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A Review of Country Case Studies on Climate Change

Jan Fuglestvedt
Ted Hanisch
Ivar Isaksen
Rolf Selrod
Jon Strand
Asbjørn Torvanger

Working Paper
Number 7

UNEP

THE WORLD BANK

GEF Documentation

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This paper is the fourth among a series of GEF Working Papers to deal with the Program for Measuring Incremental Costs for the Environment (PRINCE). The GEF is a financial mechanism that provides grants to developing countries for projects aimed at protecting the global environment.

PRINCE was initiated in February 1993 at a workshop held at the Tata Energy Research Institute in New Delhi. It covers methodological issues, field tests, and dissemination related to the technical issues of measuring incremental cost. This is a concept central to the GEF; the two conventions to which it is linked—the Framework Convention on Climate Change (FCCC) and the Convention on Biological Diversity; and the Montreal Protocol dealing with ozone depletion.

Participating governments provided US $2.6 million from the Core Fund for a three-year program. It builds on existing work concerning the phase-out of ozone-depleting substances and concentrates on the incremental costs of reducing the emissions of greenhouse gases. Parallel work will extend the concept of incremental costs to the protection of international waters and the conservation of biodiversity.

The GEF commissioned the Center for International Climate and Energy Research, Oslo (CICERO) to study ways of improving current approaches to country studies on climate change, drawing on the experience to date. This paper provides an overview of the status of country studies on climate change. It examines several methodological and reporting issues, stressing the importance of comparability. Comparisons of ecological and economic efficiency are essential in determining the eligibility of projects for GEF funding. The paper also looks at the extent to which the studies are meeting or plan to meet the obligations of the Parties under the FCCC. Areas covered include inventories of sources and sinks of greenhouse gases, impacts and vulnerability assessments, response strategies and their cost-effectiveness, the implications of country projects that have transnational benefits, and the usefulness of country studies for government policy-makers.

Ted Hanisch is Director of CICERO, Jan Fuglestvedt is a Research Fellow, and Ivar Isaksen is Research Director, as well as Professor of Geophysics at the University of Oslo. Rolf Selrod is Senior Environmental Adviser at CICERO. Jon Strand is Professor of Economics at the University of Oslo. Asbjørn Torvanger is Senior Research Officer, and Gørill Kristiansen, who compiled Appendix IV, is Research Fellow at CICERO.

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The other Working Papers currently in the PRINCE series are numbers 4, 5, 6 and 8.

Contents

Abbreviations

ADB	Asian Development Bank
BAHC	Biospheric Aspects of the Hydrologic Cycle
CFC	Chlorofluorocarbon
CF_4	Carbon tetra flouride
CH_4	Methane
CICERO	Center for International Climate and Energy Research, Oslo
CLIMEX	Climate Change Experiment
FCCC	Framework Convention on Climate Change
GAIM	Global Analysis, Interpretation and Modelling
GCM	General Circulation Model
GCTE	Global Change and Terrestrial Ecosystems
GEMS	Global Environment Monitoring System
GHG	Greenhouse gas
GLOBEC	Global Ocean Ecosystem Dynamics
GOEZS	Global Ocean Euphotic Zone Study
GWP	Global warming potential
HCFC	Hydro-chlorofluorocarbon
HFC	Hydrofluorocarbon
ICSU	International Council of Scientific Unions
IEA	International Energy Agency
IGAC	International Global Atmospheric Chemistry
IGBP	International Geosphere-Biosphere Programme
IPCC	Intergovernmental Panel on Climate Change
ISBI	International Sustainable Biosphere Initiative
IUBS	International Union of Biological Sciences
IUCN	International Union for the Conservation of Nature and Natural Resources (now World Conservation Union)
JGOFS	Joint Global Ocean Flux Studies
LOICZ	Land Ocean Interactions in the Coastal Zone
MAB	Man and the Biosphere
NO_2	Nitrogen dioxide
NO_x	Nitrous oxide
O_3	Ozone
OECD	Organization for Economic Cooperation and Development
PRINCE	Program for Measuring Incremental Costs for the Environment
SCAR	Scientific Committee on Antarctic Research
SCOPE	Scientific Committee on Problems of the Environment
SO_2	Sulfur dioxide
SPREP	Swiss-Proclim Ecosphere Greenhouse Gases Reduction Program
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organization
WCRP	World Climate Research Programme
WMO	World Meteorological Organization

Introduction

Country case studies are important instruments for determining national climate policies and for adding to the global knowledge on climate issues. They are also the basis for examining the obligations of the Parties to the United Nations Framework Convention on Climate Change (FCCC), and for developing and assessing projects eligible for financing by the Global Environment Facility (GEF). These country studies must be comparable to allow the GEF to choose effectively between potential investments in the nations being assessed. Comparisons of ecological and economic efficiency are especially important.

In this paper, the term country studies refers to official national studies on climate change covering parts or all of the following areas: inventories of sources and sinks of greenhouse gases (GHGs), impacts and vulnerability assessments, and response strategies and options. Such studies focus on adaptation and on GHG abatement.

As many of the studies are not yet complete, the focus of this review is on workplans, terms of reference, and underlying assumptions and parameters used in their development. Time constraints have prevented the inclusion of interviews with the institutions involved in the preparation of such studies.

The terms of reference of the review state that the following elements should be considered, with an emphasis in each instance on costing exercises:

- An assessment of the current and projected level of activity in the field of country studies on climate change, including an inventory of studies underway or planned
- A review of the terms of reference for such studies including a review and assessment of: their objectives; methodological approaches; parameters and assumptions used, including treatment of discount rate, costing assumptions, abatement targets, and so on; the range of policy and investment or expenditure options to be reviewed and assessed; and the extent to which local staff were involved in the design and implementation of these studies
- A review of the costs and staffing patterns of such studies, including the expertise required to undertake specific studies
- An assessment of the usefulness of those studies completed or underway, with a focus on providing a clear strategy for future activities, including provisions and expectations laid down in the FCCC.

The availability of completed studies and terms of reference for such studies was meager. This review and assessment is, therefore, built on a few studies and terms of reference, as listed in the references. While an in-depth study of all the issues mentioned was not possible, we hope that this exercise will further the discussions and the development of more comparable methodologies for future studies.

1 Country Studies

The FCCC commits all Parties, from the time of entry into force of the Convention, to develop and periodically update national inventories of sources and sinks of GHGs using comparable methodologies. It also commits the Parties to formulate and implement programs for mitigation and adaptation. All Parties are obliged to take climatic change considerations into account in their social, economic, and environmental policies and actions. National inventories are to be published and communicated to the Conference of the Parties of the FCCC.

Legal and financial commitments

Parties from developed countries must meet commitments such as the adoption of national policies and corresponding measures to demonstrate that they are taking the lead in work on climate change. They are also obliged to communicate this information within six months of the entry into force of the Convention, while developing country Parties are obliged to respond within three years, and least developed country Parties at their own discretion.

The ability of participating developing countries to present information on inventories of sources and sinks of GHGs and on programs for mitigation and adaptation prior to the first Conference of the Parties, expected by late 1994, will depend largely on the availability of bilateral and multilateral funding as laid down in the Convention. Input from these countries also depends on the availability of basic national data and on human, technological, and institutional resources.

Data and methodology

Much of the relevant data needed to make a useful country study are difficult to obtain in some countries. A comprehensive and authoritative methodology for full-fledged country studies has not yet been developed.

Much work has, however, been done regarding the methodological elements of such studies. The Intergovernmental Panel on Climate Change's (IPCC) Working Group I has, together with the Organization for Economic Cooperation and Development (OECD), provided a draft methodology for developing national inventories of emissions and sinks. A revised version will be presented by mid-1993. Working Group II has prepared a report on "Preliminary Guidelines for Assessing Impacts of Climate Change." A subgroup of the earlier Working Group III has developed "A Common Methodology for Assessing Vulnerability to Sea-Level Rise." The United Nations Environment Programme (UNEP) has, through Risø National Laboratory, initiated a project to work on a methodological framework for undertaking cost assessments of GHG abatement. The GEF has commissioned a study on economic costs of carbon dioxide (CO_2) reduction measures. Draft guidelines for a comprehensive set of country studies have also been submitted by Finland and the United States.

Ongoing and planned activities

The main thrust of information on planned and existing country studies stems from the work of

UNEP and its second country study report of November 5, 1992. The recent eighth session of the IPCC in Harare hailed UNEP for its work in this sector, and appealed to all countries to assist UNEP in its biannual updating of this activity report. A country study summary from this report is enclosed as Appendix II for easy reference.

As of October 1992, sixty-five countries had undertaken, or planned to undertake, some form of country study. Several other countries have indicated their interest in such studies, but have lacked the financial and technical resources to participate. Those country studies already underway are fairly evenly split among emission inventories, impact assessments, and mitigation analyses (see table 1).

In the multilateral arena, the involvement of the key players is as follows:

- The United Nations Development Programme (UNDP) has a country study program involving fourteen developing Asian countries. The program will deal with inventories of emissions and sinks; identify measures to reduce emissions or enhance sinks, and estimate the costs and effectiveness of these measures; develop scenarios of emissions from different sources; and prepare policy responses.
- UNEP is involved in projects on emission inventories, impact assessments, response options, and economic assessments of limiting GHGs. A country study program is underway on GHG sources and sinks in eleven countries. UNEP has supported three studies on the potential socio-economic effects of climate change in five developing countries. UNEP has also helped develop a methodology for assessing vulnerability to sea-level rise and initiated a program on techniques for GHG-abatement costing studies.
- The Asian Development Bank (ADB) has a country study program for eight developing Asian countries. The program will establish a common framework for country studies, assess the socio-economic impacts of climate change, identify policy options for limiting net emissions, analyze adaptation to climate change, and develop national and regional strategies. The ADB also provides assistance to China and Thailand.

Table 1. Reported activity on country studies or elements of such studies

Region	*Studies on inventories*	*Studies on effects*	*Studies on mitigation*
OECD region[1]	15	16	19
Countries with economies in transition[2]	4	2	3
Asia and the Pacific[3]	6	15	17
Latin America[4]	4	6	3
Africa[5]	10	9	6

Source: UNEP's second Country Study Report, November 1992.

Notes: 1. Information from 19 out of 24 countries
2. Information from 7 out of 14 countries
3. Information from 22 out of 47 countries
4. Information from 18 out of 32 countries
5. Information from 26 out of 50 countries

The United States has supported studies on patterns of GHG emissions and mitigation options in Argentina, Brazil, China, India, Indonesia, Mexico Nigeria, the Republic of Korea, Sierra Leone, Venezuela, and countries of the Gulf Council.

Major international programs that include studies related to the potential biological effects of climate change are presented in Appendix IV. The country study workshop held by the IPCC in 1992 in Berkeley, California, identified considerable information on technological options (IPCC 1992c).

2 Inventories of Sources and Sinks of Greenhouse Gases

Inventories of sources and sinks of GHGs[1] are a prerequisite for identifying the extent to which energy, industry, and other sectors are contributing to climate change, as well as for implementing cost-effective measures to limit and mitigate such change. They also form starting points for projections of emissions and provide the basis for further negotiations on GHG reduction. If comprehensive national inventories are made worldwide, they will help to explain changes in the atmosphere caused by human activity and provide the proving ground for new methods of making inventories of sources and sinks. Such inventories may also form the basis of a more permanent network for the exchange of data and information. The emphasis given to these objectives of inventories may differ among countries. To ensure that the inventories are relevant to global warming, it is crucial to have a good understanding of the effects of individual gases on the radiative forcing of the climate.

Gases affecting the climate

The source gases that affect the climate can be divided into two groups. First are the GHGs that have a direct effect on climate. Such gases are CO_2, methane (CH_4), nitrogen dioxide (NO_2), and the chlorofluorocarbons (CFCs), hydro-CFCs (HCFCs), hydrofluorocarbons (HFCs), and other chlorine compounds. Their relative impact on the climate is rather well established through the calculated global warming potentials (GWPs) that were performed as part of the IPCC assessment.

The first three compounds noted above—CO_2, CH_4, and NO_2—have important natural as well as anthropogenic sources. To understand the significance of anthropogenic emissions it is important to understand the natural cycles of these gases. Very little is presently known, and major efforts are needed to estimate the country-specific contributions to the natural cycles. The significance of the different biogenic sources may vary, and regional and country differences should be recognized. It is also important to clarify the extent to which human activity has modified the strength of the natural sources and sinks.

Most of the chlorine compounds that have a greenhouse effect are of anthropogenic origin, and their sources are well established. Furthermore, the CFCs, HCFCs, and the chlorine compounds methyl bromide and carbon tetra chloride are regulated under the Montreal Protocol due to their impact on the ozone layer, and are also considered here. The HFCs (particularly HFC-134a) have no ozone effect and therefore are not regulated through the Montreal Protocol, but could have a noticeable GWP and therefore should be included in the inventory list. The same is true for carbon tetra fluoride (CF_4), which has a high GWP and should also be included

1 The term greenhouse gas refers to all the gases mentioned below, although sulphur dioxide affects climate through reflection of solar radiation.

in the inventories. Although CF_4 is not a major GHG in global terms, it may be an important gas for certain countries (such as aluminum producers).

Not to be overlooked are emissions of gases that have a negligible direct greenhouse effect, but are indirectly affecting the climate through their impact on chemical and physical processes in the atmosphere, and thereby on the GHGs that are affected by chemistry. Source gases that belong to this group are nitrous oxide (NO_x), carbon monoxide (CO), and hydrocarbons. GHGs that will be affected by emissions of these gases are methane and ozone. Ozone (O_3) is not emitted, but is formed in the atmosphere. It affects climate through interaction with both long-wave radiation and solar (short-wave) radiation. Emissions of sulfur dioxide (SO_2) may also, through the formation of sulphate aerosols, affect climate. These aerosols reflect solar radiation, and may also affect the radiation budget through changes in cloud optical properties. The climate impact of this second group of anthropogenic gases cannot be assessed with satisfactory accuracy at present, as too little is known about their impact on GHGs and the aerosols in the atmosphere. Nevertheless, it is believed that the indirect climatic effect of such gases can be important. Studies indicate that the increased reflection caused by increased aerosol formation from SO_2 has a cooling influence on the northern hemisphere. A large effort is underway to study the indirect greenhouse effects from anthropogenic emissions, and scientists should soon be in a position to provide more reliable values for the climate impact of this second group of gases.

Sinks

Large amounts of carbon are continuously transferred between the atmosphere, the ocean, and the terrestrial biosphere. In our current understanding of the carbon cycle, there is an apparent imbalance, often referred to as "the missing sink" of CO_2. The terrestrial biomass (including soils) may account for this. The management of sinks to control atmospheric concentrations of GHGs should be oriented toward reforestation and afforestation, which will reduce atmospheric CO_2 and help control its build-up. The ocean is a net sink for excess CO_2 introduced to the atmosphere by human activities. The possibility of injecting CO_2 into the ocean is under investigation. Before such a measure is implemented, a thorough understanding of circulation and chemistry in the oceans is needed.

For the other GHGs, the dominant sink is provided by atmospheric oxidation, which is not easily controlled and is linked to other environmental problems.

Sources

Adequate methods exist for developing national inventories of the sources and sinks of the major GHGs. An important obstacle is the inherent uncertainty of current estimates of sources and sinks. The different source categories are, however, identified. The main effort should be to estimate emissions within the categories that are important for the individual countries.

The main reason for the increase in atmospheric CO_2 is the use of fossil fuels in energy combustion. Another source of increase is changing land use. A small, relatively well-known source is cement production. There are other instances where the origins of emissions are uncertain, and where the contribution from individual countries can be important. Examples include emissions from the production and use of lime, from gas wells, and from landfills. Methane comes from many sources, but the relative contributions of these sources remain uncertain. A large share is anthropogenic, emitting from livestock, animal waste, coalbed releases, oil and gas production and transportation, wet rice cultivation, biomass burning, and landfill and other human waste. The sources of NO_x are poorly known; both the natural production and anthropogenic releases are connected with large uncertainties. Anthropogenic impact is due to the use of fertilizer, fossil fuel combustion, and processes associated with the manufacture of nylon.

Since assessing emissions of some of the major GHGs is difficult, a network to monitor atmospheric distribution of the gases may prove helpful in estimating sources as well as in regulating control measures that affect their distribution. Such a network operates through the World Meteorological Organization (WMO), and could play an important role in long-term climate change mitigation.

Review and assessment of source and sink inventories

Inventories of sources and sinks for the gases that affect climate are included in most of the planned or ongoing country studies. In 1991, the IPCC set up a work program to develop an approved methodology for preparing national inventories of GHG emissions and sinks. The program aims to improve the quality and the comparability of national inventories. The IPCC default methodology is not meant to be obligatory. The countries could use other methods when better data and measurements are available. It was recommended, however, that the common reporting framework given by the IPCC be used by all countries to allow for comparison of these inventories (OECD 1991). The Conference of the Parties is later expected to decide on the format and guidelines for reporting. To assure comparability, the inventories should be transparent in approach, definitions, and assumptions. An inventory is transparent when the methods are fully described, the assumptions are documented, and the GHG data are reported in a common framework. This means that national methodologies are acceptable, provided assumptions are clearly set out and scientifically defensible, and that reporting categories consistent with the IPCC methodology are used (IPCC 1992c). The IPCC methodology is still being refined, and output from the country studies is important in this process. It is thus essential that this work be closely linked to the activity of the IPCC.

This section reviews and assesses the terms of reference for studies that are not completed (ADB 1992; UNDP 1992; UNEP 1992a), and inventories the reports from the completed studies (Norwegian State Pollution Authority 1992; Jaques 1992; and the Polish Foundation for Energy Efficiency 1992). The specific criteria that have been applied as a basis for the review and assessment are given in Appendix III. They are based on the recommendations given in OECD (1991) and Leggett (1992), and on what participating scientists consider important for assuring adequate preparation of the inventories.

Methodology

The IPCC prepared bottom-up methods for studying CH_4, NO_2, NO_x, CO, and non-methane hydrocarbons. This means that several activity data are used on a fairly detailed level together with source-specific emission factors.

For CO_2, on the other hand, a top-down approach is given by the IPCC. This is based mainly on the supply of primary fuels and requires a complete balance of primary fuels produced, plus imports minus exports, and net increase in stocks. If countries choose to use their own method, their approach should still be consistent with this default method.

Testing of the IPCC methodology is the main objective of UNEP (1992a). It is not explicitly recommended by UNDP (1992). In ADB (1992), an examination of accepted methodologies and a proposal for any modified methods are required. Refinements to the inventory methodology will be made through UNEP (1992a) and UNDP (1992). Regional studies to obtain better knowledge are promoted, and the importance of the distinctive characteristics of the regions and countries are addressed by all three agencies. Methodological requirements are, however, given in broad, unspecified terms. The roles of the sources and sinks in the natural cycles are given some attention in the studies. The Amazonian subproject in UNEP (1992a), for example, aims to gain a better understanding of the capacity of the Amazonian rainforest as a net sink of CO_2. It also sets out to analyze the effects of deforestation on the forest's ability to sequester carbon.

Disaggregated approaches have been applied in the studies from Canada, Norway and Poland (bottom-up methods). The methods are simple to update and time series are easy to make if sufficient activity data are available. Attention has been given to sources that are important for these countries, and results from national studies have been applied. The use of the total amount of carbon for calculations of CO_2 emissions varies. The IPCC method recommends that all carbon be included in the CO_2 emissions estimate (OECD 1991a). This means that carbon in hydrocarbons and carbon monoxide should be counted as CO_2. However, it may be argued that carbon sequestered in products for more than twenty to fifty years, such as through the production of silicon carbide, should be subtracted.

Canada, Norway and Poland have tested the IPCC method and compared it with national methods. For Norway and Canada this was done as the first step in

a transparency study initiated by the IPCC (Norwegian State Pollution Control Authority 1992; Graham Associates 1992). None of these three studies have used the same year as their basis. Lack of data is hampering the use of the IPCC methodology for the Polish study, and recommendations are made to determine the necessary data sets for using this method. Recommendations are also given for adapting the method to Polish conditions. This experience might also be valuable for other countries with transition economies.

Few estimates exist of natural sources and sinks with a discussion of their roles in natural cycles. Canada, however, has estimated natural emissions of NO_2 and CH_4. In addition, a carbon budget, although incomplete, has been developed. CO_2 emissions from the burning of wood are calculated in all three studies. These emissions are, in accordance with the guidelines from IPCC, not included in the total CO_2 emissions reported. In Norway, work is being initiated to quantify the strengths of natural sources and sinks.

Documentation

Little attention is given to the transparency of methods and results in the terms of reference for the three uncompleted studies. Descriptions and references sufficient for a reconstruction are not required. No direct specifications are given for reporting emission factors, activity data, and essential assumptions. Analyses and explanations for any deviations between data sets, emission factors, and results are not in the terms of reference. In ADB (1992), however, a review of emission factors for methane emissions from rice fields, and CO_2 from coal mines and coal-fired devices are requested. In addition, socioeconomic indicators should, according to the terms of reference, be collected and compared, and the results should be compared with preliminary estimates. The documentation is clear and thorough in the studies on Canada, Norway and Poland. However, the Canadian study's documentation of what is included in the activity data for marine and air transport is limited.

Reporting

Different methods may be used, but it is critical that the results be compared with other studies, and that explanations be given for any deviations.

In ADB (1992), the terms of reference examine GHGs without stating explicitly whether the gases with indirect effects on climate should be included. Neither reference year, time intervals, nor units of emission are specified. No direct requirements for a common set of source and sink categories are given, and no definitions are required. However, since gaining experience with the IPCC method is the main objective of UNEP (1992a), several reporting requirements are implicit.

The results from the completed studies are well arranged. Full molecular mass units are used. Such requirements are not given in the terms of reference for the uncompleted studies. Assessments of uncertainty are generally absent, but they are treated to some extent in the Polish study where results obtained with different assumptions and parameter values are compared. HFCs and CF_4 have, due to recent findings on their climate impact, received limited attention. A preliminary estimate for CF_4 is, however, made for Canada. Likewise, work is underway in Norway to estimate CF_4 emissions.

Possible improvements in current approaches

The terms of reference for the uncompleted studies are given in far less detail than the requirements provided in Appendix II. The completed studies are much more in accordance with the criteria in the appendix. This may be because the completed studies on inventories are from developed countries or are conducted with assistance from a developed country. In addition, to be able to carry out an estimation of the strength of sources and sinks, one has to apply a rather detailed and well-structured approach. When the planned studies are completed, the reports may therefore be more in accordance with the criteria that have been applied in this review and assessment.

Based on the review of the terms of reference and the completed studies, the following inferences can be made:

- As long as the IPCC methodology is recommended in the terms of reference, several documentation and reporting requirements are implicit. More explicit requirements for documentation and reporting would, however, help

to ensure that the projects are carried out in a consistent, comparable way, in accordance with the overall aim of the country studies. A standard summary should be included.

- Countries should clearly account for any deviations from the IPCC default methodology.
- Comparisons of the results obtained with different assumptions and methods are useful and should be performed if resources are available.
- A method with disaggregation detailed enough to use for national policy-making and for implementing measures to reduce emissions and enhance sinks should be promoted.
- The country studies should be used as an opportunity to collect data and information that have been missing in international and national statistics so far. For example, data for non-commercial energy could be made available if this was specified clearly in the terms of reference.
- The difference between countries with respect to the importance of the sources and sinks should be emphasized, and national or regional studies should be promoted to gain a better understanding of important processes. Researchers must be mindful that emission factors and assumptions that are valid in some countries or regions may not be applicable elsewhere.
- The natural cycles could be given more attention, thereby contributing to the understanding of the full cycles of GHGs. It would also be useful to study the extent to which human activities have modified the strengths of the natural sources and sinks.
- Gases that have an indirect effect on climate should be included.
- The issue of uncertainty should be given higher priority. Preferably, uncertainty ranges for the estimates should be given.

3 Impact and Vulnerability Assessment

National assessments of climate impact and vulnerability are essential building blocks in making damage-cost projections and in developing efficient national response strategies. Vulnerability to climate change may be defined as a nation's ability to cope with the consequences of the range of impacts of climatic changes that may follow from increasing concentrations of GHGs in the atmosphere. Human activities and natural systems show different degrees of sensitivity to climate change. Thus the ability to cope with a changing climate depends on political and socioeconomic conditions and on natural ecosystems. Impacts of climate change can be defined as the consequences (biological, physical and economic) of a particular scenario with respect to the path of future global GHG emissions, given estimated climate changes.

Regional climate change

A first step in a country study of the probable impacts of climate change is to establish the basis for estimating national impacts. Confidence in the prediction of regional changes based directly on the General Circulation Models (GCMs) is low, according to Houghton et al. (1992). Even if significant progress is made in simulating regional climate changes, the viability of this basis for prediction remains uncertain. The IPCC decided in their November 1992 meeting that the issue of regional scenarios should receive high priority in the program of Working Group I.

An alternative to projections from GCMs is the use of analog data from past climate events. These are related either to present day climatic variations, such as droughts or floods, or to paleoclimateological analysis. Based on such vulnerability studies of climatic variations, possible climate impacts from anthropogenic climate change may be projected and assessed. One problem with this methodology is the uncertain predictive power of past climate events when applied to the study of long-term climate change caused by anthropogenic GHG emissions.

Review of climate impact in physical and biological terms

Physical and biological climate impacts can be divided into three groups. The first consists of physical impacts such as sea-level rise, loss of land, and damage to infrastructure due to hurricanes, floods and the like. The second are biological impacts on agriculture, forestry, fishing, and aquaculture related to changes in precipitation, water supply, soil moisture, velocity of hurricanes, and other variables. The third consists of biological impacts on natural ecosystems.

There are many types of uncertainties in this area, but the IPCC Working Group II recommends that the linkages between physical and socioeconomic impacts should be further explored, and that the methodologies for quantifying these impacts should be improved.

The impacts from climate change depend on the species of plants and animals in the ecosystem

under consideration and how they inter-relate (Kristiansen 1992). The ultimate outcome of climate changes at the ecosystem level depends on that system's ability to adapt, and on a species capacity to disperse. Most studies suggest that time constraints and limited genetic variability preclude accelerated evolution; the major response will be migration. The rate of extinction may then increase. Whereas some factors tend to increase biomass accumulation, others work in the opposite way, which will affect the carbon cycle. Indications are that the terrestrial biosphere may act as a net sink for carbon. This remains controversial, however. The major international programs that include studies related to potential biological effects of climate change are presented in Appendix IV.

According to Houghton et al. (1990), the types of human settlements most vulnerable to climate change are concentrated in developing countries. These include low-income communities, residents of coastal lowlands and islands, populations in semi-arid grasslands, and the urban poor in squatter settlements.

There is considerable variation in the methodological approach taken in the country studies reviewed here. About half of the studies employ GCMs combined with impact models to estimate losses to agricultural production and soil erosion, whereas the other half are vulnerability studies based on analog data from present-day climatic variations. Most consider both physical impacts from sea-level rise and biological impacts such as crop losses in agriculture and forestry, but some are concerned only with sea-level rise and related loss of land. Coverage of biological impacts on natural ecosystems is far more limited.

Review of climate impact and vulnerability in economic terms

The economic costs of climate change can be divided into two parts. The first is the cost of adapting to climate change; the second is the economic losses resulting after efficient adaptation has occurred. Efficient adaptation on a global scale implies that net marginal adaptation cost is equal for all adaptation measures, and is equal to net marginal reduction in economic loss. Most practical cost calculations will probably be made at the national level and, eventually, for groups of countries. With no external effects between countries resulting from adaptation measures, the same basic principle can be applied to the national level. Possible external effects ought to be accounted for, but they are likely to be small for national adaptation measures.

The principle of efficient adaptation implies that the total economic costs (to the world community, to regions, and to individual countries) of a given climate change are minimized. An important aim of the country studies is therefore to try to identify efficient adaptation measures, both for individual countries (including their potential for reducing other countries' costs), and for groups of countries.

Adaptation measures are of three main types: investments in infrastructure, relocation of structures in response to climatic change or sea-level rise, and increased costs borne by businesses and households. The adaptations are needed to optimize the response to temperature rise. Two types of economic losses due to climate change can occur after adaptation measures are adopted: production losses (for example, in agriculture, forestry and industry) and direct welfare impacts on the general population from the change in climate.

Production losses and direct welfare impacts are difficult to assess. At least three calculation problems are involved:

- Choice of an appropriate discount rate
- General uncertainty concerning impacts, valuations, technological change and preferences
- Ethical issues related to intergenerational welfare comparisons.

The choice of an appropriate discount rate, while of crucial importance for cost-benefit analyses of adaptation measures, is discussed further in chapter 4. General uncertainties are also important, given the long time horizon involved. In general, the greater the uncertainty of impacts, the more serious should be an adverse impact with a given expected cost (to the world or national community), provided a reasonable assumption of risk aversion with respect to major welfare changes is made. Valuing direct

welfare impacts is especially complex. Here, special methods for valuation of environmental goods should be applied, and user, option, and existence values related to the environmental changes should be included. An increased rate of technological change is important, since adaptation costs and post-adaptation economic losses can be reduced. The direct welfare impacts on the population may change if people's preferences change. Problems of intergenerational welfare comparisons are also crucial but cannot be discussed adequately here. When calculating economic impacts of climate change, the lower the rate of discount chosen, the greater the weight accorded to future generations.

The following additional points should be noted:

- In principle, efficient adaptation and abatement should be determined simultaneously and incorporated into an optimal overall strategy to deal with climate change. This would also involve consideration of inter-relations between the two whenever they are present. At the national level, it should be legitimate to take the climate effect as exogenous when selecting an adaptation mechanism.
- The more remote and gradual the climate change, and the shorter the lifetime of investments, the lower the adaptation costs are likely to be, and the greater the likelihood that the adaptation will be optimal. This is because future investments and technological developments are likely to accommodate the climate change and be structured in such a way as to further reduce impacts, and because a more gradual climate change allows for ecosystem adaptation.
- Adaptation measures indicated in national plans may not be optimal due to: the inability to identify such measures for all relevant sectors; institutional and political constraints; and the inherent uncertainty involved in calculating the net benefits of the measures. While this paper does not provide a complete guide on how to deal with the various issues, the national plans should at least discuss the cost calculation problems mentioned above.

Country studies commonly assess climate impact in economic terms—as production losses in agriculture and other economic sectors, and as loss of habitable land used for production or occupied by natural ecosystems. These impacts are experienced as floods, droughts, increased erosion, sea-level rise, saltwater intrusion into freshwater aquifers, and so on. Production losses are often expressed as percentage losses in sectoral gross domestic product, and may therefore be relatively easily expressed in monetary terms. Few efforts have been made to value changes to environmental goods.

Most of the studies consider adaptation measures in such sectors as agriculture, forestry, water resource management, and coastal zone protection and management, but few cost calculations for these measures are reported. Calculations of costs and effects are needed to identify efficient adaptation measures, and to compare the costs of adaptation measures and the costs of remaining impacts. Such comparisons are essential to the development of cost-efficient national response strategies. One example of cost calculations is found in the case studies of sea-level rise reported in IPCC (1992a). The IPCC calculations are, however, limited to a fixed capital value of infrastructure (no depreciation or growth), and are based on the current capital cost of adaptation measures (no discounting). The robustness of adaptation strategies with respect to uncertain sea-level rise is examined, and probability distributions of sea-level rise are generated.

Possible improvements in current approaches

Based on the review of the terms of reference and the completed studies, the following statements can be made:

- Country studies should include both physical vulnerability and impacts, biological vulnerability and impacts related to agriculture and forestry, and biological vulnerability and impacts related to natural ecosystems.
- More emphasis might be placed on climate vulnerability analyses of local ecosystems.
- Country studies should focus more on the uncertainty of national and regional climate change and the uncertainty of vulnerability and impacts. Uncertainty scenarios of high, medium, and low vulnerability to climate impact could be ana-

lyzed. Moreover, the different components of climate change should, when appropriate, be considered separately. This includes temperature rise, changes in precipitation patterns, and changes in wind patterns (such as the frequency of hurricanes).

- More emphasis should be placed on calculating likely sectoral production losses in monetary terms and on estimating the monetary costs of other types of climate impacts, such as loss of land.
- Biological and physical impacts of climate change should, whenever possible, be valued, preferably in economic terms, even if there are particular problems associated with this.
- Costs should be expressed in one currency, possibly 1992 US dollars.
- The cost of adaptation measures should be clearly identified and evaluated through cost-benefit analysis. This would involve comparing the adaptation cost with the expected benefit, and estimating the reduced damage from climate change.
- A cost-efficient curve of adaptation measures should be constructed where projects or measures are ranked according to increasing net expected cost (total cost minus expected benefit).
- For the evaluation of impacts and adaptation measures, assumptions on time horizon, discount rate, and uncertain impacts and valuations should be harmonized in country studies. In particular, all country studies should include one common set of parameter values, whereas additional sets could be based on national conditions.

4 Cost-Effective Interventions

The third main component of country studies, in addition to emissions inventories and impact and vulnerability assessments, is cost-effective interventions. A discussion of cost-effective interventions should be based on the general framework of cost-benefit analysis.

Theoretical basis for cost-benefit analysis

There are three levels of aggregation at which cost-benefit analysis can be conducted:

- *The global optimum.* In this theoretical concept, the global net marginal cost of reducing GHG emissions equals the marginal gain to the world community from this reduction. In particular, this implies:

  (i) Determining the optimal global target for GHG emissions;
  (ii) Always implementing the most cost-effective measures for reducing emissions on a global scale; and
  (iii) Implementing abatement adaptation measures until the marginal cost is equal for the two types of measures. Net marginal cost should be defined here as gross marginal cost (output losses and similar items) minus net marginal external benefits beyond those due to the reduced greenhouse effect (such as reduced pollution and technological spillovers), resulting from efforts to reduce GHG emissions.

- *Global cost minimization given a global GHG emissions target.* This implies that any given global emissions target for GHGs (measured, for example, in carbon equivalents in terms of their GWP) should be implemented with a minimum net total abatement cost to the world community. In particular, this assumes that any abatement measure not yet implemented will have a higher net cost than those already implemented. It also implies that abatement projects are realized in each country until the net marginal abatement cost is the same for all countries.
- *National cost minimization.* The objective here is basically the same as at the international level—for all sectors, the net marginal abatement cost is to be equal, with no sectors where efforts not attempted imply lower net marginal cost. One problem is that national efforts to reduce emissions may have external effects for other countries—for example, reduced coal consumption in one country may imply less air pollution for neighboring countries. Such transnational effects should generally be counted when calculating a country's net abatement costs. If such external effects are important, it may be an argument in favor of grouping countries according to such effects.

Counting marginal costs

Problems may arise in comparing marginal costs across nations (or even within countries) due to missing markets, widely differing relative prices among nations, and the use of local currencies with official values that deviate from market values. For some products that contribute to emissions such as

coal and oil, prices are distorted by subsidies. Furthermore, ordinary markets may be thin or non-existent (such as for fuelwood and charcoal), and any possible observable market prices are unreliable. For countries where such distortions are severe, an argument can be made for simply considering national-level plans, and not trying to incorporate these into a global optimizing framework.

Some abatement measures may imply technological improvements that may reduce costs in sectors and countries other than those directly affected by the measures. Such cost savings should, in principle, be counted in calculating the relevant cost concepts, although this may often be difficult in practice.

Until this point, the marginal damage curve related to GHG emissions has been treated as exogenous. Some of the relevant national and international efforts to reduce emissions may, however, affect the economic cost resulting from a given rise in temperature. With a given global emission target, this should generally be treated as an externality contributing to a modification of net marginal abatement cost (upward or downward, depending on whether cost is increased or decreased).

The decision to rank projects according to rising net total marginal cost is critical. Different projects may have different time profiles for costs and benefits, and the selection of a proper discount rate is often necessary for such a ranking. Project externalities may make the computation of the optimal project sequence extremely difficult, even under certainty. For each project, one has to calculate the externalities for all remaining projects that will be implemented in the future in the appropriate sequence. Such externalities may lead to a net marginal abatement cost curve for the individual projects that does not follow a uniform upward slope if the implementation of some abatement cost efforts significantly lowers the costs of carrying out other measures.

A practical approach

The main focus of abatement efforts is at the national level. However, extra cost savings for a given abatement target are possible for collaborating countries as long as there are structural differences between them, such as different national abatement costs. Provisions exist for abatement collaboration between nations under the FCCC that confer joint implementation (FCCC, *Article 4*, paragraph 2 (a)), even if the criteria of joint implementation have to be negotiated. Even if nations cooperate, abatement costs should be minimized in each country.

To minimize national abatement costs related to targets, possible measures to reduce net GHG emissions should be evaluated. Then the least expensive set of measures for each given level of abatement can be chosen. Measures can include project investments, direct regulation, or economic policy instruments such as taxes and tradable emission allowances. The measures can be ranked according to net total costs relative to net reduction of GHG emissions, expressed in 1992 US dollars per ton of CO_2. Where GHGs other than CO_2 are involved, the measures can be ranked according to GWP (Houghton et al. 1990 and 1992). Instead of reducing gross GHG emissions, net emissions can be reduced by sequestering carbon through afforestation. Abatement measures are often not selective—for example, they might reduce pollution or lead to technological spillovers. These externalities should be accounted for by subtracting the benefits from the costs of the measure. To make the country studies comparable, sectoral and activity definitions and reporting units should be standardized.

National abatement costs should be minimized across a broad spectrum and at several levels. This applies (at the sectoral level) to efforts to reduce specific GHGs, and to policy- and project-related efforts. A cost curve can be calculated by ranking all possible projects to reduce net GHG emissions according to increasing cost. Total costs are minimized if the cheapest project is chosen first, and then more projects chosen according to increasing cost. The costs and ranking of remaining projects may be influenced by the implementation or realization of projects. To correct for externalities of this type, the costs of the remaining projects should be recalculated successively each time the cheaper project is realized. These calculations require a project overview where policy and expenditure measures are listed with cost and emissions impact data. Relevant data on project externalities for these should also be supplied.

Top-down and bottom-up approaches

Projects and measures can be divided into two main groups according to methodological approach. Projects in the bottom-up group have well-defined investment objectives and a specific investment profile—for example, replacing an existing technology in a production process with the most energy-efficient new technology. This approach is useful when choosing between different technologies, particularly when valuing public GHG abatement projects. The discussion has so far been based on a technology-specific, bottom-up approach. The basic rules for optimal project selection and sequencing should in principle, however, apply also when more general measures (such as taxes and subsidies) are used.

A disadvantage of the bottom-up approach is the difficulty in accounting for interdependencies between projects. However, some interdependencies between, for example, energy technologies or projects, can be accounted for in energy-system models. In the top-down approach, a macroeconomic model is employed to analyze the effects of more general policy measures and programs, such as a carbon tax. Thus, the interdependencies between the different markets and sectors are modelled explicitly. The relation to specific technologies and investment projects is weak, and the cost of an abatement measure must be expressed in terms of reduced economic growth, or implicitly calculated in the efficiency losses. With this approach, explicit assumptions must be made about market structure and the economic behavior of individual agents. In particular, the degree of competition in the sector contributing the GHG emissions is important to the efficiency of policy measures. For economies in transition, there are specific problems related to the instability of institutions and market structure, as in Eastern Europe.

Setting a discount rate

In a framework of cost-benefit analyses featuring abatement costs and benefits, the discount rate could be based on pure time preference, expected growth of per capita income, and the elasticity of the marginal utility of consumption (see Cline 1992a and 1992b; Pearce 1991). Here, however, a common discount rate is only required to compare projects with different cost profiles, and eventually with different benefit profiles (calculated on the basis of local and regional pollution and other externalities). If the projects are publicly financed, the relevant discount rate is the average return to public investments, or more precisely, the return to the best alternative public investment project. To the extent that direct regulation of private firms and market measures, such as taxes, are employed to induce abatement efforts, the regulation and taxing levels should be based on national cost-benefit analyses where the appropriate discount rate is applied. In such an instance, the appropriate discount rate required to compare projects and measures of different time profiles is the average return to public investments.

The average return to public investments may vary among countries due to different political systems and priorities, and due to capital market imperfections. Consequently, the appropriate discount rate for abatement project calculations may also vary.

Uncertainties about climate change complicate a long-term cost-benefit analysis, making the calculation of the discount rate more difficult. The effects of a project on GHG emissions and on many externalities may not be known. Furthermore, there are uncertainties with respect to future available abatement technologies and projects, commodity prices, economic growth, and global conditions. The only way to narrow the range of unknown externalities is through data collection and research. The best way to keep abreast of costs, emerging technologies, and global emissions data is to keep an up-to-date list of projects and abatement efforts.

Strategies for minimizing national abatement costs are based on assumptions about the global situation, international markets, and abatement policies of other countries, such as economic growth, population growth, oil price development, exchange rates, interest rates, and future technological options. National measures may influence international markets and prices. One example is a carbon tax in some countries that reduces demand in these countries, but decreases the world market oil price and thereby increases demand in other countries. Assumptions concerning these global parameters

should be coordinated between country studies to make them comparable and consistent. This would also require the coordination and harmonization of baseline scenarios to which the abatement scenarios are compared.

Review of country studies

This section reviews terms of reference for country studies that are completed, underway, or planned. Ten features of the studies are considered. The objective of most of the country studies is to identify policy options to reduce GHG emissions as part of a national response strategy. In ADB (1991 and 1992) and in UNDP (1992), a regional response strategy is presented for eight to fourteen Asian countries. In some studies there is an additional focus on cost-effective opportunities, and both abatement and adaptation measures are considered. The scope of other studies is limited to a review of existing policies with a view to minimizing conflicts with climate policy, with the industrial sector regulations, or with macroeconomic impacts of GHG abatement.

Methodological approach

The main focus is on bottom-up models and cost-benefit calculations for projects and technological options. In six of the studies, both bottom-up and top-down models are considered. Macroeconomic models are available largely for developed countries only (Denmark, Japan and the Netherlands). In the ADB studies for eight Asian countries (ADB 1991) and in the Zimbabwe study (Southern Center for Energy and Environment 1992), macroeconomic implications are discussed. In most of the other nine studies, the scope is limited to identifying technological options and potential energy savings and GHG emissions reduction, eventually including investment costs, operation and maintenance costs, and fuel costs. A few of these studies construct a cost-efficient curve of abatement projects.

Externalities between projects and economic sectors are accounted for in the top-down studies. In ADB (1991 and 1992), benefits other than those relating to climate change will be accounted for. To some degree, externalities between countries are included in the ADB studies (ADB 1991), since a regional strategy is considered. The effects of the projects on environmental externalities are generally not discussed in any of the studies. An explicit documentation of units of measurement is, to a large extent, missing in the country studies.

Range of projects, options, and measures considered

The coverage of options to reduce net GHG emissions is one of the strengths of the studies. Most studies consider different technological options to improve energy efficiency, including fuel-switching to gas, oil, or renewable energy sources (including agricultural and other waste). Just a few studies consider afforestation and change in agriculture and other land-use practices. The transport sector, particularly the potential for mass transit, is also included in several studies. In some of the studies of Asian countries, adaptation measures in agriculture, forestry, water management, the residential sector, and other areas are included. About half the studies consider policy measures such as taxes, subsidies and direct regulations.

Range of economic sectors considered

Most of the major economic sectors are covered only in about two-thirds of the studies. The agriculture sector is omitted in a few of the studies. In the Italian study (Contaldi 1992), only industry is considered.

Definition of GHG abatement costs

Few of the studies contain details on how definitions of abatement costs were formulated. In the bottom-up studies, the common approach is to calculate the investment cost of a project, eventually including operation and maintenance and fuel costs. In the top-down studies, the cost is usually reported as Gross National Product (GNP) loss. In the Brazilian study, the cost is calculated from the consumers' perspective as net project investment plus the value of energy expenses saved through the project (UNEP Collaborating Centre on Energy and Environment 1992b).

Discount rate

Documentation on discount rates is scarce. A discount rate of 12 percent is reported in the Brazilian study (UNEP Collaborating Centre on Energy and Environment 1992a), and a discount rate of 5 percent is reported in Burg et al. (1992).

Uncertainty

In a few studies, uncertainty related to model specifications and assumptions is handled by comparing the results of different models and studies. Another option considered is the inclusion of more than one baseline scenario. Besides this, scant attention is paid to uncertainty.

Baseline scenarios: assumptions on international markets and the global situation

A business-as-usual baseline scenario is mentioned in many of the studies. The assumptions with respect to fuel price, economic growth, and other factors are stated in only a few of the studies.

Realism: political and social constraints

A few studies provide a limited evaluation of political and social constraints for implementing abatement measures.

Possible improvements in current approaches

Based on the review of the terms of reference and the completed studies, the following can be stated:

- All studies should be expanded to identify cost-effective abatement projects and options, given a national abatement target and the necessary policy measures at the national level.
- In the bottom-up models, more effort should go into finding an optimal sequence of projects and thus a cost-efficient curve accounting for externalities between them. These models should attempt to account for other positive externalities, such as reduced pollution and technological spillovers. Fuel, investment, and operation and maintenance costs should also be included.
- The cost-efficient curves of abatement projects should be comparable between countries. This would allow the identification of project-sequence-minimizing abatement costs across countries, which in turn could lead to the development of joint implementation programs.
- Top-down analyses based on macroeconomic models, if available, should be employed to supplement the bottom-up analyses and account for interdependencies and externalities between sectors. In particular, more attention should be paid to the inclusion of environmental externalities in the studies (both within countries and possibly across country borders).
- In the bottom-up analyses, costs should be reported in 1992 US dollars per ton of CO_2 equivalent. In the top-down analyses, costs should be reported as a percentage loss of GNP, and in 1992 US dollars. Other reporting units should also be standardized and clearly documented.
- Some country studies need to expand the range of projects, options, policy measures and economic sectors considered.
- The discount rate used should be clearly reported. It should be the same as the discount rate applied for calculating the returns to public investments in each country. Supplementary calculations based on a low and high level could strengthen the analysis. This low and high rate should preferably be the same for all countries.
- Since assumptions about the future are intrinsically uncertain, two or more baseline scenarios should be considered. Such scenarios could focus on identifying the possible critical factors affecting uncertainty, such as those related to future parameter values, technological factors, and valuation issues.
- The baseline scenarios should be harmonized to make the country studies consistent and comparable. In particular the comparison of time horizons, economic growth, population growth, interest rates, and fuel price growth rates should be relatively easy. All country studies should include one common set of parameter values, with additional sets based on national conditions.
- More emphasis should be placed on political and social constraints that influence abatement policy measures. While such constraints should not be viewed as insurmountable, realistic national plans should not include measures that are impossible to implement for political reasons. The studies will be further strengthened if an analysis of the cost-effectiveness of such measures is included.

5 Costs and Staffing Patterns

The cost of full-fledged country studies will vary with the size and complexity of each study. The United States is offering support to developing countries and to transition economies to carry out climate change studies. They are considering funding in the range of $100,000 to $500,000 for each country (Morgenstern 1992). The costs of the country studies financed through multilateral sources were as follows:

- The ADB study had three main components: establishment of a common framework for country studies, execution of eight country studies, and preparation of a regional strategy. The country studies had three components: socioeconomic impacts, policy options, and national response strategies. The full study had a budget of $1.69 million, with an average cost of $211,250 per country.
- The UNEP study on sources and sinks for eleven countries cost $6.4 million, with an average cost of $583,361 per country.
- The UNEP-supported Brazilian study on impacts had a funding of $50,000, while the UNEP-supported impact studies in five countries had a funding of approximately $150,000 per country (Peter Usher, UNEP).
- The budget for the UNDP's fourteen-country study is presented below. Not included in table 2 is the additional $1.3 million needed for project execution.

Many country studies have an extremely wide scope and range. Topics studied include assessments in the fields of climatology, agriculture, forestry, water resources, coastal management, energy, industry, transport, health, and socioeconomic and institutional policies. Multilateral organizations often assign international consultants with economic and scientific expertise to help with the country study in addition to a project coordinator. For example, the ADB employed one team leader/resource economist, one impacts specialist, and one strategy

Table 2. Indicative budget for UNDP study of 14 countries in Asia

Component	*Approximate $*
Emissions inventory for 14 countries	72,000
Emissions measurement for 6 countries	250,000
Cost emissions reduction technology curves for 4 countries	250,000
GHG emission scenarios/impact evaluation for 4 countries	250,000
National response strategy for 14 countries	65,000
Training programs, expert consultants, study tours, etc.	25% of budget

Source: UNDP Project Document RAS/92/G31

specialist. Even if local teams are supposed to do most of the substantial work, outside specialists are expected to be back-up experts for all of the issues covered in the terms of reference.

Several viable initiatives have been undertaken in an effort to obtain better cost-effectiveness and rationalization in the overall execution of country studies. Based on the review of the terms of reference and the completed studies, the following recommendations can be made:

- Perform in-depth studies of specific elements, such as the design of regional climate change scenarios, as a joint activity between countries and organizations. This task, under the mandate of the IPCC, should receive high priority.
- Have countries that share important ecological and socioeconomic characteristics—and thus also share probable impacts and vulnerability to climate change—work harder to coordinate their climate study activities.
- Improve interagency coordination and eliminate overlapping activities such as those apparent in the ADB (1991), IPCC (1991), and UNEP (1992) studies of Southeast Asia.
- Focus on building local teams with strong connections to the relevant policy and decision-making authorities. Have such teams concentrate more on the supply of relevant data, and where necessary, bring in special expertise to assist in certain analyses.
- Make terms of reference more country-specific, and take into account differences in research capabilities.
- Organize country workshops to set priorities.

6 The Usefulness of Country Studies for Government Policy-Makers

Country studies are relevant for several reasons:

- They contribute data relevant to the sum of information that governments are committed to provide under the FCCC
- They form a necessary basis for cost-effective and national response strategies
- They form a basis for developing projects eligible for GEF funding
- All governments share an interest in improving the input of data to the IPCC, thereby improving the panel's ability to assess the long-term risks of climate change.

The degree of interest in information from country studies will depend on the extent to which governments feel exposed to the risks of damage and heavy abatement costs, assessed in chapters 3 and 4.

Governments in developed countries that may have to implement rather expensive measures to reduce GHG emissions in this decade have a clear interest in a comprehensive inventory of GHG sources and sinks. At the same time, there should be a strong interest in studies of relative abatement costs and "no regret" or low-cost options. Country studies are also necessary for the development of joint implementation projects with other countries.

Governments in developing countries may have a particular interest in the vulnerability of their country, because the standard of living is generally low and their capacity to implement large-scale adaptation measures, such as introducing drought-resistant species or making coastal zone infrastructure investments, may be limited.

All governments want the country studies to meet the IPCC's requirement for better information on specific sources of emissions. Such information will again provide crucial inputs to experts working on the design of climate models.

The WMO has established a long tradition of international cooperation and information exchange concerning the global climate system. Such exchanges are not as well established in other fields of research relevant to the country studies, and may have to be established through mutual trust. Some of the information involved may be sensitive, particularly data related to energy.

Organizational framework for country studies

The usefulness of country studies to government policy-makers will, to a large extent, depend on how findings from the studies are applied, and on governments' trust in the experts conducting the studies. In most developed countries, such studies or parts of such studies have been organized through relevant government institutions and research groups, often with the involvement of interministerial and interagency working groups. By incorporating comments from the research community, NGOs, and economic interest groups, the reports are likely to gain credibility and political support.

Several developing countries have followed such a review process as part of the preparation for and participation in the FCCC and the IPCC. In particular, such integrating efforts have been successful in Brazil, China, India, Indonesia and Malaysia .

In countries with limited national government preparation, international agencies such as the ADB, UNDP and UNEP have organized country studies. In these efforts, external consultants often start with limited experience and too little time for coordination with national governments. Often their terms of reference are overly ambitious. In such situations, there is always a danger that the country studies may fail to connect with national governments, important decision-makers, and interest groups. Local consultants may sometimes have been chosen without necessary information about the best available scientific experts. Overall, the country studies do not lend themselves to being organized as a set of consultancy contracts used for technical and engineering projects carried out by development banks or similar agencies.

Linking country studies to the FCCC and its machinery

Most of the country studies reviewed in this report were initiated before the FCCC was signed, and in many cases, before it was negotiated. Some of the studies' institutional and organizational weaknesses arose because they were planned as a contribution to a preparatory process for the negotiations by the Secretariat of the Intergovernmental Negotiating Committee for the FCCC, rather than for the implementation of the FCCC itself.

When carrying out further studies and supplementing those already in process or completed, there is a much better chance that studies could feed directly into the preparation of governments' inputs to the other Parties to the FCCC. The FCCC Secretariat and the GEF could improve these chances by clarifying the division of labor between them with regard to country studies. At the same time, they should link this to the needs of the IPCC, and use the expertise of the panel and its working groups.

Even if country studies should have a general and wide scope, one could, at a later stage of more detailed research, consider giving more attention to the most important and feasible measures and less attention to others, and even omitting some of the elements in the terms of reference. If the studies are constrained by a limited research capacity, the best use of available resources is to give priority to the most important and feasible measures. Furthermore, country studies should be coordinated with national development planning efforts to make the best use of total resources. Thus, some of the relevant components of a country study might already be covered by national planning studies. Countries with large research resources can carry out detailed research in all fields of a country study, whereas other countries might need to restrict the detailed research to fewer fields and the most important measures. At least for the latter group of countries, there is a likely gain from intercountry cooperation and from the efficient division of labor on country studies.

Agricultural water resource adaptation and coastal protection efforts are examples of important and feasible measures. Given that GEF work focuses on the energy, transport, and forestry sectors, country studies should put emphasis on the assessment of policy options likely to be discussed by governments and international agencies during the next two decades. After a decade, most country studies are likely to be outdated.

The study of health risks could be limited as well, not because the issue is not important, but because other factors in the foreseeable future will be more important for health than those related to global climate change.

One might also consider omitting from national studies the appraisal of the potential of reduction of CH_4 and NO_x emissions from agricultural practices. Such difficult studies should ideally be initiated as joint ventures through the IPCC network. Even recognizing that CH_4 emissions from livestock are substantial, it is highly unlikely that measures to change feeding practices will be given priority for global environmental reasons. Reduced use of fertilizers may be important for economic and local environmental reasons, but hardly because of climate change.

Possible improvements in current approaches

Based on the review of the terms of reference and the completed studies, the following statements can be made:

- Further country studies should be linked directly to the fact that governments have signed, and intend to ratify, the FCCC.
- Before giving further support to country studies, multinational and bilateral donors should consult closely with national governments, and link the studies to a national study board or committee set up by the government.
- Each country study should be an integral part of national capacity building.
- One should not preclude the use of international consultants. Preferably, one should choose consultants with proven experience in policy formation, not just in technical and economic assessment of investment projects.
- Efforts should be made by governments and donor agencies in cooperation with international institutions working in the field of climate change to achieve cooperation and to divide the work involved in country studies, so that in-depth studies of particular fields can be carried out more effectively. Through such arrangements, specialized information may be exchanged for mutual benefit. The sixth meeting of the Secretariat of the Intergovernmental Negotiating Committee for the FCCC gave a mandate to the Executive Secretary of the Convention to explore the possibility of organizing a clearing-house for the exchange of information and experience on relevant technical and financial cooperation activities, including GHG inventories and country studies.
- Country studies should take into account the need for continuous or regular reassessment of findings, and adaptation and integration of new scientific evidence.
- The need for continuous exchanges of information, for dissemination, and for harmonization of methodology could be met by setting up an Advisory Panel on Climate Change Country Studies. The FCCC Secretariat, the GEF, IPCC, UNDP, UNEP, and important donors should be represented on the panel.

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Appendix I

Studies, Terms of Reference and Papers Assessed

Asian Development Bank. "Terms of Reference for Regional Study on Global Environmental Issues Project." Project Number 5463-Regional (Bangladesh, India, Indonesia, Malaysia, Pakistan, Philippines, Sri Lanka and Viet Nam), 1991.

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———. "The Potential Socio-Economic Effects of Climate Change." Three regional assessments (Brazil; Indonesia, Malaysia and Thailand; Viet Nam), 1991.

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Country Study Summary (from the UNEP Country Study Report, Second Draft, November 5, 1992)

Country	Study	
Algeria	No studies	
Argentina	Internal:	Potential participant in impacts and mitigation under the Swiss Proclim-Ecosphere Greenhouse Gases Reduction Program (SPREP) through GEF financing. (SPREP is a quasi-government initiative involving the publicly-funded Proclim Institute and Ecosphere, a private Swiss company).
Australia	Internal:	Draft cost-benefit study of emissions reduction.
	External:	1. Provided partial funding of sea-level rise studies in the South Pacific through the SPREP (Kiribati study complete). 2. Initiated and is funding the South Pacific Sea-Level and Climate Monitoring Project (participating countries: Cook Islands, Fiji, Kiribati, Marshall Islands, Nauru, Papua New Guinea, Solomon Islands, Tonga, Tuvalu, Vanuatu and Western Samoa). 3. Funded by the WMO to assess climate monitoring capacity in the Pacific and to identify critical impacts issues. 4. Provided training assistance to Commonwealth developing countries to assist assessments of the effects of climate change on agriculture. 5. Provided financial assistance to UNEP's Global Environment Monitoring System to support an Australian sea-level rise expert for UNEP's Southeast Asian Regional Climate Impacts Project.
Austria	Internal:	1. Completed inventory of GHG sources and sinks. 2. Completed impacts study. 3. Analysis of emissions reduction technologies and development of a national response strategy are in progress.
Bangladesh	Internal:	1. Participating in ADB project to develop regional strategy to address the effects of climate change (includes country studies on potential effects; possible policy options to reduce net emissions and to adapt to climate change; and national response strategies). 2. Participant country in proposed UNDP/GEF project on least-cost emissions reduction.

		3. Possible study on sea-level rise vulnerability to be undertaken, with assistance from the Netherlands.
Barbados	No studies	
Belgium	Internal:	1. Compiled a national emissions and sinks inventory. 2. Performing an optimization exercise of GHG reduction strategies in conjunction with ETSAP. 3. Funding a number of research projects related to climate change impacts through the Global Chance Impulse Programme.
Bolivia	Internal:	Effects study completed.
Brazil	Internal:	1. Completed cooperative study with UNEP on potential socioeconomic effects of climate change in Brazil. 2. Completed cooperative emissions inventory study with the United States. 3. Study in progress on GHG emissions inventory and costs of abatement strategies, coordinated and funded by France (with possible further funding from UNEP under the coordination of Risø National Laboratory) and carried out by the Universidade Federal do Rio de Janeiro.
Brunei	No studies	
Bulgaria	Internal:	Preliminary assessment of GHG emissions and sinks underway.
Burkina Faso	No studies	
Burundi	No studies	
Canada	Internal:	1. Prepared "National Action Strategy on Global Warming." 2. Developing a national emissions inventory and reporting system. 3. Assessment of proposed or implemented emissions reduction actions underway. 4. Regional climate change effects studies underway. 5. National Report to the Conference of the Parties of the FCCC was expected by June 1993.

		6. National study underway on the economic effects of emissions control measures. 7. Additional related climate change activities have been undertaken, including: Canada's National Action Strategy; research monographs; a report for the United Nations Conference on Environment and Development that reviews the potential impacts of climate change on Canada; a discussion paper on the use of economic instruments to achieve environmental objectives; initiation of a research program to reduce the uncertainties associated with climate change; preliminary carbon budget modelling to assess forest vulnerability and to facilitate forest management; a series of reports on the state of Canada's climate; initiation of a series of environmental programs for citizens; and preparation of regional climate change reports.
	External:	1. Undertaking pilot study on emissions and control strategies in China. 2. Assisting Mexico in the development of emissions inventory. 3. Assisting Tanzania and Zimbabwe in a joint study on emissions and options for emissions reduction. 4. Exploring possibilities for assisting one country with a transition economy.
Cape Verde	No studies	
Chile	Internal:	Assessed potential ecosystem and socioeconomic effects of climate change on coastal regions.
China	Internal:	1. Participated in UNEP/GEF project on GHG sources and sinks. 2. Completed a paper assessing the impacts of climate change on China using Global Circulation Model results. 3. Assistance from the ADB expected for a detailed effects study. 4. Pilot study on emissions and control strategy underway with Canada. 5. Participant country in proposed UNDP/GEF project on least-cost emissions reduction.

		6. Potential participant in separate GEF Asia region least-cost emissions reduction project.
Colombia	No studies	
Congo	No studies	
Costa Rica	Internal:	Participated in UNEP/GEF project on GHG sources and sinks.
Côte d'Ivoire	Internal:	Study on inventory of GHG emissions sources undertaken, coordinated, and funded by France.
Cyprus	No studies	
Czech and Slovak Republics	Internal:	Joint project with Austria on possibilities for enhancing efficiency in the energy sector.
Denmark	Internal:	1. National inventory of sources and sinks of greenhouse gases completed. 2. National impacts study completed. 3. Action Plan completed for limiting emissions from the energy and transport sectors, including reduction technologies and national response strategies. 4. Ongoing national GHG abatement costing study through UNEP/Risø program.
	External:	Funding national GHG abatement costing study in Zimbabwe through UNEP/Risø program.
Dominica	No studies	
Ecuador	No studies	
Egypt	Internal:	1. Planning to establish a "National Climate Impacts Assessment and Response Strategies Programme." 2. Possible study on sea-level rise vulnerability to be undertaken with the Netherlands.
Equatorial Guinea	No studies	
Finland	Internal:	1. Emissions inventory and emissions reduction options report completed.

		2. Assessing feasibility of committing to GHG emissions reduction targets proposed during negotiations for the FCCC. 3. Developed a sustainable forest economy program. 4. Initiated a six-year assessment of climate change (past and anticipated change, impacts assessment, and emissions reduction strategies).
	External:	Pledged up to $200,000 to UNEP to finance cost-benefit studies in developing countries or countries in transition.
France	External:	1. Studies in progress (with possible funding from UNEP, under the coordination of Risø National Laboratory) on emissions inventory and costs of abatement strategies for Brazil, with Universidade Federal do Rio de Janeiro. 2. Studies in progress on GHG emissions inventories for Côte d'Ivoire, Mali and Senegal. 3. Studies in progress (with possible funding from UNEP, under the coordination of Risø National Laboratory) for continental Southeast Asia, with the Asian Institute of Technology, Bangkok.
Gambia	Internal:	Draft emissions inventory prepared.
	External:	Participant country in UNEP/GEF project on GHG sources and sinks.
Germany	Internal:	1. Publishes national CO_2 emissions data regularly. 2. Conducting a national research program on climate change effects. 3. Published "Protecting the Earth," a report containing proposals for reduction targets and national measures to reduce energy-related emissions of trace gases.
Ghana	Internal:	Undertaking an impacts study in cooperation with the United Kingdom.
Grenada	No studies	
Guatemala	No studies	
Honduras	No studies	
Iceland	Internal:	1. Completed report on national GHG emissions for 1990.

		2. Evaluating measures and assessing strategies to limit and reduce GHG emissions and increase fixation.
India	Internal:	1. Participating in ADB project to develop regional strategy to address the effects of climate change (includes country studies on potential effects; national response strategies; and possible policy options to reduce emissions and adapt to climate change). 2. Participant country in proposed UNDP/GEF project on least-cost emissions reduction. 3. Possible impacts study, to be funded by the United Kingdom, under discussion.
Indonesia	Internal:	1. Completed "National Strategy on the Anticipation of Climate Change Caused by the Greenhouse Effect." 2. Completed cooperative study with the national planning agency on potential socioeconomic effects of climate change in Indonesia, Malaysia and Thailand. 3. A study on impacts and response strategies has been initiated with the support of Japan. 4. Participating in ADB project to develop regional strategy to address the effects of climate change (includes country studies on potential effects; national response strategies; and possible policy options to reduce net emissions and adapt to climate change). 5. Possible study on sea-level rise vulnerability to be undertaken with the Netherlands. 6. Participant country in proposed UNDP/GEF project on least-cost emissions reduction. 7. Possible national GHG abatement costing study through UNEP/Risø program funded by the Netherlands. 8. Signed memorandum of understanding with Norway on environmental cooperation; will include assessment of ecostrategies for carbon fixation such as forest management, development of GHG emissions inventories, and emissions reduction scenarios. 9. Has been offered assistance by the United Kingdom for impacts studies.

		10. Climate change study with the Japan Environmental Agency planned for fiscal 1992.
Ireland	Internal:	1. Developing GHG emissions inventory.
		2. Series of studies on impacts and response strategies completed.
		3. Ongoing evaluation of emissions control measures.
Israel	No studies	
Italy	Internal:	Prepared report on energy related CO_2 emissions reduction options for the Commission of European Communities.
Japan	Internal:	1. Completed emissions inventory.
		2. Completed impacts assessments.
		3. Completing assessments of emissions mitigation technologies.
	External:	1. Initiated and is funding an assessment of climate change impacts and response strategies in Indonesia.
		2. Plans to conduct a study on coastal zone management planning in South Pacific countries.
		3. Participated in and provided financial assistance for numerous international climate change programs.
Kenya	Internal:	1. Impacts study underway, funded by the United Kingdom's Overseas Development Administration.
		2. Potential participant in impacts and mitigation study under SPREP through GEF financing.
Korea, DPR	Internal:	Participant country in proposed UNDP/GEF project on least-cost emissions reduction.
Korea, R	Internal:	Participant country in proposed UNDP/GEF project on least-cost emissions reduction.
Madagascar	Internal:	Produced preliminary report on national sources of green-house gases and the impacts of climate change.
Malaysia	Internal:	1. Completed cooperative study with UNEP on potential socioeconomic effects on climate change in Indonesia, Malaysia and Thailand.

		2. Participating in ADB project to develop regional strategy to address the effects of climate change (includes country studies on potential effects; national response strategies; and possible policy options to reduce net emissions and adapt to climate change). 3. Collecting information on climate research under the Global Biosphere Program.
Mali	Internal:	Study on inventory of GHG emissions sources undertaken, coordinated, and funded by France.
Marshall Isl.	Internal:	Assessed the vulnerability of the Majuro Atoll to accelerated sea-level rise, and evaluated possible response options.
Mauritius	No studies	
Mexico	Internal:	1. Participant country in UNEP/GEF project on GHG sources and sinks. 2. Emissions inventory study with the United States. 3. Emissions inventory project with technical assistance from Canada.
Mongolia	Internal:	Participant country in proposed UNDP/GEF project on least-cost emissions reduction.
Morocco	Internal:	Participant country in UNEP/GEF project on sources and sinks.
Myanmar	Internal:	Participant country in proposed UNDP/GEF project on least-cost emissions reduction.
Namibia	No studies	
Netherlands	Internal:	1. Completed cost-benefit studies on responses to sea-level rise. 2. Expects to complete comprehensive cost-benefit analysis of all sectors. 3. Completed a cost analysis of technologies to reduce CO_2 emissions from the energy sector. 4. Ongoing national GHG abatement costing study through UNEP/Risø program.
	External:	Planning to undertake sea-level risk studies in Bangladesh, Egypt, and possibly Indonesia, in cooperation with those governments.

New Zealand	Internal:	1. Completed sources and sinks inventory.
		2. Completed impact studies.
		3. Completed response strategy studies.
		4. Completed strategy on first steps to tackle CO_2 emissions.
	External:	1. Assists developing countries with studies through contributions to SPREP and UNEP.
		2. Participated in WMO study to assess climate monitoring capacity in the Southwest Pacific and to identify critical impacts issues.
Nigeria	Internal:	1. Participant country in UNEP/GEF study on GHG sources and sinks.
		2. Plans to establish a national task force to develop a climate impacts assessment and response strategies program, but requires assistance.
		3. Potential participant in impacts and mitigation study under SPREP through GEF financing.
Norway	Internal:	1. Finalized a study on global climate change (national inventory of GHG emissions, potential impacts, and policy strategies including the economic effects of CO_2 emissions and increasing fixation). Considering follow-up analysis.
		2. Green Tax Commission has made proposals for economic incentives to reduce GHG emissions.
	External:	Signed memorandum of understanding with Indonesia on environmental cooperation; will include assessment of ecostrategies for carbon fixating such as forest management, development of GHG emissions inventories, and emissions reduction scenarios.
Pakistan	Internal:	1. Plans to prepare a study on climate change and its impacts on Pakistan.
		2. Participating in ADB project to develop regional strategy to address the effects of climate change (includes country studies on potential effects; national response strategies; and possible policy options to reduce net emissions and adapt to climate change).

		3. Participant country in proposed UNDP/GEF project on least-cost emissions reduction.
Panama	No studies	
Philippines	Internal:	1. Participating in ADB project to develop regional strategy to address the effects of climate change (includes country studies on potential effects; national response strategies; and possible policy options to reduce net emissions and adapt to climate change). 2. Participant country in proposed UNDP/GEF project on least-cost emissions reduction.
Poland	Internal:	1. Completed two preliminary emissions inventories. 2. Cooperative study in progress with the United States on emissions inventory and emissions reduction options. 3. Participant country in UNEP/GEF project on GHG sources and sinks. 4. Several preliminary impacts studies completed or underway. 5. National studies underway on response strategies in fuel producing and consuming sectors.
Romania	Internal:	1. Completed several modest studies on impacts, and plans to continue studies. 2. Completed initial inventory of GHG emissions and preliminary assessment of policy options for emissions reductions, financed by the United Kingdom.
Russian Federation	Internal:	Completed preliminary inventory of CO_2 and CH_4 emissions.
Saint Lucia	No studies	
Saudi Arabia	Internal:	1. Emissions inventory underway. 2. Limited studies being developed concerning climate impacts assessment and response strategies.
Senegal	Internal:	1. Participant country in UNEP/GEF study on GHG sources and sinks. 2. Study on inventory of GHG emissions sources being undertaken, coordinated, and funded by France.

Seychelles	Internal:	Impacts assessment completed.
South Africa	Internal:	1. South African Global Change Programme established to coordinate research on global climate change in southern Africa. 2. Interdepartmental Coordinating Committee for Global Environmental Change has studied local impacts of global climate change, and will draft future policy accordingly.
Spain	Internal:	Preparation of a National Climate Program initiated.
Sri Lanka	Internal:	Participating in ADB project to develop regional strategy to address the effects of climate change (includes country studies on potential effects; national response strategies; and possible policy options to reduce net emissions and adapt to climate change).
Sweden	Internal:	1. Completed emissions inventory for 1988–89. 2. Completed emissions inventory for 1990, as well as an impacts analysis and a preliminary assessment of emissions reduction measures. 3. Conducting analysis of emissions reduction and associated costs. 4. Completed a survey on future climate change in the Nordic region.
Switzerland	Internal:	Preparing a national strategy on measures to stabilize and reduce GHG emissions from key sectors, including emissions inventory and impacts assessments.
	External:	1. Financial assistance has been made available to assist developing countries to address global environmental problems. 2. Contributed 120,000 Swiss francs (approximately $85,000) in 1991–92 to support IPCC country study activities. 3. Impacts and mitigation studies for developing countries, with the assistance of SPREP, are under consideration.
Tanzania	Internal:	1. Initiating a collaborative study with Zimbabwe (with financial assistance from Canada) on emissions, development strategies, and policy options in Tanzania and Zimbabwe. 2. Participant country in UNEP/GEF project on GHG sources and sinks.

Thailand	Internal:	1. Initiated a national study on emissions control measures and alternative energy scenarios, and international interaction. 2. Completed cooperative study with UNEP on potential socioeconomic effects of climate change in Indonesia, Malaysia and Thailand. 3. Assistance from ADB is expected for a detailed effects study. 4. Participant country in proposed UNDP/GEF project on least-cost emissions reduction.
Togo	No studies	
Tonga	Internal:	Study on effects of sea-level rise completed with technical and financial assistance from Japan.
Tunisia	Internal:	Preliminary study on sector impacts and response strategies.
Turkey	Internal:	1. Climate change studies underway through National Climate Coordination Group (NCCG). 2. National reports by two subgroups of NCCG completed.
Tuvalu	Internal:	Preliminary study underway to design and implement comprehensive climate change study through ASPEI, UNEP, and SPREP.
Uganda	Internal:	1. Prepared proposal for sector studies on emissions, impacts, and cost-benefits of response options; project requires external funding. 2. Participant country in UNEP/GEF project on GHG sources and sinks.
United Kingdom	Internal:	Produced or commissioned a number of national studies on emissions, effects, and emissions reduction options and costs.
	External:	1. Undertaking impacts studies in cooperation with Kenya, Ghana, and the Organization of Eastern Caribbean States. 2. Offered assistance to Indonesia and Zimbabwe for impacts studies. 3. Discussing funding of an impacts study in India with the World Bank. 4. Discussing with UNEP possible involvement in UNEP/ Risø program on emissions abatement costs.

		5. Funded initial inventory of GHG emissions in Romania.
United States	Internal:	Produced or supported numerous national studies on emissions, impacts, emissions reduction options, and costs and benefits of response strategies to provide the foundation for the U.S. Climate Action Plan.
External:		1. Supported numerous cooperative studies in developing countries and European countries in transition on impacts, emissions inventories, technology assessments, and emissions reduction cost assessments. 2. Offered technical support to Brazil, Mexico, and Poland for development of inventories of GHG sources and sinks, and additional support to Poland for assessment of technical options and strategies to limit emissions. 3. Committed to provide $25 million over a two-year period to support climate change country studies by developing countries and economies in transition.
Uruguay	Internal:	1. No national studies. 2. Few studies at the sub-regional level on climate change and socioeconomic impacts.
Venezuela	Internal:	1. Preliminary inventory of GHG sources and sinks completed. 2. Participant country in UNEP/GEF project on sources and sinks. 3. Potential participant in impacts and mitigation study under SPREP, through GEF financing.
Viet Nam	Internal:	1. Study on vulnerability to climate change and sea-level rise completed through UNEP. 2. Completed cooperative study with UNEP on potential socioeconomic effects of climate change in Viet Nam. 3. Participating in ADB project to develop regional strategy to address the effects of climate change (includes country studies on potential effects; national response strategies; and possible policy options to reduce net emissions and adapt to climate change). 4. Participant country in proposed UNDP/GEF project on least-cost emissions reduction.

Yugoslavia	Internal:	Preliminary assessment of GHG emissions and sinks underway.
Zaire		No studies
Zimbabwe	Internal:	1. Initiating a collaborative study with Tanzania (with financial assistance from Canada) on emissions, development strategies, and policy options in Tanzania and Zimbabwe. 2. Developing proposal for sectoral climate change impacts assessments. 3. United Kingdom has offered assistance in the preparation of impacts studies, including cost issues. 4. Denmark has funded national GHG abatement costing study through UNEP/Risø program.

Criteria for Review and Assessment of GHG Inventories

Methodology

- Promote the use of a method with disaggregation on a level of detail that is necessary for national policy-making.
- Recommend the IPCC methods, but national methodologies are acceptable provided assumptions are set out and scientifically defensible, and provided that the reporting categories used are consistent with the IPCC methodology.
- Use standard industrial units.
- Differentiate between countries with respect to the importance of different sources and sinks.
- In setting a unit for the emissions factor CO_2, treat total C as CO_2 in mass units per Tera Joule (one Tera Joule equals 10_{12} Joule) of energy input.
- Specify whether the degree of carbon oxidation and/or sequestration is taken into account. If so, use specific, clearly distinguishable factors, allowing for adjustments.
- Clearly define industrial process emissions of CO_2.
- Promote regional and domestic studies (measurements of emissions factors, and so on). Such scientific studies should be published, made internationally available, and referenced in the report. Emissions factors recommended by the IPCC should be used if better documentation is not available.
- Establish the role of sources and sinks in the natural cycles of gases.
- Apply a method that makes it easy to update the inventory and compile time series.
- Help improve the IPCC method based on experiences from the application of the method.

Documentation requirements

- Specify which methods for estimation of emissions and sinks are applied. If methods other than the recommended IPCC method are applied, the emissions inventory should be accompanied by a description of the methods used, with discussion of the differences between own method and that recommended by the IPCC.
- Give references sufficient for a reconstruction of the source and sink data.
- Discuss and account for the selection of emissions factors when the factors are different from those recommended in the terms of reference.
- Clarify whether CO_2 emissions are based on the total amount of carbon in fuel, or the degree of oxidation being taken into account.
- Report a complete set of activity data and other applied parameters needed for replication.
- Explicitly account for assumptions regarding boundaries.
- Present energy data unambiguously in Tera Joules (input) for a calendar year.
- Use the International Energy Agency energy balance conventions and definitions for presentation and reporting of the energy data.
- Present sub-categories of energy use that are necessary for CH_4 and NO_2 calculations.
- Report energy data for non-commercial energy sources such as biofuels.
- Explain any significant differences between the data sets that are used on a national level, and those published by the United Nations or the OECD/International Energy Agency. If corrections to official statistics are made or if unpublished data are used, account for it clearly.
- Encourage countries to use both a bottom-up and a top-down method (such as the IPCC for CO_2). Account for any differences between the results obtained.
- Account for the roles of the estimated sources and sinks in the natural cycles of gases.

Report formatting requirements

- Specify gases to be included (gases with direct effect on climate and gases with indirect effect, including halogenated hydrocarbons not regulated by the Montreal Protocol (see chapter 2)).
- Reference year and time intervals.
- Emphasize the requirement for a common set of source and sink categories (identical definitions among countries). Use the source sector split as identified in the IPCC method (Annex C of OECD, 1991a) for reporting of emissions from energy combustion. When further detail might be necessary for industry, International Standard of Industrial Classification categories should be used as far as possible to report industrial emissions.

- Be explicit when different definitions are used, and indicate any important similarities and discrepancies.
- When reporting emissions, present units in a full molecular mass basis in metric units per year (for instance, CO_2 and not C, NO_2 and not N, in Giga Joules per year).
- Clearly document the calculation method (all parameters and the time horizon) if gases are expressed in CO_2 equivalents.
- Include a standard summary for overview and comparison.
- Report emission factors at the same level of detail that is applied in the standard recommended methodology.
- Provide details on the range of uncertainty and explain how the range was derived.

Biological Effects of Climate Change on Natural Ecosystems—Overview of Major International Research Programs

This appendix presents some major international research programs concerned with the biological effects of climate change on ecosystems.[3] Programs aimed strictly at environmental monitoring are not included.[4] The first section deals with programs coordinated by organizations linked to the International Council of Scientific Unions (ICSU). Then activities within the framework of the United Nations are described, followed by some programs based in Europe. The North Atlantic Treaty Organization (NATO) Science Program is also briefly introduced.

International Geosphere-Biosphere Programme (IGBP)

The International Geosphere-Biosphere Programme (IGBP) is an inter-disciplinary research endeavor being conducted within the framework of ICSU. Along with the World Climate Research Programme (WCRP) and other international research efforts, it addresses critical unknowns related to global environmental change. The IPCC has identified IGBP and WCRP as the two major research programs devoted to shedding light on man's relation to global climate change. The WCRP is concerned with physical aspects of the climate system and is thus not included here.

The ICSU initiated detailed planning for the IGBP in late 1986 and appointed a special committee to guide the planning and implementation of the program. To provide for joint planning and coordination with bodies of the United Nations, an interagency coordinating committee has been formed with the participation of UNEP, the United Nations Educational, Scientific, and Cultural Organization (UNESCO), and WMO.

A secretariat for the IGBP at the Royal Swedish Academy of Sciences supports planning and implementation and provides a focal point for communication and coordination. The secretariat publishes the findings of planning group deliberations in a series of IGBP reports as well as in its newsletter, *Global Change*.

The IGBP's objective is to describe and understand the interactive physical, chemical, and biological processes that regulate the biosphere, the unique environment that is provided for life forms, the changes that are occurring in this system, and the manner in which they are influenced by human activities.

For practical reasons, the research is based on several core projects. The IGBP initially defined a number of research questions, within which the core projects were developed (IGBP 1990). The core projects are organized into foci, activities, and tasks.

The IGBP is inter-disciplinary and most of its core projects include some biological research. The Global Change and Terrestrial Ecosystems (GCTE) project, described broadly below, is the most important core project involving biological research. Other relevant core projects, which are briefly described here, include:

- Joint Global Ocean Flux Studies (JGOFS)
- Biosphere Aspects of the Hydrologic Cycle (BAHC)
- International Global Atmospheric Chemistry (IGAC)
- Global Ocean Euphotic Zone Study (GOEZS)
- Land Ocean Interactions in the Global Coastal Zone (LOICZ)
- Global Analysis, Interpretation, and Modelling (GAIM).

Global Change and Terrestrial Ecosystems (GCTE)

The information in this section is drawn from the GCTE Operational Plan (IGBP 1992).

The objectives of the GCTE are:

[3] This appendix builds on chapter 2 of the Global Change and Terrestrial Ecosystems/CICERO report entitled, "Biological Effects on Climate Change—An Introduction to the Field and a Survey of Current Research," by Gørill Kristiansen. The main report, which may be obtained from CICERO, includes a brief scientific review, research on biological effects in thirteen selected countries, as well as extensive lists of contacts for each project described.

[4] For a survey of monitoring programs, see *A Survey of Environmental Monitoring and Information Management Programs of International Organizations*, published by the UNEP-HEM office in April 1991 (second edition).

- To predict the effects of changes in climate, atmospheric composition, and land use on terrestrial ecosystems, including agricultural production and forest systems
- To learn how these effects lead to feedbacks in the atmosphere and the physical climate system.

GTCE's four foci are:

1. Ecosystem physiology;
2. Change in ecosystem structure;
3. Global change impact on agriculture and forestry; and
4. Global change and ecological complexity (proposed).

The first two foci are designed to provide a fundamental understanding of the impacts of global change on ecosystem function, composition and structure, and their feedback effects. The third and the proposed fourth foci are designed to examine the more specific impacts of global change on systems of great importance to humans—the production of food and the earth's biological diversity and complexity. Focus 3 is, however, beyond the scope of the present report and is excluded from the following description. Yet Focus 3 is closely related to work on more natural ecosystems—its modelling component is closely linked to the rest of the GCTE modelling through a network of centers for Long-term Ecosystem Modelling Activity (see Focus 2A).

Focus 1: Ecosystem physiology

The primary aim of Focus 1 is to understand and model the effect of global change on primary ecosystem processes, such as the exchange of energy, water, and trace gases with the atmosphere, element cycling and storage, and biomass accumulation or loss.

Activity 1.1: *Effects of elevated CO_2.*

This activity recognizes the critical need for information concerning ecosystem-level interactions between CO_2 and other resources, especially nitrogen and water, and for experiments that explore the suite of ecosystem feedbacks, including changes in soil nutrient availability and in grazing by animals.

Here the long-term objective is to determine and predict the effects of elevated CO_2 interacting with other environmental factors, on ecosystem physiology at the patch scale (10 to 100 meters), and to investigate potential feedback to the atmosphere.

Short-term objectives:

- To assess whether terrestrial ecosystems will serve as a source or sink of carbon under elevated CO_2 alone, and in combination with other environmental changes
- To determine, through case studies, how CO_2 enhancement will affect ecosystem productive capacity through alterations of such processes as plant-pest interactions, nitrogen mineralization, and water-use efficiency.

Task 1.1.1: Whole-ecosystem experiments by Free Air Carbon Dioxide Enrichment (FACE).

Task 1.1.2: Integrating experiments on ecosystem CO_2 response.

Activity 1.2: Changes in bio-geochemistry.

The overall emphasis of the bio-geochemistry activity is the terrestrial regulation of element pools, transformations, gains, and losses as they are altered by the components of global change.

The long-term objective is to determine the interactive effects of land use, altered atmospheric composition, and climate change on the biogeochemical cycles of carbon, nitrogen, and other elements.

The more immediate objectives are specific to each of the three regions, identified in the following three tasks.

Task 1.2.1: Humid tropical forests undergoing land-use change.

The short-term objective is to determine the effects of land clearing and agricultural intensification on quantities and pathways of carbon and nutrient loss (and their regulation) in several humid tropical regions.

Task 1.2.2: High latitude systems.

The short-term objective is to determine the interactive effects of increased temperature and changes

in nutrient availability on carbon and nutrient pools, and fluxes across the transition from boreal forest to tundra.

Task 1.2.3: Semi-arid tropical ecosystems.
The short-term objective is to determine the interactive effects of altered precipitation patterns and changes in land use (especially grazing and fire frequency) on the bio-geochemistry of semi-arid tropical systems along a moisture gradient.

Activity 1.3: Effects of changes in vegetation on water and energy fluxes.
This is to be conducted jointly with the BAHC. Modelling evaporation from land surfaces in the context of General Circulation Models (GCMs) requires knowledge of the bulk surface conductance for water vapor transport, which determines the partitioning of energy into sensible and latent heat. This strongly affects continental hydrological cycles, including evaporation, exchange between surface and groundwater, and surface water runoff. The bulk surface conductance is determined by both the structure and the stomatal properties of the vegetative cover, together with the evaporative properties of the soil surface. The vegetation canopy responds readily to changes in climate and to soil water availability. Evaporation from land surfaces can be modelled in soil-vegetation-atmosphere - transfer models as a sub-model of GCMs only if the bulk surface conductance is taken into account. Knowledge of bulk surface conductance is also important for the water balance of ecosystems and its nutrient and carbon fluxes, which in turn feed back to influence vegetation structure and stomatal conductance. The aim of this activity is to quantify bulk surface conductance, which combines stomatal regulation and physical structure of the vegetation to determine terrestrial evaporation.

Task 1.3.1: Bulk surface conductance.
The long-term objective is to develop the capability to predict the effects of vegetation changes on water and energy fluxes between land surfaces and the atmosphere, particularly the changes in bulk surface conductance with season, succession, and long-term CO_2 increase.

Short-term objectives:

- To quantify, as far as possible, bulk surface conductance from the major biomes of the earth, from data in the literature
- To assess accuracy and spatial representation on requirements for current and foreseeable models of bulk surface conductance, to set parameters on land surfaces in GCMs, and to investigate ecosystem responses to climate or composition changes
- To develop a patch-scale model of bulk surface conductance based on plant physiological mechanisms and the physics of transfer through the soil-plant-atmosphere continuum, accounting for the responses of bulk surface conductance to climate factors (light, vapor pressure deficit, soil water availability, and nutrition)
- To extend the available data on bulk surface conductance by means of appropriate ground-based measurements
- To develop the capability for inferring bulk surface conductance from remotely sensed data.

Activity 1.4: Integrating activities.
Global change will lead to the simultaneous alteration of a number of environmental variables. The whole-system CO_2 enrichment studies, the gradient studies in critical regions, and the water and energy flux studies to be conducted in Focus 1 are designed to provide insights into how global change will affect key ecosystem processes involved in the carbon balance, nutrient dynamics, and hydrologic cycling. The final requirement in Focus 1 is to integrate these changes to predict the net effect of their simultaneous actions. Task 1.4.1 undertakes this integrating effort, while Task 1.4.2 develops a better understanding of terrestrial ecosystems in the global carbon cycle.

Task 1.4.1: Integrated models of ecosystem physiology under global change.
The long-term objective is to develop and improve integrated carbon, nutrient, and water models at the patch scale to predict how global change will affect the physiology of terrestrial ecosystems in the timeframe of a few decades to a century.

Short-term objectives:

- To develop linked plant-soil models of carbon, nutrient, and water interactions at the patch scale to operate at time scales ranging from days to decades
- To use the models to predict the consequences of resource changes (CO_2, nutrients, water) for carbon fluxes and storage in conjunction with CO_2 enrichment experiments and gradient studies in the critical regions identified by the GCTE—semi-arid tropics, wet tropics, and tundra/boreal regions
- To incorporate the multiple-resource patch-scale models into the development of the patch-scale models of change in ecosystem structure and composition described in Activity 2.1.

Task 1.4.2: Carbon pools and fluxes in terrestrial ecosystems.
The objective is to understand and model the emissions and sequestration of CO_2 by terrestrial ecosystems for global carbon models.

Focus 2: Changes in ecosystem structure
Among the driving forces of global change, the most important for determining the distribution and performance of organisms are:

- The range and seasonality of temperature, precipitation, and other environmental factors
- The intensity and frequency of severe episodic events, such as fires and hurricanes
- For much of the earth, the group of demographic, economic and social pressures related to human activities.

These factors, combined with physiological responses such as sensitivity to high CO_2, longevity, and ability to disperse, will determine the future structure of the world's ecosystems.

The goal of Focus 2 is to model this complex set of impacts and responses so that the pattern of change in ecosystem composition can be predicted.

The ability to predict changes in ecosystem structure and composition is being developed for two distinct purposes:

- To predict the impacts of global change on terrestrial ecosystems in their own right (for example, independent of feedbacks to the atmosphere). If human societies are to adapt and perhaps benefit from global change, then we must be better able to predict what will happen to the terrestrial ecosystems on which we depend. Thus, much of the emphasis of Focus 2 will be on the development of a nested set of impacts models to predict changes in ecosystem structure at a wide range of scales, from patch to landscape to region. In addition, it is essential that models are developed for all the major biomes on earth.
- To build a dynamic global vegetation model that will capture the feedback effects that changes in ecosystem structure and function will have on further atmospheric changes, and which can be linked to the GCMs that predict future climate. At present, the only global models predicting vegetation distributions are static and thus not capable of forming an interactive component in GCMs. GCTE aims to produce a mechanistically-based dynamic model of global vegetation for incorporation in GCMs.

Activity 2.1: Patch-scale dynamics.
A mechanistically-based prediction of the effects of global change on structure and composition of communities can be achieved only by understanding processes. Central to this predictive ability will be the development of one or more models of patch dynamics, which will be both the nucleus of this activity and the basis for integrating over large areas such as landscapes and regions.

Task 2.1.1: Global key of plant functional types.
It will not be feasible to develop models for every ecosystem of the globe, nor represent every species within those ecosystems. Thus the concept that the complexity of nature can be reduced in models by treating a smaller number of functional types is central to the work of Focus 2.

The long-term objective is to develop a general classification system of plant (and eventually animal) functional types appropriate for predicting the

dynamics of change in ecosystem structure due to the impacts of global change.

Short-term objectives:

- To review the current state of knowledge of the functional type approach on a global scale
- To elucidate the ecological constraints and trade-offs in morphological and physiological attributes that define morphological types
- To initiate case studies where a functional type approach can be tested and assessed.

Task 2.1.2: Experiments on ecosystem structure and function.
The objective is to identify (and, so far as possible, quantify) the important mechanisms that link change in ecosystem function to change in ecosystem structure, and vice versa.

Task 2.1.3: Patch models of ecosystem dynamics.
The long-term objective is to develop patch models of ecosystem dynamics for global application, incorporating mechanistic information on the responses of plant processes to global change, and the influence of these responses on ecosystem structure. The short-term objective is to develop models of patch dynamics for two study sites based on the approach in Focus 2, and on the ecosystem structure and function experiments.

Activity 2.2: Models from patch to region.
The goal of this activity is to build on experimental and modelling efforts elsewhere in GCTE to develop a suite of models, from patch through landscape to region. These models will be specifically designed to understand and predict the impact of global change on ecosystems.

Task 2.2.1: Ecosystem dynamics from patch to region, based on change in climate and atmospheric composition.
The long-term objective is to develop a suite of models of climate- and atmosphere-driven ecosystem dynamics, based on patch models and incorporating landscape effects, on scales relevant to management decisions.

The short-term objective is to establish, via Long-term Ecosystem Modelling Activity centers (LEMA), a core of modelling groups operating at the landscape level, and develop agreed model protocols to meet GCTE requirements.

Task 2.2.2: Ecosystem dynamics from patch to region, based on change in land use.
The objective is to develop, in collaboration with Focus 3 and the Human Dimensions of Global Environmental Change (HDGEC) project, spatially explicit models of land-cover change, and to determine the effects of these land cover changes on ecosystem structure, composition, and function.

Activity 2.3: Regional-to-global models of vegetation change for element cycles and climate feedback.
At present no mechanism exists for incorporating the feedback of a changing land surface in a dynamic, interactive way into global models of the physical climate system or of the bio-geochemical or hydrological cycles. Global vegetation is assumed to be static. However, as a result of global change, the earth's distribution of vegetation will change, and this will affect the climate. The ultimate goal of this activity is to develop appropriate dynamic models that can be used to calculate direct feedback through changes in surface conductance, albedo, and surface roughness, and indirect feedbacks through changes in bio-geochemical cycles.

Task 2.3.1: Static models of global vegetation change.
The objective is to improve methodologies for directly scaling up predictions of vegetation distribution from patch to globe.

Task 2.3.2: Dynamic global vegetation model.
The objective is to develop a dynamic model of change in global vegetation that can be linked to GCMs.

Focus 2A: Integrating activities
GCTE's objectives in establishing a network of LEMA centers are to:

- Facilitate collaborative research, particularly in the development and improvement of models essential to the GCTE program
- Focus the international modelling effort on a coherent and mutually agreed set of objectives

- Synthesize GCTE results into a set of robust models designed to meet GCTE objectives
- Provide feedback to experimental efforts as priorities for model parameters, investigation of additional phenomena, and needs for model testing information arise.

LEMA centers will facilitate the entire GCTE modelling effort, across all foci.

Focus 3: Global change impact on agriculture and forestry

As mentioned earlier, this focal area is beyond the scope of this report.

Focus 4: Global change and ecological complexity (proposed)

Complexity is viewed as the suite of species interactions within an ecosystem. It includes the diversity of species, their connectivity, and spatial diversity (patchiness). Connectivity, unlike species diversity, is considered to change with scale because it incorporates such effects as variations in landscape structure and migration. This focus is therefore designed to understand and determine the importance of species diversity and ecosystem complexity as they relate to the dynamic responses of ecosystem function to environmental change. It is also necessary to consider the reverse response—the influence of changes in ecosystem function on diversity and complexity. These broad considerations are important to an overall understanding of climate change and they underlie the missions of such interest groups as the World Conservation Union (IUCN, formerly called the International Union for the Conservation of Nature and Natural Resources).

A specific issue to be considered is environmental change and the vulnerability of species diversity in wildlife reserves. Such reserves are typically on isolated lands and will be vulnerable to environmental change because of disrupted migration networks.

Global Change and Ecological Complexity was originally proposed as a separate IGBP core project (IGBP 1990) and has only recently been incorporated within GCTE as a proposed Focus 4. The operational plan for Focus 4 will be developed in detail in 1993 and published in 1994. A draft operational plan was made available at an IGBP conference in January 1993 (SAC III, Ensenada, Mexico). The following information was drawn from the draft plan. Activities and tasks, which may later be reorganized, are discussed below.

Activity 4.1: Relationships between ecological complexity and ecosystem function.
The aim is to define relationships between species diversity, complexity, connectivity, and selected processes for a range of major ecosystems. The final structure of this activity and Activity 4.2 will evolve in collaboration with the SCOPE (Scientific Committee on Problems of the Environment) component of the Diversitas program.

Task 4.1.1 Manipulative experiments on complexity and function.
The objective here is to determine through manipulative experimentation the effect of changing complexity on function, and vice versa, for a number of ecosystems.

Task 4.1.2: Models of complexity and function.
This task aims to construct theoretical models that simulate the complexity (diversity and connectivity) of real ecosystems and relate change in complexity to change in function.

Activity 4.2: Interactive effects of global change on ecological complexity and on the relationship between complexity and ecosystem function.
The aim is to examine how the interactive effects of global change will alter ecological complexity, and how this in turn will lead to changes in function.

Task 4.2.1: Experimental and observational studies.
The objective is to determine by experimentation and observation the impacts of various kinds and combinations of global change on ecological complexity, and on the relationships between complexity and ecosystem function.

Task 4.2.2: Modelling impacts of global change on complexity and function.
Here the objective is to develop predictive models of the complexity-function relationship under conditions of global change.

Task 4.2.3: Complexity and function under global change: feedbacks to further change.
The objective is to determine and quantify whether global change impacts on ecological complexity and on the relationship between complexity and ecosystem function will lead to further global change.

Activity 4.3: Consequences of global change for the viability of isolated populations.

Task 4.3.1: Habitat fragmentation, land-use and land cover change and population viability.
Here the objective is to develop, refine and verify models to predict the viability of isolated plant and animal populations under different scenarios. Changing variables include total population, differing life histories, and differences in the isolated habitat fragments on which the populations live. An effort would be made to explore the role of inter-patch migration in maintaining biodiversity in rapidly changing landscapes.

Task 4.3.2: Interactive effects of habitat fragmentation and climate change.
The aim is to examine and model the implications of climate change for maintenance of biological diversity and connectivity in isolated habitat patches set in a variety of landscapes.

Activity 4.4: Complexity, function and global change: regional and global synthesis.
The aim of this activity is to extend this information geographically to build up scenarios of change in ecological complexity, and its implications, at regional and global scales.

Task 4.4.1: Identification of areas of functional sensitivity.
The objectives are twofold:

- To develop and promulgate general methodologies for identifying areas, functional types, and species most at risk from global change
- To determine and map the regions of the world where loss of ecological complexity is most likely to lead to significant changes in ecosystem function.

Other IGBP core projects

This section briefly introduces JGOFS, BAHC, IGAC, GOEZS, LOICZ, and GAIM. For further information, consult IGBP Report Number 12 (1990).

Joint Global Ocean Flux Studies (JGOFS)

The JGOFS is primarily concerned with assessing and understanding carbon flows in the ocean and across its boundaries, both now and in the future. "In principle, this would include understanding the biological effects of climate change in the ocean, because there is potential for strong biological feedback on oceanic carbon transport. However, due to resource constraints, the JGOFS project will concentrate on assessing the present carbon fluxes and their first-order (physical-chemical) changes. It is quite possible, though, that individual research projects within JGOFS will address biological responses and feedback as well, and such extensions are to be welcomed when they occur." (G.T. Evans, JGOFS Executive Scientist).

Biosphere Aspects of the Hydrologic Cycle (BAHC)

The BAHC expresses biological relevance by examining how plant communities and ecosystems—in combination with land topography—affect the earth's water cycle.

The sub-objectives are:

- To determine the biospheric controls of the hydrologic cycle through field measurements for the purpose of developing models of the energy and water fluxes in the soil-vegetation-atmosphere system at temporal and spatial scales, ranging from vegetation patches to GCM grid cells
- To develop and implement a long-term commitment to observations designed to test the results of global change modelling of the interactions between the biosphere and the physical earth system in relation to the hydrological cycle.

International Global Atmospheric Chemistry (IGAC)

IGAC was initiated by the IAMAP Commission on Atmospheric Chemistry and Global Pollution, and its science plan was developed by an extensive group of atmospheric scientists at a workshop in 1988. It was later accepted and incorporated as an IGBP core

project. While there was a strong perception at the workshop that biological interactions with the atmosphere would have to be an essential component of the research activities of the IGBP, it was felt that the biological and ecological community was not sufficiently well represented to formulate the biological component of the overall research program. Efforts have therefore been made to establish close links to biological research by, for instance, arranging joint workshops (see IGBP Report Number 13).

The objectives are:

- To develop a fundamental understanding of the processes that determine the chemical composition of the atmosphere
- To understand the interactions between atmospheric chemical composition and biospheric and climatic processes
- To predict the impact of natural and anthropogenic forcing on the chemical composition of the atmosphere.

Global Ocean Euphotic Zone Study (GOEZS) and Land Ocean Interactions in the Global Coastal Zone (LOICZ)

It is expected that GOEZS and LOICZ will provide major contributions to our understanding of marine and coastal ecosystems in relation to global change. The objectives of these core projects are, respectively:

- To develop a predictive understanding of the basic relationships among the physical, chemical, and biological properties of the oceanic euphotic zone
- To develop a predictive understanding of the effects of changes in climate, land use, and sea level on the global functioning and sustainability of coastal ecosystems, with emphasis on the interactions between changing conditions on land and sea, and on possible feedback effects on the physical environments.

A science plan for LOICZ has recently been developed, and it will be published in the near future as IGBP Report Number 23. GOEZS still remains a proposed core project. The main implementation phase is planned to commence in 1998. Active planning, including the development of models and instruments, may be initiated as early as 1994.

Global Analysis, Interpretation, and Modelling (GAIM)

This proposed core project has been developed into a task force supervised directly by the Scientific Committee of IGBP. GAIM is undertaking a series of specific tasks and its action plan for 1993–1995 will be published shortly as IGBP Report Number 26.

GAIM's broad objective is to synthesize, with the aid of models, a fundamental quantitative understanding of the global physical, chemical, and biological interactions in the earth system during the past 100,000 years, and assess possible effects of future natural and/or man-induced changes.

Scientific Committee on Problems of the Environment (SCOPE)

The Scientific Committee on Problems of the Environment (SCOPE) program for 1992–1995 is concerned with global change issues. It consists of four elements, all of which interact with a sustainable biosphere component:

- Sustainable development
- Bio-geochemical cycles
- Health and eco-toxicology
- Global change and ecosystems.

The global change and ecosystem component includes four streams of study:

- Climate change and coniferous forests and grasslands
- Ultra-violet B effects on biological systems
- Ecosystem function of biodiversity
- Dynamics of woody plant-grass systems (to be launched in 1994).

SCOPE's primary function is "to evaluate and assess current knowledge by producing updated reports and books, and by arranging workshops on environmental issues," (Véronique Plocq-Fichelet, SCOPE Executive Director). SCOPE collaborates with other research efforts, for example, SCOPE's

synthesis and analysis are being used by GCTE in the development of its research program.

SCOPE is involved in two specific programs that are relevant for biological effects of climate change: the International Sustainable Biosphere Initiative (ISBI) and Diversitas, a joint program involving the International Union of Biological Sciences (IUBS—a member organization of ICSU).

International Sustainable Biosphere Initiative (ISBI)

ISBI grew out of the Sustainable Biosphere Initiative, an ecological research agenda for the 1990s proposed by the Ecological Society of America. Consequently, ISBI has been adopted by SCOPE. ISBI's research focuses on diversity and sustainability, sustainability in a changing biosphere, and human dimensions of sustainability.

The broad research issues of sustainability in a changing atmosphere are set out below, but only as examples indicating that new information is needed—from the micro to the regional level—to solve problems related to global change (see Huntley et al. 1991).

Assessing the state of the biosphere. The goal is to document the present state of the earth's biotic systems and the factors controlling the rate and direction of change. The following questions should be asked:

- How can the status of the earth's biotic resources be monitored over time?
- What are the climatic controls of the growth of organisms at regional scales, and of interactive controlling elements such as salinity, pollutants, and CO_2? How can these be quantified?

Responses and feedbacks of biotic systems to change. The goal is to develop the information needed to assess the responses and feedback of biotic systems to global change. Here, the questions are:

- What are the responses of organisms and whole ecosystems to multiple stress factors, including ultra violet-B, enhanced CO_2, elevated temperature, climate change, and pollutants, and how will these responses influence atmospheric projections?
- How will the controls of distribution, abundance, and productivity of organisms be altered in the context of a rapidly changing environment?
- What are the effects of ecosystem degradation or eutrophication in the past and present, and how can this knowledge guide habitat management and restoration measures?

Synthesis and modelling. The goal is to develop approaches for synthesizing information from various disciplines, at different scales, in order to understand how the earth system functions. The questions are:

- What new approaches are available to improve the linkage of information between various scales of research (for example, ecosystem change models linked with GCMs)?
- What methods (such as remote sensing) can be used to interpret patterns on a broad scale in terms of processes operating at finer scales?
- What new approaches can be used for integrating information from the level of the individual organism with that of the ecosystem?

IUBS-SCOPE-UNESCO Programme on Ecosystem Function of Biodiversity—Diversitas

The goals of Diversitas are to identify scientific issues and promote research projects that require international cooperation in investigating four areas: ecosystem function and biodiversity; the origins and maintenance of biodiversity; monitoring and taking inventory of biodiversity; and the biodiversity of wild relatives of cultivated species.

Questions to be asked in these four areas are:

- *The ecosystem function of biodiversity.* This area will require answers to the following questions: How is system stability and resistance affected by species diversity and how will global change affect these relationships? What is the role of biodiversity (species and landscapes) in ecosystem processes (such as nutrient retention, decomposition, and production) including feedbacks, over short- and long-term spans and in the face of global change (climatic change, land-use change, and invasions)?

This component will be undertaken by SCOPE, and will be linked directly to Focus 4 of GCTE. The operational plan for Focus 4 will rely strongly on the SCOPE analysis.

- *The origins and maintenance of biodiversity.* The conceptual framework and research hypotheses for this theme were identified at the Harvard Forest Workshop. The study of biodiversity at the intra-specific genetic and population levels, including research on speciation and extinction, represents an important step for understanding diversity at higher levels. Also, it is important to distinguish clearly between local and global extinctions, and to discern the management issues implied by such distinctions.
- *Monitoring and taking inventory of biodiversity.* This task carries formidable problems, including technical problems related to estimating the number of species and their distribution. These problems are compounded by the worldwide shortage of trained taxonomists, which is felt especially in the tropical countries where much of the world's biodiversity is found. The actual sites for study will be chosen from (but not limited to) a selected number of Biosphere Reserves as identified by UNESCO's Man and the Biosphere (MAB) program.
- *Biodiversity of wild relatives of cultivated species.* Within the framework of the program, four sets of priority hypotheses and recommendations have been developed at the genetic, species-to-community, and ecosystems levels to deal with monitoring and inventory-taking of species diversity and of species changes around the world. (Younes 1991 and 1992).

The Role of Antarctica in Global Change

The Scientific Committee on Antarctic Research (SCAR), an inter-disciplinary ICSU body, has, in consultation with several interested international groups, developed a plan for a regional research program on the role of Antarctica in global change. This work has been closely linked to IGBP through an IGBP-SCAR Steering Committee, and will constitute the Antarctic research component of IGBP.[5] The committee identified four major interdisciplinary themes to define and encompass the research priorities of this Antarctic component:

- Detection of global change in Antarctica
- Study of the critical processes linking Antarctica to the global system
- Extraction of paleo-environmental information
- Assessment of ecological effects.

A draft version of the program implementation plan was finished in March 1992, and the following six Antarctic core projects were identified:[6]

1. The Antarctic sea-ice zone: interactions and feedback within the global geosphere-biosphere system
2. Global paleo-environmental records from the Antarctic ice sheet, and from marine and land sediments
3. The mass balance of the Antarctic ice sheet and sea level
4. Antarctic stratospheric ozone, tropospheric chemistry, and the effect of ultra-violet radiation on the biosphere
5. The role of the Antarctic in bio-geochemical cycles and exchanges: atmosphere and the ocean
6. Detection and monitoring of global change in Antarctica.

In Antarctica, the emphasis is naturally on biota in the ocean. Although it appears that biology is not a field of priority in this program, sub-areas of core projects 1 and 6 were identified as being relevant to this overview of major international research programs on climate change.

One of eight objectives within core project 1 is to determine the role of Antarctic sea ice in marine biotic systems. The Antarctic sea ice zone is a key habitat for marine biota. The biological activity has a strong annual cycle with a very productive spring

[5] The International Arctic Science Committee (IASC) is the Arctic counterpart of SCAR. The IASC is currently planning a global change program for the Arctic, corresponding to the SCAR Antarctic program. A planning workshop on a Regional Research Programme in the Arctic on Global Change was held by the IASC in Reykjavik, Iceland, April 22-25, 1992.

[6] At the time of writing, the implementation plan was in draft form not to be cited, quoted, or reproduced. The information above is, however, given with the approval of Dr. Gunter Weller, the lead author of the document. The detailed plan will be published in the near future.

and summer period. Changes in the timing and periodicity of the cycle as a result of climate and sea ice changes would affect the food chain and marine living resources. In particular, the presence and dynamics of sea ice influence the biological habitat and distributions of organisms at all trophic levels—the level of plants and animals, and the level of food web dynamics. Sea ice also influences the flux of carbon from the atmosphere to the deep ocean and its sequestration there.

To determine the biological role of sea ice, we need to understand how major changes in sea ice may affect physical, chemical, and biological relationships between the atmosphere, the water column, the benthos, and sediments. Two topics in the Antarctic sea ice zone system which need to be prioritized are:

- The factors controlling population dynamics, life cycles, and survival of the biota
- The nature of bio-geochemical cycles of carbon, nitrogen, phosphorus, and silicon in the sea ice, water column, and benthos.

Within core project 6, the sub-area of ecosystem sensitivity and indicator species specifically addresses biologically relevant questions. It emphasizes the sensitivity of communities in Antarctic ecosystems that may be manifested as a response in their physiology, life cycle, productivity, or as an influence on ecological processes.

The primary objective of this part of the program will be to identify key organisms, biological processes, and interactions that are most likely to be influenced by changes in the climatic regime of Antarctic marine and terrestrial ecosystems.

Global Ocean Ecosystem Dynamics (GLOBEC)
This is a program jointly sponsored by the Scientific Committee on Oceanic Research (SCOR, an interdisciplinary ICSU body); the Intergovernmental Oceanographic Commission (IOC, a UNESCO commission); and the International Council for the Exploration of the Sea (ICES, an intergovernmental organization).

GLOBEC is motivated by the need to understand how changes in the global environment will affect the abundance, diversity, and production of animal populations comprising ocean ecosystems, and also by the absence of a focus on the role of zooplankton in the IGBP. Zooplankton is a critical component in our understanding of bio-geochemical cycling. Variations in zooplankton dynamics may affect the biomass of many fish and shellfish stocks.

GLOBEC will consist of initiatives undertaken directly by the international program; by regional and national programs; and by associations with long-standing programs that are oriented toward the GLOBEC mission to develop scientific communication links and networks.

The goal of GLOBEC is to understand the effects of physical processes on predator-prey interactions and population dynamics of zooplankton, and their relation to ocean ecosystems in the context of the global climate system and anthropogenic change.

The strategy for building the GLOBEC core program is oriented toward the goal of investigating global ocean issues in zooplankton dynamics, the relation between zooplankton and primary production, and the relation between fish production and zooplankton in the context of understanding the effects of physical processes on population dynamics of zooplankton.

Man and the Biosphere (MAB)
MAB is an international UNESCO research program, based on national research initiatives. The program emphasizes the use of the multi-disciplinary approach to attain an improved understanding of the inter-relationships between ecological and social systems. MAB's general objectives are to further research in order to:

- Develop a basis for rational use and preservation of biospheric resources
- Develop a basis for improving the interaction between man and the environment
- Predict the consequences of today's actions on tomorrow's world and thereby improve man's ability to effectively manage biospheric resources.

There are several networks and sub-projects within the framework of MAB, some of which are relevant

to global change. Regarding the more narrow issue of the biological effects of climate change, the following International Tundra Experiment seems to be the most relevant activity.

International Tundra Experiment (ITEX)

In December 1990, forty-seven researchers from nine countries with interest in polar issues (Canada, Denmark, Finland, Iceland, Norway, the former Soviet Union, Sweden, the United Kingdom, and the United States) participated in a workshop to develop ITEX. The workshop was held after the MAB Northern Sciences Network recommended that MAB committees in all countries with expertise in tundra research should identify experts who could contribute to, and support, the development of ITEX. The Northern Sciences Network of the UNESCO-MAB Programme was established in 1982 to help stimulate national and international MAB-type interest in northern regions.

ITEX is a long-term Arctic research program. Its objectives are to monitor shifts in Arctic climate and vegetation due to ongoing global change, and to predict the direction and magnitude of such responses in the Holarctic realm. The project was designed to obtain ecological evidence about expected or ongoing changes in Arctic ecosystems due to global anthropogenic influences.

Plans are in place to set up large permanent plots in selected Alaskan, Canadian, Russian and Scandinavian tundra ecosystems. Field manipulations will be constructed to simulate expected climatic changes, shelters built to increase tundra temperatures, and snow fences set up to increase snow cover. Plant population and response variables including phenological traits, morphological traits, and performance measures will be monitored in control and experimental sites.

UNESCO/MAB and IUBS cooperativ projects

There are three other MAB programs of relevance in this context that have been undertaken in cooperation with IUBS:

- *Soil Fertility and Global Change.* This was initiated in 1984 and is now in a transition phase. A new research agenda is being formulated to address the interaction between soil and the atmosphere. Organizationally it is within the framework of UNESCO and the Tropical Soil Biology and Fertility Programme of the IUBS. Its aims are to stimulate research in the tropics, and in particular, on the inadequately understood topic of biological processes in the maintenance of soil fertility.
- *Savannah Modelling for Global Change.* This is a proposed continuation of the UNESCO/IUBS ten-year project, Responses of Savannahs to Stress and Disturbance, which started in 1983. The project aims at developing an understanding of the way tropical savannahs respond both to natural and to human stresses and disturbances.
- *The IUBS-SCOPE-UNESCO Programme on Ecosystem Function and Biodiversity.*

Intergovernmental Panel on Climate Change (IPCC)

The IPCC is an intergovernmental panel of scientific and technical experts assigned to assess the current understanding of the scientific aspects of climate change. IPCC will examine the environmental, social, and economic impacts of such change and formulate response options and strategies for different outcomes. Strictly speaking, it does not belong within this context of research program descriptions. However, the IPCC plays a central role in the overall climate research effort. Chapter 1 of this report draws heavily on the results of IPCC-related research.

Members of the IPCC were appointed in 1988 by UNEP and the WMO. Almost 1,000 researchers from sixty countries are engaged in IPCC work.

The results of a global assessment by IPCC were presented in three volumes, each one by a working group. The volumes that comprise the first IPCC assessment report (Houghton et al. 1990) are:

- Working group I: "Climate Change—The IPCC Scientific Assessment"
- Working group II: "Climate Change—The IPCC Impact Assessment"
- Working group III: "Climate Change—The IPCC Response Strategies."

The reports were discussed at the second World Climate Conference in Geneva in November 1990. The conference stressed in its statement the special need for increased research in general, and the importance of intensifying the activities of the WCRP and the IGBP.

To produce an update of the first assessment report, the IPCC decided at its fifth session (Geneva, March 1991) to focus on the six following tasks:

- Assessment of net GHG emissions (including GHG sources and sinks and global warming potentials).
- Prediction of the regional distributions of climate change and associated impact studies, including validation studies. Steps will involve an update of regional climate models and an analysis of sensitivity to regional climate change.
- Energy and industry related issues.
- Agriculture and forestry related issues.
- Vulnerability to sea-level rise.
- Emission scenarios.

The publication of the 1992 IPCC supplement (Houghton et al. 1992) completed the short-term work on these six tasks. Long-term work on the same tasks continues.

Commission of the European Community Environment Programme

The Commission of the European Community (CEC) Environment Programme (1991–1994) is aimed at contributing to the scientific and technical basis for the implementation of the European Community's environmental policy. It constitutes an extension and expansion of the current Science and Technology for Environmental Protection program and the European Programme on Climatology and Natural Hazards.

The Environment Programme is subdivided into four areas. The first (presented here) is participation in global change programs. Since the selection procedure for projects under the different topics is still underway, details about the subjects to be covered are not available. The goal is to contribute to the understanding of the processes governing environmental change, and to assess the impacts of human activities. The program will specifically address the following:

- The reduction of ozone concentration in the stratosphere as a consequence of the release of persistent, chlorine-containing molecules, such as CFCs
- The increasing concentrations of some trace gases and aerosols (such as volatile organic chemicals, photo oxidants, nitrogen oxides, and sulphur-containing molecules) in the troposhere that overload the mechanisms for cleaning the atmosphere, in particular, the oxidation pathways, thus enhancing the long-range transport of pollution
- The perturbations of bio-geochemical cycles through man-made emissions to soil and water bodies, direct or through atmospheric deposition, enhanced by such other factors as land use.

Consequences for human health and ecosystems are included by addressing such problems as the health and ecological effects of ultra-violet irradiation and the dynamics and vulnerability of ecosystems under stress.

The research topics are naturally closely related to major international programs, in particular the WCRP and IGBP. The present program thus provides a basis for the European contribution to these efforts. In addition, the CEC Environment Programme focuses on topics of specific European interest, particularly climate change impacts.

The component devoted to climate change and climate impacts involves two objectives:

- To understand and predict anthropogenic climate change, particularly by focusing on regional change in climate statistics. This would include simulations of natural climate variability.
- To monitor ongoing changes of the global environment and climate system and, with special emphasis on the European continent and surrounding oceans, to monitor all climate related quantities, including land surface state.

The broad activities and objectives of the Environment Programme are:

- To forecast and understand the impacts of the foreseen climate change on selected sectors of the European environment
- To make quantitative assessments of impacts on sectors of socioeconomic relevance, such as human settlement and activities, taking account of both physical and human factors
- To compile guidelines for risk management and for the development or rehabilitation of areas damaged or at risk.

Research tasks include the prediction of future sea-level change, estimates of changes in storm surge risk in Europe from climatic change and sea-level rise, and an analysis of potential impacts of sea-level rise on natural ecosystems and coastal land use within Europe.

An assessment of environmental and land-use impacts on European coastal areas will be made by conducting case studies on particularly vulnerable locations. Two types of case studies may be envisaged. Analog case studies will focus on areas where impacts are already being experienced because of relative sea-level rise due to land subsidence. The second type of case study could focus on such areas as deltas and coastal plains where an increase in the rate of sea-level rise would threaten to exceed the natural rates of rejuvenation, leading to degradation of the natural resource base and endangering human habitation.

Bioclimatic shift of crops
Impacts of increasing CO_2 and climatic change on European forests and other natural plant ecosystems. This would involve the study of possible changes in productivity, mixture of species, and spatial extent of forests and other natural ecosystems. Expertise from a range of disciplines across Europe would be brought together. The purpose is to provide a rigorous methodological foundation for estimating the potential effects of CO_2 and climatic change, and for evaluating strategies for future management of the effort.

Sensitivity of European crop yields to increased CO_2 and climatic change

Factors to consider here are:

- Water resources
- Physical factors, monitoring and prevention (connected to instability and erosion of natural slopes)
- Flood hazards development and testing of theoretical and instrumental methods for the study, forecast and control of floods, and flood hazard assessment
- Land-use practices favoring or hindering floods.

Global changes in atmospheric chemistry and biochemical cycles, and their consequences for life on earth

Stratospheric ozone

Tropospheric physics and chemistry

Bio-geochemical cycles and ecosystem dynamics
The objectives are to increase the understanding about sources, pathways, and chemical/biological transformations of natural and anthropogenic compounds, including the processes controlling the cycling and exchanges of these substances in terrestrial, aquatic, wetland, estuarine and coastal ecosystems. This can be done by:

- Developing a comprehensive scientific basis for pollution control and habitat protection policies for terrestrial, aquatic, wetland, estuarine and coastal ecosystems
- Defining indicators of environmental change and damage (at different ecosystem levels) suitable for the analysis and prediction of the effects of natural and anthropogenic perturbations
- Developing or modifying existing process-based models to predict the response of ecosystems to such perturbations.

The results should ultimately allow recommendations of normative measures, appropriate management and protection practices enabling soil fertility, water regime, environmental quality, and biological diversity to be preserved and restored.

Research will emphasize investigations at the ecosystem or catchment scale, and will address in particular processes and pathways at transition zones between different ecosystem types (for example,

terrestrial-aquatic and land-ocean interfaces). Research will be divided into four sub-areas:

1. In the sub-area of *bio-geochemical cycles and hydrology*, research will focus on:

- Changes in the carbon cycle (quantification of uptake by vegetation, allocation into different compartments of ecosystems, and release to neighboring ecosystems or to the atmosphere) with particular attention to modifications of primary production and decomposition of organic matter
- Changes in the cycles of mineral nutrients, allocation to the different compartments of ecosystems, and losses to surface water and the atmosphere
- Changes in ecosystem hydrology (mainly due to changes in land use), partitioning of precipitation, evapo-transpiration and water use, circulation within ecosystems, and effects of changes in snow cover
- Identification and quantification of sources and pathways of organic and inorganic matter, and of selected contaminants, and input-output balances at the land-sea interface
- Mechanisms and rates of processes triggering the fluxes and cycles of natural and anthropogenic compounds in the estuary and coastal area, and the coupling mechanisms between water column, sediment and biota.

2. *Plant physiology*. Research will focus on:

- Tree physiology, in particular the role of hormones, the partitioning and transport of assimilates, re-mobilization and translocation of nutrients and senescence processes
- Effects of pollutants and of combination between pollutants and other environmental stresses (such as temperature, drought, and biotic factors) on physiological processes in plants, in particular forest trees
- Effects of abiotic changes (increase of temperature and CO_2 levels) on physiological functions (primary and secondary metabolisms), vegetation phenology, rooting patterns and tree ring thickness.

3. *Impacts of pollutants on soils and rhizosphere*. Research will focus on:

- Impact of pollutants on biotic processes below ground (decomposition, nitrification/denitrification, and other physico-chemical transformations involving mycorrhiza and soil microflora)
- Acidification neutralizing mechanisms, in particular the weathering of parent materials, in order to define critical deposition thresholds.

4. *Biodiversity*. Research will focus on:

- Impacts of abiotic changes on species composition and biological diversity, vegetation structures and spatial distributions, and density and successions
- Impact on genetic diversity, in particular in forest trees, focusing also on the assessment of human influences on genetic diversity and on population/ecosystem stability and adaptability.

Climate Change Experiment (CLIMEX)

CLIMEX is an international, interdisciplinary research project (Germany, the Netherlands, Norway). Approximately half of its financing comes from the CEC's Environment Programme; the remainder comes from participating institutions. Preliminary studies are to start shortly, whereas the intensive experimental phase will start in April 1994. The project will focus on ecosystem response to climate change, in particular the plant-soil-water linkages and processes. Plant physiology, soil fauna, nutrient cycling, turnover of organic matter, soil and soil solution, hydrological flow paths, and runoff water quality will be investigated. The results will aid in the development of process-oriented models to predict the response of forests and freshwater bodies in Europe to future changes in climate and in atmospheric CO_2.

Two forested headwater catchment ecosystems will be experimentally enriched with CO_2 and the temperature of the areas will be raised. The enclosures, which measure 1,200 square meters and 650 square meters and encompass the Rolf, Kim and Egil catchments, are at Risdalsheia in southern Norway. Eight years of background data are available from this site, collected as part of the RAIN project (Reversing Acidification In Norway). Greenhouses will be used to study the impact of the greenhouse effect.

The objectives of CLIMEX are:

- To measure changes in CO_2 uptake, gas exchange and plant phenology
- To measure changes in forest growth and nutrient status
- To measure changes in ground vegetation and nutrients
- To determine change in mineralization of soil organic matter
- To determine changes in soil fauna and biologically mediated processes
- To measure the effects on runoff water quality and quantity
- To develop a process-oriented model of effects linking terrestrial and aquatic responses.

The CLIMEX experiment is designed to look at climate changes alone and at the interaction between climate changes and acid deposition. The two main design elements function as follows:

- *Climate changes alone:* Ambient acid precipitation has been collected by the roof in the Kim catchment since 1984. This has been filtered and cleaned by ion-exchange, and natural levels of seasalts have been re-added and then reapplied beneath the roof and above the forest canopy by a sprinkling system. This treatment will continue in CLIMEX, augmented by increased levels of atmospheric CO_2 and increased ambient temperature (by 5°C) by means of CO_2 dosing and by hot air equipment (the kind conventionally used in agricultural greenhouses). As untreated reference for the biological studies, a small portion of the Kim catchment will be sectioned off to receive clean precipitation but not elevated CO_2 or temperature.
- *Interaction between climate changes and acid deposition:* At the Egil catchment, ambient acid precipitation collected by the roof is simply recycled beneath the roof without cleaning. For CLIMEX, levels of atmospheric CO_2 will be increased and ambient temperature raised by 5°C. The adjacent Rolf catchment (no roof, ambient acid deposition) will serve as a reference for present climatic conditions. At both enclosed catchments, there will be a step change in CO_2 and temperature, starting at the beginning of the growing season.

Impacts of Elevated CO_2 Levels, Climate Change and Air Pollutants on Tree Physiology (ICAT)

This is a survey supported by the program COST, which is the French acronym for European Cooperation in the Field of Scientific and Technical Research. COST is principally a framework for research and development cooperation. It coordinates national research projects and makes it possible for non-European countries to participate in European Community programs. Activities take the form of pre-competitive research, basic research, or public service.

Twenty-four countries participate in COST—the twelve European Community member states, six of the European Free Trade Association countries (Austria, Finland, Iceland, Norway, Sweden and Switzerland), the Czech and Slovak Republics, Hungary, Poland, Turkey and Yugoslavia.

All projects are funded nationally and fall within one of fourteen defined scientific or technical areas, including Environment, under which the ICAT survey falls.

The information below was drawn from a technical annex of the Memorandum of Understanding of COST Project 614.

Natural populations will partially have the ability to adapt to a relatively fast-changing atmosphere and altered climatic conditions by eco-typic differentiation through selection. However, the significance of this adaptation depends on the genetic variation within the population and the length of the plant life cycle. In plants with a long life cycle, such as trees, eco-typic differentiation will be slow and will have hardly any adaptive value. Here the availability of phenotypic plasticity will be the critical factor in the adaptation and survival of the species.

The primary aim of ICAT is to coordinate European research on the impact of the greenhouse effect and air pollutants, and their combination, on trees in European climates. The specific areas to be studied are:

- *Tree functioning and adaptation.* The objective is to promote, integrate, and intensify cooperative

interdisciplinary research on the impact of a combination of elevated CO_2 levels. This includes an examination of the consequences of an altered climate and a polluted atmosphere, and a look at the effects of these changes on the physiological functioning and phenotypic plasticity of trees. The overall goal is to expand the present knowledge of the impact of multiple environmental stress factors on the biophysics, biochemistry, and physiology of trees.

- *Forests*. The objective is to assess the role of forests as a sink for CO_2. This will involve developing a system for analyzing the forests of the various European regions in which the effects of combinations of elevated CO_2 levels and air pollutants on forest functioning can be simulated, and obtaining data that are essential for the modelling and prediction of the consequences of the greenhouse effect on forest fitness and commercial wood production in general.

Participating countries in ICAT are Austria, Belgium, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.

Science of Global Environmental Change (NATO)

The North Atlantic Treaty Organization (NATO) has, in addition to its better known political and military dimensions, a third dimension that seeks to encourage interaction between people to consider some of the challenges facing modern society, and to foster the development of the scientific potential of allied countries. The NATO Science Programme (Scientific Affairs Division), established in 1958, provides support for activities that foster scientific mobility and interchange between scientists. Research projects are not funded or coordinated within this framework.

The Science of Global Environmental Change is a program of the NATO Science Committee. The program aims to promote research on potential global change within the earth's environmental system. Its objective is to describe and understand the interactive physical, chemical, and biological processes that regulate the total earth system. The program's mission is to advance our capability to predict changes in the global environment, in particular those which result from human impact on the climate. Five thematic areas have been identified for special consideration:

- The climate system and the hydrological cycle
- Bio-geochemical processes and dynamics
- Ecosystems and global environmental change
- Global environmental changes of the past
- Human dimensions of global environmental change.

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Casilla de Correo
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Uruguay

4 Taras Shevchenko
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Tashkent 700029
Uzbekistan

Apartado 69005
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2 Phung Khac
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Socialist Republic
of Viet Nam

1889 F Street,
N.W.
(Gr. floor)
Washington D.C.
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Federal Republic of
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(Serbia,
Montenegro)
Szetozara
Markovica
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Harare, Zimbabwe

The GEF Administrator

1818 H Street, NW
Washington, DC 20433 USA
Telephone: (202) 473-1053
Fax: (202) 477-0551

United Nations Development Programme

GEF/Executive Coordinator
One United Nations Plaza
New York, NY 10017 USA
Telephone: (212) 906-5044
Fax: (212) 906-6998

UNEP

United Nations Environment Programme

GEF Unit/UNEP
PO Box 30552
Nairobi, Kenya
Telephone: (254-2) 621-234
Fax: (254-2) 520-825

The World Bank

GEF/Operations Coordination Division
Environment Department
1818 H Street, NW
Washington, DC 20433 USA
Telephone: (202) 473-6010
Fax: (202) 676-0483

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