reduction commitments, and as long as the existing uncertainties concerning verification of the impacts of sinks upon developing countries have not been clarified.

The exclusion of an accounting of sinks could be mandated by reference to Article 12 para 3, according to which only a "part" of the commitments of the industrialized countries can be complied with by this avenue. This part could be defined as initially generally excluding sinks. The accounting of sinks could also be excluded on the basis of the condition upon certification of emission reductions formulated in Article 12 para 5 (b), according to which these must lead to "real, measurable, and long-term benefits related to the mitigation of climate change".

If it does not prove possible to generally exclude an accounting of sinks, then it should at least be insisted that the possibility of an accounting of projects is linked to a series of conditions with respect to sustainability and the consideration of biodiversity. This can be done on the basis of Article 12 para 5 (b). Furthermore, for projects to be accountable the same requirements in terms of measurability and verifiability must be made that are demanded for the industrialized countries (Section 8.1). The recommendations concerning guidelines under Article 7 para 4 also apply here. In particular, reforestation should only be accounted on such areas that already bore no forest in 1990.

Even without the accounting of sinks in projects under the clean development mechanism, the Kyoto Protocol contains an option by which to promote the desirable conservation of natural reservoirs and sinks in developing countries. Under Article 4 para 3 UNFCCC and Article 11 para 2 (b) of the Kyoto Protocol, industrialized countries must in any case "provide such financial resources ... needed by the developing country Parties to meet the agreed full incremental costs" incurred by implementing climate protection measures, if these incremental costs were agreed between a developing country and the financial mechanism of the Convention. The present financial mechanism, the Global Environment Facility (GEF), should focus more strongly on funding projects aimed at conserving natural reservoirs and sinks, in particular primary forests and wetlands.

8.5 Cooperation between the organs of international environmental agreements

The Council has already repeatedly drawn attention to the inadequate coordination in global environmental protection (WBGU, 1996; WBGU, 1997). The formulation of objectives and catalogues of measures set up by the individual conventions and other international agreements need more harmonization (WBGU, 1996).

The Council recommends working towards an improved cooperation among the institutions of the "Rio conventions" (on climate change, biological diversity, desertification), which are all legally independent of each other. The other ongoing negotiation processes (such as the Intergovernmental Forum on Forests) also should be taken into consideration when reviewing goal conflicts and defining terms. In its annual report, the Council has recommended integrating the international political programmes in the environmental and development policy arenas into one single "Organization for Sustainable Development" of the United Nations (WBGU, 1997). This would be an important steps towards overcoming these coordination problems.

The following terms used to describe the carbon cycle are defined at the beginning of Section 4 above:

source
sink
carbon reservoir
carbon stocks or pools
carbon concentration
carbon flux
carbon flux density
carbon balance

The following terms used to describe the ecosystem productivity processes associated with the carbon cycle are explained at the beginning of Section 5 above:

gross primary productivity (GPP)
net primary productivity (NPP)
net ecosystem exchange (NEE)
net ecosystem productivity (NEP)
net biome productivity (NBP)

baseline emissions: Baseline emissions under the Kyoto Protocol are the aggregate emissions, in the base year 1990, of the six greenhouse gases listed in Annex A to the Protocol, from the sectors/source categories also listed there. Article 3 para 7 of the Protocol allows such Parties "for whom land-use change and forestry constituted a net source" in 1990 to include the net source "from land-use change" in their 1990 baseline emissions (*cf.* also Fig. 1 in Section 3 above).

continuous selection cutting: A form of management of ➔ production forests in which individual trees are continuously extracted (➔ shelterwood system). It aims to develop a dense, balanced, uneven-aged stand (i.e. one having trees of all age classes), modelled on natural forest formations and yielding high-quality timber. The German term is *Plenterhieb*.

humus: In the narrow sense, only the amorphous, organic, newly synthesized material. In the broader sense, the whole dead organic matter containing tissue residues in the soil (➔ litter, *cf.* also Fig. 4 in Section 4 above).

Kyoto forest: By "Kyoto forest", the Council means that part of forests in industrialized countries whose changes in carbon stocks during the commitment period are used to meet emission reduction commitments. Under Article 3 para 3 of the Kyoto Protocol, these are such forests that are affected by afforestation, reforestation and deforestation that has taken place since 1990, and for which verifiable changes in carbon stocks attributable to these activities are measurable in the first commitment period (2008–2012). The volume of the "Kyoto forest" depends upon the definitions chosen for "afforestation", "reforestation" and "deforestation".

litter: Wholely or largely undecomposed organic material lying on top of the mineral soil. It contains the leaves, twigs, seeds and woody parts shed by the vegetation within a year. (➔ humus, *cf.* also Fig. 4 in Section 4 above).

managed forests: Forests used for forestry purposes in a regular and more or less intensive manner. Managed forests include, among other types, ➔ timber plantations and natural production forests (➔ production forest).

natural regeneration: Renewal of a forest or stand mainly through seeds being dispersed by wind, falling from overhead trees or deposited by animals.

production forest: Form of forest management characterized by

1. monocultures and/or mixed stands managed as high forest (including clearcutting, ➔ continuous selection cutting, ➔ shelterwood systems), coppice and coppice with standards,
2. long rotation lengths (>= 60 years),
3. stand regeneration through planting and/or ➔ natural regeneration,

4. tending interventions (e.g. thinning, soil improvement) with the aim of maintaining forest functions.

secondary forest: Forest which, after destruction of the original vegetation (primary forest) as a result of human activities (e.g. land clearing, anthropogenic fire), regenerates naturally, and is thus composed mainly of natural vegetation in early successional stages. Though often associated specifically with the tropics, the term is not limited to these: boreal and temperate forests left to natural regeneration after clearcutting are also secondary forests.

shelterwood system: A form of forest management in which old trees are harvested in groups or strips (➔ continuous selection cutting). In the resultant clearings, ➔ natural regeneration of the stand takes place. The German term is *Femelschlag*.

timber plantation: The most intensive form of forest management. It is characterized by

1. monocultures of fast-growing tree species (e.g. poplar, *Pinus radiata*, eucalyptus),
2. short rotation lengths (< 60 years),
3. stand regeneration by planting,
4. application of soil fertilization and tillage, pest control and other measures aimed at increasing timber yields.

Plantations are a transitional form between forestry and agricultural land use. Most afforestation takes the form of this type of management.

wetlands: Bogs, swamps, wet meadows, fen woodlands and other areas with high levels of soil moisture or high groundwater tables. Wetlands can also be viewed as including tidal marshes and fringing mangroves, periodically inundated areas and certain types of cropland (mainly rice). Peat-forming wetlands include above all bogs and fens, and, depending upon site conditions, also swamps, fen woodlands and wet meadows.

Annex Table 1
Net carbon emissions or removals resulting from human-induced land-use change and forestry activities, and impacts upon total national CO_2 emissions, in 1990 and 1995.
Source: UNFCCC, 1997a

Country	Land-use change and forestry, net emissions or removals		Percentage reduction / increase (-/+) of national CO_2 emissions taking into account land-use change and forestry	
	1990	1995	1990	1995
	[Gigagram]	[Gigagram]	[%]	[%]
Australia	86 500	51 867	25	17
Austria	-13 300	-13 580	-21	-22
Belgium	-2 057	-2 057	-2	-2
Bulgaria (1988)	-4 657	-6 941	-5	-12
Canada				
Czech Republic	-2 281	-5 454	-1	-4
Denmark	-2 600		-5	
Estonia	-8 555		-23	
Finland	(-30 000) – (-19 000)	(-14 000) – (-7 000)	(-56) – (-35)	(-22) – (-12)
France	-33 218	-46 801	-9	-12
Germany	-30 000	-30 000	-3	-3
Greece				
Hungary (1985-87)	-3 097	-4 820	-4	-8
Iceland				
Ireland	-5 160	-6 230	-17	-18
Italy	-36 730		-9	
Japan	-83 341	-94 619	-7	-8
Latvia	-14 300	-15 831	-62	-141
Luxembourg				
Netherlands	-1 500	-1 700	-1	-1
New Zealand	-20 569	-13 487	-81	-49
Norway	-10 200	-13 637	-29	-36
Poland (1988)	-1 408	-43 861	0	-12
Portugal				
Romania (1989)	-2 925		-1	
Russian Federation	-392 690	-568 850	-17	-35
Slovakia	-4 257	-5 116	-7	-11
Spain	-23 166		-10	
Sweden	-34 368	-30 000	-62	-54
Switzerland	-4 360	-5 100	-10	-12
United Kingdom	18 776	9 945	3	2
United States	-458 000	-428 000	-9	-8
Total	-1 111 963		-8	

Annex Table 2
Distribution of carbon stocks by country and vegetation type and carbon quantity per unit of area. The data given in the table differ from the global carbon balances found by Heimann et al. (1997) and IGBP (1998) (*cf.* Section 4 above, Table 2). The table may contain double counts, eg. in the case of forested peatlands.
Sources: adapted from (1) Dixon et al., 1994; (2) Atjay et al., 1979 in IPCC, 1990

Vegetation type	Area	Carbon stocks [Gt C]			Carbon per unit area [t C ha^{-1}]		
	[mill. ha]	Total	Soil	Vegetation	Total	Soil	Vegetation
Forests of the high latitudes[1]							
Russia*	884	323	249	74	365	281	83
Canada	436	223	211	12	511	484	28
Alaska	52	13	11	2	250	212	39
Total/Average	1,372	559	471	88	407	343	64
Forests of the middle latitudes[1]							
USA (continental)	241	41	26	15	170	108	62
Europe	283	34	25	9	120	90	32
China	118	33	16	17	280	136	114
Australia	396	51	33	18	220	83	45
Total/Average	1,038	159	100	59	153	96	57
Forests of the low latitudes[1]							
Asia (excluding China)	310	84–97	43	41–54	292	139	132–174
Africa	527	167	63	52	317	120	99
South America	918	229	110	119	249	120	130
Total/Average	1,755	428	216	212	244	123	121
Total/Average Forests	4,165	1,146	787	359	275	189	86
Grasslands[2]							
(Tropical) savannas	2,250	330	264	66	146	117	29
Temperate grasslands	1,250	304	295	9	243	236	7
Total/Average	3,500	634	559	75	181	160	21
Other vegetation types							
Cultivated land[2]	1,600	131	128	3	82	80	2
Wetlands[2]	350	240	225	15	686	643	43
Tundra, alpine grass[2]	950	127	121	6	134	128	6
Desert/semi-desert[2]	4,550	199	191	8	44	42	2
Overall total/Average	15,115	2,477	2,011	466	164	133	31

*Shvidenko and Nilsson (1998) give approximately 50% lower carbon stocks for Russia than Dixon et al. (1994).

Forests	Organic layer [t C ha^{-1}]
Temperate	24 (2–100)
Boreal	15.5 (4–42)
Subtropical moist	10 (8–11)
Tropical	4.5 (3–8)

Annex Table 3
Carbon stocks in the organic layer of different forest soil types. Data referring to the total of soil organic matter were converted assuming a carbon content of 50%. The carbon stocks of the organic layer primarily depend on the climate (the colder and more humid the climate the greater the accumulation of organic matter), vegetation, age of the stand, and land use. According to the German Forest Soil Report of 1996, some 18% (18 t C ha^{-1}) of the entire soil carbon of German forests is stored in the organic layer (BML, 1997b). For Russian forests the fraction is ca. 6% (11 t C ha^{-1}, excluding peat soils) (Shvidenko and Nilsson, 1998). Carbon stocks in dead forest trees range between 1 and 225 t C ha^{-1} depending on the type of vegetation and management (Krankina and Harmon, 1995; Harmon and Chen Hua, 1991; Turner et al., 1995).
Sources: Black and Harden, 1995; Boone et al., 1988; Breymeyer et al., 1996; Burschel et al., 1993; Covington, 1981; Federer, 1984; Fölster, 1989; Gosz et al., 1976; Grigal and Ohmann, 1992; Harmon et al., 1990; Heimann et al., 1997; Liski and Westman, 1995; Liski and Westman, 1997; Matzner, 1989; Thuille, 1998; Schulze et al., 1995; Shvidenko and Nilsson, 1998; Switzer et al., 1979; Tate et al., 1993; Turner and Long, 1975; Vogt et al., 1983; Vogt et al., 1995

Annex Table 4
Estimation of net primary productivity (NPP) and net ecosystem productivity (NEP, measured by eddy covariance analysis, comparison of inventories or on the basis of models) of the various terrestrial vegetation types. NEP values are based on only a few measurements of individual stands and species of the different vegetation types. The sometimes surprisingly high NEP values for temperate forests as compared with their NPP may be an indication (1) of the immense significance of the organic layer and soil carbon for ecosystems' net carbon accumulation (EC, 1997), (2) that nocturnal respiration has been underestimated, or (3) that periodic disturbances which lower NPP and stimulate heterotrophic respiration have not been considered (Buchmann and Schulze, 1998; Baldocchi et al., 1998; Shaver and Jonasson, 1997; Reich and Bolstad, 1997; Moore, 1996; Schulze and Heimann, 1998).
Sources: (1) Valentini et al., 1996, (2) Frolking, 1997, (3) Schulze et al., 1998, (4) Miranda et al., 1997, (5) Kim et al., 1992, (6) Hensen et al., 1997, (7) Buchmann and Schulze, 1998; (8) Jarvis et al., 1997, (9) Larcher, 1994

Vegetation type	Country	Age [years]	NPP (Mean/Range) [t C ha^{-1} yr^{-1}]	NEP * (Median/Range) [t C ha^{-1} yr^{-1}]	NEP/ NPP [%]	Source
NPP AND NEP MEASUREMENTS						
Fagus sylvatica	Italy (1 year)	90	8.02	-4.7	59	(1)
Picea mariana	Canada (2 years)	80	1.39 / 1.12	-0.26 / -0.025	19 / 2	(2)
Larix gmelinii, *Pinus sylvestris*	Eurosibiria (1 month)	6–220	1.8	-0.12 to -0.36	approx. 13	(3)
NPP LITERATURE QUOTES[9] AND NEP MEASUREMENTS						
Tropical forests		-	11 (5 to 17.5)	-1	approx. 6-20	(7)
Temperate coniferous and deciduous forests		30–90	6.3 (2 to 12.5)	-1.4 to -15.5 median: -3.7	approx. 60	(7)
Boreal coniferous and deciduous forests		70–90	4 (1 to 7.5)	+0.7 to -1.3 median: -0.35	approx. 9	(7). (8)
Tropical grasslands/ savanna (C_4 grasses)	Brazil		4.5 (1 to 10)	-2.5		(4)
Prairie (tallgrass)	USA (6 months, counted as a vegetation period)		3 (1 to 7.5)	-3.75		(5)
Managed temperate grasslands (C_3 grasses)	Netherlands		3 (1 to 7.5)	+12 to +0.2		(6)

(*) NEP: A negative sign indicates a net carbon removal from atmosphere to ecosystem, while a positive sign indicates a net carbon release from ecosystem to atmosphere.

Annex Table 5
Carbon stocks of primary forests or old, semi-natural forests as compared with secondary or managed forests (SOC: soil organic carbon)
Sources: (1) Harmon et al., 1990; (2) Cannell et al., 1992; (3) Burschel et al., 1993; (4) adapted from Karjalainen, 1996, (5) Fölster, 1989; (6) Brown and Lugo, 1980; (7) Houghton et al., 1983; (8) Olson et al., 1983; (9) Schroeder and Winjum, 1995, (10) Alves et al., 1997; (11) Wenk et al., 1990; (12) Black and Harden, 1995

Vegetation	Stocks primary forest / old, semi-natural forest [t C ha^{-1}]	Stocks secondary / managed forest [t C ha^{-1}]	Age of secondary / managed forest [years]	Reduction of C pool [t C ha^{-1}]/(%)	Source
OVERALL BALANCES					
TEMPERATE FORESTS					
Temperate 450-year old natural *Pseudotsuga-Tsuga* forest vs. 60-year old *Pseudotsuga* plantation, Canada — Total	612	259–274	60	~346 (57)	(1)
Vegetation (above- / belowground)	433	192		241 (56)	
Organic layer and dead wood	123	11–26		105 (85)	
Soil (SOC)	56	56		0	
Temperate old deciduous forest vs. plantation, Europe[1]	380	230	80	150 (39)	(2)
Temperate natural beech forest vs. production beech forest, Slovakia	290 (212–368)	137 (128–146)	150 (140–160)	~ 153 (53)	(3)
Peatland vs. Sitka spruce forest, NW Europe)[1]	40 (peat)	22	55	18 (45)	(2)
BOREAL FORESTS					
Boreal unmanaged pine forest vs. managed pine forest, Finland[2]	190	~99	101–150	91 (48)	(4)
Boreal unmanaged spruce forest vs. managed spruce forest, Finland[2]	169	~93	101–150	76 (45)	(4)
Boreal unmanaged birch forest vs. managed birch forest, Finland[2]	130	~78	101–150	52 (40)	(4)
TROPICAL FORESTS					
Tropical moist forests of Africa and America					(5)
vs. secondary forest	273	127	18	146 (53)	
vs. timber plantation	273	155	20	118 (43)	
Tropical Dipterocarpaceae forests, SE Asia					(5)
vs. secondary forest	333	127	18	206 (62)	
vs. timber plantation	333	155	20	178 (53)	
Tropical seasonal forests					(5)
vs. secondary forest	141	77	18	64 (45)	
vs. timber plantation	141	82	20	59 (42)	
Tropical moist primary forests vs. secondary forest — Total	240	180	–	63 (25)	(6) in (7)
Vegetation	156	117	–	39 (25)	
Soil	84	63	–	21 (25)	
Tropical moist primary forests vs. secondary forests — Total	124	93	–	31 (25)	(6) in (7)
Vegetation	84	63	–	21 (25)	
Soil	40	30	–	10 (25)	
Tropical all-year moist primary forest vs. young degraded secondary forest, Brazil — Total	304	134	–	170 (56)	(8) in (9)
Vegetation	200	40	–	160 (80)	
Soil	104	94	–	10 (10)	

▶

Vegetation	**Stocks primary forest [t C ha-1]**	**Stocks secondary/ managed forest [t C ha-1]**	**Age of secondary/ managed forest [years]**	**Reduction of C pool [t C ha-1]/(%)**	**Source**
COMPARTMENT BALANCES					
POOL IN VEGETATION primary forest vs. secondary forest, Brazil	184	60	18	124 (67)	(10)
STOCKS IN WOODY BIOMASS (EXCLUDING SOC AND ORGANIC LAYER) Temperate primary mixed forest vs. continuous selection forest (Dobroc), Slovakia	> 227	ca. 101 (54–147)	>100	126 (56)	in (11)
STOCKS IN MINERAL SOIL (SOC) AND IN ORGANIC LAYER Temperate natural mixed deciduous forest vs. secondary forest, Canada	158	97–101	80	59 (37)	(12)

[1] average over one rotation
[2] average with respect to age

Annex Table 6

Carbon stocks in aboveground biomass and in soil after conversion of primary forest or savanna to pasture land or grassland. Studied soil depth: (a) organic layer and A_h horizon (b) 0–30 cm (c) 0–100 cm

Sources: (1) Thuille, 1998; (2) Tomich et al., 1997; (3) Olson et al., 1983; (4) Schroeder and Winjum, 1995; (5) Neill et al., 1997; (6) Gaston et al., 1998; (7) de Moraes et al., 1996; (8) Fisher et al., 1994

Vegetation type	Forest		Pasture / grassland		Time	Change in C stocks*	Source
	Biomass [t C ha^{-1}]	Soil [t C ha^{-1}]	Biomass [t C ha^{-1}]	Soil [t C ha^{-1}]	[years]	[t C ha^{-1}]	
Temperate spruce continuous selection forest vs. pasture, Italy (subalpine)(a)	207	72	–	30	ca. 200	+249	(1)
Tropical Dipterocarpaceae forests vs. *Imperata* degradation, SE Asia(c)	235	130	15	75	–	+275	(2)
Tropical primary forests vs. pasture, Brazil(c)	200	104	10	95	–	+199	(3) in (4)
Tropical primary forests vs. pasture, Brazil (soil chronosequences)(b)		32		50	81	-18	
		27		39	20	-12	
		30		45	20	-15	(5)
Lowland moist forests vs. grasslands, Africa(c)	180	–	6	–	–	+174	(6)
Tropical primary forest vs. pasture, *Brachiaria* and *Panicum*, Brazil(b)	–	37	–	46–72	20–81	-9 to -35	(7)

Vegetation type	Savanna		Pasture		Time	Change in C stocks*	Source
	Biomass [t C ha^{-1}]	Soil [t C ha^{-1}]	Biomass [t C ha^{-1}]	Soil [t C ha^{-1}]	[years]	[t C ha^{-1}]	
Savanna vs. *Andropogon gayanus / Stylosanthes capita*, Colombia(c)	–	187	–	237	3	-50	(8)
Savanna vs. *Brachiaria humidicola*, Colombia(c)	–	197	–	223	9	-26	(8)
Savanna vs. *Brachiaria humidicola / Arachis pintoi*, Colombia(c)	–	197	–	268	9	-71	(8)

* A negative sign indicates a net carbon removal from atmosphere to ecosystem, while a positive sign indicates a net carbon release from ecosystem to atmosphere.

Annex Table 7
Changes in soil carbon stocks through use of former tropical forest sites for arable farming. Two depths are given for each profile, so that depth-related changes in stocks can be derived.
Sources: (1) Vitorello et al., 1989; (3) Lal and Logan, 1995; (4) Woomer et al., 1998

Carbon stocks [t C ha-1]	Losses [t C ha-1]	Change [%]	Loss rate [t C ha-1yr-1]	Cultivation period	Depth	Source
74.0	36.0	48.6	3.0	12	20	(1)
52.0	12.0	23.1	1.0	12	70	(1)
74.0	38.0	51.4	0.8	50	20	(1)
52.0	-4.0	-7.7	-0.1	50	70	(1)
53.8	11.0	20.4	1.1	10	25	(2)
29.3	0.3	1.0	0.0	10	50	(2)
53.8	37.5	69.7	3.8	10	25	(2)
29.3	16.3	55.6	1.6	10	50	(2)
108.0	47.7	44.2	6.0	8	15	(4)
146.0	29.3	20.1	3.7	8	60	(4)
90.0	55.0	61.1	5.5	10	25	(4)
40.0	5.0	12.5	0.5	10	50	(4)

Annex Table 8
Changes in soil carbon stocks through use of former temperate grassland sites for arable farming. Two depths are given for each profile, so that depth-related changes in stocks can be derived.
Sources: (5) Brown and Lugo, 1990; (6) Bouwman, 1990; (7) Tiessen et al., 1982; (8) Voroney et al., 1981

Carbon stocks [t C ha-1]	Losses [t C ha-1]	Change [%]	Loss rate [t C ha-1yr-1]	Cultivation period	Depth	Source
23.6	9.5	40.3	3.1	3	15	(5)
16.3	2.8	17.2	0.9	3	30	(5)
23.6	10.7	45.3	0.5	20	15	(5)
16.3	4.1	25.2	0.2	20	30	(5)
23.6	14.7	62.3	0.4	60	15	(5)
16.3	5.8	35.6	0.1	60	30	(5)
53.8	30.4	56.5	0.3	90	15	(6)
39.2	22	56.1	0.2	90	30	(6)
66.5	11.9	17.9	0.7	18	15	(6)
35.4	0.2	0.6	0.0	31	30	(6)
94	38	40.4	0.2	70	25	(8)
22.3	8.3	37.2	0.1	70	50	(8)
51	16.2	31.8	0.2	65	15	(7)
33.5	-0.7	-2.1	0.0	65	35	(7)

Annex Table 9
Greenhouse gas stocks and fluxes in wetlands
a) Carbon stocks and fluxes of peat-forming wetlands
b) Methane release and corresponding CO_2 equivalent emissions from natural wetlands and from rice cultivation. GWP (global warming potential) (IPCC, 1996a) is a conversion factor by which methane releases can be converted into CO_2 emissions of equivalent warming impact. GWP depends upon the time horizon chosen (e.g. 20, 100, 500 years).
c) CO_2 emissions from the conversion of wetlands (only swamps and bogs).
Sources: (1) Aselmann and Crutzen, 1989; (2) Bartlett and Harris, 1993; (3) Gorham, 1991; (4) Crill et al., 1993; (5) Batjes and Bridges, 1992; (6) Schütz et al., 1989; (7) Bouwman, 1990; (8) Adger and Brown, 1994; (9) Neue, 1991; (10) Neue, 1997; (11) Mitsch and Wu, 1995; (12) Laine et al., 1996; (13) Sakovets and Germanova, 1992; (14) Silvola et al., 1996; (15) Kasimir-Klemedtsson et al., 1997; (16) Silvola, 1986; (17) Adger, 1994; (18) Öquist and Svensson, 1996; (19) Nykänen et al., 1995; (20) Zoltai and Martikainen, 1996; (21) Ovenden, 1990; (22) Armentano and Menges, 1986; (23) Rothwell, 1991; (24) Woodwell et al., 1995; (25) Bruenig, 1990

a	**Carbon stocks ($t\ C\ ha^{-1}$)**		**Carbon assimilation ($t\ C\ ha^{-1}\ yr^{-1}$)**	**Source**
	Soil	**Biomass**		
Global	1,181–1,537	no data	0.1–0.35	(11), (20), (22), (24)
Tropics	1,700–2,880	500	no data	(10), (25), (20)
Boreal / temperate regions	1,314–1,315	120	0.17–0.29	(16), (20), (21), (23), (25)

b	**Methane emissions ($t\ C\ ha^{-1}\ yr^{-1}$)**	**Equivalent CO_2 emissions ($t\ C\ ha^{-1}\ yr^{-1}$) GWP (factor / time horizon in years)**			**Region**	**Source**
		56 (20)	**21 (100)**	**6.5 (500)**		
Methane emissions from natural wetlands	0.05–0.21	2.8–4.4	1.1–4.4	0.3–1.4	Global	(1), (2)
	0.26–0.28	14.6–15.7	5.5–5.9	1.7–1.8	Tropic	(2), (4)
	0.08–0.15	4.5–8.4	1.7–3.2	0.5–1	Boreal / temperate	(2), (4)
Methane emissions from rice cultivation	0.13–0.89	7.3–49.8	2.7–18.7	0.85–5.8	Global	(1), (4), (5), (6), (7), (8), (9), (10)

c	**CO_2 emissions**		**Source**
	Drainage [$t\ C\ ha^{-1}\ yr^{-1}$]	**Agricultural use [$t\ C\ ha^{-1}\ yr^{-1}$]**	
Global	0.23–0.26	1–10	(11), (12), (13), (14), (16)
Boreal / temperate regions	0.1–0.32	1–19	(7), (15), (17), (18), (19)

Annex Table 10
Potentials for carbon removal and storage by means of afforestation measures (plantations) for the period 1995–2050 in different geographic regions.
Sources: following Nilsson and Schopfhauser, 1995

Geographic region	Carbon stocks biomass [Gt C]	Carbon stocks soil[a)] [Gt C]	Carbon uptake [$t\ C\ ha^{-1}$]	Uptake into biomass [$t\ C\ ha^{-1}\ yr^{-1}$]	Uptake into soil[a)] [$t\ C\ ha^{-1}\ yr^{-1}$]	Area [mill. ha]
BOREAL						
Canada	0.51	0.17	73	1.1	0.4	9.3
Northern Europe	0.025	0.0075	92.6	1.4	0.4	0.35
former Soviet Union	1.32	0.44	26.5	0.4	0.1	66.5
TEMPERATE						
USA	2.03	0.76	155	2.3	0.8	18
Australia	0.23	0.08	392	5.3	1.8	0.79
Europe	0.72	0.24	123.9	1.9	0.6	7.75
Asia	2.92	0.97	50.5	0.8	0.3	75
South America	0.77	0.25	223.7	3.4	1.1	4.56
TROPICS						
Africa	0.73	0.23	208.7	3.2	1.0	4.6
South America	6.01	2.01	327.4	4.9	1.6	24.5
Asia	5.63	1.88	172.2	3.0	1.0	37.8

[a)]Litter, soil carbon and root biomass – calculated as having a share of 25%.

Annex Table 11
Model calculations (NDEP model, pertubation model of terrestrial biogeochemistry) of the impact of raised nitrogen deposition upon the carbon sink capacity of the Earth. N depositions were computed using the MOGUNTIA (Holland et al., 1997) and GRANTOUR (Asner et al., 1997) chemical transport models. The current vegetation refers to Matthews, 1983 (following Townsend et al., 1996a). The model calculation shows that historical deforestation reduced the sink function of the continents by 30%. NH_x deposition (agricultural sources) enhances the growth of the continental C sinks by NO_y deposition by more than 50%. The model indicates that an N effect remains which roughly balances historical deforestation. The reduction of the C sink under conditions of N saturation illustrates that the notion of increasing C sequestration by means of N fertilization is not sustainable. Above all in Europe and North America, sink capacity is currently dropping due to N saturation. The models presumably overestimate the impacts of N deposition in the tropics, as there it is frequently other nutrient elements, in particular phosphate, that are the limiting factor (Vitousek, 1984; Tanner et al., 1998)
Source: (1) Asner et al., 1997, (2) Holland et al., 1997

	N deposition			Global C sequestration in the biomass / source [$Gt\ C\ yr^{-1}$]
	NO_y	NH_x	N saturation	
Native vegetation	X	-	-	1.04 [1]
Current vegetation	X	-	-	0.74 [1] 0.90–1.13 [2]
Current vegetation	X	X	-	1.42–1.97 [2]
Current vegetation	X	-	X	0.44 [1] 0.62-0.71 [2]
Current vegetation	X	X	X	1.09-1.35 [2]

KYOTO PROTOCOL TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

THE PARTIES TO THIS PROTOCOL,

BEING Parties to the United Nations Framework Convention on Climate Change, hereinafter referred to as "the Convention",

In pursuit of the ultimate objective of the Convention as stated in ist Article 2,

RECALLING the provisions of the Convention,

BEING GUIDED by Article 3 of the Convention,

PURSUANT to the Berlin Mandate adopted by decision 1/CP.1 of the Conference of the Parties to the Convention at its first session,

Have agreed as follows:

ARTICLE 1

For the purposes of this Protocol, the definitions contained in Article 1 of the Convention shall apply. In addition:

1. "Conference of the Parties" means the Conference of the Parties to the Convention.

2. "Convention" means the United Nations Framework Convention on Climate Change, adopted in New York on 9 May 1992.

3. "Intergovernmental Panel on Climate Change" means the Intergovernmental Panel on Climate Change established in 1988 jointly by the World Meteorological Organization and the United Nations Environment Programme.

4. "Montreal Protocol" means the Montreal Protocol on Substances that Deplete the Ozone Layer, adopted in Montreal on 16 September 1987 and as subsequently adjusted and amended.

5. "Parties present and voting" means Parties present and casting an affirmative or negative vote.

6. "Party" means, unless the context otherwise indicates, a Party to this Protocol.

7. "Party included in Annex I" means a Party included in Annex I to the Convention, as may be amended, or a Party which has made a notification under Article 4, paragraph 2(g), of the Convention.

ARTICLE 2

1. Each Party included in Annex I, in achieving its quantified emission limitation and reduction commitments under Article 3, in order to promote sustainable development, shall:

(a) Implement and/or further elaborate policies and measures in accordance with its national circumstances, such as:

(i) Enhancement of energy efficiency in relevant sectors of the national economy;

(ii) Protection and enhancement of sinks and reservoirs of greenhouse gases not controlled by the Montreal Protocol, taking into account its commitments under relevant international environmental agreements; promotion of sustainable forest management practices, afforestation and reforestation;

(iii) Promotion of sustainable forms of agriculture in light of climate change considerations;

(iv) Research on, and promotion, development and increased use of, new and renewable forms of energy, of carbon dioxide sequestration technologies and of advanced and innovative environmentally sound technologies;

(v) Progressive reduction or phasing out of market imperfections, fiscal incentives, tax and duty exemptions and subsidies in all greenhouse gas emitting sectors that run counter to the objective of the Convention and application of market instruments;

(vi) Encouragement of appropriate reforms in relevant sectors aimed at promoting policies and measures which limit or reduce emissions of greenhouse gases not controlled by the Montreal Protocol;

(vii) Measures to limit and/or reduce emissions of greenhouse gases not controlled by the Montreal Protocol in the transport sector;

(viii) Limitation and/or reduction of methane emissions through recovery and use in waste management, as well as in the production, transport and distribution of energy;

(b) Cooperate with other such Parties to enhance the individual and combined effectiveness of their policies and measures adopted under this Article, pursuant to Article 4, paragraph 2(e)(i), of the Convention. To this end, these Parties shall take steps to share their experience and exchange information on such policies and measures, including developing ways of improving their comparability, transparency and effectiveness. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, consider ways to facilitate such cooperation, taking into account all relevant information.

2. The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively.

3. The Parties included in Annex I shall strive to implement policies and measures under this Article in such a way as to minimize adverse effects, including the adverse effects of climate change, effects on international trade, and social, environmental and economic impacts on other Parties, especially developing country Parties and in particular those identified in Article 4, paragraphs 8 and 9, of the Convention, taking into account Article 3 of the Convention. The Conference of the Parties serving as the meeting of the Parties to this Protocol may take further action, as appropriate, to promote the implementation of the provisions of this paragraph.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol, if it decides that it would be beneficial to coordinate any of the policies and measures in paragraph 1(a) above, taking into account different national circumstances and potential effects, shall consider ways and means to elaborate the coordination of such policies and measures.

Article 3

1. The Parties included in Annex I shall, individually or jointly, ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A do not exceed their assigned amounts, calculated pursuant to their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of this Article, with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012.

2. Each Party included in Annex I shall, by 2005, have made demonstrable progress in achieving its commitments under this Protocol.

3. The net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks in each commitment period, shall be used to meet the commitments under this Article of each Party included in Annex I. The greenhouse gas emissions by sources and removals by sinks associated with those activities shall be reported in a transparent and verifiable manner and reviewed in accordance with Articles 7 and 8.

4. Prior to the first session of the Conference of the Parties serving as the meeting of the Parties to this Protocol, each Party included in Annex I shall provide, for consideration by the Subsidiary Body for Scientific and Technological Advice, data to establish its level of carbon stocks in 1990 and to enable an estimate to be made of its changes in carbon stocks in subsequent years. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, decide upon modalities, rules and guidelines as to how, and which, additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties included in Annex I, taking into account uncertainties, transparency in reporting, verifiability, the methodological work of the Intergovernmental Panel on Climate Change, the advice provided by the Subsidiary Body for Scientific and Technological Advice in accordance with Article 5 and the decisions of the Conference of the Parties. Such a decision shall apply in the second and subsequent commitment periods. A Party may choose to apply such a decision on these additional human-induced activities for its first commitment period, provided that these activities have taken place since 1990.

5. The Parties included in Annex I undergoing the process of transition to a market economy whose base year or period was established pursuant to decision 9/CP.2 of the Conference of the Parties at its second session shall use that base year or period for the implementation of their commitments under this Article. Any other Party included in Annex I undergoing the process of transition to a market economy which has not yet submitted its first national communication under Article 12 of the Convention may also notify the Conference of the Parties serving as the meeting of the Parties to this Protocol that it intends to use an historical base year or period other than 1990 for the implementation of its commitments under this Article. The Conference of the Parties serv-

ing as the meeting of the Parties to this Protocol shall decide on the acceptance of such notification.

6. Taking into account Article 4, paragraph 6, of the Convention, in the implementation of their commitments under this Protocol other than those under this Article, a certain degree of flexibility shall be allowed by the Conference of the Parties serving as the meeting of the Parties to this Protocol to the Parties included in Annex I undergoing the process of transition to a market economy.

7. In the first quantified emission limitation and reduction commitment period, from 2008 to 2012, the assigned amount for each Party included in Annex I shall be equal to the percentage inscribed for it in Annex B of its aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A in 1990, or the base year or period determined in accordance with paragraph 5 above, multiplied by five. Those Parties included in Annex I for whom land-use change and forestry constituted a net source of greenhouse gas emissions in 1990 shall include in their 1990 baseline emissions year or period the aggregate anthropogenic carbon dioxide equivalent emissions by sources minus removals by sinks in 1990 from land-use change for the purposes of calculating their assigned amount.

8. Any Party included in Annex I may use 1995 as its base year for hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride, for the purposes of the calculation referred to in paragraph 7 above.

9. Commitments for subsequent periods for Parties included in Annex I shall be established in amendments to Annex B to this Protocol, which shall be adopted in accordance with the provisions of Article 21, paragraph 7. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall initiate the consideration of such commitments at least seven years before the end of the first commitment period referred to in paragraph 1 above.

10. Any emission reduction units, or any part of an assigned amount, which a Party acquires from another Party in accordance with the provisions of Article 6 or of Article 17 shall be added to the assigned amount for the acquiring Party.

11. Any emission reduction units, or any part of an assigned amount, which a Party transfers to another Party in accordance with the provisions of Article 6 or of Article 17 shall be subtracted from the assigned amount for the transferring Party.

12. Any certified emission reductions which a Party acquires from another Party in accordance with the provisions of Article 12 shall be added to the assigned amount for the acquiring Party.

13. If the emissions of a Party included in Annex I in a commitment period are less than its assigned amount under this Article, this difference shall, on request of that Party, be added to the assigned amount for that Party for subsequent commitment periods.

14. Each Party included in Annex I shall strive to implement the commitments mentioned in paragraph 1 above in such a way as to minimize adverse social, environmental and economic impacts on developing country Parties, particularly those identified in Article 4, paragraphs 8 and 9, of the Convention. In line with relevant decisions of the Conference of the Parties on the implementation of those paragraphs, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, consider what actions are necessary to minimize the adverse effects of climate change and/or the impacts of response measures on Parties referred to in those paragraphs. Among the issues to be considered shall be the establishment of funding, insurance and transfer of technology.

Article 4

1. Any Parties included in Annex I that have reached an agreement to fulfil their commitments under Article 3 jointly, shall be deemed to have met those commitments provided that their total combined aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A do not exceed their assigned amounts calculated pursuant to their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of Article 3. The respective emission level allocated to each of the Parties to the agreement shall be set out in that agreement.

2. The Parties to any such agreement shall notify the secretariat of the terms of the agreement on the date of deposit of their instruments of ratification, acceptance or approval of this Protocol, or accession thereto. The secretariat shall in turn inform the Parties and signatories to the Convention of the terms of the agreement.

3. Any such agreement shall remain in operation for the duration of the commitment period specified in Article 3, paragraph 7.

4. If Parties acting jointly do so in the framework of, and together with, a regional economic integration organization, any alteration in the composition of the organization after adoption of this Protocol shall not affect existing commitments under this Protocol. Any alteration in the composition of the organization shall only apply for the purposes of those commitments under Article 3 that are adopted subsequent to that alteration.

5. In the event of failure by the Parties to such an agreement to achieve their total combined level of emission reductions, each Party to that agreement

shall be responsible for its own level of emissions set out in the agreement.

6. If Parties acting jointly do so in the framework of, and together with, a regional economic integration organization which is itself a Party to this Protocol, each member State of that regional economic integration organization individually, and together with the regional economic integration organization acting in accordance with Article 24, shall, in the event of failure to achieve the total combined level of emission reductions, be responsible for its level of emissions as notified in accordance with this Article.

Article 5

1. Each Party included in Annex I shall have in place, no later than one year prior to the start of the first commitment period, a national system for the estimation of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol. Guidelines for such national systems, which shall incorporate the methodologies specified in paragraph 2 below, shall be decided upon by the Conference of the Parties serving as the meeting of the Parties to this Protocol at its first session.

2. Methodologies for estimating anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol shall be those accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties at its third session. Where such methodologies are not used, appropriate adjustments shall be applied according to methodologies agreed upon by the Conference of the Parties serving as the meeting of the Parties to this Protocol at its first session. Based on the work of, inter alia, the Intergovernmental Panel on Climate Change and advice provided by the Subsidiary Body for Scientific and Technological Advice, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall regularly review and, as appropriate, revise such methodologies and adjustments, taking fully into account any relevant decisions by the Conference of the Parties. Any revision to methodologies or adjustments shall be used only for the purposes of ascertaining compliance with commitments under Article 3 in respect of any commitment period adopted subsequent to that revision.

3. The global warming potentials used to calculate the carbon dioxide equivalence of anthropogenic emissions by sources and removals by sinks of greenhouse gases listed in Annex A shall be those accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties at its third session. Based on the work of, inter alia, the Intergovernmental Panel on Climate Change and advice provided by the Subsidiary Body for Scientific and Technological Advice, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall regularly review and, as appropriate, revise the global warming potential of each such greenhouse gas, taking fully into account any relevant decisions by the Conference of the Parties. Any revision to a global warming potential shall apply only to commitments under Article 3 in respect of any commitment period adopted subsequent to that revision.

Article 6

1. For the purpose of meeting its commitments under Article 3, any Party included in Annex I may transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks of greenhouse gases in any sector of the economy, provided that:

(a) Any such project has the approval of the Parties involved;
(b) Any such project provides a reduction in emissions by sources, or an enhancement of removals by sinks, that is additional to any that would otherwise occur;
(c) It does not acquire any emission reduction units if it is not in compliance with its obligations under Articles 5 and 7; and
(d) The acquisition of emission reduction units shall be supplemental to domestic actions for the purposes of meeting commitments under Article 3. 2. The Conference of the Parties serving as the meeting of the Parties to this Protocol may, at its first session or as soon as practicable thereafter, further elaborate guidelines for the implementation of this Article, including for verification and reporting.

3. A Party included in Annex I may authorize legal entities to participate, under its responsibility, in actions leading to the generation, transfer or acquisition under this Article of emission reduction units.

4. If a question of implementation by a Party included in Annex I of the requirements referred to in this Article is identified in accordance with the relevant provisions of Article 8, transfers and acquisitions of emission reduction units may continue to be made after the question has been identified, provided that any such units may not be used by a Party to meet its commitments under Article 3 until any issue of compliance is resolved.

Article 7

1. Each Party included in Annex I shall incorporate in its annual inventory of anthropogenic emis-

sions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol, submitted in accordance with the relevant decisions of the Conference of the Parties, the necessary supplementary information for the purposes of ensuring compliance with Article 3, to be determined in accordance with paragraph 4 below.

2. Each Party included in Annex I shall incorporate in its national communication, submitted under Article 12 of the Convention, the supplementary information necessary to demonstrate compliance with its commitments under this Protocol, to be determined in accordance with paragraph 4 below.

3. Each Party included in Annex I shall submit the information required under paragraph 1 above annually, beginning with the first inventory due under the Convention for the first year of the commitment period after this Protocol has entered into force for that Party. Each such Party shall submit the information required under paragraph 2 above as part of the first national communication due under the Convention after this Protocol has entered into force for it and after the adoption of guidelines as provided for in paragraph 4 below. The frequency of subsequent submission of information required under this Article shall be determined by the Conference of the Parties serving as the meeting of the Parties to this Protocol, taking into account any timetable for the submission of national communications decided upon by the Conference of the Parties.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall adopt at its first session, and review periodically thereafter, guidelines for the preparation of the information required under this Article, taking into account guidelines for the preparation of national communications by Parties included in Annex I adopted by the Conference of the Parties. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall also, prior to the first commitment period, decide upon modalities for the accounting of assigned amounts.

Article 8

1. The information submitted under Article 7 by each Party included in Annex I shall be reviewed by expert review teams pursuant to the relevant decisions of the Conference of the Parties and in accordance with guidelines adopted for this purpose by the Conference of the Parties serving as the meeting of the Parties to this Protocol under paragraph 4 below. The information submitted under Article 7, paragraph 1, by each Party included in Annex I shall be reviewed as part of the annual compilation and accounting of emissions inventories and assigned amounts. Additionally, the information submitted under Article 7, paragraph 2, by each Party included in Annex I shall be reviewed as part of the review of communications.

2. Expert review teams shall be coordinated by the secretariat and shall be composed of experts selected from those nominated by Parties to the Convention and, as appropriate, by intergovernmental organizations, in accordance with guidance provided for this purpose by the Conference of the Parties.

3. The review process shall provide a thorough and comprehensive technical assessment of all aspects of the implementation by a Party of this Protocol. The expert review teams shall prepare a report to the Conference of the Parties serving as the meeting of the Parties to this Protocol, assessing the implementation of the commitments of the Party and identifying any potential problems in, and factors influencing, the fulfilment of commitments. Such reports shall be circulated by the secretariat to all Parties to the Convention. The secretariat shall list those questions of implementation indicated in such reports for further consideration by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall adopt at its first session, and review periodically thereafter, guidelines for the review of implementation of this Protocol by expert review teams taking into account the relevant decisions of the Conference of the Parties.

5. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, with the assistance of the Subsidiary Body for Implementation and, as appropriate, the Subsidiary Body for Scientific and Technological Advice, consider:

(a) The information submitted by Parties under Article 7 and the reports of the expert reviews thereon conducted under this Article; and

(b) Those questions of implementation listed by the secretariat under paragraph 3 above, as well as any questions raised by Parties.

6. Pursuant to its consideration of the information referred to in paragraph 5 above, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall take decisions on any matter required for the implementation of this Protocol.

Article 9

1. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall periodically review this Protocol in the light of the best available scientific information and assessments on climate change and its impacts, as well as relevant technical, social and economic information. Such reviews shall be coordinated with pertinent reviews under the Convention, in particular those required by Arti-

cle 4, paragraph 2(d), and Article 7, paragraph 2(a), of the Convention. Based on these reviews, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall take appropriate action.

2. The first review shall take place at the second session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. Further reviews shall take place at regular intervals and in a timely manner.

Article 10

All Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, without introducing any new commitments for Parties not included in Annex I, but reaffirming existing commitments under Article 4, paragraph 1, of the Convention, and continuing to advance the implementation of these commitments in order to achieve sustainable development, taking into account Article 4, paragraphs 3, 5 and 7, of the Convention, shall:

(a) Formulate, where relevant and to the extent possible, cost-effective national and, where appropriate, regional programmes to improve the quality of local emission factors, activity data and/or models which reflect the socio-economic conditions of each Party for the preparation and periodic updating of national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties, and consistent with the guidelines for the preparation of national communications adopted by the Conference of the Parties;

(b) Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change and measures to facilitate adequate adaptation to climate change:
(i) Such programmes would, *inter alia*, concern the energy, transport and industry sectors as well as agriculture, forestry and waste management. Furthermore, adaptation technologies and methods for improving spatial planning would improve adaptation to climate change; and
(ii) Parties included in Annex I shall submit information on action under this Protocol, including national programmes, in accordance with Article 7; and other Parties shall seek to include in their national communications, as appropriate, information on programmes which contain measures that the Party believes contribute to addressing climate change and its adverse impacts, including the abatement of increases in greenhouse gas emissions, and enhancement of and removals by sinks, capacity building and adaptation measures;

(c) Cooperate in the promotion of effective modalities for the development, application and diffusion of, and take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies, know-how, practices and processes pertinent to climate change, in particular to developing countries, including the formulation of policies and programmes for the effective transfer of environmentally sound technologies that are publicly owned or in the public domain and the creation of an enabling environment for the private sector, to promote and enhance the transfer of, and access to, environmentally sound technologies;

(d) Cooperate in scientific and technical research and promote the maintenance and the development of systematic observation systems and development of data archives to reduce uncertainties related to the climate system, the adverse impacts of climate change and the economic and social consequences of various response strategies, and promote the development and strengthening of endogenous capacities and capabilities to participate in international and intergovernmental efforts, programmes and networks on research and systematic observation, taking into account Article 5 of the Convention;

(e) Cooperate in and promote at the international level, and, where appropriate, using existing bodies, the development and implementation of education and training programmes, including the strengthening of national capacity building, in particular human and institutional capacities and the exchange or secondment of personnel to train experts in this field, in particular for developing countries, and facilitate at the national level public awareness of, and public access to information on, climate change. Suitable modalities should be developed to implement these activities through the relevant bodies of the Convention, taking into account Article 6 of the Convention;

(f) Include in their national communications information on programmes and activities undertaken pursuant to this Article in accordance with relevant decisions of the Conference of the Parties; and

(g) Give full consideration, in implementing the commitments under this Article, to Article 4, paragraph 8, of the Convention.

ARTICLE 11

1. In the implementation of Article 10, Parties shall take into account the provisions of Article 4, paragraphs 4, 5, 7, 8 and 9, of the Convention.

2. In the context of the implementation of Article 4, paragraph 1, of the Convention, in accordance with the provisions of Article 4, paragraph 3, and Article 11 of the Convention, and through the entity or entities entrusted with the operation of the financial mechanism of the Convention, the developed country Parties and other developed Parties included in Annex II to the Convention shall:

(a) Provide new and additional financial resources to meet the agreed full costs incurred by developing country Parties in advancing the implementation of existing commitments under Article 4, paragraph 1(a), of the Convention that are covered in Article 10, subparagraph (a); and

(b) Also provide such financial resources, including for the transfer of technology, needed by the developing country Parties to meet the agreed full incremental costs of advancing the implementation of existing commitments under Article 4, paragraph 1, of the Convention that are covered by Article 10 and that are agreed between a developing country Party and the international entity or entities referred to in Article 11 of the Convention, in accordance with that Article. The implementation of these existing commitments shall take into account the need for adequacy and predictability in the flow of funds and the importance of appropriate burden sharing among developed country Parties. The guidance to the entity or entities entrusted with the operation of the financial mechanism of the Convention in relevant decisions of the Conference of the Parties, including those agreed before the adoption of this Protocol, shall apply *mutatis mutandis* to the provisions of this paragraph.

3. The developed country Parties and other developed Parties in Annex II to the Convention may also provide, and developing country Parties avail themselves of, financial resources for the implementation of Article 10, through bilateral, regional and other multilateral channels.

ARTICLE 12

1. A clean development mechanism is hereby defined.

2. The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3.

3. Under the clean development mechanism:

(a) Parties not included in Annex I will benefit from project activities resulting in certified emission reductions; and

(b) Parties included in Annex I may use the certified emission reductions accruing from such project activities to contribute to compliance with part of their quantified emission limitation and reduction commitments under Article 3, as determined by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

4. The clean development mechanism shall be subject to the authority and guidance of the Conference of the Parties serving as the meeting of the Parties to this Protocol and be supervised by an executive board of the clean development mechanism.

5. Emission reductions resulting from each project activity shall be certified by operational entities to be designated by the Conference of the Parties serving as the meeting of the Parties to this Protocol, on the basis of:

(a) Voluntary participation approved by each Party involved;

(b) Real, measurable, and long-term benefits related to the mitigation of climate change; and

(c) Reductions in emissions that are additional to any that would occur in the absence of the certified project activity.

6. The clean development mechanism shall assist in arranging funding of certified project activities as necessary.

7. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, elaborate modalities and procedures with the objective of ensuring transparency, efficiency and accountability through independent auditing and verification of project activities.

8. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall ensure that a share of the proceeds from certified project activities is used to cover administrative expenses as well as to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.

9. Participation under the clean development mechanism, including in activities mentioned in paragraph 3(a) above and in the acquisition of certified emission reductions, may involve private and/or pub-

lic entities, and is to be subject to whatever guidance may be provided by the executive board of the clean development mechanism.

10. Certified emission reductions obtained during the period from the year 2000 up to the beginning of the first commitment period can be used to assist in achieving compliance in the first commitment period.

Article 13

1. The Conference of the Parties, the supreme body of the Convention, shall serve as the meeting of the Parties to this Protocol.

2. Parties to the Convention that are not Parties to this Protocol may participate as observers in the proceedings of any session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. When the Conference of the Parties serves as the meeting of the Parties to this Protocol, decisions under this Protocol shall be taken only by those that are Parties to this Protocol.

3. When the Conference of the Parties serves as the meeting of the Parties to this Protocol, any member of the Bureau of the Conference of the Parties representing a Party to the Convention but, at that time, not a Party to this Protocol, shall be replaced by an additional member to be elected by and from amongst the Parties to this Protocol.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall keep under regular review the implementation of this Protocol and shall make, within its mandate, the decisions necessary to promote its effective implementation. It shall perform the functions assigned to it by this Protocol and shall:

(a) Assess, on the basis of all information made available to it in accordance with the provisions of this Protocol, the implementation of this Protocol by the Parties, the overall effects of the measures taken pursuant to this Protocol, in particular environmental, economic and social effects as well as their cumulative impacts and the extent to which progress towards the objective of the Convention is being achieved;

(b) Periodically examine the obligations of the Parties under this Protocol, giving due consideration to any reviews required by Article 4, paragraph 2(d), and Article 7, paragraph 2, of the Convention, in the light of the objective of the Convention, the experience gained in its implementation and the evolution of scientific and technological knowledge, and in this respect consider and adopt regular reports on the implementation of this Protocol;

(c) Promote and facilitate the exchange of information on measures adopted by the Parties to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under this Protocol;

(d) Facilitate, at the request of two or more Parties, the coordination of measures adopted by them to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under this Protocol;

(e) Promote and guide, in accordance with the objective of the Convention and the provisions of this Protocol, and taking fully into account the relevant decisions by the Conference of the Parties, the development and periodic refinement of comparable methodologies for the effective implementation of this Protocol, to be agreed on by the Conference of the Parties serving as the meeting of the Parties to this Protocol;

(f) Make recommendations on any matters necessary for the implementation of this Protocol;

(g) Seek to mobilize additional financial resources in accordance with Article 11, paragraph 2;

(h) Establish such subsidiary bodies as are deemed necessary for the implementation of this Protocol;

(i) Seek and utilize, where appropriate, the services and cooperation of, and information provided by, competent international organizations and intergovernmental and non-governmental bodies; and

(j) Exercise such other functions as may be required for the implementation of this Protocol, and consider any assignment resulting from a decision by the Conference of the Parties.

5. The rules of procedure of the Conference of the Parties and financial procedures applied under the Convention shall be applied *mutatis mutandis* under this Protocol, except as may be otherwise decided by consensus by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

6. The first session of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be convened by the secretariat in conjunction with the first session of the Conference of the Parties that is scheduled after the date of the entry into force of this Protocol. Subsequent ordinary sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be held every year and in conjunction with ordinary sessions of the Con-

ference of the Parties, unless otherwise decided by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

7. Extraordinary sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be held at such other times as may be deemed necessary by the Conference of the Parties serving as the meeting of the Parties to this Protocol, or at the written request of any Party, provided that, within six months of the request being communicated to the Parties by the secretariat, it is supported by at least one third of the Parties.

8. The United Nations, its specialized agencies and the International Atomic Energy Agency, as well as any State member thereof or observers thereto not party to the Convention, may be represented at sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol as observers. Any body or agency, whether national or international, governmental or non-governmental, which is qualified in matters covered by this Protocol and which has informed the secretariat of its wish to be represented at a session of the Conference of the Parties serving as the meeting of the Parties to this Protocol as an observer, may be so admitted unless at least one third of the Parties present object. The admission and participation of observers shall be subject to the rules of procedure, as referred to in paragraph 5 above.

Article 14

1. The secretariat established by Article 8 of the Convention shall serve as the secretariat of this Protocol.

2. Article 8, paragraph 2, of the Convention on the functions of the secretariat, and Article 8, paragraph 3, of the Convention on arrangements made for the functioning of the secretariat, shall apply mutatis mutandis to this Protocol. The secretariat shall, in addition, exercise the functions assigned to it under this Protocol.

Article 15

1. The Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation established by Articles 9 and 10 of the Convention shall serve as, respectively, the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of this Protocol. The provisions relating to the functioning of these two bodies under the Convention shall apply *mutatis mutandis* to this Protocol. Sessions of the meetings of the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of this Protocol shall be held in conjunction with the meetings of, respectively, the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of the Convention.

2. Parties to the Convention that are not Parties to this Protocol may participate as observers in the proceedings of any session of the subsidiary bodies. When the subsidiary bodies serve as the subsidiary bodies of this Protocol, decisions under this Protocol shall be taken only by those that are Parties to this Protocol.

3. When the subsidiary bodies established by Articles 9 and 10 of the Convention exercise their functions with regard to matters concerning this Protocol, any member of the Bureaux of those subsidiary bodies representing a Party to the Convention but, at that time, not a party to this Protocol, shall be replaced by an additional member to be elected by and from amongst the Parties to this Protocol.

Article 16

The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, as soon as practicable, consider the application to this Protocol of, and modify as appropriate, the multilateral consultative process referred to in Article 13 of the Convention, in the light of any relevant decisions that may be taken by the Conference of the Parties. Any multilateral consultative process that may be applied to this Protocol shall operate without prejudice to the procedures and mechanisms established in accordance with Article 18.

Article 17

The Conference of the Parties shall define the relevant principles, modalities, rules and guidelines, in particular for verification, reporting and accountability for emissions trading. The Parties included in Annex B may participate in emissions trading for the purposes of fulfilling their commitments under Article 3. Any such trading shall be supplemental to domestic actions for the purpose of meeting quantified emission limitation and reduction commitments under that Article.

Article 18

The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, approve appropriate and effective procedures and mechanisms to determine and to address cases of non-compliance with the provisions of this Protocol, including through the development of an indicative list of consequences, taking into account the cause, type, degree and frequency of non-compliance. Any procedures and mechanisms under this Article entailing binding consequences shall be adopted by means of an amendment to this Protocol.

Article 19

The provisions of Article 14 of the Convention on settlement of disputes shall apply *mutatis mutandis* to this Protocol.

Article 20

1. Any Party may propose amendments to this Protocol.

2. Amendments to this Protocol shall be adopted at an ordinary session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. The text of any proposed amendment to this Protocol shall be communicated to the Parties by the secretariat at least six months before the meeting at which it is proposed for adoption. The secretariat shall also communicate the text of any proposed amendments to the Parties and signatories to the Convention and, for information, to the Depositary.

3. The Parties shall make every effort to reach agreement on any proposed amendment to this Protocol by consensus. If all efforts at consensus have been exhausted, and no agreement reached, the amendment shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting at the meeting. The adopted amendment shall be communicated by the secretariat to the Depositary, who shall circulate it to all Parties for their acceptance.

4. Instruments of acceptance in respect of an amendment shall be deposited with the Depositary. An amendment adopted in accordance with paragraph 3 above shall enter into force for those Parties having accepted it on the ninetieth day after the date of receipt by the Depositary of an instrument of acceptance by at least three fourths of the Parties to this Protocol.

5. The amendment shall enter into force for any other Party on the ninetieth day after the date on which that Party deposits with the Depositary its instrument of acceptance of the said amendment.

Article 21

1. Annexes to this Protocol shall form an integral part thereof and, unless otherwise expressly provided, a reference to this Protocol constitutes at the same time a reference to any annexes thereto. Any annexes adopted after the entry into force of this Protocol shall be restricted to lists, forms and any other material of a descriptive nature that is of a scientific, technical, procedural or administrative character.

2. Any Party may make proposals for an annex to this Protocol and may propose amendments to annexes to this Protocol.

3. Annexes to this Protocol and amendments to annexes to this Protocol shall be adopted at an ordinary session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. The text of any proposed annex or amendment to an annex shall be communicated to the Parties by the secretariat at least six months before the meeting at which it is proposed for adoption. The secretariat shall also communicate the text of any proposed annex or amendment to an annex to the Parties and signatories to the Convention and, for information, to the Depositary.

4. The Parties shall make every effort to reach agreement on any proposed annex or amendment to an annex by consensus. If all efforts at consensus have been exhausted, and no agreement reached, the annex or amendment to an annex shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting at the meeting. The adopted annex or amendment to an annex shall be communicated by the secretariat to the Depositary, who shall circulate it to all Parties for their acceptance.

5. An annex, or amendment to an annex other than Annex A or B, that has been adopted in accordance with paragraphs 3 and 4 above shall enter into force for all Parties to this Protocol six months after the date of the communication by the Depositary to such Parties of the adoption of the annex or adoption of the amendment to the annex, except for those Parties that have notified the Depositary, in writing, within that period of their non-acceptance of the annex or amendment to the annex. The annex or amendment to an annex shall enter into force for Parties which withdraw their notification of non-acceptance on the ninetieth day after the date on which withdrawal of such notification has been received by the Depositary.

6. If the adoption of an annex or an amendment to an annex involves an amendment to this Protocol, that annex or amendment to an annex shall not enter into force until such time as the amendment to this Protocol enters into force.

7. Amendments to Annexes A and B to this Protocol shall be adopted and enter into force in accordance with the procedure set out in Article 20, provided that any amendment to Annex B shall be adopted only with the written consent of the Party concerned.

Article 22

1. Each Party shall have one vote, except as provided for in paragraph 2 below.

2. Regional economic integration organizations, in matters within their competence, shall exercise their right to vote with a number of votes equal to the number of their member States that are Parties to this Protocol. Such an organization shall not exercise

its right to vote if any of its member States exercises its right, and vice versa.

Article 23

The Secretary-General of the United Nations shall be the Depositary of this Protocol.

Article 24

1. This Protocol shall be open for signature and subject to ratification, acceptance or approval by States and regional economic integration organizations which are Parties to the Convention. It shall be open for signature at United Nations Headquarters in New York from 16 March 1998 to 15 March 1999. This Protocol shall be open for accession from the day after the date on which it is closed for signature. Instruments of ratification, acceptance, approval or accession shall be deposited with the Depositary.

2. Any regional economic integration organization which becomes a Party to this Protocol without any of its member States being a Party shall be bound by all the obligations under this Protocol. In the case of such organizations, one or more of whose member States is a Party to this Protocol, the organization and its member States shall decide on their respective responsibilities for the performance of their obligations under this Protocol. In such cases, the organization and the member States shall not be entitled to exercise rights under this Protocol concurrently.

3. In their instruments of ratification, acceptance, approval or accession, regional economic integration organizations shall declare the extent of their competence with respect to the matters governed by this Protocol. These organizations shall also inform the Depositary, who shall in turn inform the Parties, of any substantial modification in the extent of their competence.

Article 25

1. This Protocol shall enter into force on the ninetieth day after the date on which not less than 55 Parties to the Convention, incorporating Parties included in Annex I which accounted in total for at least 55 per cent of the total carbon dioxide emissions for 1990 of the Parties included in Annex I, have deposited their instruments of ratification, acceptance, approval or accession.

2. For the purposes of this Article, "the total carbon dioxide emissions for 1990 of the Parties included in Annex I" means the amount communicated on or before the date of adoption of this Protocol by the Parties included in Annex I in their first national communications submitted in accordance with Article 12 of the Convention.

3. For each State or regional economic integration organization that ratifies, accepts or approves this Protocol or accedes thereto after the conditions set out in paragraph 1 above for entry into force have been fulfilled, this Protocol shall enter into force on the ninetieth day following the date of deposit of its instrument of ratification, acceptance, approval or accession.

4. For the purposes of this Article, any instrument deposited by a regional economic integration organization shall not be counted as additional to those deposited by States members of the organization.

Article 26

No reservations may be made to this Protocol.

Article 27

1. At any time after three years from the date on which this Protocol has entered into force for a Party, that Party may withdraw from this Protocol by giving written notification to the Depositary.

2. Any such withdrawal shall take effect upon expiry of one year from the date of receipt by the Depositary of the notification of withdrawal, or on such later date as may be specified in the notification of withdrawal.

3. Any Party that withdraws from the Convention shall be considered as also having withdrawn from this Protocol.

Article 28

The original of this Protocol, of which the Arabic, Chinese, English, French, Russian and Spanish texts are equally authentic, shall be deposited with the Secretary-General of the United Nations.

Done at Kyoto this eleventh day of December one thousand nine hundred and ninety-seven.

In Witness Whereof the undersigned, being duly authorized to that effect, have affixed their signatures to this Protocol on the dates indicated.

Annex A

Greenhouse gases
Carbon dioxide (CO_2)
Methane (CH_4)
Nitrous oxide (N_2O)
Hydrofluorocarbons (HFCs)
Perfluorocarbons (PFCs)
Sulphur hexafluoride (SF_6)

Sectors/source categories

Energy
- Fuel combustion
  - Energy industries
  - Manufacturing industries and construction
  - Transport Other sectors
  - Other
- Fugitive emissions from fuels
  - Solid fuels
  - Oil and natural gas
  - Other

Industrial processes
- Mineral products
- Chemical industry
- Metal production
- Other production
- Production of halocarbons and sulphur hexafluoride
- Consumption of halocarbons and sulphur hexafluoride
- Other

Solvent and other product use

Agriculture
- Enteric fermentation
- Manure management
- Rice cultivation
- Agricultural soils
- Prescribed burning of savannas
- Field burning of agricultural residues
- Other

Waste
- Solid waste disposal on land
- Wastewater handling
- Waste incineration
- Other

Annex B

Party	Quantified emission limitation or reduction commitment (percentage of base year or period)
Australia	108
Austria	92
Belgium	92
Bulgaria*	92
Canada	94
Croatia*	95
Czech Republic*	92
Denmark	92
Estonia*	92
European Union	92
Finland	92
France	92
Germany	92
Greece	92
Hungary*	94
Iceland	110
Ireland	92
Italy	92
Japan	94
Latvia*	92
Liechtenstein	92
Lithuania*	92
Luxembourg	92
Monaco	92
Netherlands	92
New Zealand	100
Norway	101
Poland*	94
Portugal	92
Romania*	92
Russian Federation*	100
Slovakia*	92
Slovenia*	92
Spain	92
Sweden	92
Switzerland	92
Ukraine*	100
United Kingdom of Great Britain and Northern Ireland	92
United States of America	93

*Countries that are undergoing the process of transition to a market economy.

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