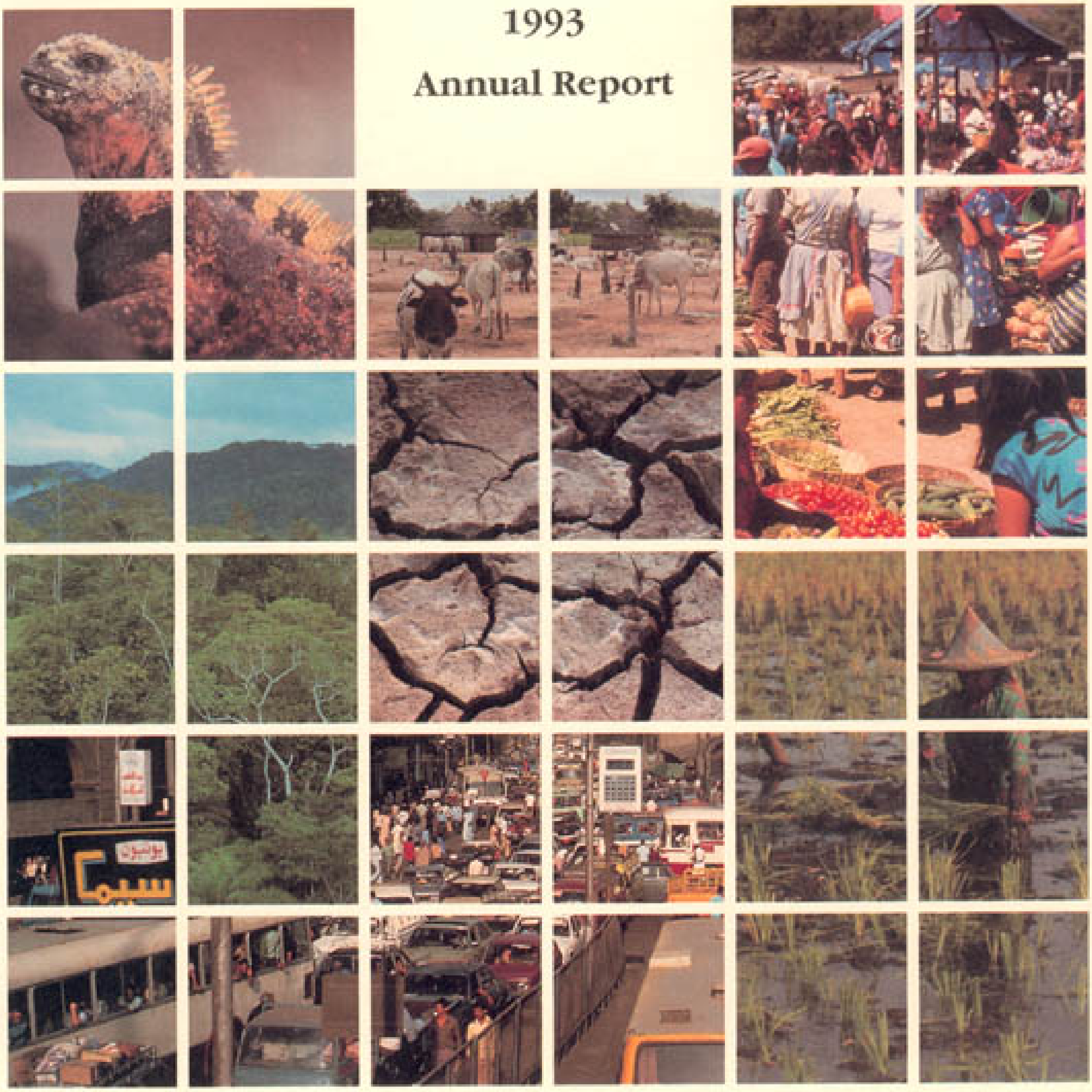
German Advisory Council on
Global Change

# World in Transition: Basic Structure of Global People-Environment Interactions

1993

Annual Report



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# The German Advisory Council on Global Change

## Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen

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## – 1993 Annual Report –

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# A Summary – World in Transition: Basic Structure of Global People-Environment Interactions

## ♦ The Council's brief

In spring 1992, increasingly concerned about the preservation of the natural basis for the life and development of humanity, the Federal Government of Germany established the German Advisory Council on Global Change. This step was taken at a time when insight into both the dimension of global change and the necessity for international action was and is growing. The principal task of the Council is to present an annual Report on the state of the global environment and the social consequences involved. Particular attention shall be given to the further development of the international agreements concluded in Rio de Janeiro in 1992, and the implementation of AGENDA 21. In addition, the Report is to present specific recommendations for environmental action, and outline areas where further research is needed.

## ♦ The concept of the first Annual Report

In its 1993 Annual Report, the Council endeavours to provide a *holistic analysis* of the Earth System, whereby the central focus is directed at the principal interactions between nature and society. The aim here is to demonstrate the complexity of environmental problems, on the one hand, and to create, on the other, the analytical basis for assessing the impact of current trends (increased greenhouse effect, declining biodiversity, loss of fertile soils, population growth, etc.) on the system as a whole. In-depth treatment of core topics will be related back continually to this global perspective, and vice versa, in order to contribute towards continuous improvement of our understanding of the system.

The Report begins with a *circumscription of its subject*, i.e. a definition of what is meant by "global environmental change". This leads inevitably to the issue of *"sustainable development"*, which will be dealt with in one of the Reports to follow. The highly condensed description of the ecosphere and the anthroposphere, and an analysis of the linkages between the two spheres in the Earth System, is followed by the examination of the main components and the relevant trends of global environmental change.

In the following an overview is given of the main statements of each section and the Council's most important recommendations for action and research strategies.

## ♦ Atmosphere

The most visible and easily understood change in the global environment is the modification of the atmosphere's composition by humans. Three global problems ensue from this: *intensification of the greenhouse effect*, and the global warming associated with it, *ozone depletion in the stratosphere*, resulting in higher levels of ultraviolet radiation, and *changes to the troposphere* and associated phenomena, e.g. photochemical smog and acid rain. These processes are closely intertwined and linked through feedback loops to one another, i.e. they can strengthen or weaken each other. The entire Earth System is affected by these changes.

*Action strategy:*

- Strict implementation of the international conventions for the protection of the stratospheric ozone layer and support for financially weaker countries using the special funds established for this purpose.
- Reduction of acid deposition and undesired fertiliser use, so that acidified soil and euthrophised waters can recover.
- Reduction of tropospheric ozone concentrations to previous levels, to prevent impairment of plant growth, human health and changes in the radiation budget.

*Research needs:*

- Determination of the extent to which ecosystems can be sustained in the face of dry and wet depositions and photochemical smog.
- Investigation of the $CO_2$ fertilising effect in natural ecosystems with simultaneous warming.

## ♦ Climatic change

If human behaviour fails to change, then the anthropogenic increase of greenhouse gases according to best available knowledge will cause a mean global *warming* of +3°C. This increase is of the same order as the fluctuations during the transition from the Ice Age to the interglacial period. Unless appropriate action is taken, major changes can be expected, above all a redistribution of *precipitation zones* and a rise in *sea level* of 65 ± 35 cm by the year 2100.

*Action strategy:*

- Rapid reduction of greenhouse gas emissions in all industrialised countries, most oil-producing countries and some tropical rainforest countries with high per capita emissions.
- Political action to increase energy and transport efficiency.
- Precautionary measures regarding rising sea levels and changes in precipitation.

*Research needs:*

- Identification of regions, social groups and economic activities that are particularly sensitive to climate change.
- Investigation of primeval ecosystems that can act as major carbon sinks in the event of climate change and increased $CO_2$ content of the atmosphere.
- Determination of the costs of failing to take action (climate damage functions).

## ♦ Hydrosphere

The oceans and polar ice caps are important elements in the Earth System, exerting a long-term and widespread influence on climate. Fluctuations in *sea level*, horizontal and vertical shifts within the system of oceanic circulation and alterations in the *polar ice caps* have drastic consequences for nature and human civilisation. Furthermore, human population in the endangered coastal regions is increasing at a fast rate.

Freshwater plays a central role in the ecosphere and the anthroposphere as nutrient, economic resource and ecological medium. Furthermore, water was and still is an important cultural element in the lives of many peoples and religions. Protection of water thus means protecting the very foundations of human culture.

Threats to water as a resource and cultural element arise through *scarcity* and *pollution*. This is frequently linked to *wastage*, e.g. when water prices fail to reflect the true cost of this resource, thus encouraging people to squander water.

*Action strategy:*

- Assuring availability of clean drinking water.
- Preventing or mitigating of water pollution.
- Promotion of water-saving.

*Research needs:*

- Assessment of the influence of increased UV-B radiation and higher temperature on marine organisms and biota.
- Development of water-saving technologies for irrigation, industrial production and household utilisation.
- Evaluation of water policies in individual countries and preparation of an international water convention.

## ♦ Litho- and pedosphere (Earth's crust and soil)

Soils represent an important natural basis for human life, one that has so far been accorded too little attention. They also play a significant role in global environmental change. Processes in soil often occur very slowly and are therefore difficult to trace. 17% of the world's soils show clear signs of *degradation* caused by humans. Erosion through wind and water are the main mechanisms, with chemical and physical damage being additional threats.

Soils are an irreplaceable component of terrestrial ecosystems and in many cases are non-renewable. Reserves are limited, and only a small proportion of these can be utilised. From the global perspective, soils, and the organisms living in them, are a natural asset requiring considerable protection.

*Action strategy:*

- Implementation of the *World Soil Charter* and the principles laid down in AGENDA 21 for sustainable land use by including them in national and international legislation and programmes.
- Reversal of the trend towards increasing decoupling of global element cycles caused by the spatial and temporal separation of the production and consumption of biomass.
- Development of global monitoring, research and information networks for worldwide soil protection.

*Research needs:*

- Monitoring the accumulation of contaminants in soils and their release as a consequence of environmental change.
- Integration of soil economy considerations into the development of sustainable land management.
- Development of land uses which preserve resources and the environment.

## ♦ Biosphere

The Report covers two selected components of the biosphere, namely forests and biological diversity. Forests are particularly important within global environmental change on account of their role in the carbon cycle, and hence for the climate. Very different problems must be given consideration, depending on the type of forest in question. Forests in the moderate zones suffer to a serious extent from damage through emissions, and biological diversity is reduced through reafforestation with monocultures. In boreal forests, especially in the taiga and Canada, over-depletion has reached threatening proportions. The tropical forests, among them the rainforests, are particularly significant in this respect due to the high level of biological diversity, the irreversibility of destruction and the urgency of the threat due to the alarming pace at which they are being destroyed.

Over the next 25 years, 1.5 million *species* are expected to disappear if ecosystems and habitats continue to be destroyed at the present rate. A loss of this order is ecologically, ethically, aesthetically and culturally unacceptable. Species have a long-term usefulness, especially for people in developing countries.

*Action strategy:*

- Agreement of an international convention for the protection of the forests (including mechanisms for financing and sanctioning), on the basis of the Rio Principles on the World's Forests.
- Greater integration of biodiversity considerations into all planning and programmes.
- International efforts for the dismantling of foreign debt problems in countries with tropical forest.

*Research needs:*

- Investigation of the possibilities for ecologically sustainable forest use in all forest types; assessment of the efficiency of sustainable forestry.
- Clarification of the role of boreal forests in global cycles and as a climate-stabilising factor.
- Determination of the critical minimum size and networking of different ecosystems, in order to maintain their biological diversity and functions.

## ♦ Population

During the 1990s, the Earth's population is increasing at approx. 100 million people per year, the greatest proportion of whom (80%) will settle in cities. By the year 2050, even with a much-reduced birth rate, the world's population will increase to double the current level of 5.52 billion.

The anticipated *population growth*, which will mainly be concentrated in Asia, Africa and Latin America, will exacerbate environmental and developmental problems considerably. Coping with these problems, however, is a crucial prerequisite for the reduction of population growth. The uncontrolled growth of *migrational flows* and urbanisation are further important areas which directly affect the industrial nations in the form of migrational pressures.

*Action strategy:*

- Reduction of the causes of population growth by combatting poverty, achieving equality for women, recognition of the right to family planning/birth control, reduction of child mortality, improvement of education and training.
- Reduction of environmentally generated displacement (migration).
- Development of detailed guiding principles for the control of urbanisation.

*Research needs:*

- Assessment of the environmental effects of population growth with respect to the consumption of resources and the generation of emissions and waste.
- Determination of the carrying capacity of urban structures.
- Analysis and forecasting of international migrational flows.

## ♦ Economy and transport

Humanity's economic activities and economic growth in particular are major causes of global environmental change. In order to analyse these effects properly, a *regional* and *sectoral* perspective is necessary. Such an approach discloses the interconnections between the sectoral structural change in the highly developed regions, and the structural changes in under-developed regions, with the concomitant effects these have on the environment.

Sectoral and regional structural changes of the economy that relieve the burden on the environment are especially significant for the reduction of global pollution.

Different types of pollution are generated by the different *groups of countries* (highly developed countries, eastern European countries, newly industrialising countries, fuel exporting countries and developing countries), each requiring specific strategies and solutions.

*Action strategy:*

- Promotion of structural changes benefitting the environment.
- Improvement of world economic cooperation, especially between industrialised and developing countries.
- Improvement of environmental policy instruments, in particular clear assignment of property rights, dismantling of subsidies that serve to increase consumption, and sharpening of liability laws.

*Research needs:*

- Operationalisation of the concept *"sustainable development"*.
- Further development and validation of methods for assessing global environmental damage.
- Improvement of existing economic indicators to include environmental aspects.

The global emissions problem resulting primarily from road traffic is dealt with in the chapter on **transport**. Proposals are made for reducing emission levels using standardised fleet consumption and global certificates strategy. Research needs are thought to be particularly evident in the evaluation of the global effects of air traffic.

## ♦ Psychosocial factors

Global environmental change is caused through the interaction of nature and society. Human action is the *cause* of global environmental change, but it is also *affected* by the latter. Ultimately, human action is also necessary in order to *adapt to* or *prevent* this environmental change.

Many environmental changes are the result of *maladjusted behaviour*. The aim should therefore be to change such behaviour. Enhancing "environmental consciousness" in a society, or improving the level of environmental knowledge is not sufficient. The effectiveness of informational or educational campaigns is often much lower than presumed. If environmentally appropriate behaviour is to be encouraged, then the role of perception and the evaluation of environmental risks must also be taken into consideration, as must incentives and opportunities for action. Behaviour cannot be changed unless the relevant structural preconditions have been created.

*Action strategy:*

- Establishing an "inter-generational contract" by taking foreseeable interests of future generations into consideration.
- Support for a change in values and lifestyles that preserve rather than damage the environment.
- Transfer of findings from social and behavioural sciences concerning the perception and acceptance of risk, and on the function of behavioural incentives and opportunities in the planning of political and educational measures.

*Research needs:*

- Evaluating public awareness of environmental problems in the various cultural regions.

- Development of culture and group-specific strategies for the promotion of environmentally friendly behaviour.
- Development of indicators and methods for monitoring social structures and processes, with the aim of improving environmental decision-making.

## ♦ Establishing links

Experience gained with the dynamics of global environmental change have led to understanding that these trends can only be understood in terms of their *linkages* and influenced through *networking*. The analyses of the ecosphere and the anthroposphere contained in this Report are an important basis for such a complex perspective.

The Council thus outlines a *"global network of interrelationships"*, produced by qualitative systems analysis. This instrument is intended for organising specialist knowledge in such a way that an interdisciplinary "expert system" can develop over the long term.

## ♦ Special recommendations to the Federal Government

Concluding its Report, the Council lays particular emphasis on three general recommendations:

1) German development aid should be increased to 1% of the Gross National Product, whereby the term "developing countries" should be redefined to include the states of Eastern Europe.

2) With respect to the instruments discussed in Rio de Janeiro, the Council recommends that negotiations concerning a certificate scheme for *reducing* $CO_2$ *emissions* should be started, with the aim of achieving its international implementation. Parallel to the reduction of $CO_2$ emissions that would then occur, efforts should be made to increase the *transfers* for the protection of the tropical forests. What would be desirable here would be the tying of such transfers to specific measures, since this would facilitate fund raising.

3) Programmes should be developed aiming at *sensitising* citizens to global environmental problems and promoting *environmentally friendly behaviour*.

# B Introduction: The global dimension of the environmental crisis

## Is humanity's natural basis at stake?

Environmental problems are becoming increasingly global in nature and will worsen considerably in coming years unless steps are taken to counteract this development. The main causes are generally well known: emissions of greenhouse gases and pollutants, especially in the highly developed countries, excessive exploitation and reduction of forests, and the destruction of the habitat of many plants and animal species. In addition, we can expect enhanced environmental deterioration in developing countries exhibiting high rates of population growth. This coincides with unsolved economic problems: more than one billion people still live in the most abject poverty, and it is feared that the poor will constitute an ever-increasing fraction of the Earth's population. Environmental destruction caused by poverty is therefore a global threat to be taken most seriously.

If the production of greenhouse gases is not slowed down, the result will be a significant global warming, with wide regional disparities, exceeding anything experienced by humanity so far and bringing in its train many feedback effects of unknown dimensions. Among them, a shift of precipitation belts and hence of vegetation and agricultural zones is no less to be expected than an accelerated rise in sea level and hence the loss of islands and coastal zones. As a result, depending on the occurrence of hitherto unknown weather extremes, the populations affected will exert greater migrational pressure on other regions of the world. However, the higher levels of carbon dioxide in the air could also favour enhanced plant growth at favourable locations.

The composition of the atmosphere has altered. The ozone layer at 20–30 km, the protective shield against harmful ultraviolet radiation, is thinning out almost everywhere. The effects of such ozone depletion will be increased incidence of skin cancer and cataracts, and could also lead to reduced production of biomass by marine algae and to crop reductions.

Biological diversity is declining worldwide, at a rate at least a thousandfold higher than at any time in the past 65 million years. The main losses are to be found in the tropical rain forests and mangroves, but species extinctions can also be observed in moderate zones.

The growing need worldwide for living space and nutrition is leading to rapid expansion of land use. Delicate soils are being put to greater use, many being degraded and some destroyed in the process.

## Human responsibility

Humanity is at the same time the cause and the victim of global environmental change. It is in their third and most important role that people respond by adapting to damage or by taking steps to avoid or mitigate such damage.

There is regional and cultural variation in the performance of these roles. Often the Report will have to enlarge on the differences that exist in this respect between industrial, newly industrialising, and developing countries. Because people tend to think and act locally rather than globally, it will be one of the most important tasks before us to communicate an awareness and understanding for these interactions, to be put into practice in the form of appropriate behaviour. Recognition of the global and supra-generational dimensions of our treatment of the environment must turn into the basis of a general system of environmental ethics. Global change is caused in many instances by local actions, its effects being transmitted back onto the local level through global interrelationships.

## The necessity for global action

The global environmental change and developmental problems which have already been observed and which can be anticipated in the future compel humanity to take immediate action. This message, sent out from the United Nations Conference on Environment and Development in Rio de Janeiro in June 1992, must be kept in mind against the background of local environmental damage and national challenges (e.g. German reunification).

There is need for large-scale action on global environmental change; the measures to be taken will have to be more complex than in the case of environmental problems restricted wholly or mainly to the territory of a single state. If production and consumption occur in a single state with no regard to the environmental damage being caused, the population of that state can weigh up immediately the benefits of consumption against the harmful environmental effects that ensue, since they are affected by both. Global environmental change, on the other hand, is generally caused by people in countries and regions not directly affected by the change, as by the example of global warming is vividly demonstrated. Even if everyone were both causal agent and victim, a global environmental policy would be much more difficult to achieve – there is no such thing as a world government that could pass an environmental law or impose an environmental levy.

Developing policies for controlling global environmental change that are based in turn on national environmental policies represent an enormous challenge. Individuals will have to be made to reconsider their values and attitudes, supported by a changing political framework and by a new educational policy. National states will be required to accept responsibility for the world as a whole. Newly industrialising and developing countries are looking with critical attention and great anticipation to Europe, an association of important industrial, cultural and scientific nations.

## The task of the Council

Against the background of these specific difficulties and acknowledging the need for consulting experts, the Federal Government of Germany instituted the *German Advisory Council on Global Change* in May 1992, in the run-up to the Rio de Janeiro conference. The Council wishes to make a contribution, through its work, so that

- the global environment and development policies initiated in Rio de Janeiro and to be specified in further conventions and protocols, will be further developed and co-determined by Germany,
- all measures and actions taken in Germany are oriented towards the amelioration of global environmental change,
- support is given towards achieving access to and transfer of environmental knowledge and environmentally sound technologies.

This will involve, on the one hand, the presentation of research results in a form suitable for political decision-making, the identification of gaps in knowledge, and the setting of priorities in research support. On the other hand, this should also involve the evaluation of the environmental impact and economic efficiency of different lines of action, in order to facilitate decision-making in the difficult field of global environmental change.

The work of the Council is carried out in the conviction that the widespread mood of despondency and gloom and the underestimation of the long-term decline in environmental quality have to be faced with a clear-cut summary of global environment and development problems. Based on this summary, steps must be derived that lead to realistic strategies for national and internationally coordinated environmental policies. Considerable attention will have to be paid to this interplay of political action and scientific research in dealing with global environmental change. The Council views its cardinal task as being the primary source of recommendations for swift action in the fields of technology, economy, education and science.

In its first *Annual Report of 1993*, the Council, through its analysis of the interaction between the ecosphere and the anthroposphere, wishes to illustrate clearly the problems that exist and to pave the way for the detailed treatment of specific issues in forthcoming years. At the same time, the Council is putting forward its first recommendations for action in this Report. Some effects of the steps to be taken will be immediately noticeable, but some will not produce benefits until a generation later. Accepting responsibility for future generations, however, means that decisions be taken today.

# C Global change: approaching the research object

## 1 Definitions

### Global environmental change

The Council uses the term *global environmental change* to refer to those changes that modify, sometimes irreversibly, the characteristics of the Earth as a system and that, therefore, have a noticeable effect, either direct or indirect, on the natural life-support systems for a major proportion of human beings. Global environmental change may be natural or anthropogenic in origin. The term *global change* is used to signify this overall context.

Environment itself is defined as the sum total of all processes and domains in which the interaction between nature and human civilisation takes place. "Environment" therefore encompasses all natural factors that influence or are influenced by human beings.

Proceeding from available knowledge about natural environmental change, the Council concentrates on *anthropogenic* global environmental change. Anthropogenic changes are often characterised by their speed in comparison with natural changes. As a result, they overtax the Earth System's repair mechanisms and capacity for adaptation.

**Box 1: Classification of global environmental changes**

1. Numerical change in the *key parameters* of the Earth's ecosystem, including the inhabited environment, with respect to mean value and variability.
   *Examples:*
   - Relative proportion of atmospheric gases
   - Temperature of atmosphere and oceans
   - Population levels and distribution
2. Depletion of *strategic resources* in the Earth System.
   *Examples:*
   - Excessive exploitation of forests and degradation of soils
   - Exhaustion of mineral resources
   - Reduction of biodiversity and the genetic pool
3. Shifts and changes in *macrostructures and patterns*
   (at total system level).
   *Examples:*
   - Expansion of the deserts
   - Distribution of species
   - Urbanisation
   - Distribution of wealth
   - North-South gradient
4. Changes in large-scale *processes*.
   *Examples:*
   - Oceanic circulation and wind systems
   - Global cycles (carbon, water, nutrients)
   - Commercial and commodity flows
   - Migrational flows

5. Modification of *connectivity* (topology) in the Earth System.
   *Examples:*
   – Networking of biotopes
   – Water catchment areas
   – Creation of new economic zones

## Sustainability

Any treatment of global environmental problems must be based on the perspective of “sustainable development”. The original definition of this term was made in the Brundtland Report:

> *Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*

This demand sets an ambitious and far-reaching objective. It also raises a number of open questions, especially concerning

- the extent to which the long-term impact of human action can be assessed,
- the extent to which irreversible changes of the ecological system can be avoided,
- the importance attached to increased quality of life in balance with nature for both present and future generations,
- the scope, content and reach of a precautionary strategy.

The Advisory Council will concentrate on these issues in future next Reports. There is no denying that the translation of such an objective into operational measures will come up against limitations of method. The Council emphasises, however, that in all conclusions regarding the steps to be assessed or recommended they are going to consider the interests of both present-day and of future generations. The Council conceives of “sustainability” as an “ecological imperative”, compelling us all to consider ecological, economic and sociocultural factors – not only in the national, but also in the global context. All passages within the Report referring to “permanence” or “sustainability” in connection with environment and development are to be understood in this sense.

# 2 Basic structure of interaction between the ecosphere and the anthroposphere

The origins of global change are to be found in dramatic developments *within* the anthroposphere (population growth, expansion of technical-industrial civilisation, the North-South divide, etc.), which radiate via the "environment" into the ecosphere and threaten to change the character of the planetary ecosystem (= totality of life on Earth + directly used, influenced or influencing abiotic components). This is all the more striking given that humanity is in fact "insignificant" as a physical factor in the Earth System. Functioning as a relay, however, i.e. through targeted diversion of energy and material flows, it alters the structure and performance of fragile but significant subsystems in the ecosphere – with unintended consequences for the stability and availability of the life-support system on which our survival depends.

Rational action that seems reasonable within the local context can lead to global and historical folly. A *"holistic"* perspective of the human environment is thus required – how else are we to identify and avoid pathways of civilisational development which could conceivably disrupt the dynamical equilibrium of the planetary ecosystem? The Council will therefore centre its attention on the synopsis of driving forces and feedback effects of global change, and transform this perspective over the next few years into a systematic analysis. On this basis, it will be possible to assess the impact of new environmental developments and to gauge the necessity or effectiveness of political strategies.

On the most aggregated level of the synopsis, the Earth System is composed of the ecosphere and the anthroposphere, whose metabolisms are intricately linked. This complex is shown in the master diagram (Figure 1): the anthroposphere is symbolically removed from the ecosphere, without the connective "threads" being cut, however. Presenting the relationship in this way means to identify and emphasise the main interactions between the two spheres.

In this diagram, the ecosphere itself consists of the following subsystems:

- *Atmosphere*
  Environmentally relevant are the *troposphere* (lowest layer, the main reservoir of the gases relevant for life on Earth and the theatre for weather), and the *stratosphere* (vertically stable layer above the troposphere containing the ozone shield against UV-B radiation).
- *Hydrosphere*
  Encompasses the total mass of *free water* contained in the oceans, terrestrial reservoirs (lakes, rivers, soils, etc.) and organic substances. The structure of the major ocean currents is of particular significance for the planetary ecosystem. A crucial component of the hydrosphere is the *cryosphere*, i.e. the frozen waters of the polar ice-caps, sea ice, glaciers and permafrost soils. Only a minute proportion of the hydrosphere exists as freshwater, most of which is frozen.
- *Lithosphere*
  Refers to the Earth's crust, including all biogenic depositions such as *sediments* or *fossil fuels*. The lithosphere is the foundation, the most important source of nutrients and – in addition to the sun – the engine driving the evolution of the ecosphere (volcanic activity, plate tectonics, etc.).
- *Pedosphere*
  Comprises *soils* as intersectional space between lithosphere, hydrosphere, atmosphere and biosphere, possessing a specific character of its own and forming the substrate for terrestrial vegetation.
- *Biosphere*
  Encompasses all life on Earth, which in turn consists of the *flora* and *fauna* of the continents and oceans, and *micro-organisms* (bacteria, viruses).

Within the *ecosphere*, myriads of exchange processes occur between the various sub-spheres listed above. The most important ones are symbolised in the diagram (Fig. 1) either by *arrows* (e.g. evaporation and precipitation) or by *fuzzy boundaries* between interactive systems (e.g. exchange of elements between oceans and the Earth's crust).
The *anthroposphere* refers to humanity in the sense of a population, together with all of its activities and products.

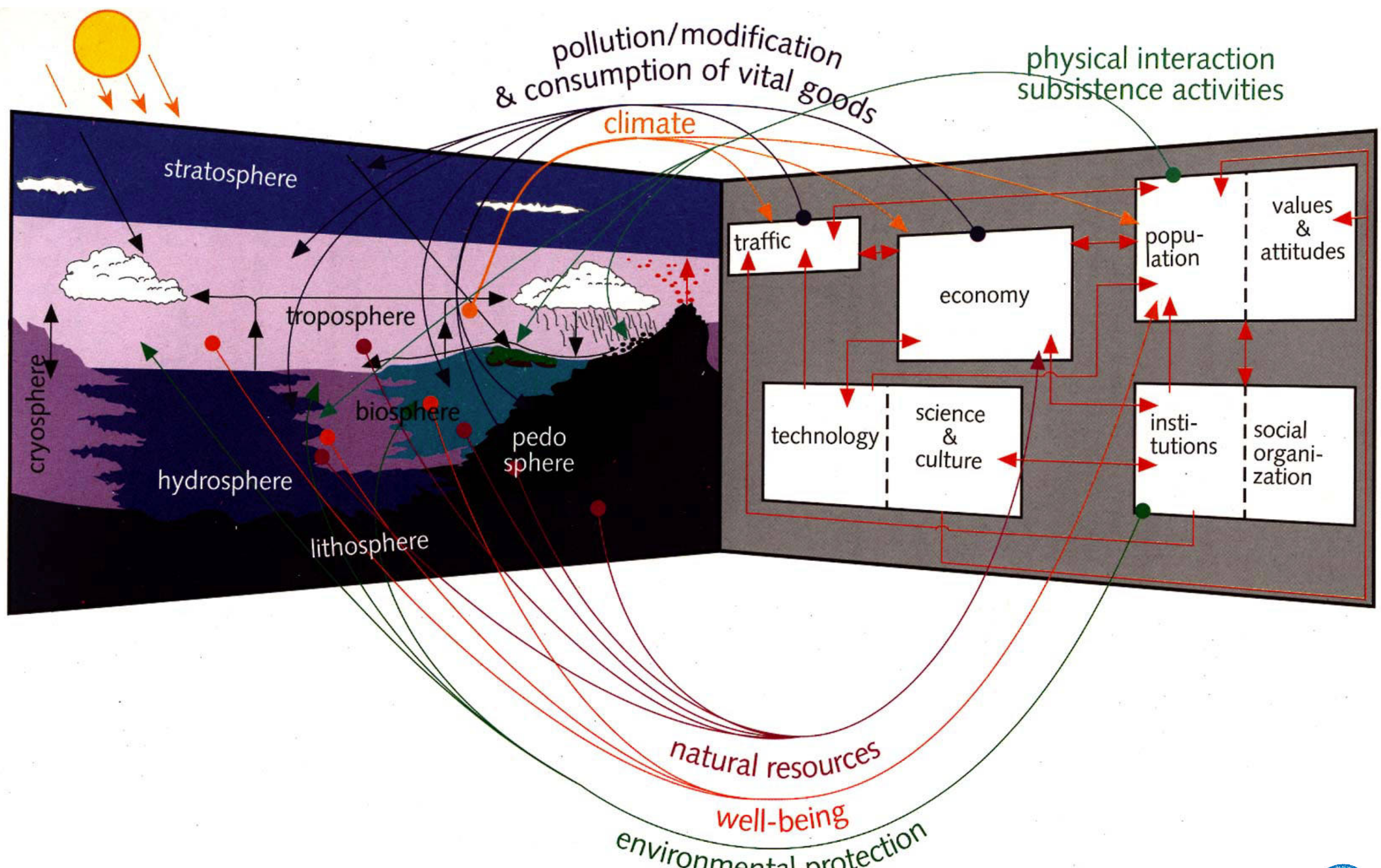



Figure 1: Master diagram of ecosphere – anthroposphere interactions

The transition to the ecosphere is gradual – one has only to think of agricultural ecosystems such as grain crops. This should not lead to any confusion of concepts if the transitional spaces, as was done above, are combined under the heading “environment”.

A sub-division of the anthroposphere into the following components is useful when analysing the various systems within it:

- *Population*
  Both physical and mental aspects, especially values, attitudes and behaviour
- *Social organisation*
  At all levels, up to and including political institutions at national and international level
- *Knowledge systems*
  Especially science, technology, religion, education and art
- *Economy*
  Production of food and raw materials (*primary sector*); manual trades and industry (*secondary sector*); services (*tertiary sector*).
- *Transport*

It is only through possession of comprehensive quantitative knowledge about the coupling of ecosphere and anthroposphere that it will be possible to answer the key question as to the potential *destabilisation* of the ecosphere through the dynamic forces of the anthroposphere. The master diagram first identifies the dominant interactions and labels them by means of *differently coloured bundles of arrows*. Effects and interactions within the anthroposphere are marked in the diagram by *red arrows* and *bidirectional arrows*.

The principal indicators are:

- use of natural resources in economic processes,
- emissions of (contaminant) substances and the manipulation and degradation of protected interests[1] through economic activity including transport systems,
- alterations to natural systems (water, vegetational cover, soils, etc.) through direct action by human beings or in the course of ensuring their subsistence (housing, fuel requirements, etc.),
- protection of landscapes, ecosystems or species through legal measures,
- consumption of vital substances (air to breathe, drinking water, trace elements, etc.) and aesthetic stimulation (big game, landscapes, etc.) by individuals,
- effects of climate on population, traffic and economies.

The systemic components and interactions are analysed in detail in Section D.

[1] Protected interests (air, water, soils, etc.) are natural assets which, given their utility or intrinsic value, must be protected against damage or risks.

# D Global change: Elements of a system analysis

# 1 Changes in the ecosphere

## 1.1 Atmosphere

Air is a mixture of many gases and different types of particles. Like water, it is essential for the existence of all higher organisms. Its composition is important for the health of human beings. Two of its components, carbon dioxide ($CO_2$) and oxygen ($O_2$), are the basic building blocks of life since they are required for photosynthesis and breathing. The composition of air is predominantly a result of the evolution of life on Earth, i.e. living organisms regulate the composition of the atmosphere via their metabolic products and thus play a major role in determining the climate on the Earth.

In comparison to the other planets of our solar system, the composition of the Earth's atmosphere is unique because the substances having the greatest radiation effect, including water vapour, which is necessary for precipitation, exist in very small quantities. Roughly 3‰ only of the mass of the atmosphere *significantly* determine the radiation budget (Table 1) and thus regulate the distribution of temperature and precipitation. Humanity is becoming rapidly and unintentionally a global "trouble-maker" through its influence on these substances. The different lifetimes of trace gases relevant to the climate – ranging from approx. 150 years for nitrous oxide ($N_2O$) to several hours for nitrogen dioxide ($NO_2$) – allow for a simple division into substances having a global effect, on the one hand, and those with a regional effect, on the other: if a substance on the average remains in the atmosphere for a few months only before it undergoes chemical transformation or precipitates, it will influence only the hemisphere in which it was formed and emitted into the atmosphere. Carbon monoxide (CO) and ozone ($O_3$), with a lifetime of a few months or days to months, are examples of such substances. If, on the other hand, substances such as methane ($CH_4$), with a lifetime of roughly 10 years, or anthropogenic carbon dioxide (at least 100 years) remain in the atmosphere for a longer period of time, they have a global effect because they will be distributed fairly equally worldwide. The site of emission of these long-lived gases is, therefore, of secondary importance.

This chapter will be divided into three sections since there are three global environmental problems connected with the atmosphere that result from the differing lifetimes of the substances produced:

- Global change in the composition of the atmosphere due to increase of long-lived greenhouse gases (section on "Increase in long-lived greenhouse gases"). Examples are $CO_2$ and $CH_4$.
- Composition and global change in the chemistry of the stratosphere, leading to regional ozone depletion (section on "Chemistry of the stratosphere"). CFCs, for example, exert an influence in this connection.
- Change in the chemistry of the troposphere as a consequence of diverse regional emissions whose scope has now extended beyond single continents. Examples include $SO_2$ and $NO_X$.

Finally, a section will report on the consequences of these three changes for the climate since it is not only the increased greenhouse effect that affects the climate, but also ozone depletion in the stratosphere as well as the increase of ozone and turbidity in the troposphere.

### 1.1.1 Increase in long-lived greenhouse gases

#### Brief description

The *natural greenhouse gases* of the Earth's atmosphere, i.e. those that hinder the radiation of heat into space to a greater extent than the penetration of solar radiation to the Earth's surface, are increasing the temperature of the Earth's surface. In interglacial periods, such as the present one, this effect brings about a global temperature increase of approx. 30°C to approx. +15°C, while in intensive phases of an Ice Age, as roughly 18,000 years ago, a figure of only approx. +10°C is reached. In order of importance, the following five gases make a significant contribution to the greenhouse effect: water vapour ($H_2O$), making up approx. 70%, carbon dioxide ($CO_2$), having a share of roughly 15%, ozone ($O_3$) with several percent, nitrous oxide ($N_2O$) and methane ($CH_4$), each accounting for a few percent. Mankind has undoubtedly increased the concentrations of $CO_2$, $CH_4$ and $N_2O$ as well as added new greenhouse gases, such as chlorofluorocarbons (CFCs), thus reinforcing the greenhouse effect (Tables 1 and 2). The contribution of changed levels in short-lived greenhouse gases, such as ozone, to the anthropogenic greenhouse effect has not yet been sufficiently assessed because the decrease in ozone in the stratosphere, observed particularly at higher latitudes,

Table 1: Properties of trace gases in the Earth's atmosphere

| Trace gas | Atmospheric lifetime | Volume mixing ratio as of 1992 | Rate of increase during 1980-1989 (% per year) | Molecular greenhouse warming potential relative to $CO_2$ | Radiative forcing since 1750 ($Wm^{-2}$) |
|---|---|---|---|---|---|
| $H_2O$ | days to months | 2 ppmv to 3.5 % | ? | <200** | >0 |
| $CO_2$ | >100 years* | 357 ppmv | 0.4 bis 0.5 | 1 | 1.3 |
| $O_3$ | days to months | 0.01 to 10 ppmv | 0 to -0.8 (S) 0 to +2.5 (T) | <2000** | ? |
| $N_2O$ | ~150 years | 0.31 ppmv | 0.25 | 200 | ~0.1 |
| $CH_4$ | ~10 years | 1.75 ppmv | 0.8 | 25 to 30 | ~0.5 |
| CFCs | 60 to 300 years | ~1 ppbv | ~4 | 10000 to 17000 | ~0.4 |
| CO | few months | 0.15 ppmv (NH) | ~1 (NH) | 2 | >0 |

NH = northern hemisphere
S = stratosphere
T = troposphere
* = only anthropogenic addition
** = maximum in the lower stratosphere
ppmv = parts per million (volume)
ppbv = parts per billion (volume)

Table 2: Ranking of individual greenhouse gases according to their greenhouse potential both in the natural and the anthropogenically disturbed system

| Ranking no. | Undisturbed system | Anthropogenic input accumulated in the period from 1759-1992 | Anthropogenic input accumulated in the 80s | Total input (natural plus anthropogenic) |
|---|---|---|---|---|
| 1 | $H_2O$ | $CO_2$ | $CO_2$ | $H_2O$ |
| 2 | $CO_2$ | $CH_4$ | CFCs | $CO_2$ |
| 3 | $O_3$ | CFCs | $CH_4$ | $O_3$ |
| 4 | $N_2O$ | $N_2O$ | $N_2O$ | $N_2O$ |
| 5 | $CH_4$ | | | $CH_4$ |
| 6 | CO | | | CFCs |
| 7 | | | | CO |

(see 1.1.2) and the ozone increase observed in the troposphere at mid-latitudes (see 1.1.3) may compensate, either partially or completely, depending on the region.

The anthropogenic sources of long-lived greenhouse gases are predominantly known. The most important is the utilisation of fossil fuels (oil, coal and natural gas), whose emissions after combustion together account for a share of approx. 50% of the disturbance of the radiation budget. Roughly 15% of the emissions, respectively, are due to agricultural activities, land use changes and industrial production (Enquete Commission, 1991).

The main effect of the altered concentrations of greenhouse gases in the atmosphere, only disputed with regard to its pattern, but not its magnitude, is a global temperature rise at the Earth's surface and in the troposphere. It may trigger a variety of intensifying or diminishing reactions of the global hydrological cycle, which are still poorly understood, as well as of other biogeochemical cycles (see 1.2).

However, the direct effects of an increased $CO_2$ concentration, frequently described as the $CO_2$ fertilising effect, also involve many risks that should give reason to take action. The Framework Convention on Climate Change signed by 154 nations in Rio de Janeiro in June 1992 must now be implemented swiftly also because of the direct effects of increased $CO_2$ concentrations. Furthermore, the rapid change in the global climate, in a form that has not been experienced by humanity for at least 10,000 years, remains the main reason for taking action.

## Causes

Of the five major, naturally occurring greenhouse gases in the atmosphere, which together cause a greenhouse effect of approx. 30°C, the concentrations of *carbon dioxide* ($CO_2$), *ozone* ($O_3$), *nitrous oxide* ($N_2O$) and *methane* ($CH_4$) are being altered by humankind on a worldwide basis. Only in the case of the main greenhouse gas, *water vapour*, is the extent to which we have increased its concentration still unclear. Water vapour reinforces a change in temperature since its concentration increases by roughly 10% per temperature rise of 1°C. Observation of a temperature change, initiated by changes in the concentration of $CO_2$, $O_3$, $N_2O$ and $CH_4$ would, therefore, prove the occurrence of an increased greenhouse effect rather than a direct change in the concentration of water vapour due to human activity. All trace gases important for the greenhouse effect taken together represent only 0.2‰ of all molecules of the atmosphere during the Ice Ages and 0.3‰ during interglacial periods. This difference is essentially determined by changes in the concentration of $CO_2$, which rose from roughly 190 ppmv 18,000 years ago to 280 ppmv in the current interglacial period (Holocene epoch) and increased exponentially to 357 ppmv from the beginning of industrialisation around 1750 to the year 1992. Methane varied over the same period to an even greater relative extent, increasing in concentration from 0.35 to 0.7 and then to 1.75 ppmv. The rise in nitrous oxide is known conclusively only for the period since the beginning of industrialisation, i.e. from 0.28 to 0.31 ppmv.

Only since the 50s have chlorofluorocarbons (CFCs) emerged as greenhouse gases. As with the other greenhouse gases, they hinder the radiation of heat from the Earth's surface into space. Up to 1974 the production of the two most important CFCs increased worldwide very rapidly, with growth rates of 8.5% to 11% per year. The first warnings of their ozone-destroying effect during chemical decomposition in the stratosphere and the subsequent action taken by some countries led to approximately constant production of roughly 1 million t per year up to around 1988. Only after the Montreal Protocol went into effect on January 1, 1989, a regulation for implementation of the Vienna Convention for the Protection of the Ozone Layer of 1985, did a decline in production begin. However, due to the extensive resident times of CFCs in the atmosphere from several decades to a few centuries, this did not lead to a stabilisation of the concentrations of CFCs. However, a decline in concentration increase became evident during the last years.

The causes of the *increase in greenhouse gases* are now known, for the most part. The utilisation of fossil fuels by humans is the primary cause, which has increased, in particular, the concentrations of $CO_2$ and $CH_4$, as well as $N_2O$ to a limited degree. This is followed, in second place, by changes in land use, which mainly cause increases in $CO_2$ and $CH_4$. Industrial emissions come in third place; they are a source of CFCs and the other halogenated hydrocarbons relevant to the greenhouse effect. In fourth place is agriculture, which above all causes additional emissions of $CH_4$ and also $N_2O$. In comparison to the sources, very little is known about the dynamics of the sinks of individual greenhouse gases, such as the change in the $CO_2$ sink in "Boreal Forest Areas" (Heimann, 1993).

## Effects

This section on the increased concentration of greenhouse gases does not yet deal with the effect on the climate because the latter is also influenced by other global environmental changes, so the climate-changing factors will be described jointly in a separate section on climate change (see 1.2). Therefore, only the direct effect of increased greenhouse gas concentrations will be discussed here. This essentially involves the direct effect of the increased $CO_2$ concentration, since the concentrations of methane, nitrous oxide and CFCs in the air, which, though higher, are still relatively low, have not had a noticeable direct influence on plants, animals and human beings up to now.

The effect of the increased $CO_2$ level is frequently reduced to a discusssion of the acceleration of plant growth, the $CO_2$ *fertilising effect*. Only few significant findings have been gained thus far from this discussion and intensified research. Many cultivated plants that are sufficiently provided with nutrients, water and light form more biomass per time unit when the $CO_2$ content of the air is higher. This effect can be counteracted by a temperature increase, especially at night (see 1.4). In natural ecosystems, on the other hand, there is frequently a lack of water and/or nutrients, so that the $CO_2$ fertilising effect for these plants may be not as significant for these plants. In some field tests on natural ecosystems, such as the Arctic tundra, it has been observed that the increased growth of plants due to a higher $CO_2$ supply is compensated for by a slight temperature rise. Not only is the respiration of the plants increased by higher temperatures, i.e. their metabolic products are consumed to a greater extent to keep themselves alive, but more $CO_2$ is released from the soil. Weighty arguments for the existence of a $CO_2$ fertilising effect of the large natural ecosystems are based on studies using carbon isotope techniques (Tans et al., 1990). These can only be interpreted consistently if a significant fraction (20%) of anthropogenic $CO_2$ is absorbed by the biosphere. Large-scale, ocean-atmosphere coupled global circulation models currently indicate no other possible sink.

## Link to global change

Since the additional greenhouse effect of the atmosphere is reinforced by an increased ozone concentration in the troposphere and is predominantly diminished by a reduced concentration in the stratosphere, the three global environmental changes caused by the altered composition of the atmosphere are closely linked to each other. Thus they are treated together in section 1.2. Because the additional greenhouse effect is also caused by agriculture (increased nitrogen fertilisation), not only must combustion processes (power generation, industrial production, transport and building heating) be included in any successful strategy for reduction as significant sources of $CO_2$ but also agriculture as an emitter of $CH_4$ and $N_2O$. A far-reaching task results from this: due to the diversity of sources of greenhouse gases, almost all human activities have to be critically examined!

The differing reaction of the various plant groups to an increased $CO_2$ concentration certainly has consequences for the production of biomass, the flora-related and, as a result, fauna-related species composition in an ecosystem as well as for biodiversity. These consequences may have a counter-effect on the $CO_2$ concentration.

The way in which the population can be made aware that a greenhouse gas altered by us, i.e. $CO_2$, has a direct and far-reaching consequence on plant communities, even before the climate change, will be of major importance for the success of reduction strategies.

## Assessment

The increase in trace gases brought about by humans since the beginning of industrialisation has reinforced the greenhouse effect of the atmosphere so radically that the change in the *radiation budget* of the Earth due to this increase already corresponds to the difference in trace gases between the Ice Age and the interglacial period. People have thus unintentionally started the largest geophysical experiment in history, with an unknown outcome.

Apart from the direct and indirect consequences for the climate (see 1.2), this experiment may, however, have another profound effect on ecosystems since the greenhouse gas with the highest increase, $CO_2$, is a basic substance for plant growth. It would be short-sighted only to look at the possible rise in primary production: different plant groups respond in different ways to a higher $CO_2$ content. Thus changes occur in the competitive situation among plant species and, as a consequence, in the animal species composition, too, which may also have an effect on mankind's nutrient basis and the susceptibility of agricultural production to pests.

Another aspect rarely taken into account when discussing the increase in greenhouse gases must be given greater attention: increased $N_2O$ and $CH_4$ concentrations bring about a greater *ozone depletion in the stratosphere* since the chlorine compounds as provided from CFCs decomposition are not the only catalysts for this process. The decomposition products nitrogen monoxide (NO) and/or the hydroxyl radical (OH), which are almost exclusively formed from $N_2O$ and, in part, from $CH_4$, are the most important catalysts in the destruction of ozone. In view of the long lifetime of $N_2O$ of roughly 150 years, a further long-term problem thus exists in stratospheric ozone depletion, despite the currently moderate augmentation rate of 0.25% per year.

Therefore, the reduction in the growth rates of the long-lived greenhouse gases $CO_2$, $N_2O$ and $CH_4$ is necessary, even without the connection to climate change, in order to slow down and finally stop significant changes in the species composition and the thinning of the ozone layer in the stratosphere. Since the emission sites for long-lived trace gases are almost insignificant in view of their worldwide distribution, local action by a small country, for example, may be meaningful in taking the first step, but globally it is an inadequate strategy. A rapid integration of national programmes is required in an international framework, which already exists in the form of the Framework Convention on Climate Change that will go into effect after ratification by at least 50 of the 154 countries that signed it. Binding implementation documents for the reduction of the worldwide emission of the above mentioned gases, primarily $CO_2$, must, therefore, quickly become part of the Climate Convention.

## Impact weighting

Up to now the increase in greenhouse gases in the atmosphere has been almost exclusively discussed in connection with the global climate change provoked by it, and it will probably remain the main point of discussion. However, the increase in concentration of $CO_2$, a gas of great importance for life on Earth, is also significant with regard to the so-called $CO_2$ fertilising effect, the change in plant communities, the composition of food, increased infestation by pests and the threat to biodiversity. Only clarification of these interconnections will permit an answer to one of the most complex questions in the area of global environmental changes: How high can the $CO_2$ content of the atmosphere be allowed to rise so that nourishment of the constantly growing population of the Earth is guaranteed, given that, on the one hand, the greenhouse effect due to $CO_2$ and other trace gases is reinforced and belts of precipitation are shifted as a result while, on the other, plant growth is stimulated by the increased $CO_2$ content?

## Research needs

Only when biogeochemical cycles have genuinely been understood can a statement regarding trends be made and the atmospheric part of these cycles be assessed.

◆ *Carbon cycle*

A central research objective in the problematic area of anthropogenic greenhouse gases is the closing of the global carbon balance given continued and intensified constant measurement of the concentration of carbon-containing gases in the atmosphere, i.e. elimination of the unsatisfactory situation that the sink for approx. 1–2 billion t of anthropogenic $CO_2$ has not yet been adequately determined. This also includes an answer to the question: Can the $CO_2$ fertilising effect be verified in natural ecosystems, even if it becomes warmer?

◆ *Nitrogen cycle*

So far the nitrogen cycle has not been understood very well, especially the role of $N_2O$. Important questions include: Are areas that are intensively fertilised with nitrogen compounds the main sources of the measured $N_2O$ augmentation in the atmosphere? How much $N_2O$ is released from automobile catalytic converters in everyday operation?

◆ *Methane cycle*

Important questions in this connection are: What kind of agriculture generates the lowest $CH_4$ emissions? How much methane escapes from thawing permafrost soils?

◆ *Cycle of halogenated hydrocarbons*

With the implementation of the Montreal Protocol, emphasis is now being placed on the greenhouse potential of CFC substitutes, which is also a decisive factor with respect to the sustainable use of these substances.

◆ *Water vapour*

The questions concerning water vapour, on the other hand, appear simpler: Is water vapour increasing in the stratosphere, as postulated? If so, is this trend caused by methane oxidation, aircraft emissions and/or the altered temperature of the tropical tropopause? How will the planned transition to hydrogen-fuelled aircrafts affect the atmosphere at altitudes of around 10 km?

## 1.1.2 Changes in ozone and temperature in the stratosphere

### Brief description

Overall, the ozone content in the stratosphere has decreased in the past two decades (Stolarski et al., 1991 and 1992; WMO, 1992). This decrease varies a great deal geographically and with regard to time, however. In the tropics and subtropics, where ozone is predominantly formed, no significant changes have occurred so far. In contrast, ozone depletion over the Antarctic is especially evident during spring; in the region around the *"ozone hole"*, with an area of approx. 15 million $km^2$, the total ozone content dropped to roughly half the figure prior to 1975. In the mid-latitudes of the southern hemisphere a decrease concentrated in the spring and early summer (–14% at 60°S in the 80s) has also been measured.

A trend analysis in the higher and mid-latitudes of the northern hemisphere is made particularly difficult by the great natural variability. However, there are also signs here of a decrease of roughly 4 – 5% during the last decade in the winter and spring months, primarily due to mainly short-term atmospheric conditions when formation of *"polar stratospheric clouds"* occurs at especially low stratospheric temperatures, similar to the situation in the Antarctic. Heterogeneous chemical reactions in these clouds, in conjunction with chlorine-containing breakdown products of CFCs lead to ozone destruction. Since the meteorological conditions over the Arctic are different, on average, from those over the Antarctic, however, it was not possible for an "ozone hole" to form there. This is expected to remain so for the near future (WMO, 1992). During the summer half-year no trend has yet been observed in the northern hemisphere (see box on "Total ozone content and temperature").

### Causes

#### *Natural causes*

In the stratosphere an evaluation of trends, i.e. long-term changes, is also made difficult by natural variability (Labitzke and von Loon, 1991) (see box on "Total ozone content and temperature"). Possible causes for natural changes include the varying activity of the sun, volcanic activity and changes in the general circulation in the atmosphere.

#### *Anthropogenic ozone decline*

Anthropogenic ozone decline is in all likelihood caused by *chlorine- and bromine-containing molecular fragments* of CFCs and halogenated hydrocarbons. However, increased $N_2O$ and $CH_4$ concentrations contribute to this effect through the ozone-reducing catalysts arising from these trace gases, NO and/or the OH radical. Since the stratospheric temperatures drop as a consequence of a reinforced greenhouse effect (see 1.1.1), this could lead to an intensification of the polar vortices, an increase in "polar stratospheric clouds" and increased ozone depletion, also in the Arctic. The mean chlorine mixing ratio in the stratosphere, which is predominantly determined by anthropogenic emissions of CFCs, has reached 3.3 to 3.5 ppbv today with growth rates of roughly 4% per year (WMO, 1992; Enquete Commission, 1992). It will continue to rise to 4.1 ppbv, even following the tougher regulations contained in the second version of the Montreal Protocol agreed in Copenhagen (November 1992), before it starts to drop, probably at the beginning of the next century (Fig. 3).

## Effects

### *Ecosphere*

Under otherwise unchanged atmospheric conditions, a decline in the total ozone content leads to an increase in the UV-B rays of the sun that reach the Earth's surface, a phenomenon, however, that has only been measured frequently in the southern hemisphere and in exceptional situations in the northern hemisphere, such as at the high alpine station at Jungfraujoch (Blumthaler and Ambach, 1990). In contrast to this, a uniform trend of changing solar UV-B radiation has not yet been detected in the U.S., presumably because of an overlapping of influences due to the change in atmospheric clouds and turbidity (Scotto et al., 1988; Brühl and Crutzen, 1989). It must be taken into account that at higher and mid-latitudes the natural change in the ozone content from day to day is considerably high and that the "ecosphere" is accustomed to that.

Many plants are able to form substances that absorb ultraviolet radiation, thus offering protection to subcutaneous cell organelles. Tropical plant species, which are exposed to the highest degree of ultraviolet radiation, are obviously very resistant and thus adapted. The extent of the tolerances in the case of a possible future increase in UV-B radiation must be subjected to thorough examination. Measurements conducted by Smith et al. (1992a) show, for example, that during an "ozone hole" situation on the edge of the Antarctic the net primary production of marine phytoplankton was reduced. Predictions regarding quantitative effects on the global food production are presently not possible (Tevini, 1992). An increase in UV-B radiation would also cause a change in the chemistry of the troposphere (see 1.1.3) and reinforce the formation of photochemical smog if, as in industrial regions, sufficient nitrogen oxides ($NO_x$) were present. The observed decline in stratospheric ozone has a further influence on the climate in that ozone, the third most important greenhouse gas, weakens the greenhouse effect of the atmosphere at high latitudes. But for tropospheric as

**Box 2: Total ozone content and temperature of the lower stratosphere are positively correlated in the northern hemisphere (Fig. 2)**

*Northern summer*

The time series of total ozone, stratospheric temperature and solar activity are similar during the observation period of 14 years exhibiting a pronounced minimum in the summer of 1986. The summer-summer ozone variation is related to a natural, quasi-biannual oscillation.

Two large volcanic eruptions led to a drastic increase in stratospheric aerosol: El Chichon, Mexico, April 1982 (CH) and Pinatubo, Philippines, June 1991 (P). The El Chichon outburst caused a major stratospheric warming (Labitzke and McCormick, 1992) and thus the summer temperatures for June/July 1982 are outliers. The warming caused by the Pinatubo event did not take place until after July 1991 and is not yet noticeable here.

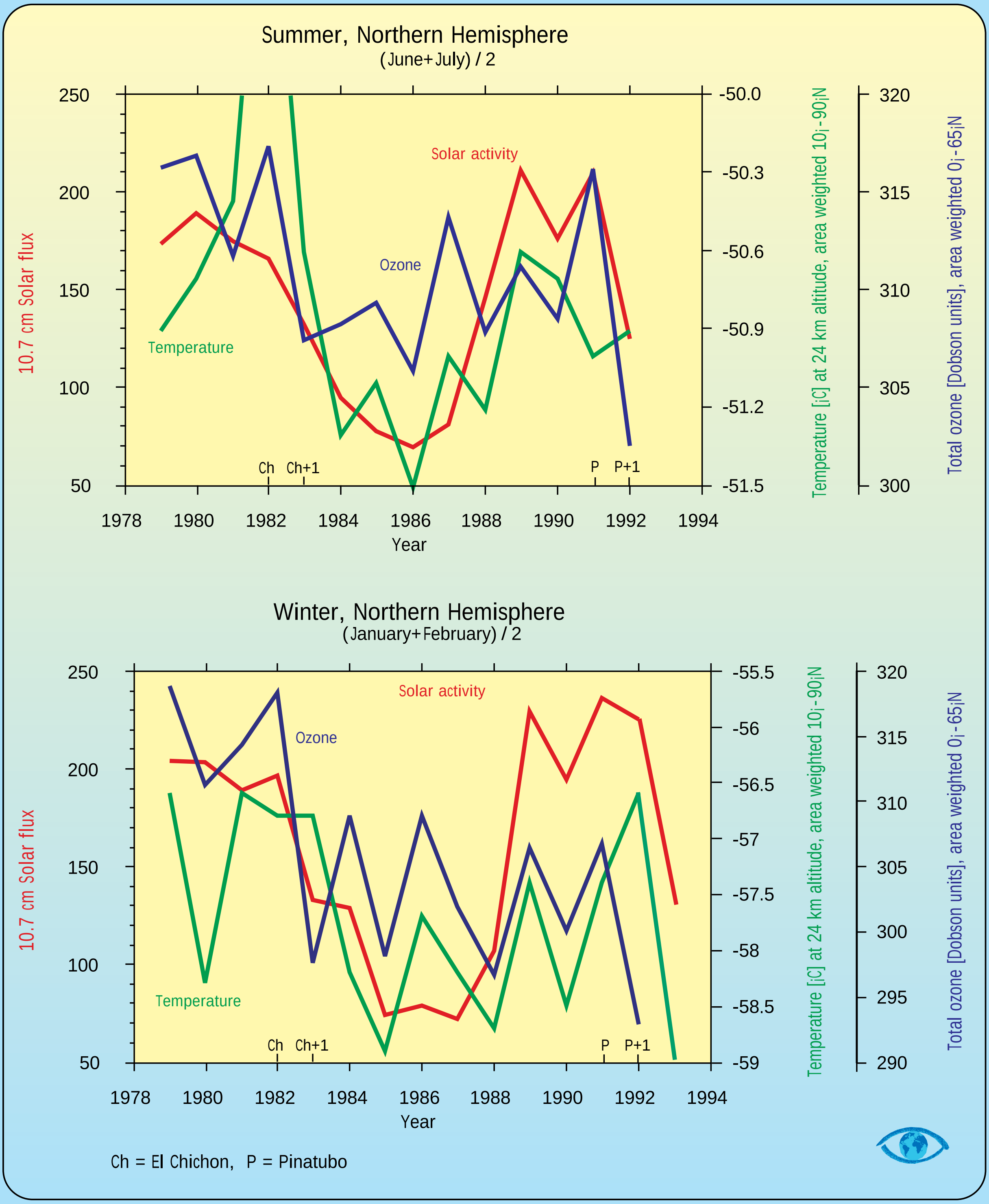
The augmentation of the volcanic aerosol enhanced stratospheric ozone depletion, thus explaining the particularly low ozone values in 1983, i.e. one year after the eruption of El Chichon (Ch+1) and in 1992, i.e. one year after the eruption of Pinatubo (P+1) (Granier and Brasseur, 1992). No significant ozone trend is detectable in the northern summer.

*Northern winter*

The natural variability of ozone and temperature is even larger in the winter half-year (altered scales!). Cold stratospheric winters, low in ozone, alternate with warm winters, high in ozone. In contrast to Antarctica, episodes of extremely low temperatures at which "polar stratospheric clouds" can form rarely occur in the Arctic. During these periods, which usually last only a few days, the anthropogenic depletion mechanisms are active, however. Presumably one must attribute the observed ozone decrease of approx. 4% (corresponding to roughly 12 Dobson units) during a period of 11 years to this process.

Similar to the northern summer situation, the ozone-depleting potential of volcanic events is expressed by pronounced ozone minima in the following years, 1983 and 1992 resp.

Figure 2: Time series for ozone content and temperature of the lower stratosphere (northern hemisphere) as well as solar activity




*Data sources:*

Ozone: TOMS Version 6: Total Ozone Satellite Data, NASA
Temperature: Institute for Meteorology, Free University of Berlin
Solar activity: World Data Centre STP, Boulder, USA

well as for stratospheric ozone this depends very much on the horizontal and vertical structure of these changes (Schwarzkopf and Ramaswamy, 1993).

### *Anthroposphere*

Besides the positive effects of ultraviolet radiation on people, such as vitamin D formation, improved oxygen transport in the blood or favourable effects on the psyche (Blumthaler and Ambach, 1990), a number of *health risks* are known. Erythema (sunburn) and keratitis (inflammation of the cornea or snow blindness) can be mentioned as acute reactions, while various forms of skin cancer and formation of cataracts are reactions that have a long latency period. Ozone depletion of 1%, for instance, allows the biologically active UV-B radiation to increase by higher percentages. Around 2 – 5% more damage may occur, depending on the type of cell affected.

Since ozone depletion outside of the Antarctic has been slight up to now, the increase in skin cancer observed in many countries is, according to the general view of medicine, the result of greater exposure of the skin in recent decades, particularly due to the changes in leisure-time activity.

This finding, however, confirms the threat to human health posed by exposure of the skin to increased UV-B radiation. It has not yet been determined whether the increase in UV-B radiation is accompanied by a weakening of the immune system. The connection between clouding of the eye lens and UV-B radiation is, on the other hand, undisputed.

### *Time scale*

Even if all nations comply with the Montreal Protocol, which was again made more stringent in Copenhagen in November 1992, a rise in the chlorine mixing ratio in the stratosphere to 4.1 ppbv is expected by the year 2000. Thus, greater ozone depletion, comparable to that during the 80s, can also be reckoned with in the 90s (WMO, 1992). According to model calculations and given strict compliance with the Protocols, one cannot expect a drop in the chlorine content of the stratosphere to values of around 2 ppbv, i.e. values that were found prior to the emergence of the “ozone hole”, until the middle of the next century (Fig. 3).

## Link to global change

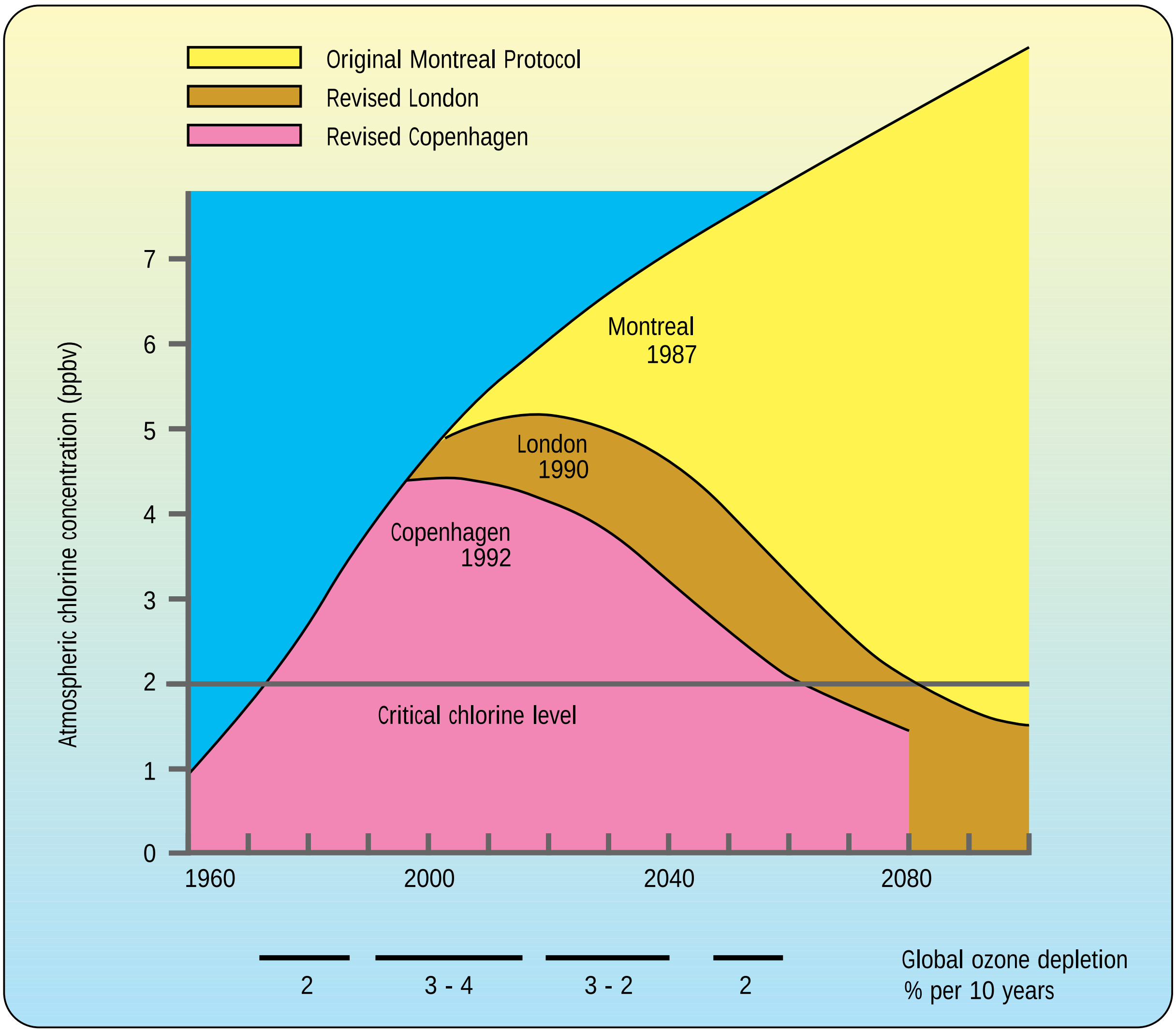
Since ozone is an important greenhouse gas in the atmosphere, a change in ozone also always means a global change in climate (see 1.2). A greater greenhouse effect, on the other hand, leads to cooling of the stratosphere, thus enabling the formation of more “polar stratospheric clouds” in the winter polar regions, and hence even greater ozone depletion.

Increased UV-B radiation reduces the *formation of biomass* (Smith et al., 1992a) by phytoplankton. Thus ozone depletion also weakens one of the major sinks for $CO_2$, the productive ocean around the Antarctic. No quantitative statements can be made about this process at this stage, however.

*Food production* for a growing population leads to an increase in the greenhouse gases methane and nitrous oxide. The methane content of the atmosphere is rising faster than the $CO_2$ content. Approximately 70% of the methane comes from plant and animal sources, such as rice fields and ruminants. Nitrous oxide is also formed by agriculture when arable land and grasslands are excessively fertilised (see 1.4). Both gases break down ozone via the catalysts NO and the OH radical that result from them, and this in turn may also lead to a reduction in harvest due to intensified UV-B radiation.

*Air traffic* emissions presumably lead to an increase in ozone concentration in the upper troposphere and a reduction in ozone in the lower stratosphere with the already described feedback effects on the climate. There is also a close link to the chemistry of the troposphere (see 1.1.3), where ozone is increasing locally, especially near industrial regions. This increase can be regarded only in part as a “healing effect” since ozone, as a toxic gas that leads, among other things, to damage of the respiratory tracts, is undesirable in the troposphere, particularly because it reinforces the greenhouse effect (see 1.1.1). On the other hand, tropospheric ozone absorbs UV-B radiation so that, in this context, it compensates for the loss of stratospheric ozone to a slight extent. Given the oxidation capacity of the troposphere,

Figure 3: Development and forecasts for atmospheric chlorine concentrations according to the various measures to phase out CFCs and other ozone-depleting substances *(from WMO, 1993)*




which depends on the effect of ultraviolet radiation on an atmosphere containing water vapour, a certain increase in ultraviolet radiation (or a decline in stratospheric ozone) would definitely have a positive effect since the current oxidation capacity is not sufficient for the polluted atmosphere (see 1.1.3).

## Need for action

The decrease in stratospheric ozone increases the dangerous UV-B radiation in many regions of the Earth and, therefore, represents a major threat to humanity, all terrestrial living organisms as well as to phytoplankton. The international community has recognised this danger; in 1985 the Vienna Convention for the Protection of the Ozone Layer was signed. The Montreal Protocol of 1987 containing the implementation regulations was given more stringent provisions in London in June 1990 and again in Copenhagen in November 1992 (Tables 3 and 4). These provisions, which call for a rapid withdrawal from the production of CFCs, HCFCs and halogenated hydrocarbons, must now be implemented. In particular, techniques for the production of substitutes in newly industrialised countries must be co-financed in order to support all producing countries in the Third World in complying with the Protocols.

After the ban on CFCs, HCFCs and some halogenated hydrocarbons, special attention must be devoted to the other precursor gases of ozone-reducing molecules: these include nitrous oxide ($N_2O$, with the decomposition product NO),

Table 3: German phase-out schedule for ozone-depleting compounds *(from Cutter Information Corp., 1993)*

| Substances/Function | CFCs | R 22 (H-CFC) | Methyl chloroform | Carbon tetrachloride | Halons |
|---|---|---|---|---|---|
| Aerosols | August 1991 | August 1991 | August 1991 | Not used | Not used |
| Refrigeration equipment<br>– large-scale<br>– large-scale mobile<br>– small | <br>January 1992<br>January 1994<br>January 1995 | <br>January 2000<br>January 2000<br>January 2000 | Not used | Not used | Not used |
| Foams<br>– Packing material<br>– Dishes<br>– Construction<br>– Insulation<br>– Others | <br>August 1991<br>August 1991<br>August 1991<br>January 1995<br>January 1992 | <br>August 1991<br>August 1991<br>January 1993<br>January 2000<br>January 2000 | | Not used | Not used |
| Cleaning agents and solvents | January 1992 | Not used | January 1992 | January 1992 | Not used |
| Extinguishers | Not used | Not used | Not used | Not used | January 1992 |

CFCs = chlorofluorocarbons, Halons = bromofluorocarbons, H-CFC = chlorofluorocarbons containing one or more hydrogen atoms.

Table 4: Withdrawal from the production of ozone-depleting compounds *(from Cutter Information Corp., 1993)*

| Year | CFCs | Halons | Methyl Chloroform | Carbon Tetrachloride | Methyl Bromide | H-CFCs |
|---|---|---|---|---|---|---|
| 1994 | 75% cut | 100% cut | | | | |
| 1995 | | | | 85% cut | cap begins | |
| 1996 | 100% cut | | 100% cut | 100% cut | | cap begins |
| 2004 | | | | | | 35% cut |
| 2010 | | | | | | 65% cut |
| 2015 | | | | | | 90% cut |
| 2020 | | | | | | 99,5% cut |
| 2030 | | | | | | 100% cut |

Global Deadlines

| Year | CFCs | Halons | Methyl Chloroform | Carbon Tetrachloride | Methyl Bromide | H-CFCs |
|---|---|---|---|---|---|---|
| 1994 | 85% cut | 100% cut | 50% cut | 85% cut | proposals expected by March/April 1993 | proposals expected by March/April 1993 |
| 1995 | 100% cut | | | 100% cut | | |
| 1996 | | | 100% cut | | | 35% cut |

EU Deadlines

All dates refer to 1 January. Base year for Halons and most CFCs is 1986 (those CFCs first controlled under the 1990 London amendments use 1989 as the base year). Base year for methyl chloroform, carbon tetrachloride, and HCFCs is 1989. Methyl bromide cap is set at 1991 levels. Hydrobromofluorocarbons (HBFCs) are phased out fully in 1996.

and methane ($CH_4$), whose oxidation in the stratosphere leads to the formation of water and, hence secondarily, OH radicals. Both greenhouse gases increase with increasing food production for a growing population.

| Box 3: Historical development of political action with regard to ozone | | |
|---|---|---|
| *International* | | *National* |
| 1985 | Vienna Convention for Protection of Ozone Layer | ratified 1988 |
| 1987 | Montreal Protocol: CFCs (11, 12, 112, 114, 115)<br>Freeze on production at 1986 levels; reduction in production of 20% by 1994, 50% by 1999 | ratified 1988 |
| 1990 | London: tightening of Montreal Protocol | approved 1990 |
| 1992 | Copenhagen: Further tightening of Montreal Protocol | approved 1992 |

## Research needs

◆ *Long-term measurements*
To record changes in ozone and temperature in the stratosphere, it is necessary to continue and intensify long-term *monitoring*. In particular, involvement in the *"WMO Global Ozone Observing System"* ($GO_3OS$) is recommended.

◆ *Diagnosis*
For a better understanding of natural and anthropogenic changes in ozone, a meticulous diagnosis of already available data and increased development of models to project trends is required, especially with regard to the vertical structure of expected changes.

◆ *Measurement of UV-B radiation*
Measurements of UV-B radiation and its effects on plants and animals are urgently required simultaneously at several specially selected stations.

◆ *Measurement campaigns*
Active participation in international measurement campaigns for a better understanding of ozone-destroying processes is necessary because new knowledge can be gained far more effectively through the coordinated utilisation of different measuring platforms.

◆ *Air traffic*
Investigation of the influence of growing air traffic on the ozone content of the upper troposphere and the lower stratosphere is already an integral part of different research projects. However, it must be maintained on a long-term basis due to the complexity of the problem.

◆ *International research programmes*
Cooperation in international research programmes, such as in the WCRP (World Climate Research Programme) and the IGBP (International Geosphere Biosphere Programme) should be ensured on a permanent basis.

### 1.1.3 Changes in tropospheric chemistry

## Brief description

The large variety of trace gases and particle emissions resulting from human activities, including vegetation fires in the subtropics and tropics, have changed the physical processes and chemical reactions in the troposphere in the course of which trace gases are decomposed naturally through chemical transformations followed by deposition processes. This change resulted in a diminishing of the self-cleaning capacity of the troposphere.
In some regions of the Earth altered levels of trace gases have led to toxic influences on the biosphere. These are the

industrialised regions of the mid-latitudes of the northern hemisphere as well as those regions of the subtropics and tropics in which, during the dry season, forest and savanna fires are lit for agricultural purposes.

The question of whether the *self-cleaning capacity* of the atmosphere in these regions has already been weakened or whether this has not yet taken place due to processes having a compensatory effect has yet to be answered. In any case, the concentration of tropospheric ozone has greatly increased in these regions. During periods of photochemical smog, particularly in industrialised regions in summer, air pollution causes damage to the health of millions of people, vegetation damage and crop losses. The increased ozone content is additionally relevant to the climate because it reinforces the greenhouse effect. The greater turbidity of the air in the troposphere promotes backscattered solar radiation. Both effects are currently major factors of uncertainty regarding the assessment of anthropogenic climate change since only their symptoms, but not their magnitude, are known. The "fertilisation" of all ecosystems that accompanies the pollution of the atmosphere threatens biodiversity and generally fosters acidification of soil and water.

Efforts to stem the air pollution described here should be linked to strategies for reduction of $CO_2$ emissions since air pollution is almost always connected with $CO_2$ emissions. Moreover, similar to the problems related to stratospheric ozone depletion and climate change due to an increased greenhouse effect, intensified international coordination is necessary.

## Causes

The chemistry of the troposphere is determined by water vapour and trace gases, which together account for less than 0.3% of the mass, while the main components of air are chemically rather inert. Human activities have globally altered the level of trace gases to a noticeable extent. Trace gases can only spread beyond their immediate region if they remain in the atmosphere for at least several weeks. Substances that are removed from the atmosphere after a short time by virtue of chemical decomposition reactions or deposition can only have a local or regional effect. Spatial scales of less than 100 km or between a hundred and a few thousand kilometers are meant here. In addition to the emitted substances, their atmospheric transformation products must also be taken into account in assessments.

The atmospheric lifetime and decomposition products of many trace substances in the troposphere are important aspects in global biogeochemical cycles. The atmospheric lifetime of many trace substances, especially those that are very water-soluble, is limited by wet and dry deposition. However, for many compounds that are emitted into the troposphere, both naturally and anthropogenically, the chemical reaction with a single trace substance, the *hydroxyl radical* (OH), is decisive for the atmospheric lifetime. The hydroxyl radical represents the natural *"washing agent"* of the troposphere because it initiates the oxidative decomposition of nearly all relevant trace gases. A reduction in the concentration of this radical is equivalent to weakening the oxidation capacity and thus the self-cleaning capacity of the troposphere.

The trace gases *methane* ($CH_4$) and *carbon monoxide* (CO) have increased worldwide since the pre-industrial age and at least in the northern hemisphere over recent decades, respectively (IPCC, 1990; Levine et al., 1985; Cicerone, 1988; Khalil and Rasmussen, 1991). Important sources of these trace gases are agricultural activities, the production, processing and distribution of oil and natural gas and incomplete combustion processes. From a global point of view, methane and carbon monoxide are the most important reaction partners of the OH radical. As a consequence of this, one can assume that the concentration of the hydroxyl radical has decreased globally, i.e. the self-cleaning capacity of the troposphere has been weakened (Levine et al., 1985; Lu and Khalil, 1992). Despite a lack of OH measurements, this can be shown indirectly based on the distribution and the temporal trend of the hydroxyl radical's reagents. Direct measurements are difficult due to the extremely low mixing ratio of roughly $3*10^{-5}$ ppbv, which is scarely detectable. A thinning of the stratospheric ozone layer may have consequences for the chemistry of the troposphere by virtue of the change in photochemically relevant UV-B radiation. The significance of this change is not known. The recently observed reduced growth rate of $CH_4$ may be a reflection of increased photochemical activity.

The chemical processes of air masses rich in nitrogen oxides have altered greatly in relation to the anthropogenically unpolluted state, regardless of the type of source (industrial emissions or biomass combustion): periods of *photochemical smog* are becoming more and more frequent. They are primarily a local or regional phenomenon with increased concentrations of radicals, oxidised and partially oxidised hydrocarbons, ozone and other photooxidants. Many of these substances are relevant from an ecotoxicological point of view.

One class of *photooxidants,* the peroxyacetylnitrates, however, definitely has the capability of being transported beyond the immediate region. These are compounds that serve as reservoirs for nitrogen monoxides and which are able to release the latter again, depending on environmental conditions. In this connection, those air masses whose nitrogen monoxide mixing ratio has not risen to more than approx. $5*10^{-3}$ ppbv are designated as pollution-free zones. This is the case only in regions subject to little anthropogenic influence. In the greatly industrialised mid-latitudes of the northern hemisphere, on the other hand, as well as in the forest and savanna regions of the subtropics and tropics during the dry season, nitrogen monoxide concentrations are much higher. In the latter areas, vegetation fires are the emitters. Under these conditions the atmospheric chemistry of carbon monoxide and hydrocarbon compounds leads to the formation of ozone under the influence of the sun. With increasing emission rates of the precursor substances, namely nitrogen monoxide and hydrocarbons or carbon monoxide, there is a growing tendency towards periods of photochemical smog. The transport sector is the most important industrial source while agricultural activities are the primary factor for the fires in the subtropics and tropics during the dry season.

The ozone concentration in these regions has most likely increased as a result of human activities. In the past 100 years it has doubled in Europe (Volz and Kley, 1989). The production of tropospheric ozone, on the other hand, has the potential of enhancing the oxidation capacity. The current state of knowledge, however, does not permit any verified statements to be made concerning a change in OH concentration in NO rich regions; initial estimates have yielded higher figures (Crutzen and Zimmermann, 1991).

Furthermore, it was determined that significantly changed nighttime chemistry takes place in fire clearing and anthropogenically influenced coastal regions. These reactions are caused by greatly increased concentrations of radical compounds, predominantly peroxy radicals. This class of compounds occurs in the chemical decomposition pathway of hydrocarbons (Platt et al., 1990).

*Inorganic acids* represent a group of substances with relatively short atmospheric lifetimes and thus, at the most, regional range. In industrialised regions they have greatly increased the natural acid content of precipitation (in addition to rain, this includes wet deposition of snow, dew and fog). The dynamics and chemistry of these processes are well understood today. Analogously, acidification of precipitation occurs in extensive areas of the tropics and subtropics as a result of fire clearing and savanna fires, though organic acids are probably more important in this context (Galloway et al., 1982; Andreae et al., 1988). The spread and significance of this phenomenon have not yet been sufficiently studied.

*Combustion of biomass* during the dry season in the subtropics and tropics deserves special mention. It is assumed that 6 – 7 billion t of biomass are burned annually, primarily in the forest and savanna regions of the Earth (data based on dry mass; Seiler and Crutzen, 1980; Hao et al., 1990). Biomass combustion releases roughly half of the anthropogenic emissions of carbon monoxide, hydrocarbons and nitrogen monoxides. Large quantities of soot-containing aerosols are emitted together with these and other trace gases, some of which are relevant to the climate (see 1.2). The combustion of large quantities of biomass perturbes biogeochemical cycles. It has been estimated that 10 – 20 million t of nitrogen annually are removed from the biosphere, corresponding to 6 – 20% of the annual nitrogen fixation (Crutzen and Andreae, 1990).

The industrial regions of the northern hemisphere emit a large variety of toxicologically relevant trace substances, some of which at least are distributed globally, including heavy metals such as lead and mercury. Presumably increasing quantities of aerosol are formed in these regions. The cause is the growing emission of aerosol forming gases, sulphur dioxide ($SO_2$) as the most prominent, in combustion processes of all kinds.

The extent to which important chemical processes in the atmosphere are influenced by increasing aerosol concentrations (greater probability of surface reactions with particles) has not yet been understood completely. The atmospheric lifetimes of aerosol particles in the atmosphere only permit local to regional effects. Since they interfere with the radiation budget, they may, nevertheless, have an influence on the global climate (see 1.2). Special meteorological constellations make it possible for isolated areas remote from emission sites to be affected as well. Such meteorological conditions occur regularly in spring known as the “Arctic Haze” phenomenon, which involves the transport of polluted air masses from Central and Eastern Europe to the European Arctic.

## Effects

Some locally and regionally occurring pollution phenomena are well known for decades and understood to a large degree (e.g. “London smog”, “Los Angeles smog”, acidification of water, new kinds of forest damage). However, larger areas are becoming affected to an increasing extent and some of these phenomena have reached national and international scales today.

In its Report for 1985 and 1987 the German Council of Environmental Advisors (Rat von Sachverständigen für Umweltfragen – SRU) made a detailed statement relating to the territory of Germany. Those effects having regional or national proportions are mentioned in the following.

- The deposition of trace substances in ecosystems via the *atmospheric path* changes the concentrations of nutrients and harmful substances, with consequences for nutritional conditions and species composition. An example of this is acid deposition in northern European lakes and in eastern parts of the U.S. and Canada. Forest damage is caused in extensive areas by an excessive deposition of eutrophying substances, overfertilisation, or through photooxidants. Wild plants are decimated to such an extent that they appear on the “Red List” of species threatened with extinction. The marginal seas, in which the explosive growth of phytoplankton is additionally stimulated by eutrophication from the air, are also affected. Soils in tropical and subtropical areas appear to be particularly endangered since they generally display little tolerance to changes as compared to soils at mid-latitudes.

- The *fertilising effect* for useful plants is accompanied by *damage* caused by phytotoxic substances. A final evaluation of these different influences is not yet possible. The same applies to forests at mid-latitudes used for economic purposes.

- The selective application of chemicals, particularly pesticides, for useful plants has undesired side effects, i.e. the increasing input of pesticides at the site of application and via the atmospheric path, so that pests develop a greater resistance on a worldwide basis.

- *Harmful effects to human health* resulting from air pollution are on the rise. In almost all countries of the world millions of people suffer from disorders of the respiratory tracts (e.g. damage to the lungs) and other health impairments. A greater susceptibility to natural allergens as well as immune weaknesses can be observed to an increasing extent. Such deterioration of the quality of life, particularly in the urban agglomerations, inevitably leads to migration of the population as well.

Effects of the changedtropospheric chemistry that are relevant to the climate exist by virtue of:

- the increasing concentration of *tropospheric ozone* in the mid-latitudes of the northern hemisphere and the forest and savanna zones of the tropics and subtropics during the dry season,

- the release of $CO_2$, $N_2O$ and $CH_4$ as well as larger quantities of *carbonaceous aerosols*. Changes of the atmospheric aerosol are capable of impairing the radiation budget via backscattered short-wave radiation as well as indirectly by the influence on the cloud characteristics. On a global scale aerosols may provide a significant contribution to the absorption and emission of long-wave and short-wave radiation in the atmosphere.

- the large additional emission of *sulphur compounds*, especially in the form of $SO_2$, which, after its transformation into sulphuric acid, increases the formation of aerosols. Thus the temporary cooling of land masses in the northern hemisphere between 1940 and 1975 is attributed to the turbidity of the air due to the rise in $SO_2$ emissions (Engardt and Rodhe, 1993) (see also 1.2).

## Link to global change

The altered chemistry of the troposphere is closely tied to a number of main elements of global environmental change. First of all, it is affected by the thinning of the stratospheric ozone layer. Secondly, it influences climate change via the trace gases relevant to the climate. Moreover, the trace gases relevant to the climate and the most important carriers of air pollution have similar, often identical sources: hydrocarbons, $NO_X$, $SO_2$ and CO are emitted together with $CO_2$. An altered level of trace gases has a great effect on soils as well as on agriculture and forestry. Increasing urbanisation, growing traffic levels and a rise in leisure-time activities multiply emissions of harmful substances. If photochemical smog is connected with increased turbidity of the air, which is certainly the case in the lower troposphere, then the greater backscatter of solar radiation reduces the greenhouse effect. Tropospheric ozone increases the greenhouse effect, particularly if it is formed near to the tropopause. Therefore, the increase in ozone caused by aircraft emissions must be given special attention.

There is no doubt that the altered chemistry of the troposphere contributes to the *acidification of soil* and *new forest damage as well as crop losses* when ozone content is high and to the *eutrophication* of the marginal seas. So far, one can only hazard a guess as to the significance of intensive farming and of the worldwide increase in fertilisation of ecosystems caused by vegetation fires. Such developments, however, are certainly related to a threat to many species which are dependent on low-nutrient ecosystems. An environmental problem with a time scale of days to weeks (period between emission and deposition) has thus initiated a second one having a very much longer time scale of decades to millennia.

*Urbanisation* fosters the formation of photochemical smog as a consequence of higher traffic and industrial density. Due to the reduced quality of life in urban agglomerations, this process, in turn, triggers a flight to suburban and surrounding recreational areas and thus greater traffic. The damage caused to the health of millions of people by air pollution, particularly in the metropolises of the Third World, is inestimable. Because it is experienced and suffered directly, continent-wide air pollution is a perfect candidate for an exemplary change of awareness, also with respect to other large-scale environmental problems. Therefore, it appears meaningful to link $CO_2$ reduction measures to those aimed at improvement in air quality.

## Assessment

The plumes of many urban agglomerations combine to a pattern of air pollution affecting the entire northern hemisphere. Despite regional successes here and there, what were originally local problems have now turned into a global problem. In addition to the harm to human health, serious long-term damage can be observed worldwide in agriculture, forestry, soils and water as well as in flora and fauna. The effect of increased turbidity of the air and tropospheric ozone content on the radiation budget in the atmosphere must also be included in the strategy for tackling air pollution because of the global dimensions of the problems involved.

The objectives are thus obvious:

- Improvement in the quality of the air we breathe, at least to the values recommended by WHO.
- Reduction in acid deposition as well as in undesired fertilisation such that acidified soil and eutrophied water can slowly regenerate.
- Lowering of tropospheric ozone levels to prevent impairment to plant growth, damage to human health and changes in the radiation budget.

The major precursors for tropospheric ozone as well as acid and nutrient deposition are the following trace gases: volatile hydrocarbons, $NO_X$, CO, $SO_2$ and $NH_3$. Thus there is need for worldwide action in the industrial sector (refineries, power stations), in the transport sector, in private households as well as in agriculture.

Since measures for the reduction of harmful substances in the air must be directed at a large variety of sources, the instruments to be applied are extremely diverse. Thus far, local and regional problem-solving approaches have dominated, but there are major differences between them due to varying local conditions.

The Council draws attention to the fact that *continent-wide coordination*, not just within the European Community, is an absolute necessity. Fields of action include, for example, European summer smog and new forest damage in Europe and North America. Only when such coordination exists is it possible, with the support of a scientific consensus, to develop uniform instruments of action. This has been successfully demonstrated by the *"Intergovernmental Panel on Climate Change"* (IPCC) for the climate change issue. Details regarding implementation of the strategy should not be part of this kind of coordination.

The necessary strategy should contain the following measures:

- greater implementation of the *principle that the party responsible is liable for the resulting damages*,
- *reduction in material flows* through recycling of wastes,
- *increasing energy efficiency* especially when fossil fuel based. A reduction in the major pollutants can thus be achieved at the same time. The Council points out that a different approach emphasising the reduction of individual pollutants involves risks due to the possible creation of new problems.

## Impact weighting

The topic of "Changed tropospheric chemistry (1.1.3)" deserves higher-priority treatment than has been the case to date in the international discussion on global change. The reason is that local problems with typically short characteristic time scales (hours and days for the deposition of dust, for example) have developed into air pollution on a continental scale, with consequences in coming decades for the soils, among others.

Anthropogenic sources already play a prime role in global cycles of sulphur, nitrogen and many trace metals. Since air pollution mostly occurs in connection with the utilisation of fossil fuels, the necessary measures should be linked to those for the reduction of $CO_2$ emissions. From a global point of view, these latter measures have higher priority.

## Research needs

As in other sections of this Report (see 1.2), research should elaborate decision-making and selection criteria for strategies and their implementation. The state of research should not be taken as a reason to postpone necessary measures, even if the interconnections are only partially known. Forest damage is probably caused to a predominant degree by air pollution. Intensive research on this topic has shown, however, that rapid understanding of such complex systems is not possible. The current situation is characterised by knowledge of individual aspects of ecological interrelationships. The central aim of research is, therefore, to develop techniques with the same or better efficiency implying less emissions into air and water.

A deeper understanding of the chemistry of the troposphere is necessary, as was also formulated in AGENDA 21 (UNCED, 1992). The following questions urgently require answers:

- How does the thinning of the stratospheric ozone layer influence the oxidation capacity of the troposphere?
- How does the altered level of trace gases in $NO_X$-rich regions of the troposphere affect oxidation capacity?
- What does an increasing concentration of aerosols mean for tropospheric chemistry and for the radiation budget?
- What ecosystems are particularly sensitive to atmospheric depositions and photochemical smog?
- How do different cultivated plants react when they are fertilised with nutrients from acid precipitation and exposed, at the same time, to photochemical smog?

## 1.2 Climate change

### Brief description

The climate of the Earth has always been changing and will continue to do so with or without the influence of human. Through variations in external parameters and interactions between air, water, ice, soil, the Earth's crust and biota, the climate is, in some cases, subject to great fluctuations in all time scales. Such fluctuations can be most simply described on the basis of the *greenhouse effect* occurring in all planetary atmospheres: for the atmosphere of planet Earth, the rise in surface temperature as a consequence of the greenhouse gases water vapour, carbon dioxide, ozone, nitrous oxide and methane amounts to approx. 30°C. Without these gases and their ability to partially absorb the heat radiation of the surface, the mean surface temperature of the Earth would only be approx. -15°C. People have been intervening in this process to an ever greater extent since the beginning of industrialisation. Because they have increased the concentrations of carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) at an exponential rate of growth as well as reduced ozone ($O_3$) in the stratosphere at higher and mid-latitudes, they have become *"climate-makers"* (Table 2). The effects described in sections 1.1.1, 1.1.2 and 1.1.3 all exert an influence on the climate, whose changes will be elaborated on in the following.

The growth in greenhouse gases caused by humans has not only reached or exceeded the difference between the Ice Age and the interglacial period, but is occurring at a rate that is accelerating by a factor of roughly 100 in comparison to said difference. According to climate models, the resulting temperature rise will reach a global mean value of approx. $3 \pm^{2}_{1}$ °C by the end of the next century. Such *rapid* climate change in relation to natural global fluctuations shifts precipitation belts (as do the latter), causes the sea level to rise, leads to vegetation that is no longer adapted, poses a danger to human nourishment due to a shift in the cultivated zones and fosters new weather extremes.

The hidden inaccuracies in climate models of low spatial resolution and feedback effects yet to be taken into consideration will modify statements on the mean temperature rise effect even further and will continue to make a finer degree of regionalisation difficult. In all likelihood, however, the basic statements will not change. In June 1992, therefore, 154 nations signed the Framework Convention on Climate Change in Rio de Janeiro, the objective of which is to *stabilise the concentrations of greenhouse gases*. If this objective is to be achieved without loss of the adaptability of vegetation and while also maintaining food production and sustainable economic development, the emission of carbon dioxide by industrial countries must be reduced by up to 80% by the year 2050, as formulated by the Enquete Commission of the German Parliament (Bundestag) "Protecting the Earth's Atmosphere" in 1990. Even with such a drastic reduction, a mean global temperature rise of up to 2°C can be expected in the second half of the next century (assuming by way of precaution the high estimated sensitivity of the climate system). Humanity has never experienced such a rapid rise before in his history. The profound changes necessary in industrial society and development in the developing countries are only possible without a relapse if efforts are started today, through joint research on the part of the natural and social sciences, to intelligently design the required package of measures, to promote technological development for saving energy and utilising renewable sources of energy and to effect a change in the awareness of the population that will support this long-term global aim through an appropriate change in behaviour.

### Causes

The climate at one place on the Earth is defined as the statistics on weather phenomena for a certain period that is long enough to obtain approximately stable statistics, but which is also short enough to guarantee clustering of the results around the mean value. These statistics with mean values and deviations as well as their probability of occurrence for climate parameters, such as wind, temperature, precipitation, etc., which usually apply for several decades, are an expression of the diverse interactions between the components of the climate system (air, water, ice, soil, rock *and* biosphere). Changing external parameters, such as solar radiation, but also long-term internal interactions, e.g. between the sluggish oceanic and rapid atmospheric circulation, ensure constant climate change. The latter are usually expressed in figures as the *"greenhouse effect of the atmosphere"*. It rose from approx. 25°C 18,000 years ago (during the most intensive phase of the Ice Age of the last 100,000 years) to approx. 30°C in the current intermediate period (the Holocene epoch that began 10,000 years ago).

The greenhouse effect is essentially determined by the difference between the solar radiation absorbed by the Earth and the heat radiation of the Earth's surface absorbed by the atmosphere. If the absorption of heat radiation prevails, the normal case for planetary atmospheres, the surface temperature rises until the same amount is radiated into space as is absorbed from the sun. The temperature increase compared to a planet lacking an atmosphere is called the *greenhouse effect*, in that it is roughly analogous to the effect produced by the glass in a greenhouse.

The physical reason for the high absorption of heat radiation can be found in the *molecular structure of the gases in the atmosphere*. In the Earth's atmosphere these gases exist only as small percentages, almost all of which are produced by living organisms or at least co-determined by the latter. Thus, in the case of an increase in solar radiation, for example, a reinforcement effect caused by living organisms may occur: if the radiation of the northern hemisphere increases by several percent (this happens roughly every 10,000 years), then portions of the bright snow and ice areas will give way to dark ground. As a consequence, the absorption of solar radiation increases, it becomes warmer, the resulting higher water vapour content reinforces the greenhouse effect, the terrestrial biosphere becomes more active and this, in turn, increases the methane content through greater decomposition of organic material, and so on. The question of which processes have prevented such *self-reinforcement effects* up to a "super-greenhouse" with boiling oceans or a complete ice desert with little greenhouse effect has not been clarified yet. Currently there is intensive discussion over the cumulonimbus clouds of thunderstorms, which, at a high surface temperature, remain in the tropics as additional reflectors for a particularly long time, and the higher backscatter capability of the clouds over the oceans, which result from augmented sulphuric acid condensation nuclei concentration as a consequence of the increased dimethylsulfide emission of marine algae.

People have essentially intervened in three areas of this complex system: first of all, through forms of land use, such as farming, livestock breeding and housing construction; secondly, through changes in atmospheric composition as a consequence of the altered biosphere and the direct emission of trace gases relevant to the climate; and thirdly, through *waste heat*. Weighting of the latter two types of intervention is relatively simple: waste heat with a global mean of 0.02 $Wm^{-2}$ energy flux density is negligibly small in comparison to the disturbance of the radiation budget of approx. 2.5 $Wm^{-2}$ due to the observed increase in greenhouse gases (see 1.1.1). These changed surface characteristics have produced different symptoms in energy flux density, depending on geographic location and land use. In the case of irrigation, light, smooth areas with little evaporation in arid regions are replaced by darker, rougher areas with high evaporation. In the case of forest clearing, on the other hand, the dark, rough, greatly evaporating forests give way to lighter, often smoother and less evaporating pastures or fields. The question of whether the change in energy flux density contributes, on the average, to the cooling or heating of the surface has not yet been clarified conclusively. The absolute value, however, should, as corresponding estimates show, be much smaller than the disturbance of the radiation budget due to the additional trace substances (primarily trace gases).

Human influence on the global climate is very difficult to determine given the natural fluctuations that occur. The following factors influencing climatic change can already be extensively ruled out: the observed, comparatively rapid mean temperature rise since 1880, which accounts for 0.5 ± 0.2°C on the Earth's surface (IPCC, 1992), is not primarily caused by volcanic activity. The directly measured variability of the radiation of the sun during the last 11-year period of activity was less than 0.1% or approx. 0.2 $Wm^{-2}$. Only if, despite similar activity parameters, earlier cycles of the sun had greatly exceeded this value, the temperature rise could be partially attributed to increased solar radiation. This leaves the internal variability of the climate system and the influence of people as important factors. We may have caused less or even more than the observed temperature rise.

Climate history findings and statements derived from *coupled ocean-atmosphere-terrestrial surface models* are available for identifying the influencing factors. The former show high correlations between $CO_2$ and $CH_4$ concentrations and temperature over the past 160,000 years. Studies of ice drill cores and deep-sea sediment drill cores indicate that in each case the temperature changed before the greenhouse gases, i.e. an altered distribution of solar radiation was the triggering factor while the greenhouse gases brought about a positive feedback effect. The present situation is different: the concentration of greenhouse gases has been increased by us whereas the positive feedback to the temperature, however, can be attributed to the same physical mechanism as in the climate history.

For the increase in greenhouse gases which has taken place between the intensive phases of the Ice Age and the interglacial period, climate models calculate a mean global temperature rise below that actually determined for this period. It is not known what additional positive feedback effects are ignored by the models but are nonetheless significant.

## Effects

The various vegetation zones are determined, or at least strongly influenced, by temperature and precipitation. Since the temperature rise on a planet with oceans and land surfaces has to differ regionally and will thus change the driving force behind general circulation, a redistribution of precipitation zones is sure to take place, given the mean temperature increase predicted by the models of $3 \pm {}^{2}_{1}$ °C by the end of the next century and a lack of countermeasures by humanity (e.g. unchanged utilisation of fossil fuels). Vegetation zones and the productive areas of the ocean will shift according to the *shift in climatic zones*, just as the cultivated areas for food will have to be moved. It has not been possible so far to forecast regional anomalies (scales under approx. 1500 km) based on models because their spatial resolution is inadequate. Given a circulation time for the world's oceans of several centuries, a stable pattern will not form within a period of only one century for such massive changes in temperature. A very rough regionalisation can consistently be found, however, in the few scenarios calculated for the next 100 years, assuming no change in human behaviour: regions having a high degree of upper ocean mixing in the area around the migrating winter low-pressure zones (near Iceland, the Aleutians and around Antarctica) show an extremely delayed temperature increase because the additional energy input due to the reinforced greenhouse effect is distributed in them over a vast layer. Therefore, the temperature gradient from the equator to the higher mid-latitudes increases over the oceans in this transitional phase. According to the models, this leads to a greater drift in westerly winds there and an increased number of intensive low-pressure zones, resulting in more precipitation at high latitudes. Moreover, precipitation in the inner tropics will intensify.

The *delay in the temperature rise* on the Earth's surface due to the high heat capacity and slow mixing of *ocean waters* prevents full development of the climate change possible from the trace gases that have already entered the atmosphere. At the current growth rate of 2 to 2.5% annually the delay will last for several decades. Thus, only the effect of approx. half the disturbance 30 to 40 years ago, so to speak, is contained in temperature, precipitation and wind measurements. This fact makes climate models an extremely important tool and, at the same time, illustrates the dilemma of climatologists, who can never perceive the full effect of a simultaneously measured (anthropogenic) greenhouse gas increase from the time series of climate parameters.

The rise in sea level accompanying a global increase in temperature is delayed further because three of the four most important processes potentially contributing to it do not start until after commencement of the temperature rise. Thermal expansion of ocean water (+60 cm for a +1°C increase in temperature of the entire water column), melting of inland ice areas and thawing of permafrost regions are delayed by additional decades to centuries while the smaller mountain glaciers (having, together with the larger ones, a potential of increasing sea level by only 50 cm) predominantly begin to melt prior to the temperature rise due to increased backradiation.

Estimates of the rise in sea level as given by the IPCC (IPCC, 1991) in its "Business as Usual" scenario are 65 ± 35 cm in the year 2100 (more recent estimates by Wigley and Raper (1992) suggest 48 cm), primarily caused by heat expansion of ocean water and melting of the mountain glaciers, slightly slowed down by the growth in the Antarctic ice sheet and increased to a small degree by slight shrinking of the Greenland ice sheet. This low rise, compared to the potential of over 70 m with complete melting of the cryosphere, would still have far-reaching consequences: loss of fertile marshy lowlands, destroyed harbour facilities, flooded coastal towns, complete or partial submersion of distinct island states. These effects will occur especially where the frequency and degree of flood tides increase at the same time. Furthermore, it must be kept in mind that the sea level will change regionally to differing degrees as a consequence of shifted sea currents as well as of a patchy picture of ocean temperature rise (Maier-Reimer, 1992). No rise as well as a doubling of thermal expansion are equally possible, but a precise regional allocation cannot be carried out so far.

*Other anthropogenic changes in climate*

Can other global environmental changes weaken or strengthen the climate change caused by an increase in greenhouse gases? Discussion must focus on ozone depletion in the stratosphere (see 1.1.2) and the changed tropospheric chemistry (see 1.1.3), including modification and finally altered surface characteristics of the Earth.

*Ozone depletion in the stratosphere* is greatly dependent on latitude and shows a distinctive annual progression. Starting from an almost unchanged concentration at the inner tropics, the ozone loss grows as one moves towards the poles. Thus, from September to November at the geographical latitude of 60°S, for example, roughly 18% less stratospheric ozone was measured at the end of the period from 1980-1990 than at the beginning of the decade. This latitude dependence of ozone depletion also makes the anthropogenic portion of the greenhouse effect more dependent on latitude, in such a way that the imbalance between solar irradiation and backradiation at the top of the atmosphere – the actual driving force behind the general circulation – is intensified. Thus, at higher geographical latitudes a greatly weakened additional greenhouse effect, whose consequences have not yet been assessed in climate models, occurs in springtime.

The *changed tropospheric chemistry* exerts, in several respects, an influence on the Earth's climate. The methane concentration is determined not only by natural and anthropogenic sources, but also by the intensity of the chemical sink, which depends, in turn, on ozone depletion in the stratosphere and on the carbon monoxide content in the troposphere. More important than this process, which is taken into account in climate models in the form of $CO_2$ equivalents, is the intensification of the greenhouse effect due to the *increase in the concentration of tropospheric ozone*, whose occasional peak values are designated as "photochemical smog". By virtue of the latter, the reduction of the anthropogenic greenhouse effect as a consequence of stratospheric ozone depletion is partially compensated for in parts of the northern hemisphere. However, due to the major overall changes in the vertical profile of ozone, a gas that is extremely relevant to the climate and decisive for the temperature structure of the atmosphere, a climate change is being initiated, even with a constant total ozone content. Since there is still a lack of three-dimensional global models of atmospheric chemistry, this secondary triggering of climate change cannot be discussed in detail, however.

An anthropogenic influence that is very closely linked to the utilisation of fossil energy sources and which might weaken the greenhouse effect must be addressed here despite the many question marks involved: *increased turbidity of the air* due to the formation of aerosol particles from trace gases. In regions close to industry, e.g. in Central and Eastern Europe, soluble aerosol particles, which also represent condensation nuclei for the cloud droplets, are formed from sulphur dioxide ($SO_2$), nitrogen oxides ($NO_X = NO + NO_2$), hydrocarbons and ammonia ($NH_3$) during periods of sunshine in the lower atmosphere. In cloudless portions of the atmosphere they increase the backscatter of solar radiation more than they hinder heat radiation and are thus able to cool the planet (Grassl, 1988; Charlson et al. 1992). This effect is diminished, or can even be reversed by the presence of anthropogenic soot particles in plumes of urban agglomerations, i.e. the turbidity of the air has complex effects on the greenhouse effect, depending on the soot content of the aerosol.

When there is a higher number of condensation nuclei per unit of volume, more cloud droplets are created with the same water content. Viewed from above, anthropogenically altered clouds are brighter, i.e. they reflect the sunlight more intensively. They do not hinder heat backradiance more than the unaffected clouds, however, and thus damp the greenhouse effect[2].

Overall, however, there is no longer any doubt that the consequences of the radiation budget altered by us will leave deep scars in human society and in nature if counter-measures are not taken soon. Especially because of weather extremes resulting from climate change, there will only be a distinction between those affected and those seriously affected, but not between winners and losers. The pressure on primeval ecosystems will further accelerate the extinction of species, the lack of availability of water will become a central issue in many regions and the

[2] A meeting of a group of experts led by the Working Group "Science" of the Intergovernmental Panel on Climate Change took place in Hamburg in May 1993 to discuss the open questions related to ozone depletion and increased turbidity of the air. Under the title, "Ozone Change and Aerosols", this aspect is to be clarified as far as possible for the next status report to the United Nations.

expected exodus from badly affected areas will confront the richer nations with far greater problems than those currently faced.

## Link to global change

Due to direct connections between global environmental changes and the most important source of energy for today's industrial societies, fossil carbon, the links to all environmental assets become immediately obvious. Table 5 of the *feedback effects in the water and carbon cycle*, which may mitigate or reinforce the anthropogenic greenhouse effect, provides an initial insight into this complexity. For only two out of the eleven mentioned feedback effects do we know more than simply the symptoms. The positive *ice-albedo-temperature feedback* and the *water vapour content*, which rises rapidly with the temperature and thus has a positive feedback effect, were always accounted for by three-dimensional circulation models. They have an effect within years, in the case of water vapour even within weeks. Since both feedbacks are positive, i.e. reinforce the effect, they are responsible for a large portion of the temperature rise due to greenhouse gases. In sensitivity studies it was shown that the global temperature rise of 1.2°C on the Earth's surface (with doubling of the $CO_2$ content) increases to values between 2 and 2.5°C in the case of both feedback effects.

The feedbacks associated with the *carbon cycle* have a direct effect on the driving mechanism; if triggered rapidly, they may become serious as early as the coming century. They include *feedbacks* 5 and 10 with different effects. The first links CFCs with the global carbon cycle by connecting the ozone content with the activity of marine and limnic phytoplankton as well as with the food production. It has the potential for creating a profound global crisis. *Feedback 10*, often called the $CO_2$ *fertilising effect*, is probably of particular importance during the transitional period to warmer conditions because then the effects of the temperature rise cannot yet be fully counteracted. Both feedback effects have been confirmed in individual studies (Smith et al., 1992b; WMO/UNEP, 1991).

Table 5: Positive and negative feedbacks of the carbon and water cycles, beside others, affecting the anthropogenic greenhouse effect

| No. | Feedback | Sign | Knowledge | Geographical scale | Time scale | Active and affected cycles |
|---|---|---|---|---|---|---|
| 1 | Enhancement by water vapour | + | well known | global | weeks | C, W |
| 2 | Ice cover – albedo – temperature feedback | + | well known | regional (NH+SH) | years to centuries | C, W |
| 3 | Increase of atmospheric backscattering gas-to-particle conversion | – | hypothesised, partially confirmed | regional (NH) | weeks | C |
| 4 | Increase of backscattering from anthropogenically modified clouds | – | hypothesised, partially confirmed | regional (NH) | weeks | W |
| 5 | Increase in UV-B irradiation reduces biomass growth and $CO_2$ sequestration and absorption in the ocean | + | hypothesised, partially confirmed | regional (SH+NH) | decades | Cl, O |
| 6 | Enhanced convection augments ice clouds occurrence which shields the surface | + | hypothesised, partially confirmed | regional | weeks | W |
| 7 | Decreasing permafrost contributes to atmospheric $CO_2$ and $CH_4$ concentrations | + | hypothesised, partially confirmed | regional (NH) | centuries | C |
| 8 | Warming of soils at constant or decreasing moisture contributes to atmospheric $CO_2$ concentrations | + | hypothesised | global | decades | C |
| 9 | Increasing $N_2O$ and $CH_4$ concentrations enhance stratospheric $O_3$ depletion and pronounced dependence on latitude | – | hypothesised | regional | decades | O |
| 10 | $CO_2$ fertilising effect could increase the soil and forest C reservoirs | – | hypothesised, partially confirmed | regional | decades | C, O |
| 11 | Warming triggers growth of the Antarctic ice shield | – | hypothesised | global | decades to centuries | C, W |

NH = northern hemisphere, SH = southern hemisphere, C = carbon, W = water, O = oxygen, Cl = chlorine

Feedback with clouds is especially complex. *Feedbacks 3, 4 and 6* are intimately linked to one another and make the main contribution to the large range of uncertainty still existing for the mean global rise in temperature ($2.5 \pm^{2}_{1}$ °C with doubling of $CO_2$). At the moment we cannot, for example, include any physically more precise parameters in climate models because of insufficient knowledge with respect to the temperature dependence of the ice content in ice clouds (*feedback 6*) and to the altered mean elevation of clouds.

*Feedbacks 3* and *4*, which are connected to *aerosol particles* and their effect on clouds, are both potentially very important, but representing negative feedbacks, i.e. with a damping effect. However, they are tied to the current degree of pollution because they are carried by short-lived gases and, in contrast to $CO_2$ and $N_2O$, do not show any accumulation. The relative damping effect was greater at the beginning of anthropogenic pollution than it is today. Its significance for the radiation budget has only been roughly estimated to date; the net effect diminishes with the soot content of air that often increases simultaneously.

In the long run, in decades or centuries, the feedback effects of the carbon content of the soil may become very important since only 3‰ of the *carbon stored in the soil* (approx. 3 billion t of C) is almost equivalent to the carbon remaining in the atmosphere every year resulting from the combustion of fossil fuels. *Feedback 7* opens the carbon reservoir fixed in *permafrost soil* during thawing, *feedback 8* increases the *decomposition of organic material* during a temperature rise and constant or decreasing ground moisture; in the case of increasing ground moisture, the effect may be the opposite.

*Feedback 11* acts over a particularly long period because the *circulation times of inland ice sheets* have a magnitude of approx. 10,000 years. Since the maximum accumulation of snow is at somewhat higher temperatures than the current mean temperature of inner Antarctica, this ice sheet probably grows during a temperature increase and *reduces the rise in sea level* due to melting of other ice regions as well as the expansion of the sea water on a long-term basis. The damping effect for the 21st century is assumed to be 2 mm per year, given an estimated rise of 6 mm annually (WMO/UNEP, 1990).

The links between climate change and the economic activities of people, and the reactions of the latter to the risks that ensure are at least as varied and as incalculable as the feedback effects of the ecosphere in response to these climate change. Thus a general boycott of tropical wood on the part of industrial nations might reinforce the greenhouse effect just as much as freer world trade at low energy prices because in the first case the tropical rainforest is, from a short-term point of view, of less value and therefore perhaps less worthwhile maintaining, while in the second case French yogurt would be transported to Singapore and in winter more apples from New Zealand would be eaten in Germany. Both reactions increase $CO_2$ emissions. Ill-considered political decisions may thus have a counter-effect on reductions in $CO_2$ emissions.

The way in which the population's awareness of long-term global environmental changes is sharpened will significantly influence measures for reducing greenhouse gases and implementation of such measures. Despite the colossal task ahead, not only must the chances of success be shown clearly, the desire to get personally involved must also be aroused.

## Assessment

Only through the debate over anthropogenic climate change was discussion stimulated on the general dependence of human society on climate change. The objective is clear now that three developments have occurred. Firstly, there now exist many indications of a significant anthropogenic climate change. Secondly, a preliminary scientific clarification has taken place with a statement of some physical reasons (IPCC 1990, 1992; Enquete Commission, 1990a). Thirdly, the largest portion of the international community of nations signed a Framework Convention on Climate Change at UNCED in June 1992. The objective was formulated as follows (UNCED, 1992; Enquete Commission, 1992):

> *The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic*

*development to proceed in a sustainable manner.*

*Stabilisation* of the *concentrations* of greenhouse gases is a lofty goal which would, in some cases, force drastic reductions in emission rates, depending on the lifetime of the gas in question. If one did not want to change the current concentrations, an immediate reduction in global emissions of at least 60% for $CO_2$, even 80% for $N_2O$ and roughly 20% for $CH_4$ would be necessary. Thus the linking of the main objective in the Convention, “stabilisation of the concentrations of greenhouse gases”, to the three secondary conditions mentioned must be interpreted with caution. Stipulation of objectives, measures and a time frame for their fulfilment is required.

This again opens up a scientific debate. What does “maintenance of the natural adaptability to climate change” mean? Is it the often mentioned mean global temperature rise of 0.1°C per decade to which ecosystems can adapt (this figure is greatly exceeded in the “Business as Usual” scenario, which mentions a value of 0.3°C per decade), or is it an even lower figure? What does “production of food that is *not endangered*” mean in a world which even now is failing to prevent starvation in the semi-arid tropics despite global trade? What kind of sustainable economic development should there be implemented if the previous type of economic activity has created the global environmental changes?

Despite the fact that such questions still have to be clarified, the central guideline for action can, nevertheless, be stated: *research needs must not delay necessary action.* The main actors responsible for the perturbed composition of the atmosphere, i.e. all industrial nations, most oil-producing countries as well as several tropical rainforest countries with high per capita emissions of greenhouse gases have to reduce these emissions drastically. Furthermore, the industrialised nations must initiate an unprecedented increase in efficiency in the utilisation of fossil fuels and other resources according to the motto, *“less per capita emissions and raw material consumption, while re-approaching the natural cycles”*. They have to start limiting energy generation from non-renewable sources and to replace it by sustainable, systematically promoted techniques for the utilisation of renewable sources. The developing countries can acquire these new, more economical, less environmentally harmful techniques, adapted to their circumstances, whereby the economically weaker nations can obtain support from the *“Global Environmental Facility”* (GEF) administered by the United Nations and funded by the industrial nations, or from new mechanisms of technology and financial transfer still to be created.

According to the current level of knowledge, a mean global temperature rise of 2°C above the figure prior to industrialisation is unavoidable due to the already existing and, for the time being, still increasing perturbance of the environment. For the industrial countries, therefore, the objective of the Convention means, in the long run, a departure from fossil fuels as the most important source of energy. By the year 2050 only 20% of the present amount of fossil fuels may be used in the industrial countries, according to present knowledge, in a world with approx. 10 billion people (Enquete Commission, 1990a). This means that the intermediate goal of *“30% reduction in* $CO_2$ *emissions”* by the year 2005, as adopted by the German Bundestag in November 1990, must be achieved, if possible, by all OECD countries and not just by Germany.

## Impact weighting

Anthropogenic climate change has now reached a magnitude similar to natural changes and, in the opinion of most climatologists, will soon predominate. Human society in general is endangered and the ecosphere continues to be polluted, in particular due to the rapidity of change. The consequences of the additional greenhouse effect are equivalent in dimension to the two other major global problems, namely reduction of biodiversity and the almost uncontrolled increase in the world population. The latter may, in future, undo the possible successes in reducing emissions achieved by the previous main polluters, the industrial nations. Since nearly all raw material flows are coupled to the rapid exploitation of fossil fuels, the reduction in $CO_2$ emissions requires a significance going far beyond abatement of the greenhouse effect. It is accompanied by many other successes (synergetic effects) that would otherwise have to be achieved separately.

### Research needs

The questions raised by strategies aimed at reducing the threat of rapid climate change can only be answered with difficulty, if at all, given the kind of research conducted up to now separately in the natural and social sciences. In view of the existing disturbance caused by these changes and their long-term nature, it will be necessary to simultaneously prevent further changes and adjust to changes that have already occurred. What is also necessary is a comprehensive research strategy, involving all scientific disciplines, aimed at optimising these processes.

This implies, for example:

- Determination of the damage by failing to implement the necessary measures, i.e. clarification of the costs generated.
- Identification of the regions and social groups particularly sensitive to climate change.
- Development of less environmentally harmful technologies and support frameworks so that obsolete technologies can be rapidly replaced.
- Creation of economic models that take account of all external costs, e.g. consumption of land in countries supplying raw materials.
- Sharpening awareness of the real risks of climate change and design of strategies for behavioural change at all levels.

There are other open questions that can be answered by smaller groups representing fewer disciplines. Well-informed precautionary policies need the support of an optimisation process with a strong natural and social sciences foundation. Some of these questions in the natural sciences are:

- What primeval ecosystems become larger carbon reservoirs in the event of climate change and increased $CO_2$ level?
- Which disruption of the radiation budget triggers the melting of the large ice sheets?
- How should agriculture be designed to provide nourishment for a growing world population if the perturbance of the atmosphere and the soils is to remain as small as possible?

Some of the questions to be clarified by the social sciences are as follows:

- To what extent can the behaviour of various groups and cultures be forecast in the event of altered living conditions?
- When and under which conditions are tradable permits preferable to the taxation of resources?
- How should production and recycling technology be set up so that the perturbation of the atmosphere remains as low as possible?

## 1.3 Hydrosphere

Water is a vitally important, generally renewable resource of the Earth. As a result of the special temperature distribution on our planet, water occurs in all three aggregate states, i.e. liquid water, water vapour and ice. The effects of global environmental change are very different in the ocean and in freshwater. The dominant topics in the sub-section on “Ocean and cryosphere” are the rise in sea level, changes in circulation, shifts among fauna and flora as well as the shrinking of the ice sheet of the seas and the melting of the ice caps. The cryosphere (ice-covered land and sea surface) is treated in the ocean section due to the problems involved, even though inland ice masses are composed of freshwater. In the sub-section on “Freshwater”, the focus is on scarcity and pollution and on the links between these and the other elements of the ecosphere and the anthroposphere.

## 1.3.1 Changes in the ocean and cryosphere

### Brief description

The world's seas cover 71% of the Earth's surface. They have very complicated current patterns, react slowly with the sea bottom, more rapidly with the atmosphere, and are the most important source of precipitation on the continents and sink for depositions from the land. Life probably originated in them. While time scales in the atmosphere are short (hours or days for a low-pressure area) and the spatial dimensions of the vortices are large ($10^3$ km), the entire ocean reacts relatively slowly to changes in the atmosphere (centuries), and oceanic eddies are an order of magnitude smaller than those in the atmosphere, and exist for months.

The discipline of *oceanography* is relatively young. The physical and chemical investigation of the ocean experienced a strong upswing in the middle of this century thanks to the introduction of new analytical tools. Knowledge of life in the ocean is still incomplete, however, despite the fact that fish, crabs, octopuses and mussels, all economically important, have been well investigated in their behaviour. Human attitude in exploiting these "living resources" is, even today, that of a gatherer and hunter. A form of management and economic utilisation going beyond catch regulations and comparable to the planned production of food in agriculture is hardly carried out at all.

The ocean is not only a *source of food* for people, but is also one of the most important traffic routes and the sink for a large portion of our wastes. It provides *natural resources* and, to an increasing extent, *raw materials* for the pharmaceutical industry.

In addition to these primarily material aspects, the ocean has recently acquired a significant non-material value as a *recreational area*. The number of people seeking recreation and relaxation in and on the water as well as on the coast is increasing constantly, and marine tourism, in many places, is one of the most rapidly growing branches of industry.

Proximity to the sea has a great value for many people for very different reasons, be they economic or non-material in nature: today, roughly 70% of the world population lives within 200 km of the coast and two-thirds of all metropolises having a population of more than 2.5 million are situated on the coast. Between 100 and 200 million people live in coastal zones that are below the storm tide level.

The effects of global environmental changes on the ocean will pose great problems for many countries; the very existence of some island states is even threatened. Given the different functions which the ocean and coastal waters, in particular, have for human society, serious conflicts of interests arise, not only between utilisation and protection efforts, but also between various forms of utilisation. Global environmental changes will, in some cases, shift these conflicts and, in others, accentuate them.

### Causes

People act on the ocean as an entity through the changes he causes in the composition of the atmosphere (see 1.1). In their spatial expansion and significance, the indirect influences of the *reinforced greenhouse effect and increased UV-B radiation* certainly surpass the direct interventions of people, which lead to short-term and long-term changes at the local and regional level only. They include

- the increasing *pollution of the ocean* due to overfertilisation, the discharge of industrial and household effluents, and the dumping of solid waste (e.g. nuclear waste) at sea,
- the *exploitation of ocean resources*, on the one hand, namely raw materials such as oil and natural gas, ore, sand, coral rag, and, on the other hand, the exploitation of biological resources such as mangrove forests, or overfishing and destructive fishing methods,
- uncontrolled *development of the coast* and *land reclamation*.

An example of regional/local *marine pollution* which can affect any coastal region in the world is the discharge of oil from shipping and offshore activities. Spectacular tanker accidents account for roughly 20%, i.e. a relatively small portion of this pollution; the predominant share enters the ocean during loading or unloading and during routine shipping operations (Bookmann, 1993).

The most important consequences for the ocean which can be expected as a result of atmospheric changes are

- higher water temperatures, especially in the surface layer,
- rising sea level,
- altered deep-sea circulation,
- shifting of oceanic fronts and currents,
- changes in sea water composition due to altered gas exchange with the atmosphere,
- changes in the marine biosphere.

The criterion on which the above order is based is the degree of certainty of forecasts: only for water temperature and sea level are time series available which provide direct, relatively high-resolution spatial and temporal measurements which substantiate the respective increase over the past 100 years (Jones et al., 1986).

Increased water temperatures are a consequence of the reinforced global greenhouse effect (see 1.1.1). The *rise in sea level*, the rate of which has been measured as approx. 1.5 mm per year over the last 100 years, has essentially two causes: increased melting of mountain glaciers (Haeberli, 1992) and the expansion of sea water due to temperature rise. Given an uncontrolled increase in the atmospheric concentration of $CO_2$ in the course of the next 100 years, the rise in sea level is estimated at 48 cm according to most recent calculations (Wigley and Raper, 1992); this projected rate is at least three times as high as that measured in the last century.

Such estimates are not yet possible for the *shifts in ocean currents* and the related changes in heat transmission. Coupled ocean-atmosphere climate models indicate regional changes in the North Atlantic. These involve reduction in the sinking of cold water masses, a central process in global circulation. Disruptions in this part of the oceanic system cause worldwide changes in circulation patterns. The same applies to bottom water formation in the Weddel Sea in the Antarctic. Calculations made by the Max Planck Institute for Meteorology in Hamburg forecast a weakening of the Gulf Stream by approx. 20% associated with a reduced formation of deep and bottom water (Mikolajewicz and Maier-Reimer, 1990). For coastal upwelling areas, on the other hand, an intensification of upwelling is expected due to stronger winds parallel to the coast (Bakun, 1990). The latter may develop as a result of increased warming of the land surface, causing the air pressure gradient between land and sea to rise and wind speed to increase.

Roughly fifty times as much carbon is dissolved in the ocean in the form of carbonates, hydrogen carbonates, dissolved organic carbon and carbon dioxide ($CO_2$) as in the atmosphere. In the surface layer alone, which is approx. 75 m deep, there is already as much carbon stored as in the entire atmosphere (Enquete Commission, 1990a). Therefore, it was justifiably asked whether the ocean could absorb the $CO_2$ additionally produced by human activities. This question is not easy to answer. Surface water is weakly acidified by the absorption of $CO_2$ from the air. As a result, the quantity ratio in sea water shifts slightly from carbonate to hydrogen carbonate and then to dissolved $CO_2$. The absorption capacity for $CO_2$ is somewhat reduced as a consequence. The factor named after R. Revelle takes this effect into account and says that a doubling of the atmospheric $CO_2$ content increases the concentration of dissolved carbon in the surface water by only just under 10%. The transport of the dissolved $CO_2$ from the surface water to the depths takes place in periods of 100 – 1000 years by means of diffusion and mixing; biological and physical sinking processes (formation of deep water) may accelerate it to a great extent.

The *net deposition* of $CO_2$ from the atmosphere into the ocean is estimated today to be 1.6 billion t of carbon annually (Tans et al., 1990). Controversial debates surround the role of marine plankton, which transports carbon to the depths of the ocean, via the so-called *"carbon pump"*, through the sinking of dead organisms or fecal pellets (Tans et al., 1990; Broecker, 1991; Longhurst and Harrison, 1989; Sarmiento, 1991). However, the potential of this carbon pump, even with greatly increased plankton production, is not sufficient to explain the carbon imbalance: in the atmosphere approx. 2 billion t of carbon per year less are measured than are released by human activity. In this case the boreal forests are more likely to be the sink (see 1.5.1).

The dramatic *ozone depletion over the Antarctic* in late winter recently attracted attention to the Antarctic Ocean, where biological systems are greatly endangered by increased UV-B radiation. Field studies have indicated a reduction in primary production in the spring of the southern hemisphere of 6 to 12% compared to areas without ozone thinning (Smith et al., 1992a). Antarctic phytoplankton shows a greatly lowered resistance to UV-B radiation in comparison to tropical phytoplankton (Helbling et al., 1992). Research on the ecological effects of the ozone hole above the Antarctic is still in its infancy, however. Too little is known about the physical and chemical conditions of the atmosphere there in spring, or about the biological reactions of the often endemic species with their repair and protection mechanisms (Karentz, 1991).

## Effects

### *Global effects*

Summarising the above points, the rise in water temperature and sea level can be predicted relatively accurately. The greatest attention in this section, therefore, will be devoted to these effects, while the other, far less studied changes will only be treated briefly.

A further *increase in air and water temperatures* means a reinforcement of certain stress factors for those species and communities that already live periodically at the upper limit of their temperature tolerance, such as corals or species communities in the tidal area of the wadden seas. The increase in frequency and intensity of short-term temperature fluctuations is thought to be much more harmful to corals and thus for the entire coral reef ecosystem than a gradual rise in the average temperature (Salvat, 1992; Smith and Buddemeier, 1992). For large portions of the population in coastal regions as well as on islands in tropical latitudes, the dying out of coral reefs would have far-reaching consequences. They serve as the foundation and material for building, are the habitat for fish and, not least of all, an important factor for tourism.

Of special significance is the change in atmospheric circulation over the oceans at *increased surface temperatures*. It has recently been discovered that there is a direct connection between the maximum intensity of tropical cyclones and the difference between surface and tropopause temperature (approx. 110°C at the site of the cyclones; Emanuel, 1988). When the water surface is heated by the reinforced greenhouse effect, this most probably results in

- extension of areas affected by cyclones,
- an increase in the maximum intensity of the cyclones,
- a change in their paths.

Although the intensification of the hydrological cycle in the tropics over the past decades was recently described (Flohn et al., 1992), i.e. an above-average temperature rise in the mid-troposphere (as also predicted in the coupled ocean-atmosphere models), it is difficult to furnish evidence of an increase in storm frequency, as is always the case for rare events. It is still disputed whether the frequency and intensity of storms over the oceans in the tropics and mid-latitudes are generally increasing. For the North Atlantic it has been shown that the number of winter depressions has more than doubled over the last 40 years. In particular, an increase in tropical cyclones would be equally disastrous for nature and people. Some coastal areas may be additionally damaged through being deprived of their natural protection, such as offshore reefs (tropical coasts), flat islands (e.g. southeast coast of the U.S.) or coastal forests (mangroves) (Titus and Barth, 1984).

The *rise in sea level* will have substantial effects on all ecosystems in coastal regions since large, low-lying land areas or deltas may be lost due to floods. A loss of biotopes in coastal regions (mangroves, sea grass fields, salt marshes) can be expected if the natural topography or anthropogenic changes of the hinterland do not permit a retreat, i.e. an inland shift of the respective ecosystem. This is not possible in natural areas either if the sea level rises so rapidly that species communities are unable to settle the hinterland area in time.

There is an additional important effect: a rise in sea level shifts the boundary between salt water and freshwater not only along the coast, but also in groundwater areas and in estuaries (UNESCO, 1990). The freshwater lenses of flat islands and atolls are particularly endangered (Miller and Mackensie, 1988; Hulm, 1989). In such a case, salinisation leads to impairment or even destruction of the flora and fauna dependent on freshwater, and deprive people of the life-support systems on which they depend.

*Sea ice* plays an important role in the climate system and influences atmospheric and oceanic circulation in several ways through its distribution in polar areas. Due to its high albedo (backscattering) and good insulation capability, sea ice modifies the radiation budget and the exchange of momentum, heat and substances between the ocean and the atmosphere. When it freezes, sea ice separates from salt-containing and thus heavier water and in this way stimulates the formation of deep water and the mixing of the oceans. The expansion of sea ice areas is therefore of paramount importance for climatic activity, but has little influence on the sea level.

An altered *circulation of the oceans* may impair biological productivity in coastal regions and thus impair (UNESCO, 1990) or, as in the case of increased coastal upwelling (Bakun, 1990), improve the food supply for the population. Other effects, such as changes in the timing of plankton bloom, shifts in food distribution between swimming fauna and those living on the bottom (Townsend and Cammen, 1988) or fluctuation in fish stocks (Southward et al., 1988), cannot be linked as yet to altered circulation of the ocean with any significant degree of certainty (IGBP, 1990). Generally, however, changes in primary production are expected in coastal regions (Paasche, 1988).

The effects of an accelerated rise in sea level *for the people affected* were described in exemplary form for the islands in the South Pacific (Hulm, 1989). 36 island states have joined together there to form the Alliance of Small Island States (AOSIS) in order to throw more weight behind their demands for action against the climate change they fear (see 2.2). Most of the points indicated by Hulm can be applied to other islands and coastal countries in the world.

A rise in sea level has consequences for

- *habitat:* the available habitat is reduced in size or, in the worst case (small, flat islands), completely destroyed; the coastal population migrates inland, if possible, causing an increasing in housing density,
- *food production:* marine (coral reef, seaweed fields), terrestrial (agriculture, drinking water) as well as sources of food bordering the coast (mangrove forests) suffer reduced yields or are lost completely,
- the *economy:* increased coastal protection or, where this is not possible, the relocation of human settlements and industrial or harbour facilities, and the loss of beaches or other coastal areas having a high leisure value involve substantial financial burdens or losses for the countries affected,
- *society/culture:* people forced to migrate are uprooted, and important cultural assets are lost.

### Regional / local effects

An increase in seawater temperature shows regionally similar differences as the temperature rise in air close to the surface (see 1.2). It is also certain that the absolute seawater volume is increasing, but again with regional differences; the increase is not noticeable as a rise in sea level on all coasts. Some coastal regions rise as a result of retreating glacial inland ice masses and glaciers (isostatic compensatory movements) so that a relative sinking of the sea level is recorded there. Scandinavia and the Canadian coasts, for example, are affected by this. However, other regions, such as the Netherlands, are sinking. Locally, coastal zones are sinking due to human intervention, as in Venice, Bangkok and in delta areas of the Mississippi and Nile (Wells and Coleman, 1987; Milliman et al., 1989). These regions are especially threatened by a further rise in sea level.

The *"Coastal Zone Management Subgroup"* (CZMS, a working group of the IPCC) deals with the threats to coastal regions posed by rising sea level. The results of the risk assessment case studies conducted so far are summarised in their Report entitled "Global Climate Change and the Rising Challenge of the Sea" (1992). According to this study, considerable losses have to be reckoned with in wet regions close to the coast along the South American and African Atlantic coasts, in Australia and in Papua-New Guinea, a third of which have great ecological and economic importance (salt marshes, tidal zones, mangroves). The coastal regions most threatened by flooding are small islands, the African Mediterranean and Atlantic coasts as well as the Indian subcontinent.

Direct interventions by humans into the oceanic systems may therefore have severe consequences for the population, particularly in *coastal regions*. In addition, the effects of direct interventions and climate-related changes mutually influence each other and often reinforce each other as regards their negative consequences. This development has become an acute problem, especially for countries in tropical and subtropical latitudes (case studies: Madagascar; Vasseur et al., 1988; Southeast Asia; White, 1987), since the natural resources of the ocean frequently represent the most important basis for the nourishment of the populations there. Increased water pollution and the overexploitation of natural resources by the fishing industry, on the one hand, and through the impairment or even destruction of natural habitats, on the other, deprives coastal populations of their livelihood. This has a direct effect on their own food basis, but also on food production for export and tourism.

In connection with *ocean pollution*, it must be taken into account that all types of waste discharge (solid and liquid) are local or regional, but that these can quickly become an international problem due to the sometimes very effective transport via ocean currents beyond national territorial waters. A typical example is the pollution and overfertilisation of the Baltic Sea via the Oder, Weichsel and Neva Rivers as well as from the air – all countries bordering the Baltic Sea are directly affected by this. A similar situation applied to the oil slicks in the Persian Gulf. Wars and the nuclear industry – as we are finding out only now – have left hazardous waste in the form of toxic gas and nuclear waste in the ocean and thus possibly created problems of international dimensions.

Most of the problems mentioned in this section still manifest themselves more at the local or regional level. The industrial countries have an obligation here, as exporters and as the main causes of the global climate change. They should furnish greater support for preventive measures, such as providing information and training (see 2.4), implement technology transfer in the fields of effluent treatment, coastal protection and sustainable use of natural resources (see 2.2), and give direct assistance in the case of disasters.

Besides climate change, intensive *population growth* and large-scale migratory movements also affect coastal regions to a considerable degree. Urban agglomerations come into being here with high traffic densities and enormous waste levels, thus leading to increasing destruction of natural habitats and the resources these provide.

### *Time-related effects*

Seawater temperature and sea level are slow to change. Effects along the coast are often not visible until disasters suddenly strike in the form of flood tides. It is not possible to forecast with adequate precision when this will occur in a specific region, because forecasts of climate change are not available on a regional basis, nor do extreme-value statistics for flood disasters permit a time-related prediction. The dramatic increase in privately insured storm damages in comparison to other natural disasters (Münchener Rück, 1992) already indicates the significance of climate change. The consequences of the alteration in the composition of seawater caused by increased $CO_2$ absorption and greater UV-B radiation may also become noticeable in the near future, perhaps even within a few years.

Several mathematical simulations indicate that the circulation pattern in the North Atlantic can already be significantly altered within a few decades through relatively small changes in freshwater intake (melt water, precipitation) (Stocker and Wright, 1991).

### Assessment / need for action

The dimensions of oceanic processes are too large for direct human control or influence. However, they react to the additional greenhouse effect and anthropogenic ozone depletion in the stratosphere caused. In order to reduce the stress that the ocean exerts on nature and on the anthroposphere as a consequence of anthropogenic alterations of other climate system components, the increase in greenhouse gases in the troposphere and ozone depletion in the stratosphere have to be slowed down and ultimately stopped.

Global effects engendered by rising sea level are not expected until decades from now, but greatly endangered regions (flat coasts and islands, river estuaries) may be threatened at a much earlier date. The aim of the Coastal Zone Management Subgroup (CZMS) is to record and evaluate the effects of the rise in sea level on the population, the economy, on ecological and social values as well as on agricultural production. To put all coastal countries, especially the poorer ones, in a position to carry out such a study and initiate the necessary measures to reduce the danger, support of the CZMS by the industrialised world is required in the form of funds, technology and knowledge. The Council recommends that Germany become actively involved here, in a manner similar to the Netherlands.

The ocean area near the coast is certainly one of the most sensitive marine systems, but at the same time the most heavily abused one. Direct local or regional human interventions, such as oil rigs, coastal reinforcements, settlements, discharges, dumping and overfishing, can be controlled by humans, however, and must therefore be limited or reversed in the short term to a acceptable level as defined by the bordering countries. A problem that arises in this connection is that the various utilisation interests compete with each other for the space available. Thus, similar to the conceptualisation of land use, it is necessary to work up planning concepts through interdisciplinary cooperation among natural scientists and economists such that sustainable use of marine resources is ensured – and this also includes tourism – given the increasing settlement of coastal regions. The concept of Integrated Coastal Management (ICM) is a promising problem-solving approach in this regard. Implementation of ICM is a continuous process. It requires a direct link-up of all groups concerned, from industry, science, politics, planning and administration, as well as the general public. In the view of the Council, there is a substantial deficiency in this respect in Germany. The North Sea and, to an even greater extent, the Baltic Sea are perfect candidates for internationally coordinated management. Germany could provide important input here, in the form of preliminary scientific and political work and experience.

International conventions are necessary in order to regulate activities on the open sea that have international, and perhaps even global, long-term impacts – one example being the dumping of nuclear waste in the deep sea. Compared to the relatively well-developed regulations governing oil transport, clean-up measures and liability in the case of tanker accidents, there is still a substantial need for legal and political action relating to the disposal of hazardous waste in the open sea.

## Research needs

Ocean-related research should now concentrate, with reference to global change, on two tasks:

- Investigation, monitoring and forecasting of the climate in the ocean. This includes understanding of the processes that control this climate.
- Investigation of the interactions between people and ocean. This means that new theoretical and empirical approaches have to be found which link natural science and socioeconomic aspects of people-environment interactions.

The following areas of research focus are derived from the above tasks:

- Monitoring the climate in the ocean and producing time series enabling longer-term forecasts in the near future going beyond the weather forecast (planned project: GOOS = Global Ocean Observing System).
- Investigation of the polar seas, focussing on sea-ice areas. The latter are of global importance: even small changes in temperature can be decisive for the melting of sea ice, which would then have serious consequences for the radiation budget and heat balance of the Earth.
- Assessment of the influences of increased UV-B radiation and a temperature rise on marine organisms and communities.
- Investigation of deep-sea processes connected with the carbon cycle and of the formation of deep and bottom water. The biodiversity and the ecological significance of the deep sea must be further studied, particularly with regard to the permanent disposal of hazardous waste or utilisation in the form of ocean mining. A great potential for the pharmaceutical industry is seen in the microorganisms on the sea floor, similar to the case of the tropical forests.

- Efforts to monitor the ocean and conduct deep-sea research are placing new demands on marine measuring and underwater robot technology. There is a need for engineering research in this field.
- Improvement of knowledge about coastal processes and land-sea interaction. This is especially important in marginal and enclosed seas as well as in the tropics, since the greatest pressure on ecosystems is exerted in these regions.
- Development of new concepts for sustainable use of ocean resources and for coastal management, which have to be harmonised with different regional needs and priorities. Greatest research needs are located in the tropics.
- Development of biotechnologies that make use of natural marine resources in mariculture (algae and the like) and which can be operated with solar energy. They represent a significant potential for developing countries if mariculture can be developed towards a user-friendly and environmentally sound technology.

## 1.3.2 Qualitative and quantitative changes in freshwater

### Brief description

Water is our most important nutrient; to survive, people need at least two litres of liquid a day. Economic utilisation of water is also of great significance; a qualitatively and quantitatively adequate water supply is a requirement for any sustainable development. In addition, water plays a major role in climatic activity (hydrological cycle, energy transport in water vapour, ice caps) and is decisively involved in processes of the lithosphere (weathering of rock, formation of landscapes via erosion, frost fissuring) and the pedosphere (shifting of substances in profile, formation of humus); it is the basis of all life processes on Earth. These functions of water as a nutrient, an economic resource and as an ecological medium are reflected in a further, cultural role: water was and is an important cultural element with highly significant meaning in mythology and religion.

More so than with other environmental media, two different perspectives or functions can be ascertained in the case of water: on the one hand, water as an economic resource to be managed efficiently, and, on the other, water as a cultural, public (occasionally even holy) asset. These perspectives or functions are often regarded separately or even in isolation from each other, but in fact are closely interlinked. A common characteristic of both is that a value is attached to water, in the one case in terms of economic assessment (“price of water”), in the other case through cultural assessment (“intrinsic value of water”).

A great variety of natural and anthropogenic factors pose dangers for water as a resource and as a cultural asset. These are expressed in basic processes, described in more detail below, as *scarcity* and *pollution*, which frequently imply *wastage*. These processes occur independently or in combination, differ in their degree of intensity and must be evaluated differently with regard to their causes, their impacts and the necessary counter-measures. They each involve specific problems, which overall, however, can be designated as “water scarcity”, i.e. the lack of a sufficient quantity and quality of water. Pollution further aggravates scarcity. Although water problems always occur at a specific site or in a certain region, it is appropriate to speak of global water problems, especially since the frequency, extent and range of local and regional problems are tending to increase rapidly.

With respect to the Leitbild (guiding principle) of “sustainable development”, water plays a decisive role in the view of the Council because it is the essential basis for the very existence and economic well-being of every human society, and this basis appears to be threatened to an increasing degree.

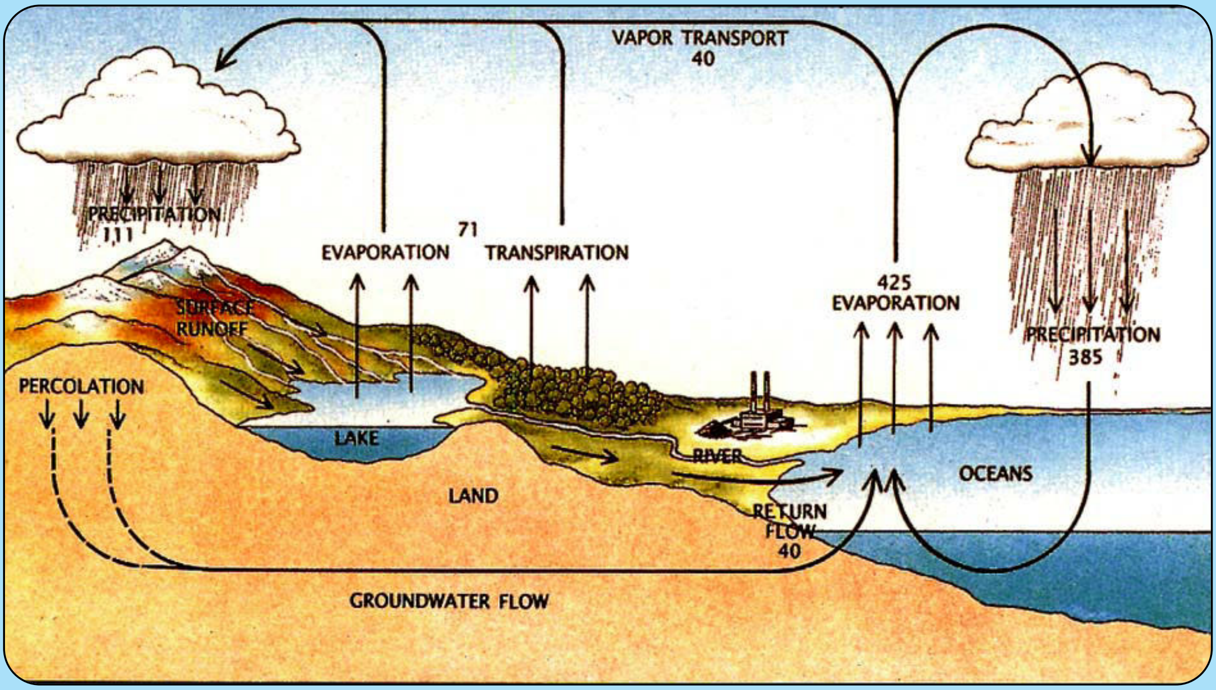
### *Water as a resource*

The water reserves of the Earth mostly consist of salt water (97%) and ice (2%); a mere 1% of all water reserves circulates as freshwater in the hydrological cycle and is potentially accessible for human utilisation. The volume of the water moved in this cycle is estimated at roughly 500,000 $km^3$ annually (see box on: “The hydrological cycle”).

## Box 4: The hydrological cycle

In the hydrological cycle, water moves as vapour, liquid and ice over, in some cases, long distances. It evaporates over the oceans and land masses and is emitted by living organisms (transpiration and breathing of human beings, animals and plants). Air currents transport water vapour, and it falls back to the Earth as rain through condensation and as snow through freezing. It flows into the oceans via runoff above ground and underground. The hydrological cycle is driven by the sun. The figures indicated reflect estimates of the transported water volume in 1000 $km^3$ (Fig. 4).

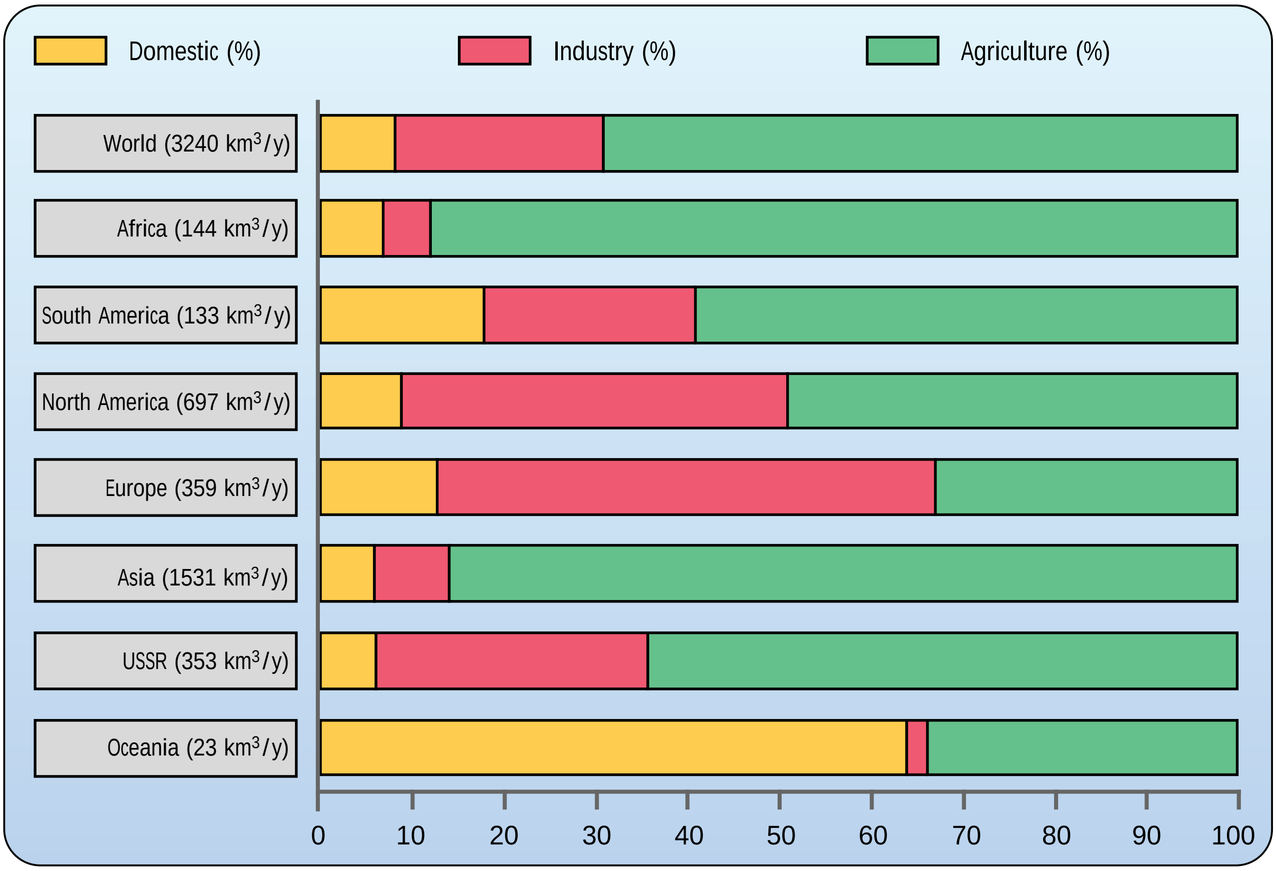
Figure 4: The hydrological cycle




From: J. W. Maurits la Rivière, Threats to the World's Fresh Water.


Phenomenologically, water stands between the environmental media of air and soil: air moves freely around the globe as part of climatic activity while soil is basically a stationary resource. Water penetrates and links these two "worlds" through the continuous alternation of evaporation, transport and condensation. It is contained both in the air and in the ground in different forms, thus influencing the character of the air masses and soils. All water-related processes have, on the one hand, fundamental significance for the energy balance of the Earth (key terms: water vapour as greenhouse gas, heat transport, intensity of climatic events) while, on the other hand, the hydrological cycle is of major importance for the global element cycles (geochemical cycles of C, N, S, P, etc.), which are essential for life on Earth. Water is the means of transport for most of the natural biogeochemical cycles; the only exceptions are pure gas movements in the atmosphere and volcanic rock movements. The locally available water is a major production factor for the economy. Agriculture, transportation, industry and, above all, the energy sector depend on an adequate supply of water. The hydrological cycle provides a framework for these forms of utilisation.

Figure 5: Sectoral withdrawal of water per region *(from WRI, 1992a)*




The catchment areas of rivers are particularly important for the water supply, though regionally very different proportions of ground and surface water are being used. Approximately half of these catchment areas (including roughly 175 of the 200 largest) are spread over the territories of several countries. The annual flow through the river catchment areas of the Earth is estimated at approx. 40,000 $km^3$, roughly 3,200 $km^3$ of which is utilised by households, agriculture and industry. The proportions of the total consumption that these three forms of water utilisation account for differ greatly from region to region, as does the respective absolute amount used (Fig. 5).

It is thought certain that water withdrawal will continue to increase on a global basis, especially for agricultural and industrial purposes. Estimates indicate a possible doubling within ten years, with the highest rates of increase in the developing countries, in particular in areas with a rapidly increasing population and growing agriculture and industry (WRI, 1992a).

Locally and regionally, water reserves are coming more and more under pressure, especially from population increase, urbanisation and industrialisation as well as from climate change. In addition, there are regional conflicts which may lead to clashes over water resources (possible cases: Near East, Nile, Rio Grande and others; Gleick, 1992). This pressure is reflected in increasing water scarcity due to reduced supply or growing demand, in contamination of water resources with harmful substances and microorganisms, as well as in wastage resulting from careless handling of water. The latter is due to failure to internalise all costs connected with the supply and treatment of water, inadequate allotment of property rights or inefficient technology despite high water prices. Pollution and wastage accelerate the rate at which water becomes scarce; additionally the former threatens the quality of groundwater unaffected until now and thus the renewal of water as a resource. The number of countries or regions with water scarcity is currently estimated at 26; they are predominantly located in Asia, Africa and the Near East and their number will most likely continue to increase (Table 6).

Table 6: Countries that suffer from acute water scarcity[2], data for 1992 and 2010 (estimated) *(from WWI, 1993)*

| Countries | Water supply[1] ($m^3$ per capita und year) | | Variation (in %) |
|---|---|---|---|
| Year | 1992 | 2010 | |
| Africa | | | |
| Algeria | 730 | 500 | – 32 |
| Botswana | 710 | 420 | – 41 |
| Burundi | 620 | 360 | – 42 |
| Cape Verde | 500 | 290 | – 42 |
| Djibouti | 750 | 430 | – 43 |
| Egypt | 30 | 20 | – 33 |
| Kenya | 560 | 330 | – 41 |
| Libyia | 160 | 100 | – 38 |
| Malawi | 1,030 | 600 | – 42 |
| Mauretania | 190 | 110 | – 42 |
| Morocco | 1,150 | 830 | – 28 |
| Niger | 1,690 | 930 | – 45 |
| Rwanda | 820 | 440 | – 46 |
| Somalia | 1,390 | 830 | – 40 |
| Sudan | 1,130 | 710 | – 37 |
| South Africa | 1,200 | 760 | – 37 |
| Tunisia | 450 | 330 | – 27 |
| Near East | | | |
| Bahrain | 0 | 0 | 0 |
| Israel | 330 | 250 | – 24 |
| Jordan | 190 | 110 | – 42 |
| Kuwait | 0 | 0 | 0 |
| Lebanon | 1,410 | 980 | – 30 |
| Oman | 1,250 | 670 | – 46 |
| Qatar | 40 | 30 | – 25 |
| Saudi Arabia | 140 | 70 | – 50 |
| Syria | 550 | 300 | – 45 |
| United Arab Emirates | 120 | 60 | – 50 |
| Yemen | 240 | 130 | – 46 |
| Others | | | |
| Barbados | 170 | 170 | 0 |
| Belgium | 840 | 870 | + 4 |
| Hungary | 580 | 570 | – 2 |
| Malta | 80 | 80 | 0 |
| Netherlands | 660 | 600 | – 9 |
| Singapore | 210 | 190 | – 10 |

[1] Estimated internal renewable water resources per year, water supply from neighbouring countries not included.
[2] Countries with less than 1,000 $m^3$ water supply per capita and year.

### *Water as a cultural asset*

In the discussion on “sustainable development”, water as a cultural asset has either hardly been mentioned at all or it is concealed behind formulations such as “protecting the quality and supply of freshwater resources” (AGENDA 21, Chapter 18). Water, however, plays at least an important cultural role in the public life of traditional societies. This applies to cleaning and meditation rituals as well as to everyday handling of water as a foodstuff. In industrial societies water has lost most of its cultural significance. Only occasionally is it used as a design element in public places, such as for fountains and water architecture.

The threat to water resources also affects it as a cultural asset. The significance of the availability and purity of water for the existence of many cultures should not be underestimated, as is shown in a great variety of water-related traditions and rules. Water protection thus entails the protection of the essential basis of human culture as well (Schua and Schua, 1981).

The links between water and culture were, and still are, particularly close in Asian and Arab countries. Hydraulic engineering and agricultural irrigation were developed and perfected in countries like China, the Philippines or Indonesia. In Mesopotamia, Jordan and Egypt technical systems relating to a “water culture” have existed for over 3000 years. Since European culture has its roots in the Near East and Mediterranean region, it acquired a high cultural esteem for water from this region in its early phase.

Cultural traditions related to water have, however, been lost to a great extent worldwide. Conversely, modern hydraulic techniques, such as the water closet and the central sewage system, cannot be transformed from our latitudes to other regions of the world without qualification. In many traditional societies faeces are, for example, composted and not brought into contact with water, which appears meaningful from a hygienic point of view in monsoon countries subject to extreme rain. Here, the installation of “modern” water facilities may not only lead to an increase in the danger of epidemics but also to the loss of traditional knowledge (Koscis, 1988).

Only in rare cases were traditional cultures in a position to protect their own value system regarding water against the advance of dominant Western values. A successful example of this is the legal dispute of a Maori tribe in New Zealand (1991) against the disposal of municipal sewage into the Kaituna River and Rotorua Lake. Since then the effluents of the installed treatment plant have infiltrated into the ground in a spruce grove; in this way, the cultural esteem of the Maori for water was officially recognised (WM, 1992).

## Causes

Five large-scale causes of global water problems can be distinguished: *population increase, urbanisation, industrialisation, climate change* and *cultural change*.

In the developing countries the high rate of population increase leads to an overproportionately rapid growth of urban settlements. Of the ten largest cities, eight will be located in the South by the year 2000, according to available estimates, while in 1960 only three of them were (see 2.1). Urbanisation and industrialisation (including mechanised agriculture) lead to an exponential increase in the consumption of water. Thus daily per capita consumption in regions with a central drinking water supply (pressure pipelines) has jumped, in many cases, by a factor of 10, as is known from several case studies (Stadtfeld, 1986). Locally, this may lead to excessive use and thus to a scarcity of water resources, which must then be compensated for by means of long-distance transport (examples: Madras, Frankfurt am Main). Both developments tend to result in increasing quantities of polluted sewage and groundwater requiring purification, which is usually only possible with considerable technical effort and financial expenditure and has, in general, not been carried out in developing countries up to now.

Industrialisation so far has been based on the input of large quantities of energy and raw materials, and on production processes using water as a means of transport and as an operating material. Through the expansion of industrial activities, the consumption of water has been increasing globally, in most cases to an overproportionate extent (Jänicke, 1993). Cases in which industrial production has been partially de-linked from water consumption can only be observed when certain production processes are converted to a water recycling system (examples in Germany).

The possible shift of climatic zones also plays a role for the water balance of rural areas and regions; desertification, disappearance of vegetation, flooding and the related soil loss and the deposition of oxygen-consuming substances in water bodies and seas are closely connected with this process (see 1.2, 1.4 and 1.5).

A distinctive loss of cultural traditions is reflected in the standardisation of technical and organisational ways of handling water. The model role of Western industrial culture and the globalisation of markets are the main factors in this respect (see 2.2 and 2.4). An important element in this change is the loss of the direct perception of water, its sources and sinks. This has effects on the anthropogenically influenced portion of the hydrological cycle (Hauser, 1992). The declining significance or loss of cultural values can therefore be seen as a cause of the global water problems.

### *Local causes*

In *developing countries* the setting up of a functioning water infrastructure usually lags behind the increase in population, despite great efforts in some cases (World Bank, 1992a). Leakage causes significant losses in the water supply network, over 40% according to estimates. Water consumption in the industrial sector is growing rapidly, frequently at the expense of an adequate supply for the surrounding region and the peripheral zones of the cities (slums). Megacities, such as Lagos, Mexico City and Sao Paulo, with their heavy drawing of water resources contribute to the desertification of the surrounding areas (WMO, 1993).

In the rural areas of the developing countries there are old, in some cases large-scale water supply systems which are often still in good condition. Due to migration from rural areas to the cities and increasing irrigation agriculture, these systems are frequently replaced by plants and practices that require a higher energy input and have a negative effect on the local water balance due to high rates of evaporation. This technological change is accompanied by a progressive break with old legal institutions and traditions as well as by subsidies for irrigation agriculture.

In *industrial countries* water is wasted in many cases in that the pricing system does not include all water supply and treatment costs and thus stimulates additional consumption. With a high average consumption per capita and day this leads to a considerable deterioration of the water balance. Although, in recent years, the demand for water on the part of households and industry was growing only slowly in most industrial countries, the water intensity of agriculture continues to increase. Pollution of groundwater and water bodies occurs in urban agglomerations as well as a substantial loss of water (leakage) due to in some cases quite old supply and disposal systems. In many cases there is a great need for renewal and repair of the water infrastructure, requiring funds of enormous proportions (example of Berlin: an estimated DM 20 billion over the next 10 years).

The most important causes of the basic water problems can be described as follows:

- *Scarcity:* decrease in availability of water due to high population increase and economic growth, altered distribution of precipitation, surface sealing, loss of vegetation cover, excessive use of aquifers.
- *Pollution:* deposition of harmful substances from the air (acid rain, dust, erosion), from utilisation processes (industry, households, effluent disposal) and soils (agriculture and waste disposal sites). Problematic substances include heavy metals, salts, acids, synthetic organic substances (particularly from chlorine-based chemical industry), nutrients (faeces, eroded soils) as well as pathogenic germs (see Table 7).
- *Wastage:* Excessive consumption of water in relation to the available long-term supply, the renewal or substitution rate due to inadequate allotment of user rights, prices that do not cover costs, and subsidisation of the water price, inefficient techniques, leakages and loss of cultural values.

Groundwater pollution has long-term impacts and thus poses special problems. The formation of new groundwater is basically dependent on intact plant cover and soils and, regarding water quality, on the exclusion of contaminants. This is no longer guaranteed in many regions. The quality of the groundwater formed greatly depends on the type of soil use. Certain forms of intensive land cultivation pollute the groundwater with pesticides and nutrients (e.g. soluble contents of liquid manure – nitrate problem). In industrial countries even under forest soils the groundwater can be polluted by nitrate, a process mainly caused by deposition of atmospheric nitrogen resulting from traffic emissions, intensive livestock farming and overfertilisation. The soil quality of irrigated farming land may deteriorate due to salinisation through the use of inappropriate techniques, and sustainable agricultural use of such areas may become impossible, as is already the case in larger parts of the world (Repetto, 1989).

### *Regional causes*

Regional causes of global water problems cannot be definitely distinguished from the local causes mentioned. Population increase, urbanisation and industrialisation are also regionally important determinants of water use; climate change and cultural change, as global phenomena, also have regional effects.

Characterisation of regional causes and impacts of water problems can be linked to the hydrological classification of the Earth's surface according to ecozones (see 1.4 and Table 8). Economic growth and demographic development and as anthropogenic influences on the water balance are closely linked to these basic ecological structures. The most important kinds of water pollution are summarised in Table 7.

The availability of water resources can also be impaired by regional conflicts over its distribution or by deficient water management. Roughly 60% of the world's population lives in multinational river catchment areas. Suitable institutional arrangements are, therefore, required in order to avoid conflicts over regional water use (examples: the catchment areas of the Aral Sea and the Ganges, Euphrates, Jordan, Nile, Rio Grande, Colorado and Rio de la Plata rivers).

### *Global causes*

Important global causes of water problems include climate change and cultural change. Differences in temperature and precipitation quantities can be expected at regional level as a result of climate change. This may lead to a completely new distribution of surface runoffs and of the water available for vegetation and human beings.

From a historical point of view, there have been significant changes in the meanings and values associated with water as a cultural asset. Two tendencies are particularly evident: first of all, the regard for water as a resource and cultural asset is relatively low or diminishing where water supplies are sufficient, as shown, inter alia, by the fact that water has been extensively dispelled ("channelled", so to speak) from people's consciousness and public life. Secondly, one can observe a high cultural regard for water in countries with absolute water scarcity, which, however, does not always result in high water prices for institutional reasons. In many cases, the utilisation of water has no price at all for some users while others, especially the poorest, do not pay a price expressed in money, but often have to carry the water over long distances on foot.

## Effects

The effects of changes in the water balance on environmental assets are extremely diverse, and characterised by simultaneous or delayed feedbacks. They can be differentiated according to their impacts on the ecosphere and the anthroposphere and to regional and time horizons.

### *Ecosphere*

The dynamics of the hydrological cycle have enormous spatial and temporal dimensions; the quantity and rhythm of all transport operations change constantly. Water as a medium or basis of all life processes is very closely related to all processes within the ecosphere, which makes a description of the effects of water problems on the ecosphere only possible in general form at this point (WRI, 1992a; Postel, 1992). The following interrelations are of particular importance:

- *Climate:* The processes of water exchange between the atmosphere and the oceans or land masses essentially determine the climate. Changes in the water balance in the ground, on the surface and in vegetation have effects on the local climate; in the case of greater changes (for example: large-scale clearing of forests), the regional climate may also be influenced.

Table 7: Principal forms of water pollution *(from WRI, 1992 and GITEC, 1992)*

| Pollutant | Key issues |
|---|---|
| Elevated temperatures | Elevated irradiation after dam constructions and land enclosures, discharges from power plants |
| Acids and salts | Inorganic chemicals, mine effluents, atmospheric depositions |
| Oxygen demanding substances in high concentrations or loads | Suspended matter and sediments, nutrients, fertilisers, washing agents, combined sewers, organic chemicals |
| Toxic chemicals in low concentrations or loads | Heavy metals, pesticides, halogenated organic chemicals, leachate from landfills |
| Pathogenic germs | Bacteria and viruses from fecal discharges, landfills and hospitals |

Table 8: Typology of regional causes and impacts of water problems *(compiled by Wissenschaftszentrum Berlin)*

| Region | Ecozone | Causes | Impacts |
|---|---|---|---|
| Europe | Humid mid-latitudes | Groundwater pollution | Closure of wells, loss of sites, costs |
| Near East | Dry mid-latitudes | Quantity conflicts, excessive use | International conflicts, high costs, loss of non-renewable resources |
| Sahel Zone | Subtropical dry areas | Excessive use, climate change | Migration, impediment for development |
| Tropics | Tropics with permanent and summer humidity | Deforestation, soil degradation | Erosion, migration, flooding |
| North America | Dry and humid mid-latitudes | Overuse, soil degradation, groundwater pollution | Erosion, shortage of groundwater |
| East Asia | Subtropics and Tropics with permanent and winter humidity | Population growth, use as sewer | Danger of epidemics, impediment for development |

- *Ecology:* Changes in the water balance have direct effects on soils, plants and animals and, of course, on aquatic habitats; indirectly, all food chains are affected by this.
- *Soil degradation:* In many areas of the world where land is used for agricultural and forest purposes, topsoil erosion is increasing, with desertification as a possible result. Salinisation of the soils is fostered by irrigation systems that do not have sufficient runoff, or which have an insufficient irrigation rate at high evaporation rates.
- *Disasters:* Changes in the distribution of water from surface, underground and atmospheric sources (runoff rates, evaporation, storage) may have an influence on the frequency and intensity of extraordinary meteorological events, particularly on flooding and droughts. The nature of the soil and ground cover are also major factors in this respect (see 1.4).
- *Tectonics:* Through the polar ice caps, but also through large water reservoirs and river diversions, local stress on the Earth's crust may be changed such that tectonic effects occur. This presumption has been expressed in connection with the Nile Valley (Assuan Dam) and the Parana Valley (Iguaçu Dam), and led to a reassessment of planned large-scale dam projects in Siberia (in addition to other reasons).
- *Albedo:* New, artificially created water areas, changes in ice coverage, changes in vegetation as well as newly formed steppes and deserts change the radiation budget of the Earth's surface and thus, in turn, climate.
- *Primary production:* Reduction in the quantity and quality of water available at the respective location may have direct, negative consequences for plants and animals: the spectrum of species is shifted, and agriculture and forestry have to adapt. The speed of such changes often is so high that the natural rates of adaptation are exceeded, leading to extinction of species (for example: water birds becoming extinct in Central Europe) due a lack of ecological niches (reserves).

### Anthroposphere

To begin with, water has a key influence on the physical well-being of human beings and society. Moreover, the immaterial appreciation of water, an important element in a society's cultural values, is also relevant in many cases. The interactions between the water problems described above and the anthroposphere can be summarised as follows (Postel, 1992; Stiftung Entwicklung und Frieden, 1991b; Schua and Schua, 1981):

- *Basic supply:* Direct consequences of a scarcity of drinking water (lack of quantity or quality) include damage to health. Indirectly, a scarcity of water leads to drought and thus to famine, both major reasons for migration. In industrial countries, supplying drinking water from unpolluted groundwater is becoming increasingly difficult.
- *Hygiene:* Inadequate techniques for handling water and sewage are causes of epidemics, high infant mortality rates and low life expectancy.
- *Production and services:* Diminishing availability and quality of water may reduce the efficiency of agriculture and industry. This may lead to intense competition between these economic activities, whereby the demands on water quality by each of these sectors may be incompatible. Many services, such as recreation and tourism, depend on the available quantity and good quality of water, and are rendered impossible or uneconomical if these fall below certain limits.
- *Hydraulic engineering for human settlements:* Combined sewage systems and insufficient storage capacity in rainy areas prevent a reliable separation of polluted water from freshwater resources. This leads to hygienic and ecological problems, especially when flow rates decline.
- *Aesthetics:* Quantitative or qualitative changes in the water balance may impair the aesthetic quality of the landscape, an important basis for culture and the well-being of its inhabitants.
- *Social harmony:* Distribution and quality of water may be a reason for local disputes (wells) or for transboundary conflicts, e.g. between those living upstream and those living downstream; in extreme cases, such disputes may lead to war.

All types of interactions mentioned above are potentially significant obstacles for economic, social and cultural development, and occur on a global basis with regional differentiation.

### Regional differences

A typology of regionally predominant causes and impacts of water problems can be found in Table 8.

Most *developing countries* are located in the tropics and subtropics; so much precipitation falls there during the rainy season within a short period of time that the capacity of the soils and surface water bodies are often insufficient to hold the water. The progressive loss of large tropical forest ecosystems is aggravating this problem. At the same time, the mean evaporation rates there are often so high that water can only be stored at great expense for extended periods of time. Long-distance transport of drinking water and effluents are costlier and pose a greater health risk than in moderate zones. In addition, water problems in the urban agglomerations in developing countries worsen the living conditions for the inhabitants (scarcity of drinking water, hygiene) much more directly than elsewhere due to the lack of adequate infrastructure.

In *industrial countries*, almost all of which are situated in temperate zones, water problems are generally less serious. The prevailing view is that water pollution requires urgent attention, particularly the question of declining reserves of unpolluted groundwater. The “long memory” of water as the medium for various cycles is demonstrated in the urban agglomerations of industrial countries: once persistent substances have entered the cycle, they spread to other environmental media, can thus accumulate in the ecosystems and, as a result, have a feedback impact on people.

Essential elements of a global water strategy are, therefore, adequate consideration of the North-South divide, maintenance or revival of cultural values, definition of appropriate technical and financial transfer mechanisms, but also the creation of functioning water markets which ensure that prices cover all costs.

### Time horizons

Depending on the type of water use by humans, animals and plants, one can distinguish the time horizons in which the above-mentioned water problems become evident. The following listing contains a few keywords on the ecosphere and the anthroposphere for each case:

- *Short term:* Water has a mean atmospheric lifetime of roughly nine days. Depending on the climatic zone, an adequate supply of water is a question of a few hours for people, while water for cleaning and hygiene can be done without for at least several days.

- *Medium term:* Water on the Earth’s surface usually runs off in a period of several days to weeks. For agricultural and industrial production water is required continuously or only at certain times during the day and year, depending on the production methods in question (examples: power stations, irrigation agriculture, food processing); here, the time horizons involve hours or days. Breakdowns in water supply are less threatening than with drinking water, and can be compensated for over a period of weeks or months, or even longer in the case of closed systems.

- *Long term:* The lifetime of freshwater is longest in groundwater; there are fossil groundwater deposits which are several millennia old. Water as a cultural asset generally has a long time horizon since it is an expression of long-developed values and traditions. The influence of landscape and vegetation on culture is closely connected with the climatic and hydrological conditions.

## Link to global change

Many of the actual and potential links between water and the other areas of global change have already been addressed above; the most important of these are summarised in Table 9. As far as aims, instruments and institutions are concerned, there are various overlaps with other sections of the Report. Water is, for example, a fundamental basis of the ecosphere (atmosphere, climate, soil, forest, biodiversity) and indirectly of the anthroposphere (population, industry, transport, culture). There is certainly extensive harmony regarding the objectives of conservation, of increasing efficiency of resource use and of avoiding environmentally harmful substances and emissions (Weizsäcker, 1992).

Table 9: Linkages between the hydrosphere and other main areas of global change *(compiled by Wissenschaftszentrum Berlin)*

| Area | Key issues |
|---|---|
| Atmosphere | Deposition of pollutants, evaporation, albedo |
| Climate | Distribution of precipitation, drought areas, energy content of weather events, water vapour as greenhouse gas |
| Oceans, coasts | Geochemical cycles, sediments and pollutant transport |
| Soils | Formation of groundwater, water erosion, vegetative cover |
| Biological diversity | Formation of drylands, droughts, flooding, cultural landscapes |
| Population | Drinking water shortage, sanitation problems, environmental refugees |
| Economy | Agriculture (irrigation, groundwater pollution), Industry (water intensity, pollutants), Energy (hydropower, cooling water)<br>water productivity, technical and organisational innovations, metabolism of the industrial system, ecological resource management |
| Transport | Urbanisation, mass tourism, waterways |
| Values and attitudes | Responsibility, economy, sustainability, aesthetics of landscapes |

### Box 5: Follow-up issues of the UN Conference on Environment and Development for freshwater resources

The topic of water plays a role in the documents of the 1992 UN Conference on Environment and Development in Rio de Janeiro. The following summary presents the key elements of three documents that are important for the follow-up process of Rio: the Framework Convention on Climate Change, the Convention on Biological Diversity and the AGENDA 21.

*1. Convention on Climate Change.*

The Framework Convention on Climate Change does not contain a direct reference to the topic of water, but it is relevant in two respects: first of all, because of the agreement of the international community on principles of common responsibility, sustainable development and recognition of the precautionary principle; secondly, due to the congruence between the objectives of energy and water efficiency. The Convention provides industrial nations with a motivational and innovational boost regarding fossil fuels, which will probably increase their efficiency in handling other substances at the same time, including substitution for water pollutants and saving water itself.

*2. Convention on Biological Diversity:*

The restoration and protection of primeval habitats also embrace aquatic ecosystems. This can only succeed if, on the one hand, strict water protection is exercised and, on the other, the water balance of ecosystems is brought into equilibrium via the hydrological cycle. Here again there is general agreement on the aims and guidelines for the protection of water resources, on the basis, for example, of sustainable development and protection and application of traditional forms of farming.

3. *AGENDA 21:*

| | *National level* | *International level* |
|---|---|---|
| Chapter 3 | | Respecting the cultural identity and rights of indigenous communities (water culture) |
| Chapter 4 | Changing unsustainable patterns of consumption and production (water as food and means of production) | International support and cooperation in pursuing the same goals |
| Chapter 6 | | Cooperation an health protection through support of drinking water protection and sewage treatment, water culture, combatting water-borne diseases |
| Chapter 7 | Integrated environmental protection, sustainable construction activities (water infrastructure, municipal hygiene) | International support and cooperation in pursuing the same goals |
| Chapter 8 | Internalising external costs (protection of water resources), avoidance of pollution and wastage | International support and cooperation in pursuing the same goals |
| Chapter 10 | Changing agriculture to sustainable methods (groundwater protection, erosion prevention) | International support and cooperation in pursuing the same goals |
| Chapter 11 | Improvement of sustainable forest management (particularly for groundwater protection) | International support and cooperation in pursuing the same goals |
| Chapter 12 | Sustainable management of fragile eco-systems; stabilisation of water balance by saving water (e.g. Frankfurt a. M., Berlin, Hamburg) | International support and cooperation in pursuing the same goals |
| Chapter 13 | Sustainable development of mountain regions (prevention of floods, water erosion) | International support and cooperation in pursuing the same goals |
| Chapter 14 | Drawing up surveys of the erosion and salinisation of soils, avoiding pollution of surface and underground freshwater resources through sustainable agriculture | International support and cooperation in pursuing the same goals |
| Chapter 17 | High-quality landscape planning and water use, emergency plans, avoidance and treatment of sewage, nature reserves, waste treatment on land | Support for sustainable management and protection of seas and coasts (prevention of water pollution, maintenance of aquatic habitats, sustainable fishing) |
| Chapter 18 | Promoting regard for water, further development of water policy, protection of water as a public asset, adaption of human activities to natural limits (environmentally sound agriculture, saving water, integrated water cycles in industry, ecological urban restructuring, precaution against floods) | International support and cooperation in combatting water-borne diseases and in the following fields: water resources, quality assurance, provision of drinking water and sanitation facilities, ecological urban development, primary production, climate change |

| | | |
|---|---|---|
| Chapter 19 | Improving chemical safety (water pollutants, accidents, transport on waterways) | International support and cooperation in pursuing the same goals |
| Chapters 20, 21, 22 | Preventing or recycling of hazardous, solid and radioactive wastes and sewage sludge (water protection through safe storage, reduction of emissions, prevention of accidents in transit) | International support and cooperation in pursuing the same goals |
| Chapters 24, 26, 27 | Participation of women, indigenous communities and non-governmental organisations in all decision-making (water culture, traditional hydraulic engineering, local knowledge) | International support and cooperation in pursuing the same goals |
| Chapters 31, 35 | Science, technology and research for sustainable development: water efficiency, hydraulic engineering, water culture, integrated biogeochemical cycles, regional cooperation in catchment areas | International support and cooperation in pursuing the same goals |
| Chapter 39 | Developing international environmental law (Water Convention), compliance with agreements (transboundary catchment areas) | (see national) |

## Assessment / need for action

In view of the basic importance of water for sustainable development at the local, regional and global level, four relevant fields of action should be looked at, without evaluation at this juncture, but simultaneously if possible: the demand for and the supply of water, water pollution, and nature-related risks. In the following, these four central fields of action shall be outlined and elements of a global water strategy proposed.

### *Demand for water*

With all we know about the interrelations between hydrosphere and anthroposphere, there cannot be any doubt that there are many ways of handling water carefully, i.e. significantly lowering water consumption or increasing water productivity (*wise use or demand side management*). In this regard, efficient use of water is just as necessary as appropriate water-saving technology in all major areas of consumption (quantitative approach). Furthermore, the quality of water resources can also be maintained through measures on the demand side (qualitative approach). Several examples of each will be mentioned below.

- *Industry, quantitative approach:* A large portion of the water required can be reutilised, the most effective means being the introduction of fully integrated water cycles. In some branches of industry, such as the iron and steel industry, or the paper industry, traditionally some of the largest industrial users and polluters of water, it has become economically profitable to keep water in closed systems, even at low water prices. *Qualitative approach:* Drinking water quality is not necessary for a large number of industrial processes, such as cooling, separation of substances and cleaning. The substitution of environmentally degradable substances for water pollutants reduces the pollution of water resources and lowers the costs for subsequently required environmental technology (example: substitution of peroxide bleaches for chlorine bleaches in the pulp and paper industry).

- *Agriculture, quantitative approach:* Efforts to achieve greater efficiency of water use for irrigation purposes are necessary, purely through the fact that agriculture is the biggest water user in many countries. Even a small percentage of saving in this area will correspond to large quantities of water. Many new and old methods are available, they merely need to be adapted appropriately to the specific needs of the plants grown and to local conditions. *Qualitative* *approach:* The use of non-renewable groundwater reserves, which takes place for irrigation purposes in several regions (including the Aral Sea, Near East, North Africa, Midwest of the U.S.), must urgently be changed over to renewable sources. Pomotion of ecological farming methods, precipitation use and choice of adapted plant species opens up a variety of opportunities in this respect.

- *Infrastructure, quantitative approach:* As far as the introduction of water-saving techniques is concerned, the developing countries have a certain advantage over the old industrial nations because it is not old infrastructures that have to be renewed and replaced, but rather new ones that have to be established in the first place. With some of these techniques one can save up to 90% water. *Qualitative approach:* In general, it is true that drinking water quality is not necessary for every application in industry, agriculture and households. Double pipeline networks, local non-potable water supply, care or repair of local drinking water wells are some of the main options in this area.

- *Households, quantitative approach:* In comparison to industrial water use and irrigation in agriculture, water consumption by private households is generally relatively low. On the other hand, storage, distribution and treatment of water here is rather expensive because of the required quality standards. Many people have drastically reduced their water consumption without the slightest economic incentive to do so. Active saving of water can significantly lower the water costs per household as well as the costs of the utility companies. Considerable savings can be achieved, particularly through technically more efficient equipment and facilities (such as more efficient toilets, washing machines, dishwashers and bath facilities). *Qualitative approach:* The public can be made more aware of the value of clean water and resource protection so that pollution and wastage are reduced. Moreover, substitution for water pollutants is also possible in the private sector (chemicals used in the household, the garden and for hobbies). Avoidance of unnecessary water consumption for precautionary reasons can even be successfully propagated in areas without acute water scarcity (analogously to the principles of waste avoidance in German legislation), and lead to corresponding technical innovations.

One requirement for successful implementation of these and similar proposals is the measurement of water consumption. In many regions of the world this is either unknown or not customary, and even Germany is still far from having a comprehensive distribution of water meters. In countries with high water consumption the price for freshwater and for sewage must be high enough so that the financial incentive to save water can take effect at all. In most cases, the water price is still low, in some countries water continues to be provided to users at no charge or is subsidised to a great degree. *Wise use* or *demand side management* can and should start from these points.

## Supply of water

The second area requiring action is supply side management. Water supply can be increased in a variety of ways; there are conventional, unconventional and still untested methods. The first, conventional, step should sensibly be to lower the current, sometimes enormous losses from existing supply systems. This ranges from renewal of supply lines to reduction of evaporation loss by means of shorter conveying distances and underground storage tanks. A separate water supply with drinking water and non-potable water (dual system) may mean an expansion of supply since water resources of lower quality can be used to a greater extent. Successful examples of this kind can be found in several industrial countries (Environmental Protection Agency, 1992; Kraemer, 1990).

Unconventional methods include artificial cloud harvesting, possible in some regions of the world, desalination of seawater and brackish water, and long-distance transport of water using tank trucks and pipelines (which, strictly speaking, is not an expansion of supply but only geographical transfer). Different desalinisation techniques have been developed, but many of them are still too expensive and, in addition, very energy-intensive. Long-distance transport of water, on the other hand, is already common in some countries and regions, for example in the Near East. An example of an unconventional method requiring little expenditure and adapted to local conditions is the extraction of drinking water from fog. Along the coast of Chile, for example, the moisture passing across the land from the sea, which normally falls as rain in the hinterland, is condensed and collected on nets set up against the wind. In addition to direct expansion of supply, water quality control or avoidance of water pollution will indirectly increase the total supply of usable water.

Expansion of the supply of clean drinking water and installation of reliable sanitary facilities are very urgent from the global perspective. Though some remarkable successes in some areas were achieved with the “International Drinking

Water Supply and Sanitation Decade" during the 80s, the number of people without an adequate drinking water supply was not lowered significantly.

## Water resource protection

As far as the third area requiring action is concerned, there is extensive agreement on the fact that great efforts are required worldwide to avoid the pollution of surface water and groundwater reserves (*pollution prevention*). Avoidance of water pollution means, in the end, keeping all hazardous substances away from water. This applies particularly to industry and agriculture, which have to be restructured to more environmentally sound methods. The use of pesticides and mineral fertilisers should and can be reduced rapidly while sustainable, environmentally sound farming can be propagated as a model. Subsidies for irrigation agriculture should be terminated and ecological farming be financially compensated for its contribution to water protection. This applies equally to industrial and developing countries, though in developing countries special consideration must be given to the food supply of the population.

In developing countries it will continue to be difficult to prevent pollution of water bodies by municipal and industrial sewage because there is a lack of functioning supply and disposal systems. Through the establishment of new businesses, however, there is a chance of ensuring low water consumption (high "water productivity") right from the beginning. Industrial production can be made considerably more water-productive through water-saving techniques and bans on water pollutants. There are also noteworthy examples of primeval sewage treatment for industry and human settlements (e.g. "pond systems" in individual tropical and subtropical countries, reedbed purification in Germany), which should be examined with regard to their international applicability and, if suitable, supported.

In the reduction or avoidance of water pollution great importance has to be attached to planning processes at the local and regional level. Integrated development planning should be more oriented to the natural conditions, taking water resources as the framework for sustainable development.

## Crisis and disaster management

The fourth area requiring action can be described as *crisis and disaster management*. The frequency and intensity of flood and drought disasters have increased in the course of time with far-reaching regional migration of population groups (Bangladesh, Somalia, Sudan). The term "environmental refugee" was coined in connection with the drought disasters in Africa. According to estimates of the International Committee of the Red Cross, already more than 500 million people can be regarded as environmental refugees (Stiftung Entwicklung und Frieden, 1991b). Although there have always been periods of drought in the course of history, the ability to cope with them seems to have deteriorated. Floods are caused by nature in various parts of the world, but are increasingly also the result of human activities. Development successes can thus be reversed in a short time.

Therefore, in the view of the Council, it is not just curative emergency aid that is necessary, but greater emphasis has to be placed on preventive disaster management, i.e. better adjustment to and prompt preparation for such events. Up to now there have only been initial proposals and plans for an "environmental and disaster relief organisation" which could act on behalf of the EU and/or the UN and whose tasks might include questions in connection with flood and drought disasters as well as water pollution.

## Elements of a global water strategy

The Council proposes the setup of a global "water strategy" as a structured, precisely formulated policy area. The water problems already existing today and, more importantly, those expected in the future make a systematic examination of the related causes and effects urgently necessary (WMO, 1993). The contours of a possible future global water strategy will therefore be outlined below. To implement such a strategy, a number of initiatives of a bilateral and multilateral nature could be taken on the part of the Federal German Government because valuable knowledge and technologies on wise use of water and prevention of water pollution are available in Germany.

- *Aims:*
  It can be assumed that the specific aims of a water strategy differ from country to country and region to region; applicable aims for all of them, however, include: wise use of water (*"water saving"*), developing new water resources (*"water supply"*), avoidance of water pollution (*"water quality"*), revival or preservation of cultural values (*"water culture"*). Concrete formulation of these aims and corresponding guidelines could take place, similar to the topics of climate and biodiversity, in a "water convention" to be agreed upon internationally.

  In the *industrial countries* more economical utilisation of water (higher water productivity) must be achieved as quickly as possible since, in many cases already, local water reserves no longer suffice either qualitatively or quantitatively. Up to now, however, focus has been on the pollution of groundwater (through hazardous waste from the past and non-point sources) and surface water bodies.

  In the *developing countries* the provision of *clean drinking water* and adapted *sanitary facilities* should probably continue to receive the highest priority. Since conflicts with the growing demand for water on the part of agriculture and industry are inevitable, sectoral priorities will have to be set and efficient distribution mechanisms established. Introduction or differentiation of water prices and, in particular, better allotment of the rights of water use can contribute to this.

  In many developing countries there is, in addition, a special problem regarding the gap in water availability between urban and rural areas. So far state measures have frequently concentrated on urban areas in which the "pressure from below" generally develops more quickly than in rural areas. This, hoever, often involved an unadapted technology transfer, which in certain situations may lead to a collapse of water supply. For irrigation, on the other hand, techniques were frequently applied which are too complicated for sustainable use or connected with high water losses (e.g. evaporation).

  Besides improvement of the price and quantity mechanisms, in many developing countries there is a great need for introduction and restoration of *infrastructures* for water supply and sewage disposal. This requires, as many examples show, more active participation of the population because only this guarantees long-term operability of new systems.

- *Instruments:*
  Understandably, different opinions prevail regarding the suitable instruments of a global water strategy. The significance and scope of *economic instruments* is presumably far greater than has been assumed up to now. In view of the increasing scarcity, continuing pollution and extensive wastage of water in the industrial countries, a proactive water price policy appears sensible there, i.e. systematic levying of fees and charges and abolition of consumption-promoting subsidies. The "polluter pays principle" should, in any case, also be applied to a water strategy and that means: water withdrawal payments as a resource tax, full cost accounting for water use, sewage charges that are felt and strict liability in cases of water pollution.

  The application of economic instruments in water policy can serve several objectives at the same time, given suitable formulation: sustainability of water use, prevention of water pollution and more careful handling of water. The actual challenge, however, will probably involve finding meaningful links between such economic instruments, ecologically sound behaviour, revival of submerged cultural traditions and conventional regulative instruments of environmental policy, such as standards and quantity allocations.

  The *regulative instruments* related to the quality of water and sewage, however, have to be examined. While more care must be taken in compliance with high standards in industrial countries (e.g. EU drinking water guideline), in developing countries water quality still has too little political priority, resulting in correspondingly high health risks. Not least of all, the failure to comply with minimum standards makes active water policy a global topic because of the possible spread of epidemics.

- *Institutions:*
  An effective institutional arrangement for sustainable use of water resources requires awareness, knowledge and funds. These factors are extremely unequally distributed in the world, in North and South. Therefore, *knowledge transfer, technology transfer* and *finance transfer* are necessary elements of a global water strategy.

Knowledge and technology transfer are successful when they lead to a situation in which more people are put in a position, within as short a time as possible, to solve the given problems of water management on their own. The institutions of bilateral and multilateral development aid should take on a greater financial commitment in this connection, increase their share of the funds for water projects accordingly and formulate concrete time frames for this.

A special problem is posed by *cooperative water management* in multinational river catchment areas, where there are questions of water access, quantitative water allocation and water quality control which can only be solved in a satisfactory manner if "common interests" are formulated and pursued. Roughly half of all river catchment areas in the world encompass several countries, over 35% of the world population is dependent on multinationally used water bodies for their drinking water supply. In view of these magnitudes and the potentially increasing demand, transfer of successful management models is becoming more and more important. The Council is of the view that the successes of the Rhine Commission and the ECE agreement on the protection and utilisation of multinational water bodies may be of significance for numerous river catchment areas in the world. This experience should be brought into the discussion as a contribution to a global water strategy.

At the global level so far there is only a rudimentary institutional framework for a future water strategy. The UN Secretariat for Water Resources was formed in 1978 to coordinate the activities of the various UN institutions. After formulation of the "International Drinking Water and Sanitation Decade" in 1980 a steering committee was set up, composed of representatives from eleven UN institutions involved in water issues. Improvements in global water management are undoubtedly necessary and therefore recommended.

While good arguments can be put forward in favour of comprehensive approaches for a global water strategy, there are many reasons for using an approach which is not too complex. The four central areas of action of such a future strategy (demand for water, supply of water, water protection, crisis and disaster management) were described above. In order to cope with the related tasks, greater commitment on the part of the responsible institutions as well as improved *international cooperation* are necessary. The developing countries themselves must provide more funds and personnel for their water problems (and the same applies to individual industrial countries, too); but they will not be able to come to grips with these tasks alone. Finance transfer must, therefore, be an element of a global water strategy (see also AGENDA 21, Chapter 18). In a future Report the Council will examine more closely the question of whether new international institutions should be proposed for this purpose. It already appears meaningful, however, to establish a "water partnership" between Germany and two or three developing countries with different problems in the form of an innovative pilot project.

## Box 6: Historical development of political action with regard to freshwater

An overview of the historical development of political action with regard to water and water protection can be found in Schua and Schua (1981). A list of important steps is given below.

*National:* Hammurabi's Code; Greek water regulations; Roman water policy; medieval trade code; Prussia; 19th century nature conservation; WHG (Water Management Policy Act) and subsequent regulations.

*International:* International coordination in river catchment areas; Water Charter of the European Council of May 6, 1968; EU laws and water association policy; UN activities: Recommendation 51 of the "Action Plan" of the 1972 Stockholm Conference, Report on Freshwater (January 1991) of the Preparatory Committee of UNCED in Rio de Janeiro, 1992 Dublin Conference, Chapter 18 of AGENDA 21.

## Impact weighting

It is obvious that, regarding the aims, instruments and institutions of a global water strategy, different basic positions can be taken and, as a consequence, different priorities for action can be derived from them. It has already been mentioned that concrete formulation of these aims, instruments and institutions will differ from country to country and region to region. There are countries and regions where an expansion of the water supply is of primary importance while in others demand management has higher priority. It is, however, evident that a shift of the focus has taken place in the historical course of the discussion on water problems. While attention during the 80s, especially within the framework of the "International Drinking Water and Sanitation Decade", was clearly focussed on an expansion of the water supply, since then emphasis in the international discussion among experts has been placed on the demand side (*wise use or demand side management*), without these two having to be regarded as polar positions exclusive of one another (Postel, 1992; Water Quality 2000, 1992). A more fitting picture here is that of a continuum in the discussion, in which the menacingly increasing pollution of water reserves has become an additional element. Accordingly, it is difficult to propose a weighting of the aspects involved in treating global water problems as a strict order of priorities. Nevertheless, the Council feels that it is important to point out that the following three elements are essential and should be dealt with as consistently as possible:

1. Ensuring the availability of *clean drinking water:* access to qualitatively and quantitatively adequate water for all people in the world and restoration and/or protection of intact ecosystems in the hydrological cycle.

2. Prevention and mitigation of *water pollution:* water hygiene in the large cities of the developing countries, cleanup of hazardous waste sites in industrial countries, substituting substances in industry and trade (e.g. for water-polluting chemicals containing chlorine), ecological farming.

3. Invention and innovation of *water saving:* efficient use of water in households, lowering water consumption or increasing "water productivity" in industry and agriculture; appropriate finance and technology transfer, particularly for locally adapted water supply and sewage disposal, for water recycling systems in industry and efficient irrigation methods in agriculture.

## Research needs

In the view of the Council, there appears to be a great need for explanatory and empirically oriented knowledge concerning the subject of water. The handling of water on a daily basis must be adapted to a larger degree to local conditions ("sustainable water use"). Up to now there has been a lack of suitable learning approaches and models. Moreover, knowledge of ways of preventing water problems seems to be fundamentally inadequate. This not only applies to the developing countries, but also to many industrial countries. Therefore, the Council regards the following research topics as pressing:

- *Statistical data:* determine the availability of water; evaluate water quality standards; ascertain water intensities at the sectoral, regional and product level ("water eco-balances"); improve water price statistics; record and describe the exchange processes between the biosphere and the hydrosphere at the global level ("hydrological cycle").

- *Water efficiency:* develop and disseminate technologies of low water consumption for drinking purposes, irrigation and industrial production.

- *Water saving:* sustainable, economical use of water; develop appropriate aims, methods and institutions; build capacity for ecological resource management.

- *Water culture:* preserve cultural values related to water; disseminate empirical knowledge and practical learning approaches; promote water-related environmental education.

- *Environmental refugees:* analyse links between water scarcity and decision to migrate and work up appropriate countermeasures.

- *National water policy:* comparative evaluation of examples of optimum water policy: aims, instruments (price and quantity solutions) and institutions (private and collective water rights, regional water associations); initiate a public "water discourse".

- *International water policy:* analyse experience with multinational water management and indicate appropriate conflict solutions; prepare and support pilot projects of "water partnership" between Germany and two or three developing countries; develop global water diplomacy; include approaches existing in Germany, such as precipitation climatology, world runoff data register, etc., into an international water institute to be set up.

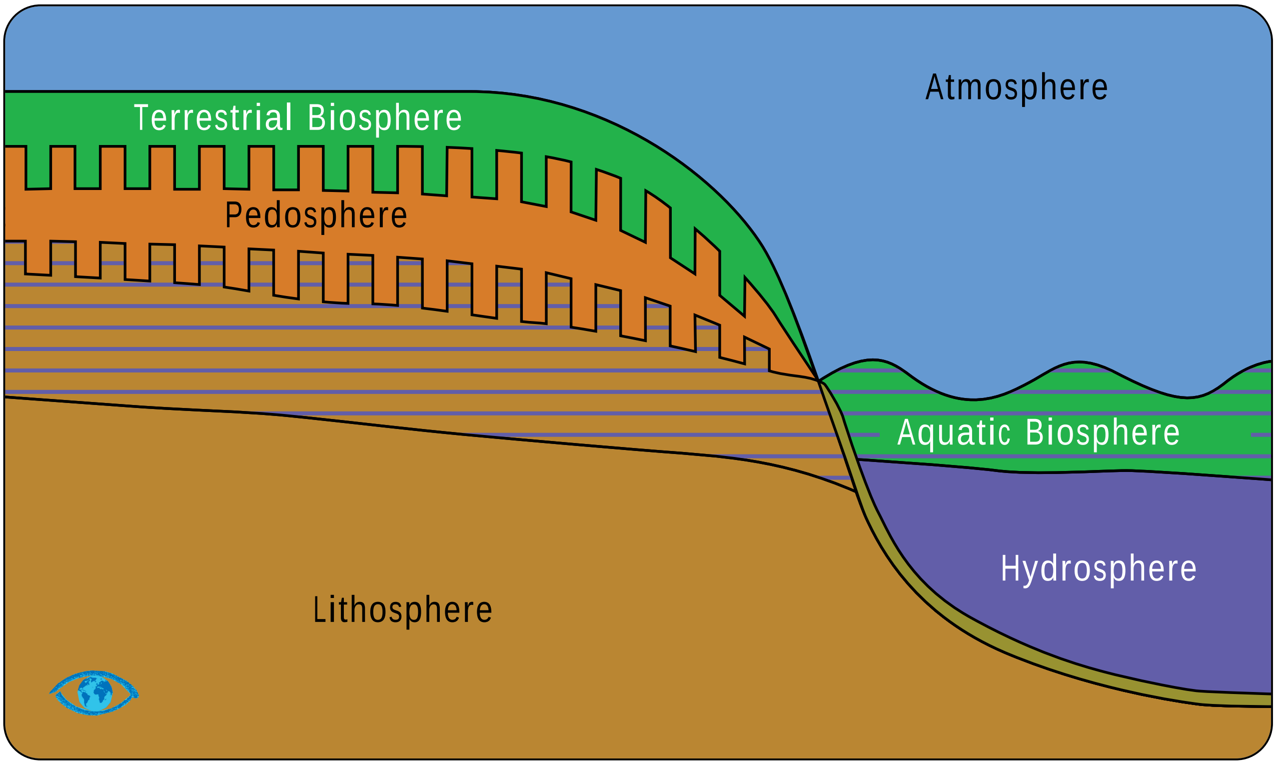
## 1.4 Lithosphere/Pedosphere

### Brief description

The solid outer section of the Earth is designated as the *lithosphere or petrosphere*. It comprises the continental and oceanic crusts and parts of the Earth's upper mantle. The dynamics and composition of the lithosphere, with its huge mass, are hardly subject to change by humans. However, it does serve as a source of raw materials (coal, oil, natural gas, ore, gravel, sand, ground water, etc.) and is used as a disposal site for wastes of all kinds. The lithosphere's outer zones of contact to the other spheres, on the other hand, represent a sensitive area which is of great significance for living organisms and can be greatly changed by humans: these are *soils* and *sediments*.

Soils cover large portions of the ice-free surface of the continents like a thin skin. In a zone that may have a thickness ranging from a few centimetres to several metres, the lithosphere, hydrosphere, atmosphere and biosphere form the *pedosphere* (Fig. 6). Thus defined, soils represent *structural and functional elements of terrestrial ecosystems.*

Figure 6: Linkages between the pedosphere (soil) and the remaining ecosphere



*Soils* do not possess uniform characteristics, rather, as *three-dimensional sections of the landscape*, they form a colourful mosaic of different types, in which the varied possible combinations of the factors and processes comprising them are reflected. Depending on local conditions, these mosaic elements may have dimensions from a few square metres up to square kilometres. Soil diversity contributes decisively to the diversity of terrestrial ecosystems and their biocoenoses as well as to the characteristics of landscapes.

*Sediments* are the biotically active zones in aquatic areas corresponding to soils. They are, therefore, frequently referred to as underwater soils, although they are extensively free of oxygen due to the lack of atmospheric components. Because of their great importance for biogeochemical cycles and because similar processes take place in sediments as in soils, they are also treated in this chapter.

The significance of soils and sediments for plants, animals, microorganisms and humans as well as for the balance of energy, water and elements can be summarised on the basis of three overriding functions:

### *Habitat function*

Soils are the habitat and basis of life for a wide variety of plants, animals and microorganisms, on whose metabolism the regulation function and production function of soils is based. Soil organisms are, in their entirety, the media for synthesis, conversion and decomposition of substances in the soil. Due to their diversity, they influence the stability of ecosystems by decomposing toxic substances, delivering substances for growth and generating a flowing balance between processes of synthesis and decomposition. Soils are the basis for the primary production of terrestrial systems and thus the basis for existence of human societies as well (see utilisation function).

### *Regulation function*

This includes transport, transformation and accumulation of substances. Via various processes, soils are agents for the exchange of substances between the hydrosphere and atmosphere as well as neighbouring ecosystems. The regulation function comprises all abiotic and biotic internal processes in the soil which are triggered by material inputs and non-material influences. As subfunctions, they include the buffer capacity for acids, the storage capacity for water, nutrients and harmful substances, the recycling of nutrients, the detoxification of harmful substances, the destruction of pathogenes as well as the balancing capacity for matter and energy.

### *Utilisation function*

Soils are locational components of agricultural and forestry production (*production function*). This refers to the capacity of supplying primary producers (plants) with water and nutrients and serving as their rhizosphere (root sphere). Particularly in view of the aspect of soil management in agriculture and forestry, this also applies to the aim of producing biomass that is usable for people (human and animal food, regrowing raw materials).

In addition, people utilise the soil in many different ways. For example:

- as a site for obtaining raw materials (production function),
- as an area for settlement, transport, supply and recreation (carrier function),
- as an area for industrial use (carrier function),
- as an area for waste disposal (carrier function),
- as a gene pool (production and information function),
- as an indicator of productivity (information function),
- as an archive for natural and cultural history (cultural function).

### *Soils as vulnerable systems*

Soils are open and thus changeable systems. They exchange energy, matter and genetic information with their environment and are thus susceptible to all forms of external stress. This situation makes soil degradation a global environmental problem. The resulting *changes frequently take place very slowly or are not easily perceptible*. Once damage occurs, however, it can often only be remedied over very long periods of time. Soil losses must, therefore, be regarded as irreversible if one does not set geological time scales.

Of the soil covering approx. 130 million km$^2$ of the ice-free surface of the Earth, nearly 20 million km$^2$, i.e. 15%, display *obvious signs of degradation* caused by humans. This is the result of a comprehensive study carried out within the framework of the United Nations Environmental Programme (UNEP) by the International Soil Reference and Information Centre (ISRIC) (Oldemann et al., 1991). *Erosion by water*, with a figure of 56%, makes up the largest portion of this soil degradation, followed by *wind erosion* with 28%, *chemical degradation* with 12% and *physical degradation* with 4%. These figures do not include degradation of forest soils and latent stresses that accumulate over longer periods of time as well as changes in the biocoenoses of soil organisms.

From the recognition that soils play an important role in terrestrial ecosystems, that reserves are limited and that only a relatively small percentage of soils can be used for agricultural purposes, it follows that *soils* and the organisms living in and from them *merit a high degree of protection*[3]. If soils are to be preserved in their existing structure and function, it must be ensured that the external stresses remain within the scope of endogenous possibilities for compensation or repair. For the evaluation of stresses occurring in connection with global environmental changes, therefore, it is important to determine the *stress-bearing capacity of ecosystems and their soils*. Classification is to be carried out and stress limits and guiding parameters must be specified for this purpose. Finally, appropriate measures have to be taken so that these limits are not exceeded. Due to the complex interrelations and slow reaction of soils, however, it is extremely difficult to define stress-bearing capacity in some cases. Therefore, the *principle of precautionary protection of the environment* must fundamentally be given high priority with regard to the conservation of soils.

## Causes

### *Geographical differences in soil degradation*

*Degradation* of the soil is, in the first place, a natural process. Constant alteration of the soil takes place as a result of weathering as well as through supply and discharge of substances with water and air. An important aspect here is that, apart from a few exceptions, these natural processes occur at very *low rates*, i.e. extremely slowly. By virtue of this fact, it was and is possible for communities of organisms to adapt to the respective situation and they can, in many cases, slow down the degradation process. The ecosystems which thereby come into being and of which soil represents a part turn out to be relatively stable, i.e. over periods of decades or centuries, subject to the naturally occurring fluctuations of the boundary conditions (weathering, climate).

This situation has drastically changed in the last decades. Not only must the basic human needs of food, clothing, shelter and heating material be met for the exponentially growing population of the world, something which is still not guaranteed for a large proportion of people; to an increasing degree, it is also “higher standards” which can only be satisfied through industrial production as well as services. This leads to a greater number of activities that directly or indirectly pollute the soil and can result in accelerated degradation.

At the *local level* such activities are predominantly connected with the *expansion and intensification of soil use*, such as forest clearing, ploughing up grassland, draining wetlands or irrigating dry areas, the mechanisation and application of chemicals in agriculture and forestry as well as the overexploitation of fields, pasture land and forests, and have a direct effect on the soil, leading in some cases to positive, though primarily to negative changes. Characteristic of this development is the fact that the gain in arable land through constant cultivation of soil has, from a global point of view, been offset by losses due to soil destruction. As a result, the arable area of the world, i.e. approx. 11% of the total area, has remained roughly constant or has even decreased somewhat over the last three decades, despite continuous forest

[3] From an anthropocentric point of view, all assets that are impaired by human activity in their functions or sustainability merit protection.

clearing (WRI, 1990). This development is extremely problematic because the possibilities for growth are becoming more and more limited.

The local causes of change also include the increasing cultivation of monocultures up to large-scale cultivation of genetically uniform types. This is linked to a reduction in the biodiversity up to the ecotope level. This not only has an influence on the communities of organisms themselves, but also on the regulation and habitat functions of soils and thus on the long-term usability and conservation of these resources as well.

Moreover, mention must be made of soil destruction and pollution resulting from deposition or *output of toxic substances, surface sealing and fragmentation of areas* by means of roads and settlements. These forms of harmful environmental impact are frequently connected with the intensification of industrial activities and traffic and, therefore, play a great role in industrial nations and urban agglomerations.

*Emissions* of *acidifiers, nutrients* and *toxic substances* of an anorganic and organic nature which cross borders can be referred to as causes at the regional level. Increasing *urbanisation* and the related geographical decoupling of food production and consumption also lead to harmful environmental impact. Exportation of biomass not only results in a reduction in soil nutrients, but also in acidification and release of toxic ions. This is linked to a large-scale decrease in productivity. In urban agglomerations the excessive supply of nutrients leads to disposal problems, eutrophication of soil and water as well as pollution of the atmosphere. *Hydraulic engineering measures*, such as regulation of rivers, construction of dams, lowering or raising of the ground water table and construction of dikes as well as irrigation and drainage, affect the water balance of soils. This may result in harmful environmental impact leading to soil degradation. The *expansion of settlement, production and traffic areas* also poses a growing problem at the regional level.

At the *global level* changes occur in the soil which are caused by *changes in the physical and chemical climate*. First of all, altered temperatures and precipitation may have a direct effect on the soil by means of acceleration or reduction of conversion and transport processes and, secondly, an indirect effect via the vegetation cover by virtue of changes in the cover and in biomass production. Increased ultraviolet radiation resulting from ozone depletion and increased $CO_2$ concentrations in the atmosphere may have direct and indirect effects on the soil. Furthermore, a *rise in the sea level* occurring together with climatic changes may influence the structures and functions of the soil in large areas, just as climate-related *migration of species* and *destruction of species* may. In this connection, one must also mention the anthropogenic spread of species not indigenous to the region, and which may also drastically alter the soil. This includes the worldwide spread of the rapidly growing eucalyptus tree and the introduction of a fluke that outcompetes earthworms in Ireland and England. There is an increasing trend towards such processes, which occur even beyond natural barriers due to the greater mobility of people.

Soils are subject to *economic interests* (utilisation function) so that many of the causes mentioned have an economic background. The property rights connected with the soil are very often applied without consideration for long-term yield capacity but oriented to *short-term* benefit. This effect is reinforced by lacking or incorrect planning and cultivation structures or by state subsidy programmes that do not, or only insufficiently, take into account long-term effects, such as overfertilisation and increased concentrations of harmful substances, or may even foster such effects.

## Effects

The above mentioned causes may lead to degradation of the soil at the local, regional and global level. Possible negative changes that occur in soils are summarised in Table 10. In general, a distinction is made between degradation in connection with a shifting of soil material and degradation in the form of internal physical, chemical and biotic properties of the soil. The extent of the soil degradation caused by humans up to now is shown in Table 11.

All types of degradation listed may impair the functions of the soil stated at the beginning on a short-term or even long-term basis, and the effects can be reversible or irreversible. These effects have been described in a large number of reviews (Andreae and Schimel, 1989; Arnold et al.; Bouwman, 1989; Scharpenseel et al., 1990; Sombroek, 1990; Kimball, 1990). The most important results are outlined below.

Table 10: Soil degradation processes

| Displacement of soil material | | Internal soil transformations | | |
|---|---|---|---|---|
| Water erosion | Wind erosion | Physical processes | Chemical processes | Biotic processes |
| Loss of topsoil | Loss of topsoil | Surface sealing, crusting | Loss of nutrients (export of biomass, leaching) | Changes in biocoenotic structure |
| Terrain deformation (rills, gullies, valleys) | Vegetation damages | Compaction (use of machinery) | Salinization (irrigation) | Changes in biocoenotic function |
| | Terrain deformation (depressions, drifts, dunes) | Structural changes (dispersion, degradation of organic matter) | Acidification (deposition, export of biomass) | Decoupling of production and degradation processes |
| | | Waterlogging (compaction, irrigation) | Pollution (heavy metals, organic substances) | |
| | | Dessication (drainage) | Changes in red/ox potential | |
| | | Sedimentation | Subsidence of organic soil | |

Table 11: Anthropogenic soil degradation *(from Oldeman et al., 1991)*

| | Total degradation area (million km²) | % of land area | Causes of degradation | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Water erosion (million km²) | % | Wind erosion (million km²) | % | Chem. degradation (million km²) | % | Phys. degradation (million km²) | % |
| World | 19.64 | 17 | 10.94 | 56 | 5.48 | 28 | 2.39 | 12 | 0.83 | 4 |
| Degradation: | | | | | | | | | | |
| – *light* | 7.49 | 6 | 3.43 | 17 | 2.69 | 14 | 0.93 | 5 | 0.44 | 2 |
| – *moderate* | 9.10 | 8 | 5.27 | 27 | 2.53 | 13 | 1.03 | 5 | 0.27 | 1 |
| – *severe* | 2.96 | 3 | 2.17 | 11 | 0.24 | 1 | 0.42 | 2 | 0.12 | 1 |
| – *extreme* | 0.09 | <1 | 0.07 | <1 | 0.02 | <1 | 0.01 | <1 | <0.01 | <1 |
| Degradation – continents: | | | | | | | | | | |
| *Africa* | 4.94 | 22 | 2.27 | 46 | 1.87 | 38 | 0.62 | 12 | 0.19 | 4 |
| *North/Centr. America* | 1.58 | 8 | 1.06 | 67 | 0.39 | 25 | 0.07 | 4 | 0.06 | 4 |
| *South America* | 2.43 | 14 | 1.23 | 51 | 0.41 | 17 | 0.70 | 29 | 0.08 | 3 |
| *Asia* | 7.48 | 20 | 4.40 | 58 | 2.22 | 30 | 0.73 | 10 | 0.12 | 2 |
| *Europe* | 2.19 | 23 | 1.15 | 52 | 0.42 | 19 | 0.26 | 12 | 0.36 | 17 |
| *Oceania* | 1.03 | 13 | 0.83 | 81 | 0.16 | 16 | 0.01 | 1 | 0.02 | 2 |

## *Habitat function*

Soils form the habitat for a great number of plants, animals and microorganisms. In the course of evolution a nearly perfect waste utilisation system has developed in soils with the food webs contained therein. Soils can thus also be regarded as complex bioreactors. It is important to preserve these "services" of the communities of organisms in the soil and to make use of the "experience" gained by the complex biocoenoses, which are very well adapted to their location with respect to effective use of energy carriers and recycling of scarce resources. This also applies to the disposal of waste. Furthermore, the various and frequently still undiscovered metabolic functions of soil organisms and the genetic information forming their basis should be made use of more than has been done up to now (soils as a gene pool). Antibiotics and enzymes for the decomposition of toxic substances represent examples of this.

The synchronisation that exists between decomposition of biomass and the related release of nutrients and their absorption by plants in the process of production must be preserved for reasons of sustainability. Interventions resulting from changes in climate and use which disrupt the functional structure between organisms and lead to uncontrolled accumulation or release of substances (chemical time bomb) must be reduced or shaped such that the spatial and time-related decoupling of the two main processes in ecosystems, production and decomposition, is minimised.

The spatial structure of soils must be retained so that the habitat requirements of the complex communities of organisms are met. This means that the erosion of soil material and compaction must be avoided.

Thus far the function of soil as a habitat has been primarily studied with regard to plants and their water and nutrient supply. The significance of the communities of organisms in the soil for other processes is still little understood. Influences of global climate change are, therefore, difficult to assess. This also applies to the interventions that people effect on the soil through alteration of their own habitat.

*Knowledge needed:* Reliable answers must be found for the following questions:

- Which environmental and soil factors influence biodiversity in soils?
- What are the structural and functional consequences of biodiversity in soils?
- What role does biodiversity play for the stability of soils and ecosystems?
- What significance does soil heterogeneity have for the function of landscapes?
- On what scale is an integration of processes possible?

### *Regulation function*

The regulation function of the soil is, as already mentioned, not only restricted to internal processes in the soil, but also comprises the exchange of energy and matter with neighbouring systems, such as the atmosphere and the hydrosphere (ground water, surface water bodies).

#### *Influence of the soil on radiation exchange and tangible heat as well as reflection of solar radiation*

The surface characteristics of the soil determine the transfer of heat and the reflection of solar radiation. Dark, rough or open surfaces absorb a great deal of heat. The transport and storage of heat depends on a number of soil characteristics. Light, incrusted or salt-covered surfaces with little or lacking plant cover, on the other hand, effect a high degree of reflection (albedo). Soil use and intermittent removal of vegetation have a direct effect on energy turnover via these processes.

*Knowledge needed:* Standardised recording of soil characteristics as part of soil mapping is necessary so as to be able to check albedo values or heat flows recorded by satellites. This is required in order to include changes caused by humans at the global level in climate models. With the help of satellite-aided or aircraft-supported Earth resources survey methods, the physical properties of the soil surfaces must be recorded at the regional and global level in order to study, on that basis, scenarios for possible changes (application of remote sensing).

#### *Soil as a buffer system in the water cycle of the Earth*

The surface characteristics of soils also determine the portions of precipation that infiltrate into the soil or run off on the surface. Some soils have open, crumbly surface structures and have a high degree of infiltration. Others form crusts and tend to lead to clogging and surface sealing. In this case, surface runoff and thus erosion dominate, and evaporation may be increased or insufficient vegetation cover may result from the prevention of germination. As a consequence, the water balance of landscapes may be greatly altered.

Textural and structural characteristics of soils as well as their vertical and lateral arrangement and variation determine the hydraulic conductivity and thus the retention and dynamics of infiltration water in landscapes. The internal characteristics of the soil also determine the storage capacity for water and thus the water supply of the vegetation cover. Depending on the porosity and compactness, the clay and humus content as well as the type of clay minerals, structure, horizontal order, soil depth and rhizospheric characteristics, the storage capacity may vary by as much as a *factor of 10*. This is linked to the ability to supply plants with water in dry seasons. The productivity of ecosystems and the composition of vegetation communities are decisively influenced by the availability and quantity of stored water.

*Knowledge needed:* The specific measurements of hydraulic soil and vegetation characteristics available up to now must be applied to landscapes in order to make regional statements at a later time. It is important here that information on the soil is linked to that derived from remote sensing (application of remote sensing).

Soils are important sources or sinks in biogeochemical cycles of carbon, nitrogen and sulphur. This has a direct influence on the dynamics of the gases $CO_2$, $CH_4$ and $N_2O$ which are relevant to the climate.

### *The organic substance of soils as a source and sink for carbon*

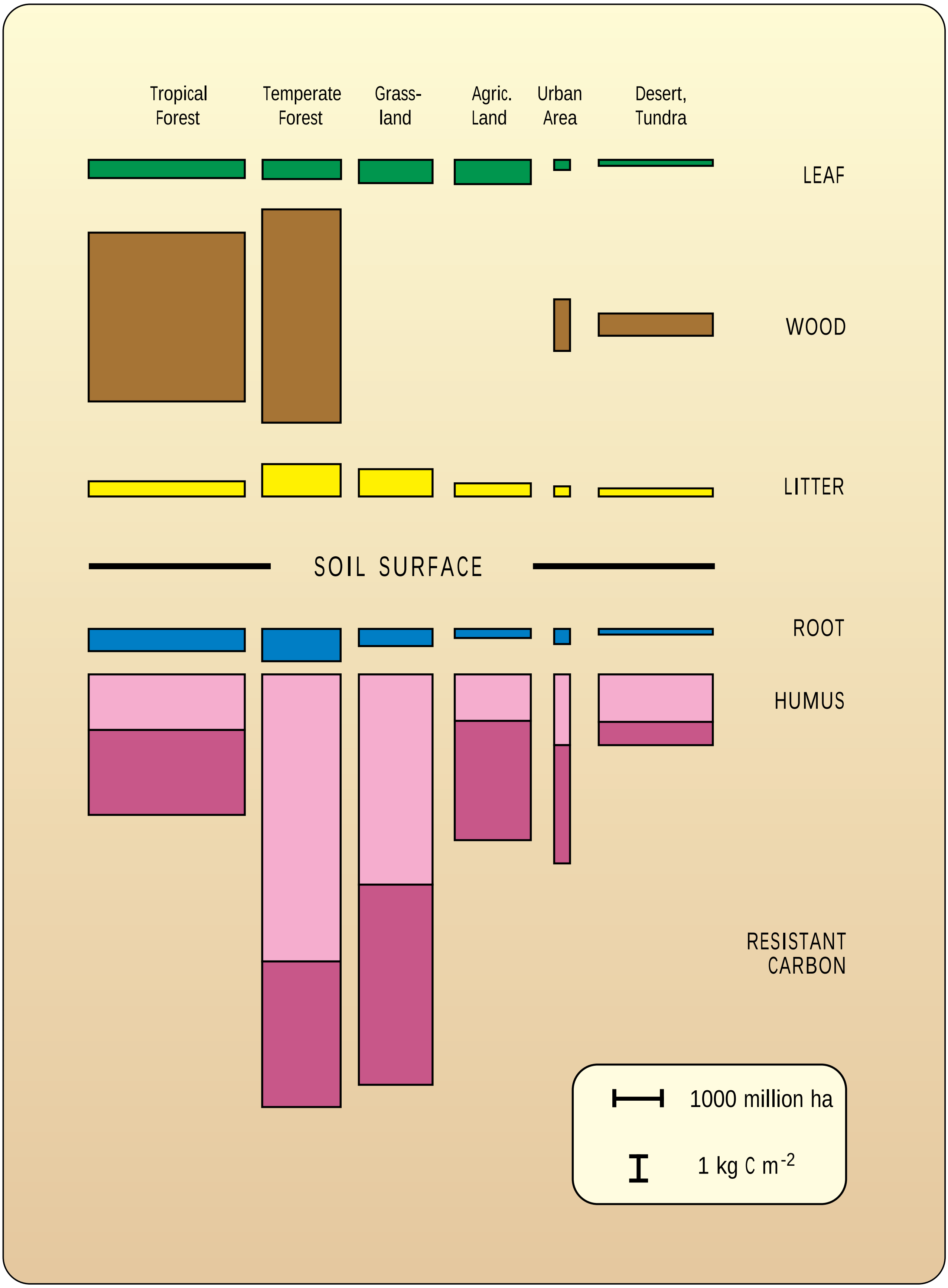
The quantity of carbon that is stored in the soils of the world in the form of living biomass, humus or charcoal exceeds the quantity of carbon in the living substance of vegetation above surface by a *factor of 2-3* (Post et al., 1992). Even in regions in which the vegetation cover is very dense, such as in the tropical rainforests, there is still as much carbon stored underground as above the surface in the vegetation cover. Soils in grasslands or cultivated areas contain up to ten times more carbon than above-surface vegetation (Fig. 7).

The predicted global warming due to the greenhouse effect and changes in the distribution of precipitation may lead to a reduced storage of soil carbon. Higher $CO_2$ concentrations in the atmosphere may, however, increase photosynthesis and thus result in great formation of organic substance in the soil ($CO_2$ *fertilising effect*). This will be the case particularly for C3 plants, which represent the largest portion of woody plants and cultivated plants. If nutrients, water, temperature and radiation are not limited, a doubling of the $CO_2$ concentration may lead to an *increase in biomass production* of more than 30%. Furthermore, this may also result in an up to 50% more efficient use of water per photosynthesis unit since the ratio of transpiration to $CO_2$ uptake is shifted. The $CO_2$ *fertilising effect* represents a negative feedback process via increased $CO_2$ uptake on the part of plants. It might compensate for the $CO_2$ increase in the atmosphere, which is expected as a result of increasing deforestation. Corresponding studies have not yet been conducted, however. If one only considers the production of agricultural plants and the 10 billion people who will have to be fed after 2050, the fertilising effect could be viewed as positive. Since many woody plants utilise water much more efficiently at higher $CO_2$ concentrations, growth of forests is also conceivable in regions which are currently too dry for this purpose. These are only two aspects, however, and must not be regarded separately. Other effects connected with the greenhouse effect also have to be included, such as the competitive behaviour of plants within ecosystems and the possibility for vegetation communities to shift. The resulting ecological consequences are not foreseeable at the moment and not at all calculable.

If it should prove to be necessary to reduce the rise in $CO_2$ concentrations with selective storage measures, one must not only consider large-scale reafforestation and afforestation, but also give thought to long-term storage of carbon in soils as a possible measure. The latter could be supported by suitable management and tillage methods.

*Knowledge needed:* The influence of altered biomass production with an increasing concentration of $CO_2$ and altered temperature and precipitation conditions on carbon reserves in the soil has been difficult to assess up to now. The influence of changes in land use on carbon reserves in the soil also requires further quantification (Post and Mann, 1990). The question of the altered competitive behaviour of plants in ecosystems and of quantification of the altered efficiency of the water consumption of different plants under different local conditions is still open, too.

Figure 7: Organic carbon in soils compared with carbon stored in biomass above ground
*(from Goudriaan, 1990)*



### *Soils as sources for nitrous oxide ($N_2O$)*

It has been possible to quantify the exchange of $N_2O$ between terrestrial ecosystems and the atmosphere only approximately up to now. Roughly half the $N_2O$ sources cannot be determined reliably. It is assumed that at least *90% of the* $N_2O$ *emissions* are of biotic origin and, for the most part, come from terrestrial ecosystems, such as the tropical rainforests, the tropical and subtropical savannas as well as the fertile or greatly fertilised areas of arable land and grasslands. In the case of the latter, the $N_2O$ emissions will increase particularly if worldwide intensification of soil cultivation should become unavoidable due to the imminent growth in population.

Nitrous oxide is mainly formed through biotic processes during nitrification and denitrification in soils. The regulation of release is effected via ecological parameters, whose quantification has not yet been carried out at the regional and global level. Currently only rough interconnections can be seen. There are, for example, connections between the nitrification potential as well as the soil fertility or nitrogen fertilisation and the release of $N_2O$ from the soil.

*Knowledge needed:* Information is urgently required to record and set up a model for the role of physical and chemical properties of soils in the regulation of nitrification and denitrification. The influence of the water and heat balance needs to be quantified. Worldwide there are too few measuring stations where the release of $N_2O$ from the soil is continuously tracked. Geographical expansion of the studies is necessary in order to be able to carry out reliable extrapolations at a global level.

### *Soils as sources and sinks for methane ($CH_4$)*

In contrast to $CO_2$, there is no fertilising effect for methane. Approximately *70% of the methane comes from terrestrial sources*, such as rice fields, wetlands as well as the stomachs of ruminants and termites. The creation of methane differs very greatly from region to region, resulting in political consequences in the reduction of emission.

*Knowledge needed:* The mechanisms of microbial methane formation as well as methane oxidation under field conditions are still not understood well. To record the microbial processes that control the formation and release of methane, studies must be conducted at a large number of locations. Both natural systems and those created and disrupted by human activity must be included as well as, to a greater degree than previously, natural and people-made wetlands. The role of small wetlands and valley riverside soils in addition to their sum effect has presumably been underestimated up to now and requires more precise analysis. The area and intensity of cultivation of rice fields will further increase in the future. The cause of this is the rapidly increasing food needs of the world’s population and changing consumption habits. Soil tillage and water management as well as farming methods must be altered to reduce $CH_4$ emissions. The release of $CH_4$ by soil animals has not been sufficiently studied thus far. The interaction between biomass formation by vegetation and the dynamics of decomposition must be studied in important ecosystems, and the relationship between $N_2O$ release and $CH_4$ uptake must be quantified.

*Knowledge needed regarding trace gases:* In order to improve the global quantification of $CO_2$, $N_2O$ and $CH_4$ fluxes, databases are required which contain the distribution of soils and climate in addition to that of land use systems, rice farming, pasture farming and biomass combustion. Furthermore, more long-term data records are needed to enable assessment of process-oriented models as to their broad (global) applicability.

### *Soils as a buffer and filter for harmful substances*

The buffer and filter capacities for harmful substances in soils, such as acids, heavy metals and organic substances, are limited. When the storage capacity is exceeded, the harmful substances are passed on to neighbouring systems. The buffer and filter characteristics of soils are greatly dependent on their physical and chemical condition and thus location-specific. Changing environmental conditions may lead to changes in the capacities and thus to release of these harmful substances. Viewed in this light, harmful substances that accumulate in the soil represent *chemical time bombs*. The way in which the change in soil use and climate change may affect storage characteristics and mobility of chemicals in soils is depicted schematically in Fig. 8.

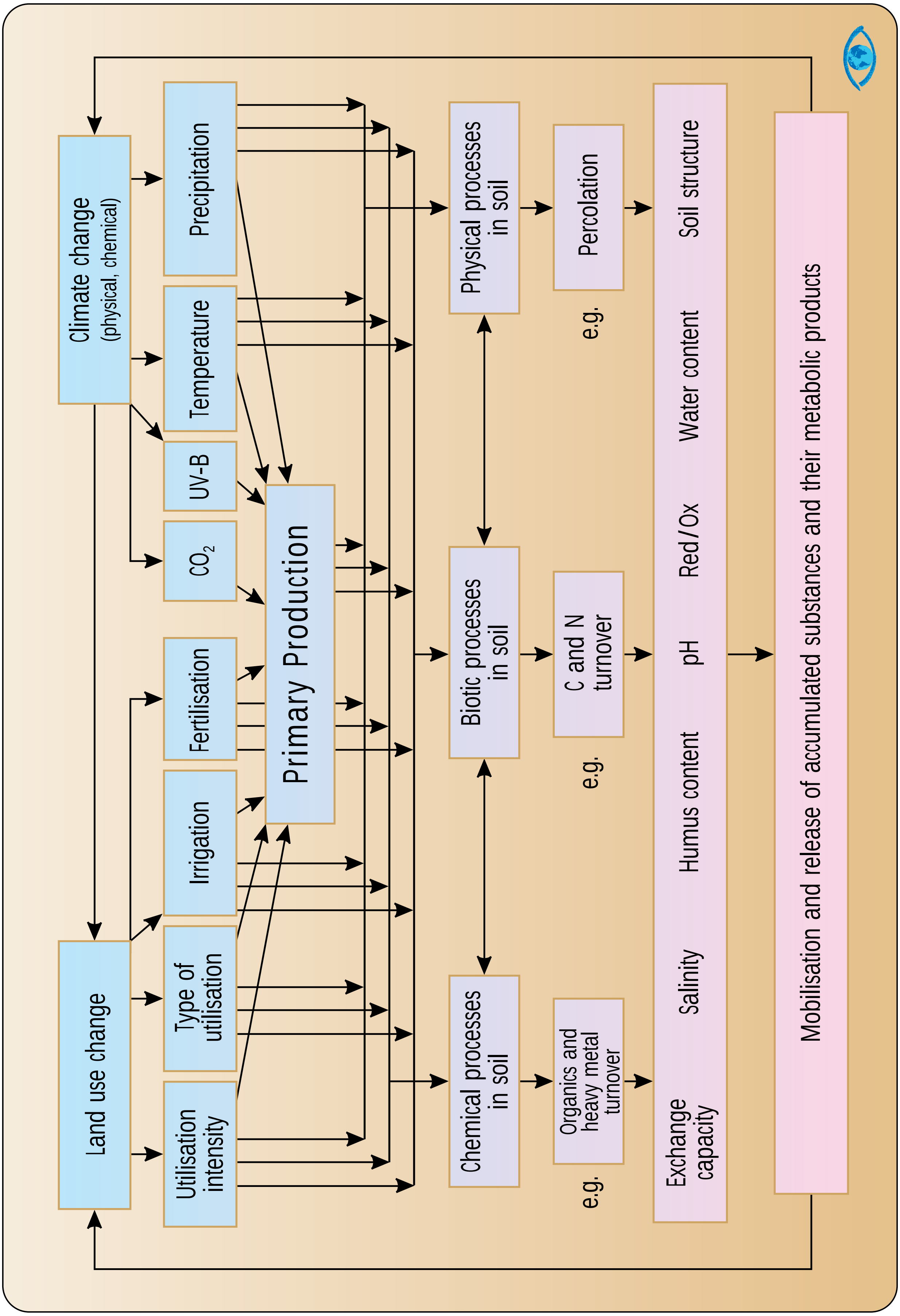



Figure 8: Impacts of climate and land use changes on release of substances in soils

*Knowledge needed:* The location-specific environmental stress-bearing capacity of soils with harmful substances and the critical loads oriented to the principle of sustainability are to be determined for changing environmental conditions (climate, utilisation). The mobilisation capacity of harmful substances and the resulting pollution of neighbouring systems must be ascertained. Available time series and long-term observation areas must be evaluated and amended.

### *Soils as stores and transformers for nutrients*

The two overriding ecosystem processes, the production of biomass and its subsequent *decomposition*, meet in soils. Here nutrients from primary producers are taken up, stored and then released again by animals and microorganisms after death. To ensure sustainable use of soils, decoupling processes that disrupt the linking of production and decomposition must be minimised. This can be done via a synchronisation of the synthesis and decomposition processes of biomass. According to present knowledge, this can best be guaranteed if soils have communities of organisms with a high degree of diversity (see 1.5.2). A maximum of synchronisation concerning space and time reduces, at the same time, the pollution of water bodies and the atmosphere with C and N compounds.

*Knowledge needed:* The internal regulation of the C and N turnover in the soil as well as humanities extreme steering of the processes involved require further clarification. Although many studies have already been conducted in this area, they hardly take into account the importance of the biological processes. The natural biotic potential of soils should be utilised to a greater extent than up to now for those parts of the Earth in which the population is growing most rapidly and where knowledge concerning the soils found there and their characteristics is inadequate.

## *Utilisation function*

### *Production function*

Increased $CO_2$ concentrations and UV-B radiation as well as altered temperature and precipitation have an effect on the *photosynthesis* and *growth of plants* and thus influence biomass production and the degree of soil cover. Here both positive and negative changes in production may occur. A detailed description of this is presented in section 1.5.

In addition, people directly intervene in the production of terrestrial ecosystems and thus in soils to an enormous extent. This takes place with varying intensity, such as through farming, irrigation, grazing, livestock breeding, shifting cultivation, fire, afforestation, plantation farming. Table 12 depicts the current division of the land areas of the world and shows that the portion used for farming only accounts for approx. 11%. The great intervention in terrestrial ecosystems, on the other hand, makes it clear at the same time that soils represent a major basis for human life and well-being. They determine to a decisive degree agricultural productivity and thus secure humanities *food base*.

Table 12: Distribution of ice-free land area *(from UNEP, 1991)*

| Total land area – ice-free | 130.69 million km$^2$ |
|---|---|
| arable land | 11 % |
| grassland | 25 % |
| forests | 31 % |
| other land | 33 % |

Table 13 shows the distribution of arable land on the continents as well as the respective area of arable land per capita. Satellite pictures show that the area of the soil suitable for farming is between 20 and 40 million km$^2$, depending on what is considered arable. It is a fact that farmland resources in large parts of the world have already been exhausted; this applies to North Africa and for parts of Asia. Wherever reserves are still available, expansion is only possible at the expense of other ecosystems. This means that sensitive soils with low environmental stress-bearing capacity have to be cultivated to a greater extent. Fragmentation or isolation of the remaining natural ecosystems is increasing rapidly. If large portions of the cultivated soil continue to be lost due to degradation and have to be compensated for by cultivating new areas, the agriculturally usable soil reserves will probably become scarce in twenty years. In some regions they are already no longer sufficient.

Table 13: Distribution and per capita distribution of arable land – 1990 *(from UNEP, 1991)*

| | million $km^2$ | hectares per capita |
|---|---|---|
| World | 14.78 | 0.28 |
| Africa | 1.87 | 0.29 |
| North America | 2.74 | 0.64 |
| South America | 1.42 | 0.48 |
| Asia | 4.54 | 0.15 |
| Europe | 1.40 | 0.27 |
| CIS | 2.31 | 0.80 |
| Oceania | 0.51 | 1.90 |

Use-related human interventions, as already mentioned, frequently result in destabilisation of ecosystems. As a consequence of this, soil degradation occurs, as described in the section on “Effects”. Table 14 lists the causes on which they are based and their proportion of the soil degradation on different continents. If one takes a look at this data, it becomes evident that vegetation changes (clearing), overgrazing and farming, with roughly equal proportions, are the main causes of degradation; obvious regional differences emerge, however.

Table 14: Causes of soil degradation *(from Oldeman et al. 1991)*

| Degraded areas (million $km^2$) | | Causes of degradation in % | | | | |
|---|---|---|---|---|---|---|
| | | Deforestation | Over-exploitation | Overgrazing | Agricultural utilization | Industrial activities |
| World (total) | 19.64 | 30 | 7 | 34 | 28 | 1 |
| Africa | 4.94 | 14 | 13 | 49 | 24 | <1 |
| North/Centr. America | 1.58 | 11 | 7 | 24 | 57 | <1 |
| South America | 2.43 | 41 | 5 | 28 | 26 | <1 |
| Asia | 7.48 | 40 | 6 | 26 | 27 | <1 |
| Europe | 2.19 | 38 | <1 | 23 | 29 | 9 |
| Oceania | 1.03 | 12 | <1 | 80 | 8 | <1 |

To secure the food supply for the further rapidly growing world population, worldwide efforts are needed to check the continuing decline in production in soils due to degradation.

*Knowledge needed:* A lack of alternatives because of the population growth as well as the rate of change will make adjustments in land cultivation urgently necessary in certain regions of the Earth. Therefore, more agricultural and forestry research must be conducted and the results made known and implemented on a worldwide basis. This requires inclusion of the research results in development policy decision-making processes.

### *Environmental impact of erosion and leaching on neighbouring aquatic systems*

Deposited and released substances are leached into the ground water with the percolating water or conveyed into neighbouring water bodies with the surface runoff and transported to the sea via these water bodies. On the way they may bring about various harmful effects on organisms in aquatic ecosystems. It is important, therefore, to record and evaluate not only the depositions in soils but also the critical exports of substances from the soil.

The soil material carried off in the course of water erosion is, in some cases, deposited in valleys (flood silt) and can lead to sanding or silting up of rivers. Large amounts, however, are transported by rivers to the sea and deposited in the estuary (formation of deltas). Table 15 provides examples of the magnitude that this transported material can reach. The resulting nutrient-rich sediments may significantly eutrophy and alter the marine ecosystems. In the case of rivers whose water comes from regions with great settlement of industry and intensive land use and flows into shallow seas or inland seas, harmful substances carried off from soils may cause substantial pollution of aquatic ecosystems. Examples of this are the Baltic Sea and the Persian Gulf.

Table 15: Soil erosion in the catchment areas of major rivers *(from WRI, 1986)*

| River | Mouth | Size of catchment area in 1,000 $km^2$ | Average anual sediment load in million t | Estimated anual soil erosion per hectare in t |
|---|---|---|---|---|
| Niger | Gulf of Guinea | 1,114 | 5 | 0 |
| Congo | Atlantic Ocean | 4,014 | 65 | 3 |
| Nile | Mediterranean | 2,978 | 1,111 | 8 |
| Amazon | Atlantic Ocean | 5,776 | 363 | 13 |
| Mekong | South China Sea | 795 | 170 | 43 |
| Irradwaddy | Bay of Bengal | 430 | 299 | 139 |
| Ganges | Bay of Bengal | 1,076 | 1,455 | 270 |
| Huang He (Yellow River) | The Yellow Sea | 668 | 1,600 | 479 |

## Link to global change

Links exist to nearly all main elements of global environmental changes. This is a result of the central role played by soils both in the ecosphere and in the anthroposphere. In the ecosphere soils, as buffer systems with their storage characteristics, are integrated in the water cycle (hydrosphere). Moreover, they are involved in the biogeochemical cycles of carbon, nitrogen and sulphur, resulting in close links to the problem of gases relevant to the climate (atmosphere, stratosphere).

Feedback effects exist in connection with those effects on soils, on the vegetation cover as well as on people which are related to climate change and increased UV-B radiation. Soils are the habitat of a large number of plants, animals and microorganisms so that there are close links to the biosphere (see 1.5).

Sustainable use of the soil is of outstanding significance for the survival and prosperity of humanity. The most important link here is to agriculture and forestry as well as to settlement structures up to big cities. The need for ground area for transport, waste disposal sites and industrial activities increases with the growth in population and the rising demands of people.

Effective sustainable soil or land use requires an exchange of information and advisory and training measures to clearly depict the role of people as the causal agents, the persons affected and, in particular, the potential managers of soil problems.

## Assessment

### *Ecological assessment of soils*

If one lists the global soil problems to be solved in the order of their urgency, then, in the view of the Council, *soil degradation* and the processes causing it should be placed at the top of the list. Erosion through water and wind represents the main degradation problem worldwide. It is the reason why the productivity of the soil is dropping, soils are completely destroyed and more and more new areas have to be utilised at the expense of other ecosystems.

At the same time, the dilemma of *global soil protection* emerges in connection with soil degradation. The most damage occurs at the local level and its cause can frequently be found there. Regional and global causes, which are the subject of much discussion today, have not been researched to a great extent up to now and their effects can only be described superficially. Since the sum of local effects also has global consequences, as already stated above, these effects must also be subjected to international regulation. Particularly in the developing countries, many people are threatened in their existence by progressive soil degradation; the problems there can, however, hardly be solved at the local level due to economic and social circumstances.

This realisation was the basis for the creation of the *World Soil Charter*, which was adopted at the 21st session of the FAO Conference in 1981. The principles of this Charter, specified in 13 theses, are still applicable. They demand that governments, international organisations and land users create conditions for sustainable soil use and to preserve soil as a resource for coming generations (see box on World Soil Charter). Up to now, however, little has been done to implement these principles internationally, although the necessity for protection of the soil has been emphasised in UNESCO, UNEP and UNDP programmes. Furthermore, there are a number of additional international and national institutions, including the European Council, which have taken up the problems of soil protection. Regulations and laws for the protection of the soil also exist at the national level in various countries. All of these resolutions and declarations of intent have not, however, led to energetic tackling of the problem of worldwide soil degradation.

**Box 7: World Soil Charter**

The principles of land use and soil conservation (World Soil Charter 1982), which were recommended by the 21st FAO Conference of the United Nations and the international organisations involved within the scope of their respective responsibilities, are:

1. Among the major resources available to man is land, comprising soil, water and associated plants and animals: the use of these resources should not cause their degradation or destruction because man's existence depends on their continued productivity.

2. Recognising the paramount importance of land resources for the survival and welfare of people and economic independence of countries and also the rapidly increasing need for more food production, it is imperative to give high priority to promoting optimum land use, to maintaining and improving soil productivity and to conserving soil resources.

3. Soil degradation means partial or total loss of productivity from the soil, either quantitatively, qualitatively, or both, as a result of such processes as soil erosion by water or wind, salinization, waterlogging, depletion of plant nutrients, deterioration of soil structure, desertification and pollution. In addition, significant areas of

soil are lost daily to non-agricultural uses. These developments are alarming in the light of the urgent need for increasing production of food, fibres and wood.

4. Soil degradation directly affects agriculture and forestry by diminishing yields and upsetting water regimes, but other sectors of the economy and the environment as a whole, including industry and commerce, are often seriously affected as well through, for example, floods or the silting up of rivers, dams and ports.

5. It is a major responsibility of governments that land-use programmes include measures toward the best possible use of the land, ensuring long-term maintenance and improvement of its productivity, and avoiding losses of productive soil. The land users themselves should be involved, thereby ensuring that all resources available are utilised in the most rational way.

6. The provision of proper incentives at farm level and a sound technical, institutional and legal framework are basic conditions to achieve good land use.

7. Assistance given to farmers and other land users should be of a practical service-oriented nature and should encourage the adoption of measures of good land husbandry.

8. Certain land-tenure structures may constitute an obstacle to the adoption of sound soil management and conservation measures on farms. Ways and means should be pursued to overcome such obstacles with respect to the rights, duties and responsibilities of land owners, tenants and land users alike, in accordance with the recommendations of the World Conference on Agrarian Reform and Rural Development (Rome, 1979).

9. Land users and the broad public should be well informed of the need and the means of improving soil productivity and conservation. Particular emphasis should be placed on education and extension programmes and training of agricultural staff at all levels.

10. In order to ensure optimum land use, it is important that a country’s land resources be assessed in terms of their suitability at different levels of inputs for different types of land use, including agriculture, grazing and forestry.

11. Land having the potential for a wide range of uses should be kept in flexible forms of use so that future options for other potential uses are not denied for a long period of time or forever. The use of land for non-agricultural purposes should be organised in such a way as to avoid, as much as possible, the occupation or permanent degradation of good-quality soils.

12. Decisions about the use and management of land and its resources should favour the long-term advantage rather than the short-term expedience that may lead to exploitation, degradation and possible destruction of soil resources.

13. Land conservation measures should be included in land development at the planning stage and the costs included in development planning budgets.

The second important area in connection with an examination of soil problems is that of the *release or uptake of gases relevant to the climate* ($CO_2$, CO, $CH_4$, $N_2O$). In this context there are certain activities for the recording of the gas flows at the regional and global level within the framework of the IGBP (International Geosphere-Biosphere Programme), i.e. in the core projects, IGAC (International Global Atmospheric Chemistry Project) and GCTE (Global Change and Terrestrial Ecosystems). Measures to reduce the release of gases relevant to the climate or increase $CO_2$ storage in the soil have not been taken in practice thus far.

A third important topic is the *recording of the accumulation of harmful substances* in the soil and their *possible release* due to altered environmental conditions. Because of the long-term effects, the term *chemical time bombs* will be used here for both topics. As in the case of the gases relevant to the climate, the *quantity and quality of the organic substances* and their biotic transformation play a significant role here. There is an urgent need for research at the regional and global level for quantification of the related processes.

While international projects and agreements, which still have to be activated, already exist concerning the first topic, the two other areas have hardly been studied on an international basis and only recently have they been included in the analysis to a greater degree.

Further topics requiring analysis and treatment in the medium term include

- the change in the *structure and function of biocoenoses* in soils due to altered use and climatic conditions as well as the introduction of organisms not indigenous to the region,
- the *decoupling of biogeochemical cycles* due to increasing spatial and time-related separation of production and consumption of biomass and its subsequent decomposition,
- the role of soils as *regulators of the energy and water balance* of landscapes, regions and continents.

**Box 8: Historical development of political action with regard to soils**

*National*

| | |
|---|---|
| BMI, 1985: | Soil protection concept of German Government<br>Bundestag Form No. 10/1977 |
| BMU, 1987: | Soil protection measures<br>Resolution of German Cabinet of 8. 12. 1987 |
| BMU, 1992: | Soil Protection Act, Draft |

*International*

| | |
|---|---|
| European Council, 1972: | European Soil Charter |
| UNEP, 1978: | Action plan for combatting desertification |
| UNEP, 1979: | Action programme of World Conference for Agricultural Reform and Rural Development |
| FAO, 1981: | *World Soil Charter* |
| UNEP, 1982: | World Soils Policy |
| UNO, 1992: | Res. 47 / 188: Elaboration of an international convention to combat desertification |

**Box 9: Follow-up issues of the UN Conference on Environment and Development for soils**

| AGENDA 21 | *National* | *International* |
|---|---|---|
| Chapter 3 | | Creation of basic legal frameworks for land management, access to land resources and land ownership and for the protection of tenants (in developing countries) |
| Chapter 5 | | Assessing and eliminating the causes of change in traditional (environmentally sound) land use because of internal population pressures (in developing countries) |
| Chapter 7 | Promotion of sustainable land use planning | Promotion of sustainable and environmentally sound human settlement (in developing countries) |

| | | |
|---|---|---|
| Chapter 9 | Promoting sustainable land management compatible with conservation and enhancement of sinks and reservoirs of greenhouse gases (biomass, forests) | as national |
| Chapter 10 | Development and implementation of programmes for sustainable and integrated planning and management of land resources (especially arable land) | Promotion of integrated planning and management of land resources in developing countries |
| | Drawing up of basic general frameworks for land use on the basis of current surveys on suitability for certain uses | as national |
| Chapter 11 | Expanding forest areas, especially protected areas | as national |
| | Exploiting the protective function of forests in preventing erosion and desertification | as national |
| Chapter 12 | | Support for countries concerned (especially developing countries) in monitoring deforested lands |
| | | Support for measures aimed at the conservation and rehabilitation of protective vegetation cover to maintain soil fertility, to stabilise groundwater balance and reinforce unstable ecosystems in drylands |
| | | Participation in programmes to promote environmental consciousness and the application of environmentally sound land management methods to prevent soil degradation |
| Chapter 13 | Surveying the different forms and uses of mountain ecosystems and their climatic conditions | as national |
| | Environmentally sound economic and touristic development of mountain regions and creation of nature reserves | as national |
| | Application of environmentally sound management methods, conservation and expansion of trees and plants as protection against soil erosion | as national |
| Chapter 14 | Creation of the legal frameworks for an economically sensible size of farmland and to prevent further partitioning | as national |
| | | Promotion of measures to protect marginal soils and sensitive ecosystems against degradation and destruction through agricultural use |
| | Planning of optimum land use by means of progressive and environmentally sound technologies for land management while adapting to the respective soils and climatic conditions | as national |
| | Preparing a land resource survey of soil degradation through erosion, salinisation, compaction, pollution and loss of soil fertility | as national |

| | | |
|---|---|---|
| | Preserving soil fertility through the application of natural organic and inorganic fertilisers instead of synthetic fertilisers | as national |
| Chapter 19 | Introduction of regulations and measures for the protection of soils against application- or accident-related pollution via toxic chemicals | as national |
| Chapter 20 | Introduction of regulations and measures for the protection of land against the effects of toxic chemicals | as national |
| Chapter 21 | Avoidance or limitation of soil contamination by means of suitable disposal of solid wastes and compliance with standards for harmful substances in the use liquid waste substances or sewage sludge | as national |

In summary, it can be stated that a comprehensive set of instruments already exists for *soil as a site for plant production*, whereas this is not the case for other functions.

## Economic assessment of soils

### Needs

By virtue of their services and uses, soils are resources that make a decisive contribution to ensuring the survival of human societies; to this extent, soils are assets of global importance from an economic point of view.

In the view of the Council, the services and uses connected with the functions of soils are values whose long-term conservation, improvement and, to the extent that it is necessary, restoration must also be striven for worldwide with respect to economic aspects. Impairments of the functions reduce the utilisability and efficiency of soils (Table 16). In addition to the economic losses thus caused, the costs for compensatory and cleaning measures have to be taken into account, insofar as such measures are feasible in the first place.

Here there are close economic links between the individual functions, such as between habitat and production function. The regulation function also has economic significance when processes in the soils, such as the formation of ground water or of greenhouse gases, are important for humanity or society.

Moreover, one must distinguish between the costs incurred directly as a result of impairment of the soil function and those that are brought about by the effects of soil changes or contamination or damaged soil functions on people or on other environmental media. From these interrelations follows their dependence on global changes, such as through the greenhouse effect. As a rule, the occurrence of soil damage has local causes which lead to global consequences only when they take place repeatedly.

In an economic assessment of soil changes one must particularly take into account the fact that soils are, for all practical purposes, not expandable and only available to a limited extent. It must also be considered that the possible ways of utilising soils are restricted by their characteristics. This is of special importance regarding the value of soils as a protected interest in relation to other environmental assets and with regard to a cost comparison between reversible and irreversible damage or impairment.

Table 16: Soil impairment costs caused by global environmental changes

| Primary impairments | Cost factors | Functions | | |
|---|---|---|---|---|
| | | H | P | R |
| Impairment of habitat function | Disturbance of the balance between production and degradation of organic matter | | | x |
| | Measures to minimise impacts of climate and land use change (accumulation and release of substances) | | | x |
| Impairment of production function | Production losses due to climatic impacts ($CO_2$, UV-B, temperature, precipitation) | | | x |
| | Fertilisation and pest control to increase yields and sustain production | | | |
| | Protection of sensitive, vulnerable soils | x | | x |
| | Protection of other ecosystems | x | | x |
| | Making additional production areas available | | | |
| | Research and application/distribution of the results | | | |
| | Residues in water, other ecosystems and food | | | x |
| | Additional supplies of food | | | |
| | Losses of natural soil cover | x | | x |
| Impairment of regulation function | Irrigation, water supplies (despite surface sealing, compaction and scarcity of organic matter in soils) | | x | |
| | Poor vegetative soil cover (inhibits $CO_2$ assimilation) | x | x | |
| | Conservation of soils as carbon storage | x | x | |
| | Compensation for $N_2O$ release from fertile and intensively fertilised agricultural areas (water / heat budget) | | | |
| | Reduction of $CH_4$ emissions from natural and artifical wetlands (particularly from rice cultivation) | | | |
| | Release of pollutants from soils at decreasing storage capacity | | | |

H = habitat function P = production function R = regulation function

## *The environmental area of "soils" in an environmental accounting system*

No ready-made concepts are available for the position of soils in an environmental accounting system. A definition of the total economic value of soils is also lacking. The extent to which the

- *current use value* of soils (as an expression of the utility for the private sector or national economy),
- *option value* (as an expression of a preference, i.e. willingness to pay, for the conservation and protection of soils, e.g. as a habitat for soil organisms)
- *existence value* (as a preference for the conservation of soils and the landscape, regardless of future use, e.g. as an archive of natural and cultural history)

results or should result in an *overall economic value* would have to be examined within the framework of a research project for different soils on the basis of different examples, while including developing and newly industrialised countries.

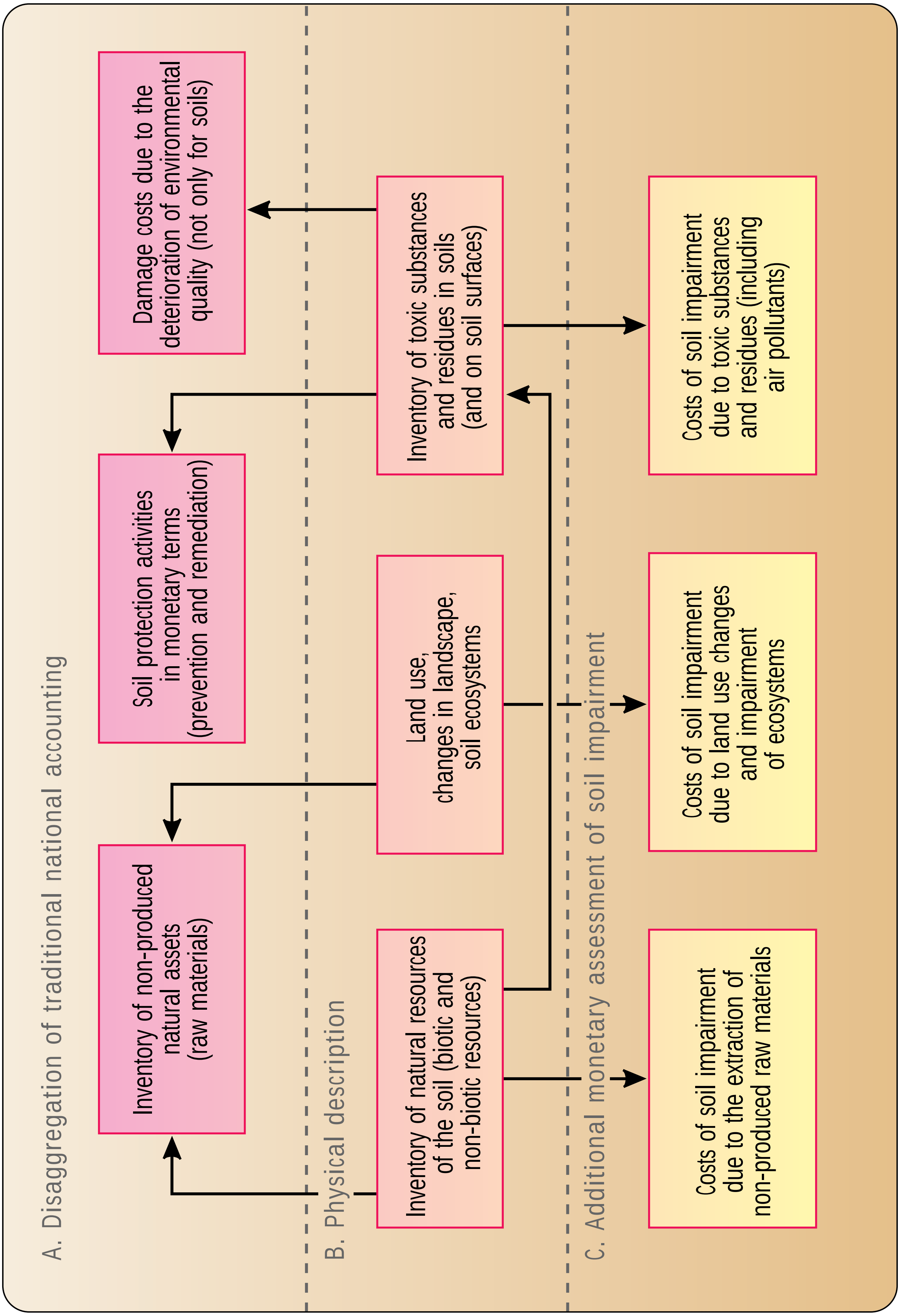



Figure 9: Components of the integrated macroeconomic "environmental accounting" system as applied to soils (*modified from Statistisches Bundesamt, 1991*)

The German Federal Office of Statistics is currently developing an environmental accounting system with scientific support from the “Overall Environmental and Economic Assessment” Council at the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. A link to the area of soils can be shown (Fig. 9) by using “modules” of this accounting system.

Such accounting systems can be an important instrument in reinforcing awareness of the worldwide increase in soil damage and the related losses in utility and welfare and in encouraging avoidance strategies. For completeness such concepts still require more details: in particular for monetary assessment of the individual resources, they need a great variety of data which are not yet available in adequate quantity and quality. There is, therefore, a great need for action in determining and recording national and international data.

As a statement of flows and stocks, the services listed in Table 16 are to be allocated to the stand potential of the soils, whose use leads to changes via natural processes and human activities. Hübler (1991) studied the relation between the impairment of soil functions and the resulting costs of soil pollution in Germany for different types of harmful environmental impact. While taking into account the methodological approaches used there regarding the cost structure of different kinds of harmful environmental impact on the soils, cost factors can be allocated to the individual soil functions, defined according to direct impairment of the soils as well as according to impairment of other environmental assets and environmental media indirectly caused by changes in the soils or by damaged soil functions. The impairment of the habitat, production and regulation functions brought about by global environmental changes can also be included here. Cost factors which are necessary for measures to reduce negative effect of global environmental changes, such as reduction of $CH_4$ and $N_2O$ emissions, should be taken into account, too. The required expenditures for soil protection must also be counted as avoidance costs; for example, expenditures of DM 28 billion for 1992 and DM 48 billion for the year 2000 are estimated for worldwide erosion protection (WWI, 1992).

To set up such structures, there is a substantial need for coordination, both nationally and internationally. The focus here should be on recording the costs for measures against the loss of soils (especially cultivated soils) due to degradation and for measures against the progressive decline in production on utilised soils in the newly industrialised and developing countries. It appears meaningful to provide support in the recording of costs in these countries.

The Council views the following as *focal points of future action*:

- improvement and expansion of worldwide data and databases for observation of the changes in the terrestrial area and greater cooperation within the framework of international measuring networks (GEMS, GTOS, CORINE),
- incorporation of the principles and tasks set down in the World Soil Charter and AGENDA 21 into national and international legislation and programmes.

*It should be the task of the German Government to vigorously pursue a policy of ensuring that the principles contained in the World Soil Charter and AGENDA 21 are recognised and applied worldwide. It may be necessary in this connection to work up a Soil Convention.*

## Weighting

Soils represent a protected interest of very great importance. Due to their extremely slow development – the age of soils is, in some cases, centuries but predominantly millennia – irreversible harmful impact, such as building over soil, erosion and soil shifting, heavy metal and acid contamination, etc., must be minimised. Reversible damage, such as structural changes or harmful environmental impact via organic substances that are biotically degradable, have been regarded as less dangerous up to now. Secondary effects occurring during degradation, however, must be taken into account as well as the direct and indirect interventions of people in the biocoenoses of the soils.

In addition to further clarification and quantification of the effects that may occur in the soils due to global changes and of the resulting harmful impact on neighbouring systems, a major portion of future tasks will consist of applying already available knowledge on a worldwide basis and implementing action strategies. Since in many countries in which soils are increasingly polluted the parties responsible for environmental damage do not possess the relevant knowledge and the government is not able or willing to intervene, the problem must be solved through international cooperation.

### Research needs

- *Data basis:* Improvement of comprehensive soil assessment at the national and international level, making use of remote sensing. Calibration of remote sensing data to international measuring networks. Development of assessment programs to derive action strategies.
- *Soil functions:* Determination of the importance of soils and their ecological complexity for the sustainable stability and productivity of ecotopes and ecoregions as well as of the influence of increased $CO_2$ concentrations and use strategies on biomass production and C storage in soils of different ecosystems. Quantification of the ecological regulating variables of soils regarding uptake and release of trace gases ($CO_2$, $CH_4$, $N_2O$). Development of strategies for the reduction of trace gases.
- *Pollution of soils via harmful substances:* Analysis of the environmental elasticity of soils with harmful substances and nutrients, while taking into account the changing environmental conditions; pursuance of a dynamic approach, such as that of the *"Critical Load Concept"*.
- *Soil degradation:* Examination of the influence of the altered physical and chemical climate and altered land use on the degradation of soils and development of a forecast model.
- *Soil use:* Development of adaptation strategies for agriculture and forestry with regard to the global environmental changes as well as study of interactions between soil use and climate change.
- *Soil economy:* Assessment of the criteria (current value of assets, option value and existence value) for determination of an overall economic value for different soils. This should be carried out on different national examples with the inclusion of developing and newly industrialised countries.
- *International soil policy:* Examination of the possibilities for expanding worldwide information, observation and research networks and their effectiveness for worldwide soil protection.

## 1.5 Biosphere

A separate and comprehensive treatment of the "Biosphere" would require roughly the following structure:

- structural questions,
- environmental problems of individual biomes, e.g.
  - forests,
  - seas,
  - regions threatened by desertification,
  - agriculture in developed regions,
- biodiversity as a major aspect of the biosphere.

Such an approach cannot be strictly maintained in this chapter, however, because certain domains are addressed in other chapters of the Report. Thus agriculture is treated in the chapter on "Economy" and the seas are dealt within the chapter on "Water". The problems of desertification will not be looked at until the following annual Report. Therefore, the chapter on the "Biosphere" in this Report only comprises two sections: first of all, a selected biome, the forest, is treated and then we will deal with biodiversity. These two topics have been picked out in the first Report not least of all because an international agreement was adopted on each of them at UNCED in Rio de Janeiro in 1992: the Rio Principles on the World's Forests and the Framework Convention on Biological Diversity.

## An overview of the biosphere

The term biosphere does not have a standard scientific definition and is, therefore, used differently. First of all, the *biosphere* encompasses the entire flora, fauna and microorganisms of the continents and seas; human beings as living beings are also part of the biosphere. This definition is not very helpful for practical purposes because it does not take into account either geographical differences or abiotic components. Therefore, a definition not based on living organisms alone but also on ecosystems is frequently used.

In the following, *biosphere* will refer to the continental and marine ecosystems in their entirety which interact with one another at the global level and exchange energy, matter and information with the other spheres via their system boundaries. According to this definition, the pedosphere, aquatic sediments and the living zones of the hydrosphere are also included in the biosphere.

For practical reasons the biosphere is divided into *ecosystems* of differing aggregation states. An ecosystem represents the interrelational structure of living organisms among themselves and in their habitat. Ecosystems are open and have, to a certain degree, the ability of self-regulation. They include terrestrial and aquatic ecosystems (such as marine ecosystems) and the corresponding ecological complexes.

With increasing size and complexity ecosystems are divided into *ecotopes*, *ecoregions* and *ecozones*. In contrast to organisms or physical systems, ecosystems frequently do not have sharply defined boundaries. The boundaries become even less sharply defined with increasing size. Nevertheless, even arbitrarily drawn boundaries may be of help in structuring and allocating processes and balances. At the same time, one cannot regard the communities of organisms in ecosystems as static units, rather they are subject to constant change in space and time. The subdivision into ecosystems has the additional advantage that the thus defined natural biosphere can be compared to the anthroposphere with its various subsystems.

A division of the terrestrial ecosystems on the basis of *ecozones (biomes)* appears meaningful for an analysis of global problems. For the following descriptions a subdivision into nine ecozones is used, as was suggested by Schulz (1988) (Table 17), while a division into regions according to Lüning (1985) was adopted for the seas (Table 18).

Table 17: The Earth's biomes *(from Schultz, 1988)*

| | Share of zones from land area in | |
|---|---|---|
| | % of total area | % of ice-free area |
| 1. Polar/subpolar zone | 14.8 | 4.4 |
| 1.1 Tundra and Permafrost zone | 3.9 | 4.4 |
| 1.2 Polar desert | 10.9 | – |
| 2. Boreal zone | 13.0 | 14.7 |
| 3. Humid mid-latitudes | 9.7 | 10.9 |
| 4. Dry mid-latitudes | 11.0 | 12.3 |
| 4.1 Grass steppe | 8.0 | 8.9 |
| 4.2 Desert and semidesert | 3.0 | 3.4 |
| 5. Tropical/subtropical drylands | 20.9 | 23.4 |
| 5.1 Thorn savanna and steppe | 9.2 | 10.1 |
| 5.2 Desert and semidesert | 11.7 | 13.3 |
| 6. Humid subtropics (winter) | 1.8 | 2.0 |
| 7. Humid tropics (summer) | 16.3 | 18.3 |
| 8. Humid subtropics | 4.1 | 4.6 |
| 9. Humid tropics | 8.3 | 9.4 |

Table 18: The regions of the Earth's seas *(from Lüning, 1985)*

| |
|---|
| 1. Arctic region |
| 2. Cold temperate region of the northern hemisphere |
| 3. Warm temperate region of the northern hemisphere |
| 4. Tropical region |
| 5. Warm temperate region of the southern hemisphere |
| 6. Cold temperate region of the southern hemisphere<br>6a. Sub-Antarctic islands region |
| 7. Antarctic region |

Ecozones are characterised by a specific climate in each case. This means that the annual amounts of radiation, precipitation and heat as well as their distribution over time differ among the individual ecozones. The latter have characteristic soil communities. The significance of soils in ecosystems has already been described in the previous chapter. Furthermore, ecozones are characterised by typical plant and animal communities. On the basis of topographical and geological conditions, azonal ecosystems are also contained in ecozones, in some cases with greatly varying structures and functions. They may play an important role for the biodiversity of the ecozones and they may be essential for their stability.

### 1.5.1 Changes in the biosphere based on the example of the forest

#### Brief description

Forests cover roughly one-fifth of the Earth's land surface and they produce more than a third of the terrestrial biomass. They play an important role within the framework of global environmental changes in that they determine, to a significant extent, the carbon cycle between the biosphere and the atmosphere. A large quantity of carbon (C) is emitted into the atmosphere every year as a result of human activities, some of it coming from the consumption of fossil fuels, some from the destruction or use of the tropical forests. The role of forests, in addition to the atmosphere and the oceans, as a sink for carbon is not yet known precisely. One hypothesis says that primarily the forests of the moderate zone form this sink. Forests are an effective filter for air pollution; to a certain degree, they "clean" the air. They protect the soils against erosion. The forests directly serve humanity as a resource for wood and food and they are additionally important for recreation and tourism. Forests possess a great genetic potential, and there is a great diversity of species, particularly in the tropical rainforests. Not least of all, forests have, similar to water (see 1.3), a cultural value. At many latitudes people have developed in coevolution with animal and plant species. This may be one reason why many peoples have an emotional relationship to the forest, which in Germany, for example, is extremely positive (Hampicke, 1991). In Brazil, on the other hand, one finds a rather hostile attitude in places where people no longer live in the rainforest because the forest appears as a threat to a civilised way of life. In other countries with an urban culture, such as Italy or France, a more indifferent attitude towards the forest prevails. In any case, this cultural tradition of the respective country must always be considered in political measures concerning the forest.

The various functions of the forest have been threatened in several ways for some considerable time. Forests are both destroyed and endangered in their stand directly, e.g. through fire clearing or logging, as well as through long-term damage by virtue of environmental pollution. According to a Report of the Enquete Commission of the German Bundestag (1990b), the destruction of the tropical forests has "increased dramatically: in 1980 the annual destruction in closed tropical forests was roughly 75,000 $km^2$ and in open tropical forests approx. 39,000 $km^2$ according to the estimates of the Food and Agricultural Organisation of the United Nations (FAO). According to recent, provisional estimates, the increase in the rate of destruction in relation to 1980 is 90%. This means that, with regard to closed primary forests alone, 142,000 $km^2$ of forest are currently destroyed every year. Up to the year 1980 the tropical forest area had already declined to roughly half its original size. At that time there were still approx. 19.4 million $km^2$ of tropical forests, which covered roughly 13% of the land surface. Today the stand probably comprises, overall, only 18 million $km^2$. By the year 2050 a further decline down to approx. 5 to 8 million $km^2$ is expected. In many countries hardly any forest at all will remain then."

For several years damage of a large magnitude has been observed in the forests of the moderate zones. This forest damage occurs as a result of a complex of factors, including air pollution and climatic influences. This damage can also take place at a great distance from emission sources, in so-called clean-air regions (Dässler, 1991). It is estimated that up to 50% of these forests are damaged. They are impaired in their function as a sink for $CO_2$, depending on the damage.

A more recent development involves large-scale logging in the boreal forests, particularly of Russia and Canada. Thus the taiga, a belt of forest covering over 5 million $km^2$ of eastern Russia, has recently been subject to increasing use, especially by the foreign wood-processing industry. Awarding of rights to foreign companies for large-scale clearing in Russian forests is certainly done, in part, in expectation of medium-term contributions to the development of the respective regions, but particularly serves to provide short-term returns of foreign currency.

## Causes

Since the beginning of the 18th century the world's population has increased eightfold and the average life expectancy has doubled. The international volume of trade has risen by a factor of 800. Agriculture is expanding, power generation and industrial production have increased drastically. Since then, 6 million $km^2$ of the world's forests have been lost (Clark, 1989). This has been accompanied by a significant growth in soil degradation combined with an increase in sediment transported in large river systems. As a result, up to 2 billion tonnes of carbon enter the oceans annually. During the same period the quantity of water removed from the global water cycle annually increased from approx. 100 to 3,600 $km^3$. These trends are continuing today. The rapidly growing population of the tropical countries is penetrating into the jungle in order to earn its living from logging and agriculture.

Damage to *tropical forests* can be attributed to a complex combination of causes. In most tropical countries clearing for the purpose of agricultural use (pasture land, plantations) is the most significant factor. Here one must distinguish between small-scale agriculture, shifting cultivation within the framework of autochthonous subsistence farming methods and agroindustrial land use for the production of agricultural export products (cash crops such as soybeans, corn or coffee, cocoa, rubber) as well as extensive cattle farming. Furthermore, the felling of timber (export, firewood, charcoal), exploitation of mineral resources as well as the carrying out of large-scale industrial and infrastructural projects number among the determinants of damage (FAO, 1988; Enquete Commission, 1990b).

Additional causes of forest destruction in developing countries can be demonstrated using India as an example (Haigh, 1984). In India modernisation efforts represent the starting point for many environmental problems. The deforestation of India began during the period of British rule and continues today as the country endeavours to develop into a "modern state". This requires, among other things, a modern transport system (road construction) and improved water supply (building of dams). The population growth and the resulting land needs have a negative effect on the forest stands of the mountain regions. Deforestation leads to floods in the fluvial plains.

Overall, the fact that the poor members of the population are forced to earn their living in this way, the effects of agricultural overexploitation of whole regions and the industrial extraction of raw materials have led to new forms of landscape changes in many areas whose effects are not yet entirely calculable. The loss of species and a decline in biological productivity seem to be inevitable (Clark, 1989).

Upon closer examination these activities have deeper causes. First of all, there is population pressure. Up to the year 2000 additional needs of 80 million hectares of agricultural land are expected in the developing countries and will probably be met through further changes in the utilisation of forest areas, which is particularly problematic given the unadapted forms of soil cultivation. This development is also connected to the economic underdevelopment of many tropical countries, which very frequently rules out long-term planning and thus ecologically oriented action as well. One must also point out here the international influences, such as import restrictions on the part of the industrialised countries or great debt service burdens.

A more profound analysis of the causes also has to look at the deplorable state of affairs in tropical countries themselves, which, in turn, must not be viewed independently of the above mentioned basic socioeconomic and political conditions. Such factors as unjust distribution of land or lack of land reform, tax systems favouring the destruction of the forest, corruption, uncontrolled migrations or settlement programmes directly connected with forest damage are examples (Enquete Commission, 1990b; World Bank, 1992a).

In the industrial countries of Europe and America (forests of the humid mid-latitudes) forest damage occurs, induced by immissions of air pollutants and soil acidification. Large-scale vegetation damage was caused in the past, in particular by sulphur dioxide ($SO_2$) and nitrogen oxides ($NO_X$); in addition, fluorine and chlorine compounds as well as various dusts influence the vegetation in many cases. The high degree of $SO_2$ pollution was primarily due to the sulphur content of fuels (brown coal, hard coal, oil). Air pollution via $SO_2$, however, was able to be reduced in the Länder of former West Germany by two-thirds through the installation of flue gas desulphurisation units in power stations. Nitrogen deposition predominantly comes from road traffic and agriculture (ammonia from liquid manure basins, large-scale livestock farms). Moreover, ozone ($O_3$), photooxidants and ammonia number among the major gas-type, plant-damaging air pollutants. Acid-forming air pollutants ($SO_2$, $NO_X$) or acids such as HCl and HF lead to acid rain.

A forest ecosystem consists of primary producers (all plants able to carry out photosynthesis), secondary producers (soil organisms and other animals) and destroyers (microorganisms) as well as the abiotic components of the atmosphere, of soils and of water. All components are impaired by air pollutants to a differing degree. Ulrich (1990) summarised the causes of forest damage as well as their magnitude. They include acid stress at the roots, which results in negative effects on the intake of nutrients and water, changes in the branching of trees, premature leaf or needle discoloration as well as the disappearance of the wax layer (cuticula) on needles.

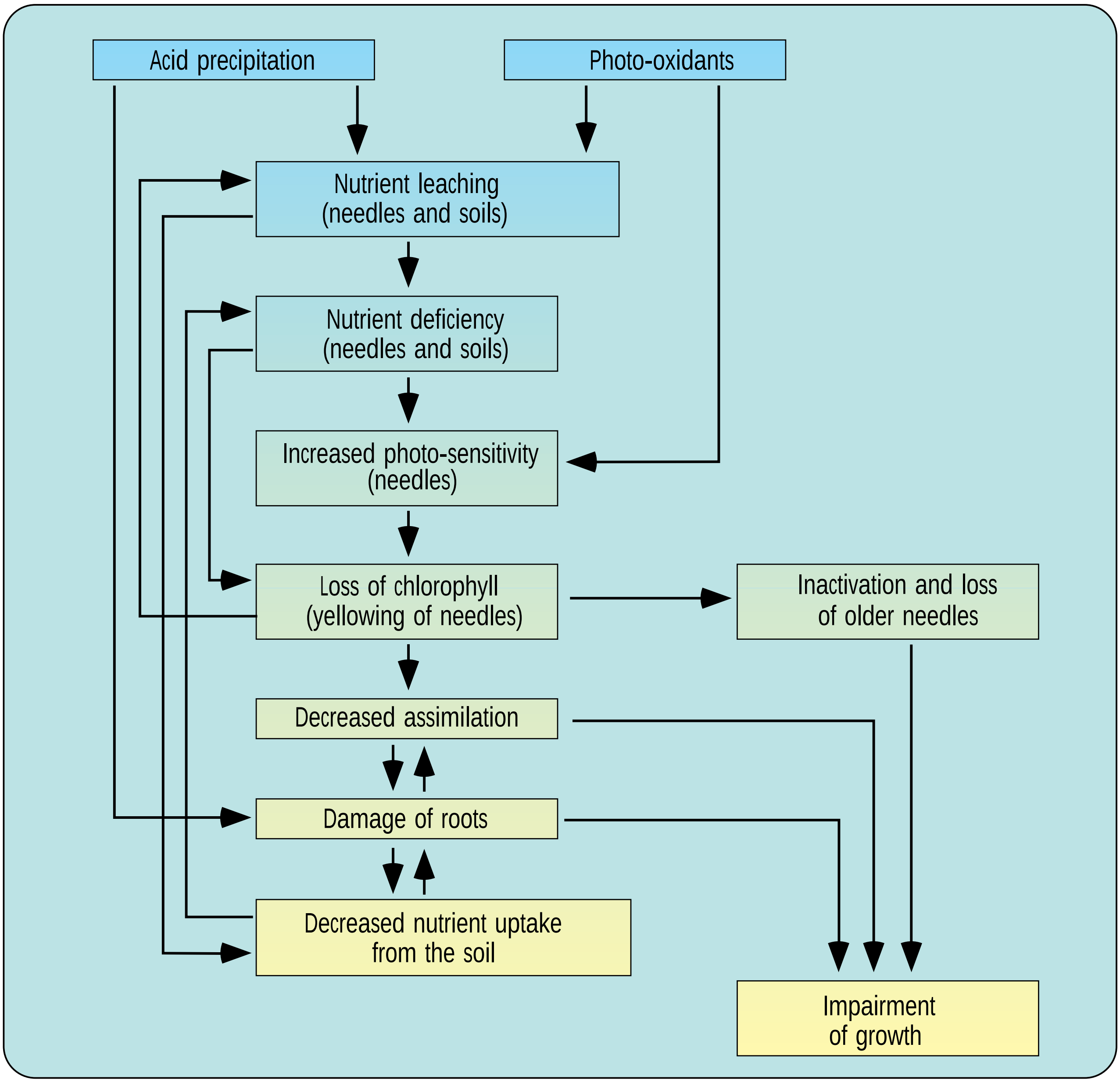
Other authors (Esher, 1992; Rampazzo and Blum, 1992; Chadwick and Hutton, 1990) also attach great importance to the role of acid rain in the occurrence of forest damage; soil acidification causes, among other things, a reduction in mycorrhiza (fungi living in symbiosis with the roots) and a decrease in root growth in European forests. There are different hypotheses for the occurrence of forest damage and its causes and effects (Fig. 10). Nevertheless, the reactions of forest ecosystems to the interaction of harmful factors and climate have not been clarified completely. One difficulty in determining the connections between cause and effect is the often delayed reaction of organisms and biological systems to harmful influences. It will also be necessary in the future to study the dynamics of the processes taking place in the ecosystem and their mutual influences as well as the outward effects.

The *boreal forests* are not so much threatened by immission damage as by large-scale logging. As in tropical forests, the latter leads to loss of the young trees replacing the old ones, thus preventing natural regeneration, as well as to a change in the soil structure (Shugart and Bonan, 1991). Clearing is, moreover, linked to an impairment of additional areas (e.g. infrastructural development of previously untouched regions).

### Effects

From an economic point of view the reductions in quantity and quality of the worldwide forest stands must be interpreted as different types of costs. In many cases, these costs do not currently appear in the economic calculations of private economic subjects and in national budgets (external effects), but they will emerge in the course of time in the form of losses in prosperity or harmful effects on health. In particular, this development involves impairment brought about in the use of the various functions of the forest as well as the related consequential costs: the forest serves human societies directly as a resource (wood, food, gene pool, etc.) or as an asset for consumption (recreation, tourism, cultural

Figure 10: Combined effects of photo-oxidants and acid precipitation on forests *(from Dässler, 1991)*




value). The forest stands also serve important functions for the environmental assets of air (forest as an absorption medium for harmful substances, $CO_2$ sink, climate stabiliser), water (water reservoir) and soils (erosion protection).

## *Biosphere*

The effects on the carbon cycle as well as on the water balance and climate of the Earth can be designated as the most profound consequences of the large-scale clearing of forests. As a result of the burning of organic substance, there is, on the one hand, an increase in the $CO_2$ content of the atmosphere and, on the other hand, the reduced forest area is able to absorb less $CO_2$ from the atmosphere. The equilibrium between carbon assimilation and release, which has evidently remained stable for a long time, is thus disrupted (Plachter, 1991).

Large-scale logging in forests can lead to floods, landslides and soil erosion, as has been observed on the Indian subcontinent. Especially the forests there on the edge of the Himalayas, which have already been significantly decimated, have great importance for regulation of the water cycle in these regions. The reduction of the forests leads to seasonal increases in water runoff. Bangladesh, for example, which is located much further downstream, is particularly hard hit by this effect. This country is additionally threatened by the fact that approx. 50% of its area lies less than 8 m above sea level. In China, too, severe floods and soil erosion can be attributed to the clearing of forests.

Local effects can be perceived relatively well. On deforested areas, for example, a 3 to 6°C higher temperature during the day with greater cooling down at night was measured in comparison to adjacent wooded areas. The global effects of the greenhouse effect on forests as well as possible influences of forest decline on the global climate cannot be predicted precisely. Presumably, however, there is a shift in the climate and vegetation zones towards the poles.

Even slight changes in the $CO_2$ concentration can alter the energy balance of the atmosphere such that feedback effects on the biosphere can be expected. The magnitude of the carbon sources and sinks and the carbon fluxes goes into the global carbon balance. The vegetation in land takes carbon from the atmosphere in the process of photosynthesis and releases it again during respiration. Part of the absorbed carbon is stored in plants (particularly in trees). Also tiny marine algae (phytoplankton) and photosynthesising bacteria turn over large amounts of carbon (Simpson and Botkin, 1992). However, these organisms lack the longevity and storage organs of trees necessary to store carbon for years.

Although it is known that terrestrial vegetation plays an important role in the global carbon cycle, knowledge concerning the size of the reservoir and the flow rates is not yet sufficient. Even with the help of already existing models, it still is not possible to calculate the global carbon balance with adequate precision. Statements on the carbon pool, which plays a significant role in the carbon balance, deviate greatly from one another. In the future it will be necessary to determine the exact figures for the quantities of biomass as a sink and as a source. This requires that the relationship between forests and the atmosphere be studied in detail in order to obtain data on the reaction of the forest stands in various regions. Within the scope of the EUREKA project, EUROTRAC, studies are being conducted on widespread types of coniferous forests (Enders et al., 1992). They are focussing on the influence of important meteorological variables on local sources, the sites of consumption, the flows and thus the balances of different trace gases.

The structure of the vegetation influences the roughness of the Earth’s surface and thus the wind speed, at least regionally. Furthermore, 20% of the water vapour in the Earth’s atmosphere comes from the evapotranspiration of terrestrial systems. In some regions, like the tropics, the high amounts of precipitation can be attributed to local evapotranspiration. A change in evapotranspiration caused by destruction of vegetation influences the quantity and distribution of precipitation, at least at the regional level. Global effects on precipitation, photosynthesis and plant growth are possible (Waring and Schlesinger, 1985).

### *Anthroposphere*

One serious consequence of the deforestation in the anthroposphere is the destruction of the habitats of indigenous population groups. The few still existing cultures, some of which are millennia old, will have died out in 30 years if appropriate measures are not taken. The possibility of sustainable economic use of forests, which, in many cases, is probably superior to the use methods prevailing today, even taking into account efficiency aspects, will also be lost. Further socioeconomic aspects include the increase in social tension due to land use conflicts as well as migration problems (“environmental refugees”).

Forest damage in the moderate zone has negative effects on forestry, water and soils as well as on leisure time and recreation and, not least of all, on the forest as a cultural asset.

## Link to global change

### *Phenomena of the ecosphere*

*Air:* Forest destruction and degradation lead to, among other things, emission of trace gases relevant to the climate and are, accordingly, causes of the additional greenhouse effect; local climate change, in turn, bring about a weakening of, in particular, forest ecosystems of the moderate zone ("climate stress") or their destruction in the event of a too rapid shift of the climate zones.

*Water:* Reduction of amounts of precipitation (prolongation of dry periods); reduction of water storage capacity of soils and vegetation; impairment of the supply of watercourses and of the regulation of the ground water level.

*Soil:* Nutrient leaching; erosion; increase in avalanches and landslides in mountains.

### *Phenomena of the anthroposphere*

*Population:* Population pressure as well as migration and settlement policy as causes of the transformation of forest areas; on the other hand, displacement due to direct consequential damage (like erosion) or forest reduction.

*Economic development:* Poverty as a cause of forest destruction (lack of knowledge, abilities, production methods as well as other preference structure); on the other hand, forest destruction in the long run as a loss of development potential; industrialisation as a cause of forest damage (emission of harmful substances; land consumption in the moderate zones); on the other hand, provision of knowledge (preferences) and potential for action (technical, institutional, pecuniary) concerning forest protection; the objective of "sustainable development".

*Traffic:* Emission of harmful substances as a cause of forest damage in moderate and boreal zones.

*Values:* Greatly diverging assessment of forest benefit depending on cultural group (e.g. notion of "forest as an enemy of humanity" in parts of South America and southern Europe); notion of the "limitlessness" of existing forest stands in Russia and, in some cases, in tropical forests as a cause of excessive use.

*Science and technology:* Adapted agricultural technologies (more space-saving, more efficient) as an instrument of forest protection, particularly in the tropical forest countries.

*Institutions:* On the one hand, existing institutions at the governmental and non-governmental level run forest protection projects (see, for example, individual UNEP programmes); on the other hand, existing institutions, such as in the area of international trade, tend to cause overexploitation of forests; necessity of an international forest convention.

## Assessment

In contrast to the ozone layer or, to a great extent, the world's oceans, the forest is not, from an economic point of view, a "global public asset" in all its functions. For the owner countries, especially to the extent that they are among the economically less developed or newly industrialised countries, focus is often on profits from its short-term utilisation as a consumer and investment good or as a location. This short-term utilisation is frequently connected with damage to the forest substance. The forest, however, is of global importance as a surface carbon reservoir and as the habitat for most species of the Earth because these functions serve all countries of the world. The damage resulting from destruction of forest stands thus first of all affects the owner countries themselves, but is also of a worldwide nature. A conflict between national property rights and global interests is, therefore, characteristic of the entire forest problem.

In this connection, the basis for environmental policy action in industrial and developing countries must be to determine the value of currently practised forms of forest use and their alternatives, including the costs of environmental policy measures. The questions of valuation are analysed more precisely in a later chapter on biodiversity because this example permits one to describe all types of evaluation problems because of its special difficulty. The value of the worldwide forest stand or even of individual forest formations is, therefore, not easy to determine because the forest must also be interpreted, in many respects, as a global public good. Those responsible for forest reduction and those for whom the global role of the forest is important can be found, to a great extent, in different parts of the world and in very different income situations; thus they arrive at entirely different assessments of the problem as well as of the necessity and possibilities for taking action. All of this is additionally complicated by the fact that the consequences virtually make consideration of the high estimation for the forest, also on the part of future generations, unavoidable.

The difficulties of the procedure connected with assessment are shown here based on the example of the reduction of tropical forests by the owner countries in favour of economic use in the strict sense, i.e. as agricultural land or for logging, which, for the purposes of simplicity, is merely compared to the benefits of an intact forest stand in the form of a stable climate for all nations. This requires several steps:

(1) First of all, it is important to determine the advantages of the currently practised method of utilisation. For 40 tropical forest countries studied the results show, on the average, relatively high shares of the gross national product, of export as well as positive employment effects by virtue of the currently practised forms of utilisation. This benefit, however, is usually only of a short-term to medium-term duration. Studies indicate that sustainable use would be more efficient (Amelung and Diehl, 1992).

(2) Furthermore, the valuation of a temperature rise – to the extent that it is triggered by a reduction in tropical forests – is necessary, but far more difficult since a "stable climate" is clearly a global public good. A statement of some sort is possible if a pessimistic scenario is assumed. If rises in temperature take place with regard to extent, distribution and the time dimension in a manner that scarcely permits natural and socioeconomic systems to adjust to them, then the costs of such a development – from an anthropocentric point of view – would be immense. To avoid this, it is necessary to define minimum quality standards in close cooperation with natural scientists.

(3) Finally, the costs of possible environmental policy measures must be taken into account and, after selection of the most advantageous measure, compared to the previously calculated costs of the lack of an environmental policy. Various studies are available concerning the, indeed, very different degrees of efficiency of environmental policy measures. Thus, for example, projects on conservation of the rainforests are evaluated by means of cost-benefit analyses. The necessary transfer calculated on this basis is between 15 and 1,575 ECU per $km^2$ annually. The maintenance of the entire Korup National Park, for example, would first become economically interesting at a minimum inflow of funds of 5.4 million ECU according to such a calculation (Ruitenbeek, 1992). This study, in particular, pursues the goal of providing a basis for donor countries to decide among different projects. Studies on the quantification of selected damage and a comparison with the costs of the measures necessary for its elimination have not yet been published in this connection.

Valuation of forest problems in general can, it seems, not be conducted in a satisfactory way from an economic point of view. Even the apparently easy-to-make judgements on the economic value or "non-value" of the use of the forest by the tropical forest countries themselves cannot result in operable statements through arithmetic calculation; for environmental policy action must take into account, especially at the international level, a number of significant non-economic circumstances as well as some economic factors, which can hardly be operationalised. The necessary consideration of the already largely concluded extensive reduction of forests and the transformation of the remaining stands into ecosystems in industrial countries that are entirely anthropogenically influenced, the recognition of the political sovereignty of the owner countries as well as the development of the world's population indicate further limits of an economic analysis. However, it can be shown that, when taking into account costs that have been externalised up to now, the present type of use can be more expensive for nations overall than the implementation of environmental policy protective measures. In this case, certain transfers from other states to the tropical forest countries furnishing ecological services are not to be interpreted as a measure motivated by development policy but as a compensation for services rendered.

## Need for action

Extensive conservation of the worldwide stand of forests (as an equilibrium between losses and gains) and checking of degradation are required from an objective point of view. In many regions reafforestation, to the extent that it is still possible, is also necessary. If priorities are to be set, then a stopping of further direct interventions in the ecosystems of tropical forests would stand at the top of the list because of its great significance for the entire world community. However, reference must be made to the not yet calculable development in boreal zones, which currently represents a great risk factor. Although the northern forests are less important for climate development, an immediate stop of large-scale deforestation in these areas is just as pressing as in the tropical forests. From an ecological and economic point of view, extensive conservation of the stand of forests at mid-latitudes is also to be striven for as an initial step while a return to more natural forms coupled with the application of sustainable use systems should be aimed at in the long run.

A forest convention with binding measures was not reached at the UNCED in Rio de Janeiro. This is regrettable, even for economic reasons, because only through such an agreement would it be possible to tackle global forest problems in the most cost-effective manner for the entire community of nations. Due to the obvious differences, particularly between industrial and developing countries (such as Brazil, Malaysia), this agreement cannot be expected in the medium term. Efforts should, however, continue to focus on a convention since it would also make solutions possible at lower levels. Until an agreement is reached on a joint forest convention, numerous steps can be taken at the bilateral and multilateral level with the participation of Germany. We refer to the great number of institutions and initiatives that were set up prior to UNCED. They include the international Tropical Forestry Action Plan (TFAP), measures taken by the FAO, UNEP, UNESCO as well as initiatives of non-governmental organisations, in connection with which the German commitment can be positively emphasised on the basis of an international comparison (Enquete Commission, 1990b). The measures taken up to now, however, do not match up to the significance of the problem. Despite all the advantages of decentralised, economically motivated agreements, there is a necessity for a more effective and more rapidly implemented solution within the scope of a binding forest convention according to international law as increasing international consensus is reached on the global importance (uniqueness of the ecosystem; irreversibility of destruction) and thus on the need to protect forests. This requires accordance with the Climate Convention as well as with the aims of economic development.

Regarding the political feasibility, the simplest measures to be taken from the point of view of the countries concerned are those that do not require financial expenditures on the part of the governments and make a contribution to economic development as well as to environmental protection. Examples include the elimination of subsidies for forestry and livestock farming or securing land rights for farmers. Furthermore, there are public investments having a positive effect both on the environment and on the economy, such as expenditures for soil conservation or education. In this connection, the spread of adapted agricultural technologies enabling more intensive and sustainable use of existing areas is an important measure. Only then will cost-intensive environmental protection measures follow, i.e. those that solely compensate for the failure of the market; instruments in this category would include, for example, the increased designation of nature reserves or the imposition of fees for logging (World Bank, 1992a).

There is also need for action concerning the forests in the moderate zones. Although the output of sulphur dioxide was drastically lowered through suitable measures, there still has not been a decline in nitrogen monoxide and ammonia. Suitable concepts for the areas of transport and agriculture still have to be developed (see 1.1 and 2.3).

### *Measures at the international level*

- Continue immediate programme for the protection of the tropical forests (in accordance with the Enquete Commission),
- strive for international convention for the protection of the tropical forests (including financing and sanction mechanisms), in particular by Germany. The monies should be collected in a special fund for this purpose because linking the purpose to the tropical forest, which is also highly esteemed in the donor countries, facilitates the raising of funds,
- reinforcement and expansion of programmes and institutions within the UN for protection of the tropical forests:
  - United Nations Environmental Programme (UNEP)
  - Food and Agriculture Organisation of the United Nations (FAO)
  - United Nations Educational, Scientific and Cultural Organisation (UNESCO)
- within GATT: negotiations on the introduction of socially and environmentally sound minimum standards (see Enquete Commission),

- expansion of financing concepts compensating the environmental services rendered by the developing countries to the world community,
- international efforts to eliminate debt problems,
- transformation of the existing tropical forest action programme into tropical forest protection plans since the previous regulations are more oriented to use and less to protection.

### *Measures at the national level*

- *In principle all countries:*
  - creation or reinforcement of the possible methods for planning, valuation and systematic observation of forests
  - greening of fallow land by means of forest renewal, afforestation and other restoration measures.
- *especially tropical forest countries:*
  - designation of more nature reserves (overall protection of primary forest)
  - elimination of subsidies for forestry and livestock farming
  - securing land rights for farmers
  - investments in soil conservation and in training (e.g. spread of adapted agricultural technologies)
  - levying of fees for logging.
- *especially for countries with boreal forests:*
  - setting up a forest inventory and a systematic survey of damage
  - development of long-term, sensible forest use systems.
- *special contribution of the Federal Republic of Germany:*
  - provision of capital, knowledge and technology for the protection of the forests
  - easing of debt burden for tropical forest countries
  - consideration of environmental compatibility of international trade
  - afforestation in Germany to an extent still to be clarified.

**Box 10: Historical development of political action with regard to the forests**

| | *national* | *international* |
|---|---|---|
| 1) Charter, convention | | at UNCED, Rio, only *Principles* on World's Forests |
| 2) Protocol | | open |
| 3) Legal texts | | open |
| 4) Instruments | e.g. sustainable management, protected zones | e.g. compensation solutions |
| 5) Financial framework | DM 300 million Brazil programme not implemented; then directed via World Bank | estimated figures in AGENDA 21 |
| 6) Implementation | | open |

## Box 11: Follow-up issues of the UN Conference an Environment and Development for the forests

A.
- Preservation of the various tasks and functions of all forests,
- reinforcement of institutional and personnel capacities for management, conservation and development of forests as well as for their sustainable use and production of forest products,
- setting up and maintenance of a detailed information system on existing forest areas and those to be reforested as well as on their use, taking into account demographic and socioeconomic aspects.

Cost estimate: US$ 2.5 billion per year (1993 – 2000)

B.
- Increase of the protection, sustainable management and conservation of all forests as well as the greening of fallow land by means of forest renewal, afforestation and other restoration measures,
- setting up of programmes for the conservation and expansion of wooded areas with respect to their ecological compensation function as well as their contribution to the needs and well-being of humanity,
- use of the protective function of the forest through afforestation in mountains, highlands, fallow areas, in arid and semiarid areas and coastal regions, particularly to prevent erosion and desertification as well as to improve its function as a carbon reservoir and sink,
- improvement of the protection of the forests against air pollution, fire, diseases, pests and other anthropogenic influences, such as introduction of non-indigenous species of plants and animals,
- support of developing countries in the protection of their forest resources through limitation of the consumption of tropical wood, improvement in energy supply and creation of other ways of obtaining income.

Cost estimate: US$ 10 billion per year (1993 – 2000)

C.
- Stocktaking in order to be able to evaluate completely goods and services through use of the forests,
- improvement of the methods for including the forest in national costing systems,
- development of methods for multifunctional use of different types of forest with regard to wood and other forest products, touristic use and ecological functions of the forest,
- support of developing countries in the conservation and restoration of their forests as a sustainable economic basis and in the development of suitable technologies for further processing of wood and other forest products into marketable products.

Cost estimate: US$ 18 billion per year (1993 – 2000)

D.
- Creation or reinforcement of methods for planning, evaluation and systematic observation of the forests as well as appropriate programmes, projects and activities, including trade and production,
- introduction or improvement of systems for recording the state of and changes in forest areas as well as for assessing influences of certain measures on the environment, social and economic development,
- support of developing countries in the setting up of institutions and the introduction of methods for long-term planning with respect to effective conservation, management, restoration and sustainable development of their forest stands.

Cost estimate: US$ 750 million per year (1993 – 2000)

### Research needs

- Interaction of all causal factors, distinguished according to tropical forest and new types of forest damage; analysis based on natural sciences and socioeconomic aspects and coordinated to one another in each case.
- Further studies on possible ways of implementing sustainable forest use in the tropic forests, the forests of the moderate zones and the boreal forests. Examination of the economic efficiency of sustainable forestry.
- Examination of the possibility, necessity and extent of afforestation programmes in the various forest zones, including in Germany.
- Role of the boreal forests in the biogeochemical cycles of the Earth and as a regional climate-stabilising factor (e.g. influence on wind by virtue of surface roughness).
- Interaction between forest ecosystems and $CO_2$ concentrations in the atmosphere (role of forests as carbon sink).
- Interaction between biodiversity and stability in forest ecosystems.
- Studies on implementability of political measures with the aim of reaching an agreement on a forest convention, in particular according to the experience of UNCED.
- Analysis of connection between forest protection and economic development, distinguished according to forest zones.
- Analysis of individual types of measures of an economic nature against forest reduction.
- Development of economic valuation methods that include economic as well as environmentally and socially tolerable aspects.

## 1.5.2 Loss of biodiversity

### Brief description

Two of the most important global environmental changes, climate change and the destruction of habitats of individual species or entire biocoenoses, will have considerable effects on biodiversity. “Biodiversity” refers to the number and variability of living organisms both within a species and between species and ecosystems. The term “species diversity” in the stricter sense encompasses the number of species both within a certain biocoenosis and worldwide, but it is frequently used as a synonym for biodiversity. The latter forms the basis for biological resources, which comprise genetic resources, organisms – or parts of them – as well as populations having an actual or potential value for human societies.

The precise number of species existing on the Earth is not known. Estimates by biologists vary between 5 and 30 million, though only 1.4 million species have currently been described. This incomplete information base does not permit an exact statement of the number of endangered or already extincted species; many species become extinct even before they become known. More recent analyses of the tropical forests, which represent the largest reservoir of biodiversity, come to the conclusion that, given the current rate of habitat destruction, 17% to 35% of the species in the tropical forests will be threatened with extinction by the year 2040. This corresponds to 20 to 75 species per day if one assumes a total of 10 million species worldwide. If nothing decisive changes, it is expected that 1.5 million species will become extinct in the next 25 years.

In addition to the tropical forests mentioned, the forests of the moderate zones, the habitats of the subtropics that are wet in winter (southern Europe, North Africa, the Cape region of South Africa and certain regions of California) and islands number among the most important habitats.

The classification of the species of marine ecosystems is far more incomplete than that of the terrestrial ecosystems. Its abundance of species must not be underestimated. Coral reefs are, like the rainforests, known for their great diversity of species. This also applies to the deep sea, as more recent studies indicate (WRI, 1992b).

In general, the moderate latitudes have large populations but less diversity of species while tropical regions are characterised by a large abundance of species and small population sizes. Accordingly, the greatest diversity of species can be found in Central and South America and Southeast Asia, i.e. where the largest portion of the rainforests is indigenous. Northern countries, such as Canada, Norway, Sweden, Finland and Russia, as well as southern countries, such as Argentina and Chile, are characterised by comparatively little diversity of species (WRI, 1992b).

What significance do biodiversity and the loss of species have for the biosphere and, in particular, for humanity? The loss of species has many dimensions. The ethical aspects include the question as to whether people have the right to intervene in Creation to such a drastic degree and to eliminate species of plants and animals on Earth. There are aesthetic and cultural reasons to conserve species or entire landscapes that are unique. Reference is made in this context to the representation of plants and animals in religion, art, architecture and fashion or as a symbol of power as well as to the significance of biodiversity for recreation and tourism. Furthermore, people use wild species as the genetic basis for the development of pharmaceutics as well as for plant and animal breeding. Interbreeding cultivated with wild forms is decisive for resistance and thus for the productivity of cultivated species, which, in turn, represent the food basis for humanity. Moreover, there are a great number of other plant raw materials. Finally we would like to point out the scientific benefits of the diversity of species; many species that have not yet been described may possess biological features which help to further promote an understanding of nature.

A more indirect, but extremely great benefit is provided to humanity by ecosystem stability, which is closely linked to biodiversity. Intact ecosystems represent the basis for drinking water supply, regeneration of soils, prevention of air pollution and regulation of the climate at the local and regional level (Solbrig, 1991; Hampicke, 1991).

To ensure the highest possible degree of quantity and quality of renewable natural resources for the present and the future, resources must be utilised on a sustainable basis. This means that the right relationship must be found between resource use, on the one hand, and regeneration of forests, savannas, grassland and other ecosystems, on the other.

Biodiversity is threatened by great dangers stemming from changes in land use. To obtain land to be used for agricultural purposes and improve the infrastructure, large sections of the tropical rainforest and thus many, also unknown, species are destroyed. In the industrial countries species are threatened, above all, by fragmentation of the landscape, caused by its urban sprawl and expansion of the traffic network, as well as by overuse of natural resources and increasing environmental pollution. To effectively counter further deterioration of nature and the basis of human life, it is not only necessary to protect individual species currently threatened with extinction; rather, the plant and animal stock in its habitat must be preserved. This will require great efforts within a national and international framework to make well-founded scientific statements on the role and protection of biodiversity as well as to make these statements the basis of political and economic action.

## Causes

The search for measures to protect biodiversity requires, first of all, an analysis of the causes of the threat to or extinction of species. The following complexes of causes can be defined as those that actually or potentially contribute to the destruction of species:

- destruction or fragmentation of the habitats of species or biocoenoses,
- destruction or displacement of species by depositions of harmful substances in the air, water and soils,
- losses of species through *anthropogenic interventions* which cannot be compensated for by the natural reproduction of the ecosystem,
- bringing species into other habitats, in which they destroy the ecological equilibrium.

According to available estimates, less than 0.1% of the species existing in nature are utilised directly by humans (Perrings et al., 1992). Public discussion is always ignited by the extinction of individual plants and animals, particularly if “popular” animals, such as elephants, whales, panda bears or seals, are concerned; the threat to diversity of species, however, stems less from direct use of individual species, but primarily from the destruction of habitats. Human activities, such as changes in land use, urbanisation, infrastructural development and industrialisation, lead directly to the destruction of habitats; they are indirectly damaged by utilisation and exploitation of environmental resources as well as the discharge of harmful substances into the air, water, and soils. Consequently, emission restriction measures also serve the purpose of species protection.

Structure and function of ecosystems are maintained through feedbacks between organisms and their environment. The abiotic environment influences the growth and development of biological subsystems, which, in turn, actively modify their environment. Species and environment are incorporated in a network of interactions. The driving force for almost each of these systems is solar energy, which acts on the systems and thus provides for the flow of energy and matter necessary for self-organisation and self-preservation in the system. It is this capability of self-organisation that keeps the entire system functioning after stress. The internal biogeochemical cycle is irreversibly impaired in an ecosystem subject to excessive stress; the system can then no longer regenerate itself.

All self-organising ecological systems require a minimum of biodiversity to absorb solar energy and set up a cyclical relation between producers, consumers and destroyers (decomposing organisms). If this minimum is not reached, the ecosystem can no longer function and collapses. Lack of clarity still prevails, however, with regard to the minimum number of species that is necessary to maintain the stability of the respective ecosystem.

Direct human damage of ecosystems includes the fire clearing customary in the tropics, which destroys large portions of the rainforest. Rapid degradation and erosion of the soils results. The intensification of agriculture in industrial countries has many effects: enlargement of clearing areas (with corresponding danger of erosion), increased use of fertilisers (loss of species with little nutrient needs, eutrophication of water bodies, disruption of equilibrium in aquatic systems) and pesticides (pollution of ground water, water bodies and aquatic ecosystems) as well as cultivation respectively keeping of a low number of highly productive species and varieties of useful plants and animals (decline in the diversity of cultivated species and types; monocultures). The diversity of vegetation species in the ecosystem plays an especially important role since they form a significant element of the habitat for the fauna.

The adaptation of different species to altered environmental conditions will depend on their genetic and physiological tolerance to stresses, their ability to spread and their dependence on the habitat. Animal species which are specialised in very specific types of vegetation, for example, are more endangered than less specialised species.

The phenomena mentioned up to now are not the actual driving forces behind the loss of biodiversity. The discussion of the functions of biodiversity has made it plain that the entire international community of nations derives benefits from this resource and is affected accordingly by the damage related to a reduction in the diversity of species. Biodiversity is, therefore, a “global public asset” that is increasingly deteriorating. The question that must be asked then is: Why is biodiversity frequently evaluated differently from a national point of view than from a global point of view? Or to put it differently: Why does a conflict arise between national and global interests? Various forms of failure on the part of the market and state can be identified in this context, and they will be briefly outlined below.

Of the previously mentioned functions of biodiversity, at least two types of benefits accruing to the entire world community can be filtered out: first of all, the diversity of species furnishes information, such as for the development of new medicines, and secondly it provides security, for example, through the possibility of increasing the resistance of cultivated plants by interbreeding them with natural species or subspecies. The maintenance of biodiversity, in this sense, represents a kind of insurance against potential future risks, such as in the form of diseases or lack of resistance to pests. Although these functions are of value to humanity, there are no market mechanisms that permit owners of the species or the discoverers of the resource to benefit from these values. Rather, they have been, up to now, assets whose utilisation is open to every individual or country, without the need for articulation of demand on the market or for payment of a price. Therefore, there is a lack of sufficient incentives to conserve the resource of biodiversity and ensure its efficient utilisation (*failure of the market*) (Swanson, 1992).

This problem is further aggravated by state intervention, such as in the form of subsidies. The most greatly subsidised sector, both in most industrial countries as well as in the majority of developing countries, is that of agriculture and forestry. Examples are the agricultural policy of the EU and subsidies to forestry in Brazil, which distort the price relations to the disadvantage of species protection: the private costs of overuse of species or ecosystems drop and the incentives to expand and intensify agriculture and forestry increase. The market mechanism is thus deliberately put out of action (*government failure*); it could become effective again through elimination of these subsidies.

For many areas of nature no individual property rights have been stipulated, or they are not enforced. This applies to individual species, land areas, watercourses, etc. The inadequate definition and allocation of property rights is responsible for the fact that no one can be excluded from the use of nature. In this situation, as a rule, it is not the individuals and enterprises whose existence depends on sustainable use of the resource or who want nature to be protected that are able to assert themselves, but those who strive for short-term maximisation of benefits or profits without regard to the above aspects (WRI, 1992b). It can be said, therefore, that the cumulative effect of both market and political failure is a cause of the continuing destruction of species.

### Link to global change

Pollution of the environmental assets of air, water and soils is a cause of the worldwide loss of biodiversity. The change in the climate can have an influence on the abundance of species; possibly only intact ecosystems can adapt to climate change. The destabilisation and loss of ecosystems may have negative effects on other environmental assets, such as in the form of additional release of $CO_2$. Consequently, measures for the protection of other environmental assets may also serve to protect species and vice-versa. For example, forest protection benefits the protection of species when afforestation provides for mixed forests.

Population growth and the related increase in demand for natural resources affects biodiversity in two ways: on the one hand, the pressure on transformation of natural biotopes is increased, for example, for agricultural or infrastructural purposes and, on the other hand, the emission of harmful substances tends to rise. These trends can be countered by stabilising the population, through more efficient use of resources, by increasing the recycling rate and via emission control. For land cultivation or rural development strategies must be developed that consistently reduce the pressure on natural resources.

### Assessment

The effects of a reduction in biodiversity on the biosphere and anthroposphere result, necessarily, from the already mentioned functions of biodiversity (or its restriction by virtue of losses in diversity). The extent of these effects cannot be determined until biodiversity as an asset has been evaluated in one form or another.

This evaluation of biodiversity represents a central step prior to a formulation of objectives, working up of political measures and their implementation. The area of “biodiversity” along with other global environmental problems has to be added to the already existing environmental problems at the national level. Tackling all environmental problems with the same intensity at the same time would not be feasible and is, moreover, not efficient. Rather, it is necessary to consider the significance of the various political areas in comparison to one another as well as to set focal points within the problem areas.

**Box 12: Procedures and problems with regard to an economic assessment of biological diversity**

An *economic* valuation of the resource of “biodiversity” is based on a *utilitarian, anthropocentric* and *instrumentalist* point of view: utilitarian because it is assumed that a species only has a value if humanity derives a benefit from it; anthropocentric because people determine the value of the species; and instrumentalist because plants and animals are regarded as instruments for satisfying human needs. The assessment is, therefore, based on the preferences of individuals (Randall, 1992). However, the value of “biodiversity” as a resource for humanity is not as obvious as, for example, the value of clean air or clean water. In addition, as the analysis of the causes has shown, a market valuation of biodiversity is currently incomplete and faulty.

Fundamentally, one can make use of a cost-benefit analysis to evaluate “biodiversity” as a resource. If, for example, one must consider whether the conservation of a biotope or, instead of that, intensive use as agricultural land is more advantageous, the benefits of biotope conservation have to be compared with those of agricultural use. According to the cost-benefit principle, the project with the greatest net present (discounted) value is considered to be the optimum (efficient) one.

The total value of biodiversity can be determined by adding the value of the actual use, the expected future benefit (option value) and the value of existence (existence value). The actual use results, for example, from the use of a species as the basis for the development of pharmaceutical products or plant breeding. Option values express the willingness of individuals to pay, which results from the fact that present and/or future generations will possibly draw benefits from biodiversity. Existence values are based on the fact that the knowledge of the existence of intact ecosystems or species may represent a form of satisfaction for individuals. The value, therefore, exists fully independent of any direct or indirect use (Randall, 1992). The recording of this total value thus also encompasses the mentioned cultural and aesthetic values.

However, apart from the known difficulties of any cost-benefit analysis, this approach results in several basic problems which are specific for an assessment of biodiversity.

The first point to be clarified is the degree of aggregation on which the valuation is to be based. On the one hand, it would be desirable to submit a priority list to politicians with the contribution that each individual species makes to the abstract variable of “diversity of species”. The little knowledge available on the complex biological and ecological interrelations, however, currently represents a considerable obstacle for such an approach. Even in rather easy-to-understand ecosystems, ecologists are not able to indicate all interrelations (Norton, 1987, 1992). On the other hand, an assessment of biodiversity overall does not necessarily serve as a basis for making decisions; its value is infinite since the destruction of all non-human life would also mean the extinction of human life. Rather, the question to be answered is that of the loss in value that results if a small part of biodiversity is lost here and a larger portion there (Randall, 1992).

The valuation would have to record the current and future benefit of species as completely as possible. It is quite difficult to assess what benefit the already known species might provide, and the potential for uncertainty is further increased by the large number of unknown species. In addition, the preferences of future generations are unknown. If, for example, the preference for the enjoyment of untouched nature increases, which can be presumed to occur with increasing income, then the losses in welfare tied to destruction today are far higher than is currently assumed (Hampicke, 1992a). Besides the uncertainty of future benefits, a valuation is made difficult by the irreversibility of the extinction of species. Decisions made today can not be reversed; the decision to dispense with a potential future benefit of species is final and thus not only affects the present but all future generations as well (Arrow and Fischer, 1974; Bishop, 1978).

To eliminate uncertainty and avoid irreversibility, an attempt should be made to record the option values in the assessment. Uncertainty and irreversibility suggest that payment should be made for the preservation of “biodiversity” even if it is not utilised at present but the option of falling back on the asset in the event of need is kept open. Although it is generally agreed that an option value should be taken into account for reasons of prudence, the value to be set for this potential benefit is still unclear (Hampicke, 1991).

Important uses of biodiversity have, as mentioned, the nature of a global public good, which is why market pricing is not carried out. The valuation methods for goods that are not subject to market pricing can be divided into two groups: the so-called “indirect methods for recording preferences” are based on the fact that “nature” can often only be used in conjunction with complementary private goods (for which there are market prices). The “travel cost approach”, for example, is based on the private asset of “transport”: the demand function for a commodity is derived from the varying travelling costs, depending on the distance to a biotope. According to the “direct method”, on the other hand, the focus is on how much an individual is willing to pay for a concrete protective measure or how high the compensation must be in the event of destruction of a species or ecosystem. The primary advantage of the direct valuation methods lies in their broad applicability. Accordingly, the studies conducted up to now have centred on determination of the willingness to pay for conservation of individual species (e.g. the grizzly bear), entire ecosystems and even for stopping the extinction of any species. Fundamentally, it is also possible to record option values with this method (Hampicke, 1991).

The willingness to pay, however, depends very decisively on the information status. Faulty information and any form of uncertainty regarding current and future benefit are directly reflected in the willingness to pay. Moreover, it can be expected that the latter deviates greatly in the industrial and developing countries. The willingness to pay in the industrial countries for nature conservation can merely be regarded as the willingness to finance measures for the protection of species in developing countries, but not as an indicator of an average worldwide appreciation. A great deal is still open here with regard to methodology and content.

Further problems arise in connection with the recording of the current benefits of the diversity of species: many biological resources are consumed without market transactions. This applies, for example, to food, firewood and medicine which are taken directly from biotopes by the indigenous population. To what extent are they consumed and what value should be set for these goods? Even though the recording of these benefits poses problems, they should not be ignored in a complete valuation of the protection of species (Swanson, 1992).

Despite or for the very reason of the above mentioned valuation problems, the demand for the most complete recording and consideration of the short-term, long-term, monetary and non-monetary benefits of biodiversity possible is one of the most important elements of an effective policy for protection of species.

Measuring the benefit of a species in an individual case is, therefore, connected with substantial difficulties. Another method for making political decisions, therefore, defines the *safe minimum standard* as the yardstick for the protection of species. The starting point of this approach is the idea that society should choose the strategy which minimises the possible losses in welfare. Since the future benefit of conservation of the biodiversity may be very high while the decision for extinction of a species is, however, irreversible, the following decision-making rule has been formulated: minimum protection is to be guaranteed to the extent that the current social costs of conservation, i.e. the loss in benefit to the society due to dispensing with exploitation of the resource, are not unacceptably high (Ciriacy-Wantrup, 1968; Bishop, 1978; Randall, 1992). To put it another way: How much is lost in other areas that are important for humanity if a safe minimum standard of protection for species is maintained? Since it can be assumed that every species has a positive value, the problems related to a systematic recording of benefits are avoided and, at the same time, those who want to exploit the natural resource or prefer the use alternative resulting in destruction of species will be given the burden of proof.

Thus – as within the framework of the cost-benefit analysis – there is the question of the costs related to species protection. They generally correspond to the lost benefits from an activity resulting in species extinction, i.e. the value of the products from intensive agricultural use, for example. Since this frequently involves private goods, such as grain, i.e. there are market prices, valuation of the costs of species protection appears to be unproblematic. As already stated, however, agricultural and forestry production is subsidised through prices kept artificially high (e.g. EU agricultural policy), the prices consequently do not reflect the actual scarcity of these goods: the products should be cheaper. As a result, agricultural and forestry areas are artificially made more expensive and thus the costs of species protection appear higher than they actually are. In a concrete case, an activity that results in species extinction might not be justified at all from an economic point of view because of its obvious unprofitability, such as if a dam or canal can never recover its construction and operating costs.

From these considerations on the valuation of biodiversity the following conclusions can be drawn (Hampicke, 1992a): not only theoretical considerations, but also empirical studies suggest that the benefits of species protection have been underestimated and, at the same time, the costs overestimated up to now. With the help of correct economic valuation, i.e. not only those that record the easily quantifiable, short-term benefits and costs of species protection, it can be verified that species protection often represents the more efficient, i.e. economically sound, alternative for use and thus may lead to gains in welfare for the entire economy.

The approaches of “cost-benefit analysis” and “*safe minimum standard*” are not be viewed as competing, but as complementary concepts. The preservation of the diversity of species is carried out in view of the uncertainty of future benefits and the irreversibility of extinction in the service of intergenerational justice. Providing for the future, however, is only conceivable by means of guaranteeing a certain minimum standard of protection. This limit represents a collective safety barrier which must not be overstepped, even if this means doing it without individual economic advantages.

## Need for action

Since the diversity of species is not equally distributed throughout all regions of the world, one cannot ignore, with regard to the extent of damage, the question of where this environmental asset is endangered – in contrast to the atmosphere, for example. Consequently, the package of measures to be taken by the international community of states must be aimed at those regions in which diversity is particularly pronounced and, at the same time, endangered. Such a setting of priorities ensures that the expenditures for species protection yield high net returns (marginal returns). There is extensive agreement that the developing countries should receive high priority because the tropical ecosystems, especially the rainforest, are among the richest in species. If, in view of this background, however, politicians in the industrial countries urge developing countries to push forward with species protection, then this is inconsistent: it is an appeal not to repeat the mistakes of the industrial countries in dealing with nature, which, however, are possibly a result of their development success. Such appeals will be rejected by the developing countries as eco-imperialism unless their credibility is enhanced through financial support. If the developing countries conserve natural resources of global importance, the industrial countries must also be willing to pay for that. This is all the more imperative in that several of the countries with the richest biodiversity are, at the same time, the poorest in the world (World Bank, 1992a).

Up to now international conventions on species protection have covered – while supplementing one another – individual areas of species protection and stipulated the instruments for achieving the objectives in each case. They include the 1973 "Convention on the International Trade in Endangered Species of Wild Fauna and Flora" (CITES) and the "Convention on the Conservation of Migratory Species of Wild Animals" (1979). The Framework Convention on Biological Diversity signed within the framework of UNCED in 1992 is currently the most important basis for this area. In view of the background of existing agreements, this convention can be regarded as a "Framework Convention" for many species protection agreements as well. If species protection can, to a great extent, only be carried out effectively via biotope protection, then some of the international agreements that have hardly been implemented up to now due to lack of a financing arrangement might be filled with new life, not least of all because concrete financing regulations are provided for in this convention.

Article 8 of the Framework Convention on Biological Diversity demands protection of the natural habitats (*"in-situ protection"*), e.g. designation of nature reserves. A traditional protective measure of the industrial countries, which was also used later by the developing countries, is the setting up of *national parks* and *reserves*, from which human activities are more or less banned. These areas were typically set up to protect "popular" species, such as elephants, tigers or bears, or "spectacular" geological formations and recreational areas. Up to recently, however, few of these areas were explicitly set up for the protection of biodiversity. In their present structure nature reserves can merely provide minimal protection: in any case, it has not been possible to prevent the continuing extinction of species with this measure. A number of problems stand in the way of a greater contribution to species protection by means of this instrument.

Thus the delimitation of the reserves usually follows political rather than ecological guidelines. In addition, many parks are too small to be able to effectively protect intact biotopes or individual species; animals, for instance, must look for food in non-protected areas or human activities outside of the reserves have an effect inside of them so that the actually untouched area is further diminished. Frequently conflicts arise between local and national interests if the benefit of the protective measures falls within the responsibility of the government or certain enterprises while the indigenous population has to bear the costs in the form of restricted utilisation. Finally, many nature parks suffer from ineffective management and insufficient financial endowment (WRI, 1992b).

*Biosphere reserves* are an example of the new generation of conservation techniques. They are based on concentric areas for different uses: theoretically the "core zone" receives total protection, which completely excludes human activities. The "core zone" is surrounded by a "buffer zone", in which certain settlements and also resource use are permitted. This zone is, in turn, contained within a so-called "*transition area*" in which sustainable development activities are allowed.

Since the first biosphere reserves were set up by the UNESCO *"Man and the Biosphere Programme"* (MAB) in 1976, their number in the world has risen to roughly 300 today. In practice, however, these reserves frequently came into being by renaming previous national parks or nature reserves, without any real change in their area, functions or the provisions for use. Moreover, in rare cases was a suitable management set up which was able to make the zone system function and which had the authority to enforce the corresponding regulations (WRI, 1992b). The ability to migrate, i.e.

to escape from drastic regional environmental changes, plays an important role for the ability of species to survive. When reserves are planned, therefore, provision should be made for the creation of so-called “corridors” that foster the survival of entire biocoenoses through support of migration.

In principle, biosphere reserves combine the idea of species protection and nature conservation with that of sustainable development. Their number should, therefore, continue to be increased and support expanded. Protective measures in the form of reserves, however, remain ineffective in the long run unless action is taken to reduce the overall pressure on nature reserves and natural habitats. This includes measures which increase agricultural productivity and thus decrease the necessity of area expansion and promote sustainable management of the forests and development of ecological tourism. These measures promise “double benefit” since they both serve the purpose of species protection and promote economic development. In this way their chances of implementation are increased significantly (World Bank, 1992a).

As a supplementary species protection measure, Article 9 of the Framework Convention on Biological Diversity provides for the so-called *ex-situ conservation* of plant and animal species, i.e. their conservation outside of their natural biotopes in aquariums, zoological and botanical gardens or gene banks. Since the 70s a large number of these institutions have been carrying out systematic collection of rare and endangered species, which can be returned to nature after securing or restoring their biotopes.

Ex-situ conservation often offers the last chance of saving a few highly endangered species from final extinction. For different reasons, however, it must by no means be viewed as a substitute for in-situ protection, i.e. the protection of plants and animals in their natural habitat. Time pressure poses one problem. The existing financial, personnel and logistical capacities do not permit one to save the large number of species that is currently endangered. Nevertheless, this obstacle could still be reduced by ample expansion of capacities. The most significant limitation of this strategy, however, is inevitably found in the standstill of the process of evolution. Natural selection and adaptation in a changing environment cannot be simulated and the complex interrelations between coevolution and mutation cannot be preserved in an artificial environment – insofar as they are known at all – because the populations are too small. Thus with the increasing duration of ex-situ conservation there is a greater danger that it will become impossible to return the species to their natural habitats and that species will continue to depend on human support for their future existence. Returning species to nature is, however, the very objective of every ex-situ project. Protection and restoration of the natural habitats must, therefore, be given priority (Weisser et al., 1991).

According to Article 10 of the Convention, the use of biodiversity should be sustainable and environmentally sound and included in all internal national decision-making processes. It is urgently necessary, therefore, to examine all economic policy measures at the national level in order to determine whether they promote the loss of biodiversity. They include agricultural policy measures that promote the massive use of pesticides, herbicides and fertilisers as well as the planting of monocultures and also subsidies for the transformation of natural biotopes into agricultural land and for deforestation. As long as such incentives direct the behaviour of individuals, the efficiency of global measures, including possible compensation payments to the developing countries, remains substantially restricted; scarce funds are wasted in some cases.

This makes it evident that national policy areas in the individual countries have to be better coordinated. Species protection must be integrated into national policy. Agricultural and forestry policy as well as regional planning and development aid policy must not be carried out in isolated fashion so as not to work against species protection policy.

Article 16 of the Convention provides for technology transfer to the developing countries to enable them to refine their resources by themselves. So as not to impair research in the industrial countries, the Convention is based on the principle that intellectual property will continue to be protected. At the same time, access to biotechnology is to be facilitated for developing countries (Article 19). Enterprises are to receive compensation from the public sector for this internationally agreed technology transfer. The question of what the amount of the compensation should be oriented to is still open, however. Enterprises will be tempted to overvalue the worth of the patents they hold; the compensation would then be too high. On the other hand, if the compensation lies below the value of the patents, the incentives for innovation will be diminished. It remains questionable whether state regulated technology transfer can serve species protection on a sustainable basis and whether, at the same time, negative effects on innovation behaviour can be avoided (Heister et al., 1992).

Article 15 is based on the fact that the developing countries have, up to now, rarely profited financially from their "biodiversity" as a gene pool, although the latter can, after refining by means of technologies in the developed countries, yield substantial profits. It is required that the results of research and development and the advantages arising from commercial utilisation of the resources be shared in a just and balanced manner. To avoid access to national resources free of charge for foreign enterprises, Costa Rica, for example, founded an organisation (Instituto Nacional de Biodiversidad, INBIO) in 1989 which gathers information on the indigenous plant and animal world: name, location and potential economic utilisation are recorded. In return for a fee, commercial users are granted insight into the data. The first important customer was one of the world's largest manufacturers of pharmaceutical products, who promised payment of one million dollars plus percentage shares of the sales of all products developed on the basis of species from Costa Rica (WRI, 1992a).

In spite of these attempts to strengthen the property rights of the developing countries, the central problem at the international level remains that the genetic base has extensively been, up to now, a public good from whose use no one can be excluded. With regard to international law, it remains to be clarified how gains from the use of species are to be allocated to the physical property rights of the developing countries and the intellectual property rights to the refining operations in the industrial countries.

The profits from use of the diversity of species as a resource thus fall into the lap of the industrial countries whereas the developing countries use the biotopes for purposes that rule out protection of the species. If this conflict is to be solved, the developing countries must be compensated for their species protection services (Heister et al., 1992). In Article 20 of the Framework Convention on Biological Diversity, therefore, the industrial countries are required to provide new funds to the amount of the *"incremental costs"* in order to support the developing countries in the implementation of the obligations stipulated by the Convention. Even if the concept of *"incremental costs"* has not been completely worked out yet, it is roughly based on the following calculation: the additional costs of the species protection policy of a country are determined by subtracting the national benefits of species protection from the costs of the species protection policy (direct costs + opportunity costs). The difference indicates the financial transfer to be rendered by the international community of states.

The question of how high the incremental costs are for a species protection project can scarcely be answered if the national economic policy subsidises the destruction of species. The incremental costs of species protection may even be negative if efficiency gains for the overall economy result from the elimination of price distortions. On the other hand, the costs incurred are very high if protective measures have to be financed while price distortions are retained. Thus, as long as national economic policy measures number among the causes of species extinction, the incremental costs of species protection projects remain difficult to calculate (Heister et al., 1992). If, however, the developing countries can profit from the genuine value of their natural resources, i.e. they are compensated for the benefits of species protection, then differences between national and international concerns are reduced. The interest in industrial countries in a higher level of protection is, therefore, to be transformed into a flow of funds into the developing countries. It has to be emphasised that these payments must be regarded as compensation for services rendered to the entire international community of nations by the diversity of species and not as humanitarian or another kind of development aid. This implies a transfer of additional funds and not, for example, the restructuring of existing payments (World Bank, 1992a).

According to Articles 21 and 39, the Global Environmental Facility (GEF) will serve as a financing instrument until the first conference of the states party to the Convention. The GEF was increased from US$ 1.4 billion to US$ 7-8 billion within the framework of UNCED in Rio de Janeiro. At the moment it concentrates on four areas: protection of the ozone layer, limitation of emissions of greenhouse gases, protection of biodiversity and protection of international waters. It is estimated that the effective protection of already designated reserves in the developing countries and the expansion of reserves by 50% in the course of this century, which is deemed to be necessary, will alone cost US$ 2.5 billion per year (World Bank, 1992a). Therefore, the amount of funds from the GEF that can be expended on protection of biodiversity will, in all likelihood, not be sufficient by any means.

The GEF is supposed to promote the financing of projects that have a positive influence on the global environmental situation. Thus clear criteria have to be developed for projects suitable for support with regard to protection of biodiversity. When granting funds, the responsible institution must then have reliable information regarding the project applied for. After funds have been granted, their use in accordance with the purpose must be monitored. Finally, it must be clarified how sanction mechanisms can be structured in the event that the funds are used for a different purpose. The question of national sovereignty, regarded as sensitive in most developing countries, may substantially impair the collection of information as well as the monitoring and sanction possibilities of the institution deciding on the granting of funds, however. Therefore, controversies can be expected between the donor and recipient countries in the implementation of the financing mechanism: the latter are worried about their independence, the former about use of the funds granted for a different purpose.

Since the mid-80s *"debt-for-nature swaps"* have been developed as an additional source of financing for species protection, i.e. exchange of debts for nature conservation services. Given the extent of its use up to now, this instrument can only contribute a small share to the reduction of the debt burden of developing countries and thus cannot make a significant contribution to species protection.

In summary, it must be underlined that there is no single instrument for effective species protection. Rather, a comprehensive strategy has to be conceived which is based on the local as well as the national and global level and whose tools must be coordinated with other political areas. In all measures initiated by the industrial countries it must be kept in mind that the developing countries usually react very sensitively to sovereignty restrictions.

The irreversibility of the damage and the continued unslowed rate of species extinction makes protective measures urgently necessary. Because worldwide implementation of the Framework Convention on Biological Diversity still requires some time, one must fall back on a variety of smaller instruments, even if their contribution to species protection, from a isolated point of view, appears rather small. This applies, for instance, to *"debt-for-nature swaps"* or the commitment of German development aid to species protection.

**Box 13: Historical development of political action with regard to biological diversity**

| | *national* | *international* |
|---|---|---|
| 1) Charter, Convention | | Various agreement prior to UNCED,<br>Framework Convention on<br>Biological Diversity, AGENDA 21 |
| 2) Protocol | | Not available yet |
| 3) Legal texts | Conservation Act<br>Government bill submitted | |
| 4) Instruments | | Technology transfer,<br>compensation solution, global fund |
| 5) Financial framework | | Specified in protocol |
| 6) Implementation | | Still open |

**Box 14: Follow-up issues of the UN Conference on Environment and Development for biological diversity**

- Increased inclusion of questions of biodiversity in planning and programme going beyond single sectors; studies of their significance for sustainable use of biological resources as well as their assessment in an economic and ecological context.
- Support for developing countries in the conservation of biodiversity, in the use of biotechnological knowledge and in making use of their rights as countries of origin for genetic resources.
- Support for long-term research programmes on significance of biodiversity for the function of ecosystems as the basis for production and consumption, environmental protection in general and protection of ecosystems as the basis for the conservation of biodiversity.
- Inclusion of environmental impact assessments to determine the possible effects of planned projects on biodiversity.
- Participation in worldwide cooperation and regular drawing up of reports on biodiversity on the basis of national surveys.

Cost estimate: US$ 3.5 billion per year (1993–2000)

## Research needs

### *Area of natural sciences*

Reference has already been made to the importance of the self-organisation of ecosystems as the basis for resistance against stress. This self-organisation is based on flows of energy and matter between the organisms (species) belonging to the system in interaction with their environment. Considerable research is necessary in this context. Although there are a number of research results on the relations between the complexity (number of species and individuals) and the resistance of an ecosystem, the conclusions are, in part, contradictory. Therefore, there are still a great deal of open questions regarding research:

- relations between biodiversity, structure and function of ecosystems,
- specific composition of the species necessary for the functions of the system,
- determination of critical factors of different ecosystems to maintain their biodiversity and services,
- adaptability of individual species to climate change,
- effect of climatic extremes on the distribution of species,
- determination of those variables important for the description of the reaction of ecosystems (integrative parameters on many species or indicator species, i.e. species typical for an ecosystem),
- study of feedback effects between ecosystem and environment,
- analysis of the “corridor” hypothesis as an important requirement for the survival of ecosystems, including selection and management plans for suitable refuges for endangered ecosystems,
- working up or further development of suitable research methods for solving problems still open, such as:
  - long-term studies on the reaction of ecosystems in different environments,
  - setting up a suitable observation system for the recording of biotic changes on the Earth,

- dynamic, complex models:
  - models for distribution of ecosystem types on the Earth with different climate scenarios;
  - models for quantification of ecosystem functions and the relation to biodiversity,
  - models that quantify the interaction between ecosystems and the expected climate,
  - models that describe the influence of multiple stress effects on the diversity of species as well as flows of energy and matter in the system.

### *Socioeconomic area*

- Studies on the relations between ecology (here: biodiversity) and economy in ecosystems used on a sustainable basis,
- working up of economic valuation criteria that take into account all functions of species or ecosystems,
- analysis of precise structure of instruments, such as compensation solution and technology transfer,
- influences of GATT and international agreements on trade with wild species or gene resources on biodiversity.

# 2 Transformation of the anthroposphere: Introduction

The changes in the ecosphere analysed in the previous section are primarily caused by human activities or failings. Anthropogenic effects on the environment result from the *production* and the *consumption* of goods and services and can be characterised as follows:

- Consumption of non-renewable resources. *Special problems:* detecting and evaluating resources which can be utilised in the long-term; efficient management of resources; search for possible substitutes and more efficient uses.
- Use of renewable resources. *Special problems:* conservation and expansion of the reproductive basis (e.g. prevention of soil degradation and water pollution); environmentally sound increases in productive capacity.
- Emissions. *Special problems:* pollution of atmosphere, water and soils; negative consequences for the protected interests of human beings, animals and plants; possible depletion of the basis for renewable resources; task: avoidance or reduction of emissions and the effects of emissions.
- Waste. *Special problems:* recycling and disposal lead to further resource consumption, emissions and waste; task: avoidance or reduction of waste; recycling offers the opportunity to lower resource consumption.

In addition, the current situation is characterised by the following global problems:

- more than 1 billion people live in absolute poverty,
- a further 3 billion people are inadequately supplied with goods and services,
- there is a major lack of medical care and education in many regions of the Earth.

“Environment” and “development” are two problem areas that mutually interact. On the one hand, environmental problems (e.g. reduction of renewable resources, increase of emissions and waste) lead to the aggravation of poverty, diseases and illness. On the other hand, starvation, poverty and inadequate education and training are causes of environmental damage.

For the reasons listed below, the Council is of the opinion – as was the international community of nations’ in Rio de Janeiro in 1992 – that *environment and development cannot be considered as exclusive alternatives, but represent tasks to be tackled in conjunction and simultaneously with one another*.

Quantity and quality of global environmental effects from the global perspective are determined through

- the quantities of goods and services produced, distributed and consumed worldwide
  *and*
- the manner in which production, distribution and consumption are organised (technology).

This interrelationship can be illustrated using the following well-known formula (see DGVN, 1992a):

| Effect = Population fi Consumption of goods and services (real, average, global) fi Technology effect |
| --- |

Thus, the following determinants are of crucial importance:

- global population growth,

- change in global per capita consumption,
- changes due to the technological impulses.

An assessment of the potential impact of these crucial determinants leads to the conclusion that the *Earth's population* will increase further to the middle of the next century. This problem is exacerbated by environmentally conditioned migration and by urbanisation. This conclusion is also valid if one is optimistic about the success of efforts to stabilise the world's population as major effects can only be achieved in the long term (see Section 2.1 below). No options are available which could lead to major success in the short term.

*Global per capita consumption* must be increased on account of problems such as starvation and poverty. This continues to apply even if one assumes that the highly developed nations consciously reduce their consumption levels and that redistribution occurs in favour of the developing countries. The *tendency*, at least, will be towards further environmental damage as a result of the necessary expansion of production – even for the case that the structure of goods is changed through the substitution of environmentally sound products for goods that are environmentally harmful (see Section 2.2 below). Here, too, it must be stated that there are no options available for reducing global per capita consumption. The hope remaining is that, through changes in *applied technologies* and the introduction of *new technologies*, there will be a strategic action potential available with which improvements in the short and medium term can be achieved (the technological option).

Technologies are important for global change in many respects:

- Technologies in use can be the *cause* of global environmental change, with negative effects as described above. This was very much so in the past, and is still the case today – to a much greater degree in any case than population growth or the increase in per capita consumption (Commoner, 1988). Current damage to the environment is mainly caused by the type and the methods of production and development in the industrial nations.
- Changes in applied technologies and the introduction of new technologies signify an *action potential* and a *strategic leverage* point for
  - organising production and consumption in the future in such a way that environmental effects are avoided or at least mitigated;
  - making a significant contribution to sustainable development.
- Furthermore, the development and diffusion of new technologies represent a *corrective potential* that enables
  - negative developments from the past to be corrected (e.g. revitalisation and remediation of soils and rivers);
  - adaptation to or protection against irreversible developments (e.g. safe final disposal of nuclear waste).

For these reasons, and given the opportunity to achieve progress in the short to medium term, the Council underlines the importance of generating, testing, transferring and implementing new technologies.

### Box 15: Examples for technology in three different fields

*Finite resources*

Technological developments with respect to "finite" resources are often aimed primarily at

- preserving existing resources through the use of substitutes,
- increasing the efficiency of resource use and
- converting known resources into utilisable reserves.

Solar energy, for example, is a renewable energy resource that, in contrast to fossil fuels, can contribute to the conservation of finite energy reserves or which can extend their availability over time.

Another important research field, in addition to substitution, is finding ways to increase the efficiency of known procedures for utilising fossil fuels and other resources. During the transformation of primary energy into forms of energy that can actually be utilised, a large proportion of energy is dissipated and cannot be used. Especially in large combustion plants, improved extraction of primary energy can be achieved by using the principle of co-generation of heat and power – i.e. tapping the waste heat that is produced.

Mechanical, biological and chemical separation processes enable access to mineral resources considered in the past to be technically impossible or too expensive to mine.

*Renewable resources*

It can be vividly documented, taking the example of "soils" as an environmental sphere, that the application of pro-environmental technologies need not always involve major expenditures of time and money. To combat the widespread occurrence of soil erosion in tropical countries, arable land can be enclosed using high-growing and very resistant vetiver grass, thereby counteracting the threat of surface runoff and wind erosion.

Biotechnological innovations make numerous contributions towards making plant cultures in agriculture and forestry, and their fruit, more resistant against damaging environmental effects. Millet plantations are very drought-resistant and can also be made more resistant against increasing salinisation with the help of biotechnology. By applying so-called "gene shearing" techniques it is now possible to remove undesired genetic information from plant chromosomes without harming other genetic information.

Reducing the volume of chemical fertilisers and pesticides by planting more resistant plant species also improves the quality of groundwater.

*Waste*

Even if there has been a trend recently – at least in the developed countries – towards so-called *"low waste"* or *"no waste production"*, there is still a need for recycling and disposal technologies which minimise environmental damage.

As a result of enormous research efforts, the industrialised countries now possess a variety of environmentally sound techniques for the recycling and disposal of waste, which can be applied in various combinations within the context of integrated waste management concepts. Many variations of thermal, biological and physical-chemical processes are being tested out or indeed applied.

As far as the transfer of these technological innovations is concerned, account must also be taken of the fact that the fractional composition of waste in the developing countries includes a much higher proportion of organic substances than in the industrialised nations. Accordingly, the treatment and the disposal of waste in these countries requires processes specifically designed to match local conditions.

The role that "new knowledge – new technologies" can play in coping with the existing problems was shown by reactions to the "Club of Rome Study" of 1972. This study emphasised in particular the scarcity of resources and made forecasts as to when individual raw materials would be totally depleted. Favoured by high raw material prices, the "oil crisis", etc., private interest (cost savings/income gains) and state-funded research (long-term assurance of raw material supplies) led to "new knowledge", that in turn resulted in a partial "détente" in the debate over raw materials depletion.

- Despite increased consumption of non-renewable resources (minerals, fossil fuels), there was also growth in accessible stocks (i.e. knowledge about new raw material reserves and the technical and economic opportunities for extracting them) (Crowson, 1988).

- Fear of political and economic dependence and growing environmental awareness led in the industrialised world to a reduction in raw materials input per unit of product, to the discovery of technical substitutes, to an increase in the yield per unit of raw material, and to the development of recycling processes.

The "détente" mentioned above does not mean, of course, that the problem of non-renewable resources can be neglected. It merely signifies that other areas in which the application of new technologies is essential must be viewed as being especially urgent:

- protection and conservation of the basis of renewable resources (e.g. water, soils),
- avoidance and/or reduction of emissions and the effects they cause (e.g. $CO_2$),
- avoidance, reduction and recycling of waste.

In order to do justice to the central importance of changing those technologies in use and introducing new ones, the Council will concern itself in a future Report with the possibilities and preconditions for generating, testing, transferring and implementing new environmentally sound technologies. We refer here, for example, to the options for developing a comprehensive information and communication system through the establishment of so-called clearing houses (AGENDA 21, Chapter 34).

This could produce the following benefits:

- Clearing houses collect, process and transfer information on existing technologies, their resources, their potential for damaging the environment, and about the conditional frameworks and acquisitional opportunities necessary for using such technologies.
- This applies, for example, to technologies in the fields of agriculture, the manufacturing and processing industries, energy production and supply, and waste disposal.
- The work carried out by the clearing houses is user-oriented, i.e. information is processed and transferred in a manner appropriate for users; opportunities are developed for and offered to users who are interested in the system but unfamiliar with its operation.
- In addition, other well-known and related services are provided in the fields of consulting, training in technologies and in technology impact assessment.
- In this way, clearing houses facilitate joint ventures and other partnerships between industrial and developing countries.

An important prerequisite for the successful management of the development/environment complex is a transformation of individual and societal values and attitudes (see 2.4). If, for example, consumers experience global environmental quality as an individual benefit and are prepared to purchase only goods that are produced in an eco-friendly way, then producers will be "forced" to use "clean" technologies.

The idea that private decision-making could provide the guarantee that such solutions would be developed has turned out, however, to be a mistaken one. What is absolutely necessary are governmental interventions and initiatives which influence private decision-making with respect to production and consumption, in the form of

- rules or bans (changing the framework of private decision-making),
- price levies (e.g. taxes, duties, levies) or price relief (e.g. investment aid, subsidies),
- the creation of general and enterprise-specific infrastructures,
- awarding of contracts,
- information, appeals.

Local and regional problems must be coped with first and foremost through state policies in the respective countries. However, national policymaking is inadequate as a means for solving *global* problems. Instead, there is an absolute requirement for international cooperation and coordination, and for the creation of supranational institutions. This assessment is based on the idea that global environmental quality from the viewpoint of individual national states is characterised by the following features:

- no-one can be excluded from this quality, regardless of his own behaviour (if "others" provide the requisite quality, then one obtains the full benefit without having to pay the costs),
- the degree of "impact" differs considerably between regions (an example being the ozone hole, where those causing and those affected by the problem are to be found in different countries),
- an individual contribution to the improvement of this quality would appear not to have any effect in relative terms as long as the behaviour of the "others" remains unchanged.

This interrelationship underlines the importance and the necessity of state environment and development policies at national *and* international level.

## 2.1 Population growth, migration and urbanisation

### Short summary

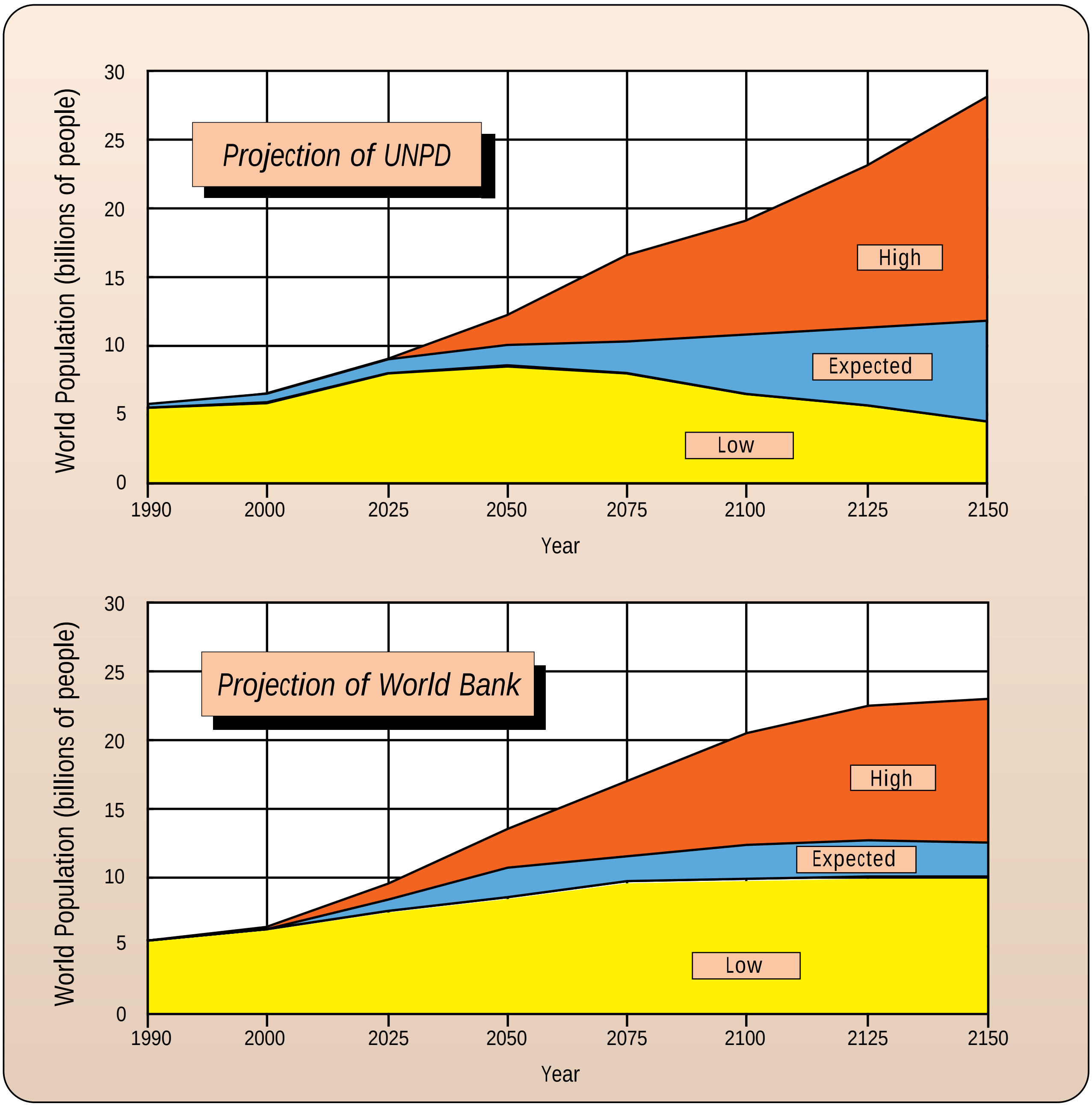
One of the greatest challenges associated with the global task of managing environment *and* development is without doubt the strong and regionally very uneven growth of the world's population. In the long term, human reproduction is indeed the central problem: *every human being has the right to the fulfilment of his/her basic existential needs;* this is bound up with substantial levels of additional consumption of non-renewable and renewable resources, and places severe demands on ecosystems already suffering from environmental stress, especially if production technologies and consumption patterns fail to change.

The world is currently witnessing a rate of population growth what is probably the highest in the history of humanity. Whereas approx. 5.5 billion people were living on the Earth in 1992, the median of three population forecasts of the United Nations Population Division (UNPD) assumes this will grow to 6 billion by 1998 and 10 billion by the year 2050. This means that, on average, an additional 97 million people will be added each year to the Earth's population over the next century, reinforcing existing processes of global change. As can be seen from the following diagram (Fig. 11), the estimations of the United Nations deviate only slightly from those made by the World Bank in its 1992 World Development Report, which predicted a base scenario of 5.3 billion and an annual growth of 93 million for the coming decade. However, in view of the dimensions involved, these differences are marginal. By contrast, there are extreme differences in the scenarios produced by UNPD and the World Bank. The highest estimate of the United Nations is 28 billion people by the year 2150, the corresponding scenario by the World Bank shows a world population of approx. 22 billion. The deviation between the minimum forecasts is even greater, however. The UNPD predicts a total population of 4.5 billion, whereas the World Bank forecasts around 10 billion people. This discrepancy roughly corresponds to the difference between the respective estimates of the world population in 1992, and shows just how difficult it is to estimate birth and death rates.

Despite these differences between forecasts, we must assume that the world population will increase steadily *at least* until the year 2050, even if birth rates continue to fall, and we must at least anticipate a doubling of the present world population. Some 97% of this population growth will occur in Africa, Asia and Latin America (DGVN, 1992a). However, it would be a mistake to conclude from this geographical polarisation that the problem is restricted to particular regions or continents. The extent of population growth and the unequal spatial distribution of the human race will trigger off or reinforce global change and may cause strong migrational pressures. These problems will also confront countries with stable populations, such as Germany; to this extent we are dealing with a genuinely global phenomenon.

Estimates for the total number of migrants in the world today fluctuate between a few million and over half a billion. The International Red Cross Committee, for example, states that 500 million people migrated for environmental reasons. The United Nations High Commissioner for Refugees' (UNHCR) estimation encompasses all official estimations of legal immigration and assume a figure of 16 million. The differences between these estimates are mainly due to incomplete data, to problems distinguishing between legal and illegal immigration, and to a large number of unreported cases.

Figure 11: Population projection up to the year 2150
*(from United Nations Population Division, 1992 and World Bank, 1992)*




The number of migrational flows may increase rapidly in the future, exacerbating the present situation still further. There could be an increasing tendency towards intra- and interregional migration due to economic and ecological pressures. The number of people migrating from rural to urban areas worldwide is estimated at around 40 million annually; this *intra-regional migration* occurs predominantly in developing countries.

Migrational flows across national boundaries *(international migration)* are developing into a problem of global dimensions. At present, no less than 70 million people, mostly from developing countries, are working legally or illegally in other states. According to DGVN (1992a) the annual number of registered refugees rose from 2.8 million in 1976 to 17.3 million in 1990. These figures, and the number of “environmental refugees”, will increase radically over the next few years, according to an FAO study. International migrational flows are almost exclusively into cities.

What all estimates have in common is that in a strict methodological sense they cannot be compared, due to the different concepts and statistical bases they use, and that they are imprecise as far as their reliability as forecasts is concerned. They do show, however, that the number of migrants has been growing and will continue to grow in the future. The simple fact that the population of the developing countries is growing at a faster rate than the population in the industrialised nations results in:

- migrational pressure in developing countries caused by a combination of poverty and environmental degradation,
- greater "pull" towards industrialised countries on account of their high standard of living and changing age structure (more old people, fewer young people).

Since the 1970s, and especially in newly-industrialising and developing countries, there has been a growing degree of urbanisation, in addition to population growth at regionally very different levels. Some 83% of world population growth occurred in towns and cities, i.e. the urban population increased annually by approx. 80 million people. This is equivalent to eight "new" megacities coming into being each year, in addition to existing urban agglomerations.

Population growth on this scale puts existing settlement systems under additional and considerable stress. Urban infrastructures are already overloaded in many cases both in developed and developing states. Within 15 years, the developing world may have to expand by 65% its capacity to produce, its urban infrastructure, its services and its settlement structures if it is to guarantee at least current living and working conditions. To improve them, even greater efforts would be necessary.

The enormous and rapid expansion of urban systems gives rise to increasing social costs and environmental degradation. Neither of these problems can easily be compensated for or reduced by the cities and metropolises of the world themselves. The quality of drinking water and the percentage of households attached to the sewage system, for example, are important indicators for the state of development and the level of environmental stress. If population growth and the degeneration of settlement systems are not brought under control or reduced, then towns and cities will be the first to disintegrate, because their air, soils and water are polluted and because the urban climate – atmospheric and socioeconomic – deprives human beings of the very basis for their existence. This is certain to magnify existing migrational pressure at the international level.

Table 19 shows the expected development of population in some megacities. Even though there may be major differences in the figures quoted by various sources (different spatial entities, parameters and forecasting methods), the trend is obvious.

The spatial-functional division of labour at the regional and global level, and the polarisation of humanity (into urban and rural population, rich and poor, people with and without medical care, educated and non-educated people) will reinforce those migrational flows already perceptible today. Growing urbanisation exacerbates the negative effects of population growth and may become a factor exerting the most negative impacts on the global environment.

A self-reinforcing effect can be identified here, too: human reproduction, increasing migration and agglomeration lead to effects on the global environment, e.g. in the form of higher $CO_2$ levels in the atmosphere. These environmental changes then affect human lives. An increase in sea level, for example, unleashes further displacement and migration.

## Causes

### *Causes of high population growth*

Statistically, high population growth is the result of an imbalance between fertility and mortality. The "balance" that can be calculated on this basis does not, however, permit any conclusion to be drawn about causal relations determining the current ratio of birth and death rates, which itself shows high regional variation. In order to outline alternatives for action that can also apply to Germany, and which are capable of reducing global population growth, the determinants of fertility and mortality must be subjected to analysis, as must the interlinkages between them.

Table 19: Size and growth of some selected megacities
*(from Statistisches Bundesamt, 1992; Otterbein, 1991; DGVN, 1992b; Linden, 1993)*

| | In million of inhabitants | | | | | | |
|---|---|---|---|---|---|---|---|
| | Statistisches Bundesamt | Otterbein | DGVN | Linden | Otterbein | DGVN | Linden |
| | different years | data for 1990 | data for 1990 | data for 1992 | estimations for 2000 | estimations for 2000 | estimations for 2000 |
| Mexico City | 18.7 (1990) | 19.4 | 19.4 | 15.3 | 24.4 | 26.3 | 16.2 |
| Tokyo | 28.3 (1989) | 28.7 | – | 25.8 | 21.3 | 17.1 | 28.0 |
| Sao Paulo | 16.8 (1989) | 17.2 | 15.8 | 19.2 | 23.6 | 24.0 | 22.6 |
| New York | 18.1 (1990) | 17.4 | 18.1 | 16.2 | 16.1 | 15.5 | 16.6 |
| Shanghai | 9.3 (1989) | 9.1 | – | 14.1 | 14.7 | 13.5 | 17.4 |
| Calcutta | 9.2 (1981) | 12.8 | 9.2 | 11.1 | 15.9 | 16.6 | 12.7 |
| Buenos Aires | 11.1 (1988) | 12.4 | 10.7 | 11.8 | 13.1 | – | 12.8 |
| Rio de Janeiro | 11.1 (1989) | 10.9 | 10.5 | 11.3 | – | 13.3 | 12.2 |
| Seoul | 9.6 (1985) | 15.8 | 9.6 | 11.6 | – | 13.5 | 13.0 |
| Delhi | 5.7 (1981) | 9.8 | 5.7 | 8.8 | – | 13.3 | 11.7 |
| Bombay | 8.2 (1981) | 12.9 | 8.2 | 13.3 | 15.4 | 16.0 | 18.1 |
| Cairo | 7.9 (1986) | 11.0 | – | 9.0 | – | – | 10.8 |
| Lagos | 4.6 (1990) | – | – | 8.7 | – | – | 13.5 |
| Jakarta | 7.8 (1985) | 9.9 | – | 10.0 | 13.2 | – | 13.4 |

Among the principal causes for the imbalance between fertility and mortality are the following:

## *Children as a form of pension insurance*

The theory of demographic transition describes the development of a society with high fertility and mortality rates to a society with low birth and death rates. The completion of this process can already be seen in the developed nations. In poor countries with a high rate of infant mortality, on the other hand, demographic transition is often obstructed by a mentality that calculates in terms of progeny, since having many children is often the only answer to the lack of state pension schemes. An increase in average life expectancy does not lead to a lower birth rate as long as infant mortality remains high. Successor generations "disrupt (sometimes with a time delay) tightly financed development programmes, the health system, the education system and factories, and exert pressure on housing markets, water supplies and urban zones." (DGVN, 1992b). This development can only be counteracted by additional financial support, i.e. transfer payments, which will improve the economic situation.

## *The social position of women*

Women's right to self-determination is being increasingly acknowledged as playing a key role in sustainable development. Critically important in this respect, in addition to the obvious ethical arguments, is the recognition that through better health care and education for women, and easier access to employment, important steps can be taken towards reducing population growth.

Results obtained from studies in Brazil provide impressive evidence of the interrelationship between educational level and fertility. It was shown, for example, that women with more than basic primary education have four children less on average than women without school education.

Furthermore, statistics published by the United Nations show that over 10% of all births in Africa and Latin America are to women aged between 15 and 19 years. Aside from the fact that these women are denied access to higher-level schooling early on, mothers in this age group are more liable to suffer damage to their health than older women; infant mortality is also higher among children of younger mothers.

Another problem in this connection is the fact that many women who would not like to have any more children do not possess the means for active birth control. This state of affairs affects 77% of women in Africa, 57% in Asia and 43% in Latin America (UNFPA, 1991).

### *Deficits in the field of population policy and family planning*

Population control programmes as a component of organised population policy definitely have a significant effect on the rate of population growth. However, not all countries with high population growth rates are aware of this significance. Some countries totally reject family planning as an instrument of population policy. One reason for this may be that population control measures take much longer to have an impact than economic policies, for example. This explains in many cases why initiatives in the field of population policy fail to receive the necessary support and priority. To be successful, even in the long term, population policy must be firmly anchored as an institution in the political structures of a given country; however, this approach is taken by only 45 nations in the world. Partial successes on this level which can already be witnessed indicate a major potential that can still be exploited.

### *Medical care*

Providing medical care fulfils an ambivalent function with respect to demographic effects. The discovery of antibiotics, the increasing use of vaccinations and the combatting of malaria have led to marked increases in life expectancy, especially in the developing world (DGVN, 1992a). Medical progress is therefore directly responsible, on the one hand, for the particularly high level of population growth from the mid-20th century onwards, and for the effects this has had on the global environment. On the other hand, it has been possible through advances in medical care to achieve sustained reductions in infant mortality levels. Higher survival rates have led to a lower number of children per family.

The demographic effects of medical progress cannot be quantified exactly. The effects that occur when societies are provided with medical goods and services will remain an uncertain variable within population forecasts.

At the same time, the figure of 1.5 billion people who had no access to modern medical care in 1990 (DGVN, 1992a) signifies an obligation on the part of the international community to act.

### *Causes of increasing migration*

Migration refers to any “spacious” movement of individual people or groups of people who move from the region in which they had previously lived most of their lives to a different region in order to live there for a longer period of time, or even permanently. Migrations are conditional on the capability and willingness for regional mobility.

The *capability* of regional mobility is determined by

- type and condition of transport routes and available means of transport,
- the costs involved (financial costs, duration and strains which must be endured).

*Willingness* to be regionally mobile depends on

- migrational pressure (“push” factors): dissatisfaction with location to date; pessimistic expectations regarding the future; impairment or destruction of life-support systems.

- migrational attractors (“pull” factors): attractive target regions for migrations; hope for improvement of personal circumstances (safety, economic livelihood, future opportunities). This also applies in cases where the target region is not clearly defined at the beginning of migration (refugees).

The causes for migration can thus involve a greater or lesser degree of compulsion, or of voluntary factors (a clear distinction between the two is not possible in every case):

- human rights violations and persecution on political, religious and ethnic grounds,
- natural catastrophes,
- anthropogenic catastrophes, such as chemical or nuclear accidents,
- military conflicts at national or international level,
- epidemics,
- reduction and destruction of the economic basis (e.g. desertification, rising sea level),
- displacement due to large-scale construction works (e.g. dams),
- growth of rural population and the exploitation of natural resources associated with this,
- poverty,
- hopes for safeguarding a basis for existence,
- hopes for upward social mobility.

Estimating the scale of present and future migrations is a highly problematic endeavour. However, this is without doubt a *globally significant and upward trend.*

The largest proportion of migrational flows so far have occurred within national borders. Intranational migrations are (still) determined primarily by economic factors. This is demonstrated, for example, by the roughly 400,000 people who migrated within one year (1990) from the ex-GDR to the states of former West Germany. Migrations from the countryside to the city – especially in the newly industrialising and developing countries – take place because rural areas are generally economically disadvantaged in comparison with urban areas. They possess little more than half the facilities needed for health, drinking water and sanitation. Opportunities to earn a livelihood are much fewer in the countryside than in cities (DGVN, 1992a).

Migrations are ecologically engendered to an increasing extent. This is also the case in industrialised regions. The reactor catastrophe in Chernobyl resulted in more than 100,000 people leaving the region (Keller, 1990).

Most ecologically motivated migrations arise through anthropogenic land degradation. The reasons for this are

- mismanagement and excessive use of land,
- disruption of the hydrological cycle,
- shifts of natural vegetation zones through anthropogenic climate change.

According to FAO figures, 6–7 million hectares of new desert are created each year as a result of soil mismanagement. Floods, salinisation and alkalisation of soils degrade a further 1–2 million hectares of arable land beyond any agricultural usefulness. In total, approx. half a billion hectares of arable land will be irrevocably lost (Keller, 1990). Almost one billion people are affected by desertification in the medium to long term, most of whom are compelled to migrate as a result (Wöhlke, 1992).

Through population growth, on the one hand, and agricultural use, on the other, the per capita area of agricultural land is declining, regardless of the state of development of the countries observed. According to present-day knowledge (e.g. given the level of best available technologies), it is not possible over the long term to expand the area used for agricultural production or to increase agricultural productivity to the extent or at the speed at which agricultural land is being lost through natural agro-climatic constraints. Intensive cultivation of agricultural land in developing countries entails the risk of higher energy input into agriculture than energy output.

Water scarcity can be another cause for rapid migration of people to areas with a greater abundance of water. Poor water quality, in contrast, only leads to migration in the long term, if at all, because the danger is underestimated by the population or because they have no alternative. Estimates for the number of people who fell ill from drinking bad water for the reasons mentioned run to more than 1 billion (Wöhlcke, 1992).

The number of major dams has risen sharply in recent years. Of the more than 35,000 dams that exist worldwide, more than half are located in the People's Republic of China. This country needs water and energy supplies that are adequate to cope with the rapid population growth. The negative effects of dams are frequently subordinated to these objectives:

- Entire landscapes are flooded, or dry out through the regulated water flow.
- The local climate can change.
- Large, stagnant areas of water can become sources of infection and pollution through the accumulation of salts and chemicals.
- Human settlements must be abandoned as a result of flooding, and the population in question has to be resettled.
- Resettlement often leads to a change in social structures and hence to unforeseeable economic and social restructuring.
- Changes in water management change the economic behaviour and lifestyles of people in the catchment area of a dam. This applies principally to those employed in agriculture and forestry.
- The construction of dams in the developing countries burdens the latter with high debt levels and repayment interest.
- Whereas the construction of dams, and the negative effects that ensue, are financed in advance by industrialised countries, this does not apply when the negative effects have to be removed or lessened. Processes of social change occur over extended periods of time and cannot be measured in monetary terms. The countries in which dams were built therefore have to carry the resulting burden themselves.

A rising sea level caused by global warming of the Earth's atmosphere will have a very pronounced effect on migrational patterns. The growing risk of storms and floods will play a similar role.

Wars are an important factor causing environmental destruction, pollution and migrations (refugees), although their impact is difficult to assess. Such effects are mostly local or regional in nature initially. However, the fact that since the Second World War more than 150 wars have been fought worldwide, but also the style of modern warfare (e.g. igniting the Kuwaiti oil fields during the Gulf War; the risks of nuclear or chemical weapons) underline the global significance of this problem.

The causes listed above can lead to a major increase in migrational movements, and especially to the flow of refugees across national borders. International migrations are still relatively insignificant in quantitative terms compared to intranational flows, however. Most migrations at present are from poorer countries with high population levels to wealthier "low population" states

- within the countries of the European Community, and especially from Eastern to Western Europe. In 1989 alone, over a million people emigrated from the Warsaw Pact countries, for example.
- from Asia Minor (Turkey) and (mainly) northern Africa to Europe. Substantial economic and demographic imbalances exist here. It is expected that 25-30 million people will drift towards Europe over the next three decades from the Maghreb zone alone (Stiftung Entwicklung und Frieden, 1991).

- from highly populated Arab and South or South-East Asian states to lowly populated, wealthier Gulf states and to Far Eastern, West European and North American states.
- from Latin America and the Caribbean to North America.

Developing countries often experience fluid transitions between international and intranational migrational flows that make them difficult or impossible to track statistically. The borders of many developing countries date back to colonial times and were demarcated relatively arbitrarily and without regard to national, ethnic or religious distinctions.

### *Causes of rapid urbanisation*

"Even if the globe had a perfectly uniform surface, there would still be cities!" Lösch's thesis of 1943 refers to the social behaviour of human beings, their tendency to settle in families, groups and neighbourhoods. This basic principle of general concentration (centralisation) is considered a fundamental tenet as far as the social use of land is concerned (Lösch, 1943).

This guiding principle can to some extent explain why urbanisation occurs, i.e. the process whereby land is converted and developed for urban use resulting in spatial concentration. However, it does not explain why there have been such massive and extremely rapid urbanisation boosts since the 70s, especially in the developing countries, continuing or even accelerating to this day, and leading to concepts such as "primate city" or "megacity". There is no commonly accepted definition of these terms, however, e.g. in terms of the parameter "population", so that the various concepts overlap to a certain extent. In the literature (Mertins, 1992) cities with more than 2 million and less than 10 million inhabitants ar defined as *"metropolises"*, and cities with more than 10 million inhabitants as *"megacities"*. "Primate cities" such as Buenos Aires or Bangkok are characterised by the fact that a very large proportion of the entire population as well as the administrative, economic, social and cultural functions of the country are concentrated in them, and that similar settlement patterns do not exist elsewhere. Whereas in 1950 there were only 3 megacities in the world, there could be 25 by the end of the century, 19 of these in developing countries. By then, about half the world's population will be living in cities, whereby the regional disparities of urban growth are striking. Cities with populations in the millions, such as Mexico City or Sao Paulo, have gained more inhabitants within a span of 20 years than London or Paris in 2000 years.

The main cause for the growth of major cities in the first phase of urbanisation is rural exodus. In later phases, natural population growth within the cities becomes more important. This can be attributed to the fact that the 15–35 age groups are disproportionately represented amongst those migrating from rural areas and hence that the proportion of women of childbearing age is increasing rapidly in urban areas.

The main reason for rural exodus, on the other hand, is the inadequate development of rural areas as compared to cities. Rural areas often lack appropriate facilities due their inadequate social and technical infrastructure ("push" factors), whereas in cities the respective situation is relatively good due to certain benefits of agglomeration ("pull" factors). The greater the degree of urbanisation, the more economic and demographic investments are concentrated on urban structures. Funds appropriated to support programmes in rural areas are often cut, because existing land property structures prohibit any effective deployment of such funds. This interrelationship reinforces existing income disparities between urban and rural populations.

## Effects

### *Effects of high population growth*

Every form of human action leads to environmental changes, some of which on a global scale. The qualitative and quantitative dimensions of such effects are known for many of these cause-effect relations, but the causal interconnections between them have still to be researched.

The Council sees substantial deficits in knowledge and research in this complex of factors, and these deficits preclude a conclusive overview of the global environmental effects of population growth at this point in time.

Population growth means the reinforcement of migration and urbanisation. These processes can lead potentially to a reduction of the basis for economic development, and at the same time to a worsening of their global environmental effects. The lack of facilities and environmental quality (e.g. high infant mortality, low life expectancy, inadequate training) tends to result in an increase in population growth. This “vicious circle” therefore contains self-reinforcement effects that render an integrated solution and rapid action a matter of necessity.

### *Effects of increasing migration*

The global impact of migration on atmosphere, climate, water, soils, biodiversity and the economic basis of human existence could be assessed at present as being relatively insignificant. Other causes, such as population growth, in combination with resource use, emissions or the waste problem, appear to be more serious. The role that the regional distribution of population growth will play in future depends critically on whether

- the problems listed above are exacerbated or not or,
- whether the explosiveness of the issues discussed can be reduced, with the consequence that valuable time for solving the principal tasks (environment and development) is gained.

Migrations display the following main effects:

- Spatial mobility depends on age and level of education. Young and better-trained people are thus more inclined to emigrate than older or less well-educated people. This leads in areas of outmigration (source areas) to shrinkage of the basis for development and hence to an increase in the already existing migrational pressure.
- The target regions experience an additional burden on their economic and ecological systems, the precise extent depending on their initial situation. If this burden turns out to be excessive (e.g. through the collapse of urban structures), then migrational attraction turns into migrational pressure, i.e. migrational targets become sources of outmigration.
- The process of urbanisation is reinforced, as the destinations for both national and international migration are almost exclusively cities.
- Refugees form a smaller percentage than voluntary migrants in the total number of migrants. But because the reasons why refugees must flee their respective countries often develop quite suddenly and trigger off migrational flows that are very difficult to control, refugee movements have more serious effects on environmental assets than voluntary flows do.
  The war in Afghanistan, for example, caused 5 million people to flee into the neighbouring countries of Iran and Pakistan (Dannenbring, 1990), where they have been living for over a decade, degrading their social and economic support systems. In Somalia, one of the poorest countries in the world, a seventh of the more than 6 million people living there were refugees at one stage. The situation is similar in many other African states, such as Malawi or the Ivory Coast.
- In most cases, refugees move to target regions in the vicinity that exert a particular attraction. Because target regions, as described above, become sources of outmigration as a result of over-burdening, a renewed wave of migration is caused in which the problems constantly worsen as one stopping place after another is used.
  In Africa or South Asia, for example, migration from densely populated areas to sparsely populated areas where the land is barren and difficult to cultivate can be observed. Cultivating barren land produces little yield. Within a foreseeable period, such areas can no longer provide any subsistence at all, with renewed migration the predictable result.
- The consequence: when intranational target regions for migration have been used up and migrational pressure constantly mounts, international migrations will increase and will ultimately point in the direction of the developed countries.
- The main effect of national policies for restricting immigration is to encourage efforts to circumvent such restrictions:

- the attractiveness of target regions remains unchanged (high availability of basic requirements, lack of alternatives in developing countries);
- due to increased scarcity of options, “suppliers” can be found who offer illegal opportunities for immigration.

In conclusion, this means that migration processes

- can – insofar as they occur spontaneously – multiply the level of difficulty in solving the combined problem of “environment *and* development”,
- acquire global dimensions as a matter of course due to self-reinforcement,
- affect – with time delays – every state; they represent not only a general problem that has to be solved worldwide for ethical and humanitarian reasons, but attain national dimensions for every society, including the Federal Republic of Germany,
- give rise to an acute need for action: internationally coordinated and responsible policies offer a chance to influence migrational flows; as mentioned above, this is not equivalent to a genuine solution, but only a lessening of the problems described; it would, at least, create a breathing space in which to cope with the central task of “environment and development”,
- opens up for highly developed countries the opportunity to equalise their “age structure deficit” (increasing life expectancy, lower working hours, low “indigenous” birth rate).

### *Effects of rapid urbanisation*

When taking a historical perspective of society’s use of land, there has always been a positive correlation between the size of a city and its state of economic development. The furious pace of today’s urban growth, in contrast, can only be seen as disquieting for the urban population and as an indicator of increasing pauperisation of the rural population.

Experience gained in the past shows that rapidly growing urban systems lead to serious degradation of the environment, high traffic levels and major social problems (e.g. rising criminality) (DGVN, 1992a). The question this poses is whether these phenomena are confined to the local or regional level, or whether the process of increasing urbanisation in fact conceals problems that are interconnected with *global environmental change*.

If one looks at analyses of the climate situation in cities, one frequently encounters the following type of diagram (Fig. 12). Urban space is viewed as an isolated, closed system separated from its environment by a dome. It is not possible to derive any conclusions for the global dimension of such environmental change from this form of representation. Concepts such as *urban climate* or *heat island* underline the local or regional demarcation of urban systems in precisely the same way as the quantifiable, higher pollution levels of city air compared to air in the surrounding countryside, which is “visibly expressed by the haze over the city, reducing the amount of sunlight falling” (Heyer, 1972). Temperature differences compared to surrounding areas, less hours of sunlight due to increased cumulus cloud, and modified wind systems indicate that urban areas cause local rather than global environmental change, at least as far as climatic conditions are concerned.

In the case of *urban heat islands*, a high correlation can be shown between the temperature difference between the city and the surrounding rural areas, on the one hand, and the number of inhabitants, on the other. The higher the number of inhabitants within a particular urban area, the greater the difference between the urban and rural temperature level, as shown by the scatter diagram in Fig. 13.

At the end of this century, about half the world’s population will be living in cities, which means that approx. 3 billion people will contribute towards and be affected by environmental changes at the urban level. What appears on the surface to be locally or regionally confined environmental changes may thus acquire global relevance.

Figure 12: Changes in urban climate *(from Hutter, 1988)*

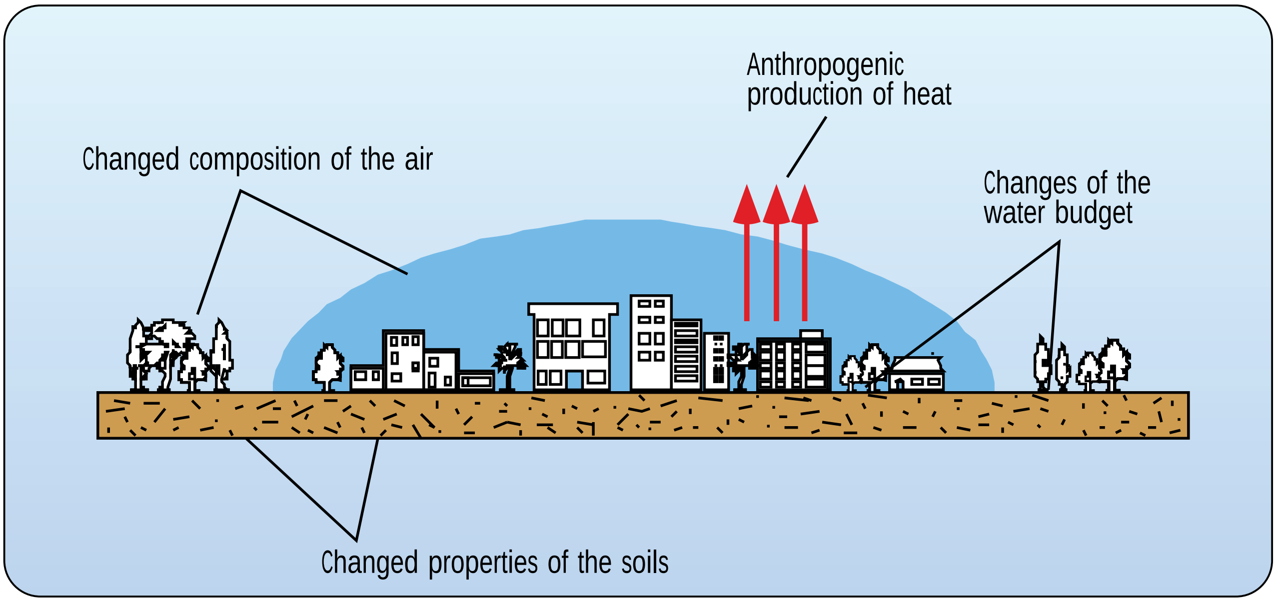
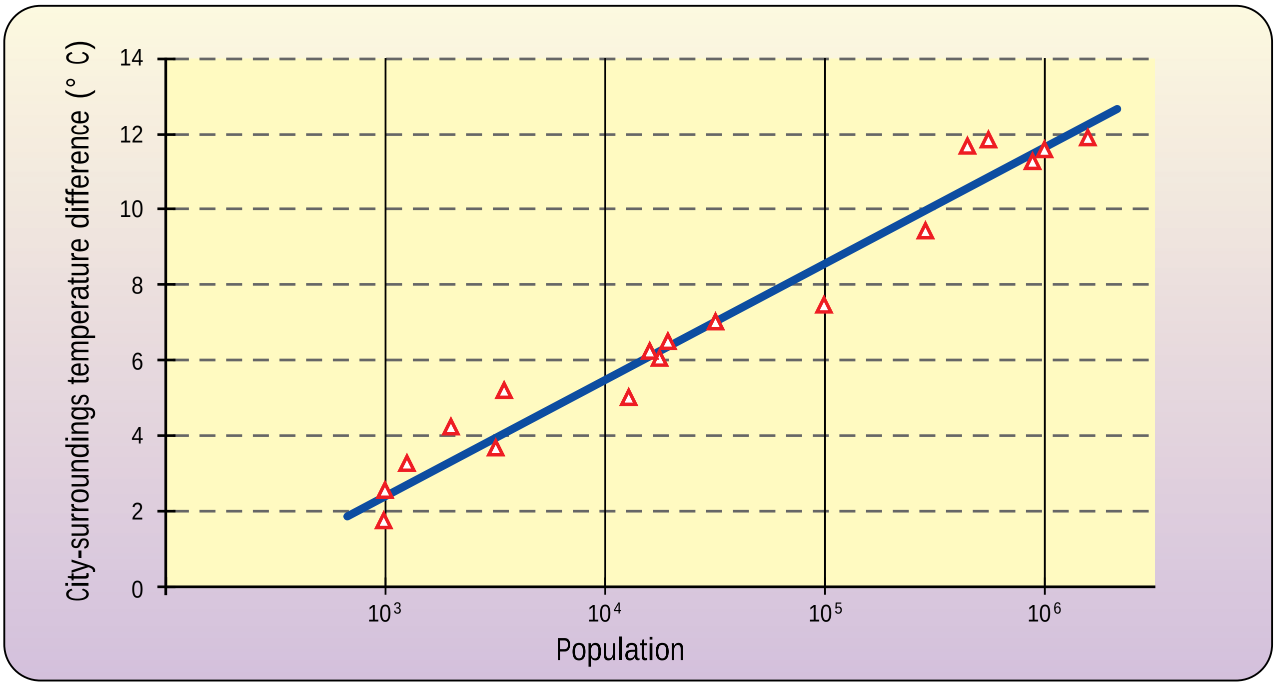



Figure 13: Correlation between the city-surroundings temperature difference and the size of urban population *(from Changnon, 1992)*




Humanity is in many respects a victim of its own actions. The state of "ecological emergency" is the most recent megacity problem. It manifests itself in air and water pollution beyond all standardised threshold limits, in noise emission, sealing of soil surfaces and, last but not least, in the rampant growth of waste disposal sites.

Outdated or badly maintained vehicles cause lead and soot concentrations in the air which far exceed the level that is technically necessary. In Lima, for example, air pollution is 200% above the internationally accepted level. The lack of, or overburdened disposal systems compel inhabitants to incinerate their waste in the open air, without any controls, causing the release of large volumes of toxic gases (Otterbein, 1991). Untreated sewage pumped into rivers imposes limitations on the utilisation of river water for agricultural production and the supply of drinking water. Rising demand for drinking water in rapidly growing cities causes a situation where the capacity of existing wells no longer suffices. The construction of new and ever-deeper wells leads to subsiding groundwater levels. This, in turn, may cause the transformation of arable land into desert and also pose an enormous risk to decrepit buildings, which can collapse as a result, especially in the peripheral areas of major cities.

Through deforestation in the periphery of cities, the oxygen production and water evaporation is reduced over a wide area. In combination with the high concentration of emissions caused by automobiles, which account for 80% of all air pollutants in Mexico City, for instance, the health of the entire population is acutely at risk. At least 50,000 deaths per year in this megacity are directly attributable to smog. The level of air pollution in Mexico City is about six times higher than that defined as tolerable for humans (Schteingart, 1991); as a consequence, 90% of all respiratory illnesses that the city's population suffers from stem from poor air quality.

Through the massive concentration of human activities in urban areas, environmental change takes on extreme forms in both quantitative and qualitative terms. All spheres of the environment are exposed to stresses far above average, which often reinforce each other synergetically or develop into a self-destructive cycle. Density of population undoubtedly plays an important role in this respect. It is easy to imagine that high-density areas with approx. 4,000 inhabitants per $km^2$, such as Berlin or Munich, produce much greater environmental change in qualitative and quantitative terms than rural areas such as the Allgäu in Southern Germany, where population density is about 90 inhabitants per $km^2$. In megacities like Cairo, there are as many as 29,000 people living on one square kilometer, in Calcutta up to 88,000 (UNDP, 1992), thus representing an extreme burden on the various spheres of the environment. To give a last example: air pollution in New Delhi is thought to be responsible for a 30% decline in agricultural yields in the surrounding rural areas (Otterbein, 1991).

In summary, we can state that:

- high population growth involves even higher growth of urban agglomerations,
- the more people that live in a city, the greater are the negative effects on the environment,
- the greater the increase in urban population per year, the less developed are the urban facilities for ensuring basic supplies (especially sewage and waste disposal), and the greater the probability that urban systems may collapse,
- the more clearly urban decline can be "felt", the greater the cross-regional or international migrational pressure.

## Links to global change

Population growth, increasing migration and self-reinforcing urbanisation processes pose the greatest challenge of global change. Below, the *particular* effects of population growth and distribution are outlined once again.

### *Atmosphere*

Population growth is responsible to a critical extent for the production of greenhouse gases. In Africa, for example, 68% of the increase in $CO_2$ is due to population growth; in Brazil the figure is as high as 76%. Population growth also accounts for 69% of the increase in cattle stocks. The higher volume of methane production leads to further global warming and greater ozone depletion. Greater global warming can lead in turn to rising sea level, which has caused 16% of Egypt's population and 10% of the population in Bangladesh to become ecological refugees (DGVN, 1992a).

### *Water*

As a consequence of population growth, the consumption of water by agriculture, industrial and energy production and private households increases. This higher level of demand has led to severe water scarcity in many parts of the world, which in many regions is combined with a lowering of the water table. The number of people affected by water supply problems could amount to as many as 1.1 billion by the year 2025 (DGVN, 1992a).

The constantly increasing volume of sewage in urban areas can no longer be treated to the required extent. Insufficiently treated sewage is a health hazard for all living beings, however. The deployment of chemical fertilisers to push up agricultural yields is endangering groundwater and surface water. Heavy algae growth indicates that too many fertilisers and phosphates are seeping into the water.

### *Soils*

High population growth leads to further expansion of agricultural land. Nevertheless, in 2050 there will be about 50% less agricultural land per capita, because expansion of agricultural land cannot keep pace with population growth (DGVN, 1992a).

Overgrazing, agricultural over-use of land through shortened fallow periods, and prolonged periods of drought weaken vegetation first of all. The unprotected soils are blown away and a crust forms. Rain can no longer seep through the soil, but drains off the surface instead. The soil erodes and loses fertility. Efforts are made to compensate for this loss of agricultural land by creating new arable land through deforestation. This process is repeated until the land is unfit for agriculture and migration is triggered.

As early as 1975, many countries could no longer produce enough food for their own needs. These are predominantly developing countries with a high proportion of marginal land. In the long term, only 1/3 of the population in these countries can be fed from national agricultural production (DGVN, 1992a).

The requirement of land for non-agricultural purposes will also assume substantial proportions. In the developing world alone, approx. 2.75 million $km^2$ of land will be needed for housing, the production of goods, services and infrastructure by the year 2050. Worldwide, additional land requirements are expected to be in order of 4.5 million $km^2$, with all the effects that land sealing entails (DGVN, 1992a).

### *Biodiversity*

When natural habitats shrink or become fragmented, then the diversity of species living in them also declines. Since 1900, about half the wetlands of the world have been destroyed as a result of human intervention in the form of drainage for agricultural use, loss of forests for forestry purposes or for expanding cities. Viewed statistically, there is a clear positive interrelationship between population density (as a function of population growth) and the loss of natural habitats.

Global warming and the ensuing rise in sea levels will trigger off migrations that will give rise to a shift in the boundaries of human land use in the direction of the two poles and to higher altitudes. Plants and animals living in these regions are therefore threatened with extinction.

### *Economic development*

The relationship between population growth and economic growth has been a controversial issue for more than two decades. One side saw population growth as being the greatest obstacle to economic progress. The other side argued that population growth can be of enormous benefit for long-term economic growth.

No such interrelationship between population growth and economic growth can be shown in the industrialised world to this day. In the developing world, on the other hand, where 97% of future population growth will occur, a negative correlation between population growth and per capita income has been established since 1975, as confirmed by the World Population Report of 1992 (DGVH, 1992a).

High population growth has a negative effect on the provision of school education in developing countries, for example. Because only very limited financial resources can be provided in these countries for educational facilities and hardly any new capacities can be created, existing educational facilities are confronted with a constantly increasing demand for education. The quality of education will thus inevitably deteriorate. Many people, women especially, do not even have access to education.

Statistically, however, there is a correlation between educational level and economic development in a given country. The longer the average amount of schooling received, the greater the economic prosperity. A similar correlation can be found between education and agricultural production, i.e. the better and the longer school education is, the higher is the yield per hectare of arable land as a rule.

## Need for action

The Earth's population is proving to be a crucial determinant in coping with the combined tasks of environmental protection and development. The greater the rate of population growth, the less chance there is to provide solutions that address both environmental and developmental problems at the same time. Uncontrolled migration and urbanisation processes render this task considerably more difficult. The following objectives in the field of population development and distribution are the logical consequence of this situation:

- long-term stabilisation of population levels;
- prevention and/or reduction of involuntary migrations;
- creation of sustainable urban structures.

As already stressed, there is an immediate and acute need for action in all areas, as documented in the Rio Declaration and especially in AGENDA 21 (UNCED, 1992):

- Population development:
  Reduction of the causes of population growth by
  - eradicating poverty,
  - promoting equality for women through improved access to education systems and to employment,
  - recognition of the right to family planning as an individual human right,
  - improvement of opportunities for family planning,
  - reduction of infant mortality,
  - improvement of education.

- Migration:
  - reducing migrational pressure,
  - international coordination of international migrational flows.

- Urbanisation:
  - internationally coordinated spatial policies,
  - definition of guiding concepts for spatial policy that provide for harmonisation of "environment and development"; e.g. through a balanced mixture of land use within cities (Chap. 7 of AGENDA 21) or through the preservation and the development of existing urban parks and green areas in inner-cities (Chap. 6 of AGENDA 21),
  - creation of polycentric rather than monocentric land use structures (Chap. 7.19 – 7.22 of AGENDA 21),
  - technology transfer aimed at the avoidance or reduction of emissions and waste in urban agglomerations.

If, in the face of this required action, one enquires about the actual possibilities for action that exist, one is struck by the fact that *sustainable* stabilisation of the Earth's population, a reduction of migrational pressure and the avoidance of uncontrolled urbanisation can only be achieved if development problems (e.g. eradicating poverty) and environmental problems (e.g. water pollution) are surmounted.

Surmounting the population problem in the long term demands that solutions be found for environmental and developmental problems; this itself is made more difficult through population growth, migration and urbanisation. This "vicious circle" severely restricts the possibilities for action aimed at any *short-term* influence on population development. Use of coercion by the state, e.g. by "punishing" high birth rates, cannot, in the Council's opinion, be considered for ethical reasons. Population policies that promise success must therefore be aimed first and foremost at influencing individual family planning

- by combatting the causes of high birth rates,
- through educational campaigns dealing with methods and availability of suitable birth control.

Aware that this touches upon an extremely sensitive area in which cultural and religious persuasions play a major role, the Council stresses the individual right and the personal responsibility of every human being to make his or her autonomous decisions with respect to family planning. Implementing this demands not only worldwide recognition of the right to individual family planning, but obliges the *international community* to create opportunities for the responsible exercise of this individual right.

The international community must take action, because

- population growth is a central problem of global change,
- the global importance of this problem is still underestimated in many states,
- such measures only produce results over long periods of time, and because the necessity for immediate action is doubted as a result,
- even the relatively modest expense of such a programme is not provided in many areas due to the various other tasks that have to be managed at the national level.

Through international cooperation (conventions; approaches can be found in AGENDA 21, Chapter 2) and financial programmes, an institutional anchoring of population policy should be ensured in all states, enabling such programmes to be carried out independently by the state in question, bearing in mind the respective conditions and sensitivities.

The Council believes that the Federal Republic of Germany (as all other highly developed countries) must assume a special responsibility in this regard. This is derived, both directly and indirectly, from

- the signing of the Rio Principles and AGENDA 21,
- the demand for international solidarity,
- its position within the international community of nations,
- the immediate effects of international migrational pressure,
- the fact that present global change is mainly attributable to production and sales in the industrialised countries, and that the management of these problems is critically dependent on population development.

Precisely because measures to control population only show results over the long term, *immediate* action is now required. Modest successes in reducing population growth can make important contributions to the solution of global environment/development problems.

Besides the initiation, participation and co-financing of international programmes with the above objectives, emphasis must be laid on the key role of the highly industrialised nations in the development and transfer of new technologies. Since the stabilisation of the world's population cannot be achieved in the short term and is greatly influenced by solutions to environment/development problems, technology policies adapted to fit the circumstances faced by newly industrialising and developing countries would offer an important potential for action (see box in Section 2: examples for technology in three areas).

## Research needs

Research into socioeconomic interactions within the context of global environmental change is still in its infancy, in Germany at least. This is shown by the overview of German involvement in international scientific programmes, where only the environmental research programme *"Human Dimensions of Global Environmental Change"* organised by the *International Social Science Council* (ISSC) is listed as a socioeconomic research topic (BMFT, 1992a).

The Council sees a substantial discrepancy between natural science and social science research. There is an urgent need to balance the major impact of socioeconomic factors, such as population development and distribution, on global environmental change.

Studying the People-Society-Environment system is one of the crucial analyses regarding "population growth, migration and urbanisation" that needs to be conducted in order to determine the stress limits and carrying capacity of the environment. The information basis currently contains too many gaps for any definitive statements to be made about the long-term development of per capita consumption of renewable and non-renewable resources, for example, as a result of high population growth. It is not possible at present to make reliable forecasts about the qualitative and quantitative extent of local, regional and global pollution in the future. There is also a lack of suitable information about the utilisation of new, environmentally sound technologies or about the prospects for success regarding the internalisation of external environmental costs. Finally, it is difficult to estimate the extent to which individual and social patterns of behaviour will become geared towards sustainable development and what influence will be exerted at the political level in this respect.

Beyond the collection of environmental data and the development of relevant databases in the natural and social-science fields, as demanded in Chapter 35 of AGENDA 21, there is a need to analyse interrelations within the People-Society-Environment complex that can offer explanation. Proceeding in this way demands, above all, in addition to the corresponding institutionalisation of research activities, the development of innovative analytical and forecasting procedures with the help of which anthropogenic influences can be taken into account.

The Federal Office of Statistics' concept of *environmental accounting* points in the right direction. Such procedures, which can be transferred to other economies when adapted to the respective conditional framework, offer at least the possibility of a cost-oriented assessment of environmental impacts, and can form the basis for the targeted deployment of environment policy instruments.

At the international level, this could lead to the expansion of coordinated scientific databases, which would open up the possibility for establishing global networks for rapid data exchange, and enable the international community to react quickly and effectively to perceived problems.

### *Research field: population growth*

- Analysis of explanatory interrelations within the People-Society-Environment system
- Development of methods for estimating carrying capacity (stress limits)
- Analysis of real and potential consumption by individuals of renewable and non-renewable resources
- Research into the influence of individual and social behaviour patterns and political structures on global environmental change
- Examination of the technical, institutional and financial conditional framework for technology transfer

### *Research area: migration*

- Development of methods for analysing and forecasting international migrational flows
- Qualitative and quantitative analysis of migrational "push" and "pull" factors

### *Research area: urbanisation*

- Determination of an "optimum city size"; assessment of the determinants of the carrying capacity of urban structures; qualitative and quantitative analysis of urbanisation in relation to global environmental change
- Determination of the environmental impact of different types of cities
- Designing technologies for integrated solutions concerned with environment and development in urban areas

## 2.2 Changes in the world economy

### Preliminary remarks and definitions

#### *Introduction*

The economic activities of human society and economic growth play a significant role as causes of global change. The Council shares this view and therefore places special focus on the economy along with population growth as the most important, though very complex causal system.

To be able to better comprehend economic activities and the powerful dynamics they possess, one must first realise that economic action was, first of all, a reaction to bottlenecks in the natural environmental system and thus represented an intentional attempt to overcome these bottlenecks by expanding the material scope for action. In view of the poverty and hunger afflicting large portions of the world's population – during the second half of the 80s over a billion people were still living on less than US$ 370 a year, thus making them poor according to the World Development Report (World Bank, 1990; Walton, 1990) – this is still the reason behind economic activity or behind the demand for economic growth for a great proportion of the world's population. More recent studies for 1990 show that the number of people affected by poverty has increased rather than declined (UNDP, 1992) and has reached a figure of roughly 1.1 billion today (World Bank, 1992a). Economic activities are a question of survival for these people. Hence, the demand for a change in economic growth based on long-term environmental considerations is not likely to find much support there.

This situation applies in particular when – as was already emphasised at the first environmental conference of the United Nations in Stockholm in 1972 – poverty itself is the cause of many environmental problems, because it forces people to exploit their natural resources to a non-sustainable extent and – as the most recent World Bank Report (World Bank, 1992a) shows in many examples – economic growth and an increase in the efficiency of resource exploitation go hand in hand. Even in the industrial countries, however, economic growth may generate desirable side effects from an environmental policy point of view if growth triggers investment and environmental protection using technology is boosted via capital-dependent technical progress.

Another point to be underlined is that economic action is frequently more than just a reaction to existential economic constraints. Value added activities – and this is of major importance for an understanding of the dynamics of growth – are an expression of a "basic need" in people to overcome finiteness or dependence itself. Therefore, economic action can also be interpreted as an implication of a more profound striving for freedom. This makes it difficult to make judgements on the appropriateness of a certain form of consumption or a concept of affluence, or to speak too quickly of the highly developed nations as "wasteful societies".

Finally, it is a fact that social and global distributional conflicts are usually easier to solve with economic growth than without growth, and to a large extent the social policy practised in highly developed nations could not be achieved without economic growth. For example, medium-term financial planning in Germany, the "Social Pact" currently being debated and the institutionalised system of statutory pension insurance are based on economic growth. Moreover, the large-scale problems related to prosperity in reunified Germany can hardly be coped with if there is no economic growth. In comparison to this, however, the implications of global disparities in affluence are even more profound. This is shown very impressively in the most recent UNDP Human Development Report

1992 (UNDP, 1992), which points out that the richest twenty percent of the world population currently earn an income which is over 150 times higher than that of the poorest twenty percent and that this disparity has increased even further over the last ten years. In view of the expected global growth in population and its concentration in the least developed countries, there is reason to fear that the gap between the poorest and the richest nations of this world will continue to widen in the future.

The "distributional interests" visible in the protectionist development tendencies of most industrial countries indicate little "willingness to share" or to solve the problem of disparity through a policy of redistribution. This is also shown by the fact that the demand made at the UN Environmental Conference in Stockholm in 1972, i.e. that industrial countries should spend 0.7% of their GNP on development aid, was only met by the Netherlands, Denmark and other Scandinavian countries in the last twenty years, while the U.S. only managed to reach a figure of 0.19%, Great Britain 0.27% and Germany 0.42% (Abbasi, 1992). On the basis of an annual financial contribution to be provided by the industrial countries of US$ 125 billion, the figure regarded as necessary for environmentally sound development of the developing countries by the UNCED Secretariat, this contribution would amount to *1% of the GNP of the industrial countries* (Raghavan, 1990). *The Council fully supports this appropriate and necessary demand.* However, Germany should be given credit for the aid it furnishes to many countries of Eastern Europe since the latter are in a situation similar to that of the developing countries concerning their economic conditions and current environmental problems.

## Growth and development

Economic growth and development are ambiguous terms that require explanation. The current discussion revolving around the limits of growth suffers greatly from the fact that different interpretations of the notion of growth and development exist. A very superficial view interprets economic growth as the constant expansion of the economic production of goods with given structures. Structure here is defined as the physical appearance of the national economy with its sectoral, regional and company size characteristics as well as the production methods in their entirety, defined with regard to, for example, resource intensity or emission coefficients.

It is necessary, however, to include the transformation of economic structures in our considerations because demand preferences will be decisively influenced by the relative prices. The external and, for the environment, relevant structure of the economy changes constantly through the effects of other basic conditions (such as the formation of economic zones via politically desired integration, institutional shaping of the global economic order, etc.). Global environmental change is thus not only the consequence of the respective level of production achieved, but the result of its structure. These structural changes can, but do not have to be of an environmentally positive nature. For some time now there has been a constant observable trend towards globalisation of markets and thus towards expansion and intensification of trade, internationalisation of production as well as an increasing division of labour between companies (*"lean production"*, *"just-in-time production"*, etc.). This has an especially negative effect on energy consumption and traffic emissions, two other important determinant factors of global change.

Viewed over a longer period of time, moreover, the sectoral shares in real net output have changed and continue to change. On the basis of the classical three-sector hypothesis (Fisher, 1939; Clark, 1960; Fourastié, 1971), for example, countries like Germany have been in the process of becoming service societies for some time now. Some speak of the post-industrial society (Touraine, 1972; Bell, 1973), though this development is frequently linked to the hope of achieving a positive environmental impact through structural change. As will be shown later, the hypothesis of positive environmental effects resulting from such a structural transformation can, by no means, be regarded as verified.

The above-mentioned processes of transformation in the structure of the economy can also be described as development. Here, development not only stands for the explanation of statistically observable and theoretically explicable structural change in the economy over time (in terms of sector, region or company size), but also encompasses those aspects going beyond the economic dimension. According to recent debate (Pearce et al., 1990) on the notion of development, it is not only supposed to comprise

- the increase in real per capita income, but also
- improvement of the state of health and food situation,
- improvement of the level of education,
- access to resources,
- a “fair” income distribution and
- recognition of basic rights.

Initial attempts at operationalisation have now been undertaken. The work of the United Nations Development Programme (UNDP), which has been analysing the notion of *“sustainable development”* intensively for some time, appears particularly relevant. In the most recent Human Development Report (UNDP, 1992), the *Human Development Index* (HDI) proposed earlier in the 1990 and 1991 Human Development Reports (UNDP, 1990 and 1991) is taken further through the addition of a *Political Freedom Index* (PFI), calculated worldwide. On the basis of this HDI, Canada, Japan, Norway, Switzerland and Sweden are at the top of the world development table, Germany is number 12 while countries like Afghanistan, Sierra Leone and Guinea rank last.

Moreover, environmental protection was to become an important element in the concept of development as well. Therefore, characteristics taking into account the environmental stresses on people as well as on the natural environment were to be added to the customary list of criteria.

In such a broadly defined notion of development economic growth is a subdomain. Even if great importance is still attached to economic growth as a starting point for alleviating poverty (thus the Brundtland Report, 1987; World Development Reports of the World Bank; Economic Outlook of IMF), the Council supports such a concept of development whose operationalisation, however, has not been undertaken yet.

As already stated, the latter also applies to the notion of *“sustainable development”*. This term can be regarded as a “strategic imperative” for economic action in order for humanity to survive in the future. What still has to be clarified is, for example, the extent to which this notion must take into account social and economic concerns (social and economic acceptability of a specific development), the time horizons to be considered and the discount rate to be used.

## *Growth and the market economy*

As evolutionary and institutional economics are able to show (Dopfer, 1992; Schenk, 1992; von Hayek, 1975 and 1981), a wide variety of rules and institutions have come into being through a kind of social learning process. These, in turn, have an impact on the economic behaviour of people and also influence the environment. The market economy is a search process based on the principle of private enterprise which is decentralised in nature and oriented to efficiency criteria. This process involves a constant search for newer and better ways of allocating resources with individual economic planning being coordinated through prices determined via competition, as far as possible. These relative prices reflect a wide variety of information that includes assessments of the future as well as economically relevant environmental conditions, provided that it is possible to express ecological scarcity in prices. Market economy mechanisms can therefore be used to take consideration of environmental concerns in the individual economic planning processes.

The price system functions as a mechanism for conveying information and also provides individual orientation, while very few cognitive demands are made on individuals – a decisive advantage. Under certain conditions – such as with assets having non-excludable, collective features, information asymmetries and external effects or under certain market conditions – market failure or failure of competition may occur. As more recent discussion shows (Blankart, 1991; Eickhof, 1992), however, these cases arise less frequently than expected and are caused to a considerable extent by government failure (for example, inadequate allocation of property rights).

Although this market economy system fundamentally develops substantial growth dynamics, it is, in principle, compatible with the idea of zero growth – in contrast to many a claim to the contrary – if the basic ecological conditions make this necessary. Economic growth is, in fact, the hardly foreseeable and thus hardly predictable result of individual economic decisions. If, in their assessment of the conditions for action, the individual economic units came to the conclusion, on balance, that growth is no longer possible for individual economic enterprises, this would have to be noticeable as a shift in the economy to a stationary development path. If there is a marked preference for economic growth in the political arena of the most highly developed countries, therefore, this cannot really be attributed to the market economy as such. It is rather – as has already been emphasised – an expression of the fact that many institutional provisions of these states, such as in the area of social security, would become fundamentally questionable without economic growth and could, accordingly, trigger social tensions. In other words, social or global conflicts of distribution are generally easier to solve with economic growth than without.

## Causes

### *World economic growth*

In order to be in a better position to analyse the global changes associated with economic growth, determine future research needs and set priorities regarding required action, the Council feels that a distinction between different approaches is imperative:

1. A (highly) aggregated approach, primarily based on a view of world economic growth, regardless of its sectoral and regional features, as the triggering element for the global environmental problems to be explained,
2. a regional approach which is oriented more to the interrelations between the regional distribution of this global growth process and the hereby induced negative global or regional environmental impact,
3. a sectoral approach emphasising the relations between global or regional environmental aspects and the sectoral structural transformation of the world economy, or segments thereof, which causes them, and
4. a desirable combination of these regional and sectoral approaches which underlines the connections between the structural transformation of more highly developed regions and the structural changes in underdeveloped areas and the hereby induced global or regional environmental effects, with explicit consideration of the institutional conditions influencing them.

The aggregated approach, which seeks to explain global environmental problems primarily on the assumption that world economic growth, without any further subdivision, is the actual causal agent, was the basis for the construction of the first world models (Meadows et al., 1972 and 1974; Forrester, 1971) and for the discussion it triggered regarding possible limits of world economic growth. These models view the global ecosystem

- as the source of all material flows, which via resource depletion or use (renewable resources) then enter the economy
- as inputs and throughputs, and subsequently leave this subdomain
- as "wastes" (including emissions), i.e. return to the ecosystem.

Such economic growth means throughput growth and then becomes a problem when exploitation of finite resources results with limited options of substitution for the individual input categories, and/or the regeneration or assimilation capacity of the global ecosystem is greatly overtaxed. Therefore, the world models examine the question of whether such relevant throughputs or bottleneck situations can be determined.

In summary, the highly aggregated world models currently focus on several bottleneck components. On the resource or input side they include

- the globally limited area of arable land, which primarily has to produce the relevant biomass for food, which cannot be substituted and, in the view of some experts (Vitousek, 1986; Daly, 1992) has been exploited extensively,

- in connection with this, the demand for protection of large portions of the Earth's surface (habitat conservation) for the purpose of conservation of biodiversity by restricting further expansion of the settlement areas or land used for agriculture,
- furthermore, the increasingly emerging water scarcity (World Bank, 1992a) as well as
- in some case the limited reserves of fossil energy sources. It must not be overlooked, however, that the thesis of the limiting effect of finite energy reserves is expressed rather cautiously today.

On the emission or waste side they include

- the limited *absorption capacity* of the atmosphere for greenhouse gases (see 1.1.1), the most important being carbon dioxide, methane, nitrous oxide and, in part, nitrogen oxides (Enquete Commission, 1990a),
- the thinning of the ozone layer due to emissions (see 1.1.2), with special emphasis on chlorofluorocarbons,
- soil degradation due to emissions and farming (see 1.4), which has the long-term effect of reducing arable land and destroying biotopes, as well as
- in part, water pollution (see 1.3), which overtaxes the self-cleaning capacity of existing water bodies.

As far as the bottlenecks of the emission or waste side are concerned, they inevitably placed the focus of analysis on renewable resources. More and more, it was realised that the natural environment represents a kind of "production system" that produces goods and renders services (such as the disposal site function) which are useful for society. These services are offered without any human action and are not adequately taken into consideration in our economic accounting, despite their beneficial effect (Klemmer, 1987). The assets of this natural "production system", not explicitly shaped by people, develop spontaneously and are extensively oriented to the recycling principle. They are usually interpreted as production or yield, regulation, disposal and habitat services (SRU, 1985). While removals from and inputs into the natural environment were, in the past, substantially compensated for by the latter through its spontaneous capacity, there is widespread agreement today that the capacity of the natural production system to renew itself is questionable in many areas. If one assumes a complementary relation between the natural and the people-made production system of the economy, in other words, given that real ecological capital cannot be replaced by real "artificial" capital created by human beings, bottleneck effects are theoretically possible which can threaten stable economic activity in the long run. If, namely, the capacity of the natural production system is no longer available – and that is the basic message of most world models – a collapse may occur with irreversible consequences, i.e. possibly a new ecological balance, for example, but at a significantly lower ecological carrying capacity level. In the end this would imply a societal welfare loss.

One question that arises in connection with such an analysis is the degree to which the ecosystem can cope with extraction, but especially with emissions (wastes), without losing its spontaneous capacity. This inevitably leads to the further relevant question as to which growth or development paths can be regarded as ecologically stable or *sustainable*.

The, for the most part, highly aggregated "world models" available to date furnish a number of important references to this central question, but no definitive answer as yet. Such models attempt to examine the Earth System as a whole and to determine to what extent the most important sources and sinks change as a result of energy and material flows. In particular, they have shown that exponential population and economic growth does not enable sustainable development (Meadows, 1974; Meadows et al., 1992).

Whereas earlier world models do not adequately take global environmental problems into account, a new generation of "integrated models" places the focus of analysis on the interplay between environment and development ("World 4", personal message from Meadows; "IMAGE 2", Rotmans, 1990). An attempt is also made to provide a higher geographical resolution, i.e. a "regionalisation" of economic and ecological interaction on this planet. The extent to which it is possible to go beyond that and include innovative processes as well as price- or income-induced changes in behaviour appropriately remains open.

Existing models can essentially do two things:

- Sound out the consequences of different long-term scenarios regarding possible, but not predictable future developments.
- Short-term forecast of global dynamics on the basis of extrapolated trends and substantiated or presumed "economic laws".

These models frequently use extrapolations from empirical studies, e.g. growth expectations, as input variables or are oriented to parameters derived from targets, e.g. ensuring a minimum nutritional level for the population in all regions of the world.

Given the special features of the economy, the demands on good "world models" can be summarised as follows: regionalisation as well as sectoralisation of the model studies are urgently needed. Furthermore, it appears necessary to use an approach that takes better account of the learning capacity and adaptability of social systems and of their self-organisation processes. In particular, development and impacts of institutions must be looked at more closely.

### *The regional structure of world economic growth*

A regional analysis of world economic growth as a cause of global change is necessary, especially since

- pronounced regional differences exist concerning the above addressed "carrying capacity" of the natural environment which suggest regionally divergent profiles of environmental assets requiring protection,
- people's environmental preferences possibly diverge, depending on the socio-cultural environment and the level of economic prosperity achieved,
- comparable economic activities or demographic development processes vary from region to region in their impact on global change, based on regionally different environmental conditions,
- large-scale interlinkage of emission-immission effects exists, characterised by spatial separation of causal agents and those affected and requiring international agreements on environmental policy coordination with regard to the environmental problems hereby induced, and
- profound differences emerge in the spatial distribution of global economic growth and the prosperity effects induced by this and exert an influence on environmental consciousness, the willingness to take environmental policy action as well as options for environmental policy reaction, thus holding consequences for recommendations for political action as well.

The importance of a regionalised view of a development process can be shown clearly on the basis of population development. For example, it is of decisive significance for an analysis of the expected impact on global change to know how the currently forecast increase in the world's population of 3.7 billion people during the period from 1990 to 2030 will be regionally distributed. If it is concentrated in areas with a high population density, for example, urbanisation problems will grow; if it takes place in areas with a limited area of arable land, on the other hand, a mobilisation of marginal land may occur, followed by soil degradation or irreversible destruction of ecologically valuable land. If it takes place in underdeveloped regions, it may accelerate the process of economic impoverishment, while in highly developed regions one can expect an acceleration of economic growth. In view of the fact that this population growth has, indeed, a very unequal regional distribution, a geographically differentiated analysis is necessary: 90% of this population growth will, in all likelihood, be concentrated in the developing countries, with possible increases in the coming four decades from 500 million to 1.5 billion in Black Africa, from 3.1 to 5.1 billion in Asia and from 459 to 750 million in Latin America (World Bank, 1992a; UNDP, 1992).

Population development and economic growth do not run parallel, however. Rather, for reasons that will be explained below, it can be assumed that these processes will sharply diverge geographically, resulting in special global environmental problems. To illustrate this better, countries will be divided into groups, taking into account extensive results from developing country research, in such a way that the global interrelations focussed on in this Report are defined more precisely and a basis can be provided for political recommendations. Rough differentiation criteria here include population development and density, level of economic prosperity achieved, economic development perspectives, globally relevant interest positions, global functions and the feasibility of environmental policy measures. According to these, one might make the following distinctions:

### *Group 1: The highly developed countries or economic world centres of gravitation*

This group can roughly be characterised by the OECD members (the "Organisation for Economic Cooperation and Development" comprises: Australia, Belgium, Denmark, Germany, Finland, France, Greece, Great Britain, Ireland, Iceland, Italy, Japan, Canada, Luxembourg, New Zealand, the Netherlands, Norway, Austria, Portugal, Sweden, Switzerland, Spain and the United States). From a global point of view, they are certainly the main emitters of pollutants and greenhouse gases. The core of this group, especially with regard to its influence on world economic activities and its role within the scope of UNCED, is composed of the G-7 countries (in alphabetical order: Canada, France, Germany, Great Britain, Italy, Japan and the U.S.), though more strictly speaking just the G-5 countries (France, Germany, Great Britain, Japan and the U.S.). Thus Germany has special significance in the context of dealing with global environmental issues.

These countries are currently the focus of the triad formation described in more detail below and are referred to as highly developed because they not only possess an above-average per capita income and a corresponding degree of social and political consciousness, but are usually also characterised by stable political conditions, an extensive environmental legal system with regulations that are enforceable by virtue of a functioning administrative system (few implementation shortcomings), and can afford a high level of technical environmental protection (such as a well-developed infrastructure for supply and disposal) on the basis of its affluence.

Despite all the current economic problems, their prospects of future growth can also be regarded as good (UNDP, 1992). Prior to UNCED in Rio de Janeiro, however, it became apparent that the G-5 countries show little inclination to make firm pledges as to the extent and time of increased development aid. Their position on the question of debt relief is one of restraint, and they tend to have little interest in the establishment of new world institutions.

The countries of this group develop a considerable gravitational force. They are especially important for economic development of the developing countries as importers and exporters in that these countries are frequently in a position of dependence. An increase in the growth of the OECD countries of 1% over three years, for example, triggers an annual rise in exports of US$ 60 billion in the developing countries (World Bank, 1992b). A weakening of growth in this group of countries or a protectionist policy usually affects the states of the other groups overproportionately.

The developed states are the starting points of new technological developments. They thus possess the majority of property rights to new products and production processes and play an important role with regard to technology transfer.

Moreover, these countries are often able to handle economic activities to which the environment reacts sensitively (such as power generation based on nuclear energy or chemical production) in an efficient manner by virtue of their control mechanisms (government agencies, neutral monitoring institutions, public opinion) and are, to a great extent, the starting point for new product life cycles, production methods and thus new environmental technologies. In addition, they are responsible for global environmental problems in a different way than the developing countries (World Bank, 1992a). The main role with regard to the global aspects of pollution is played by carbon dioxide, carbon monoxide, nitrogen oxide and sulphur dioxide emissions, the destruction of the ozone layer of the stratosphere by CFC depositions, photochemical smog and hazardous wastes. The latter are of global significance when they are transported to other countries with problematic disposal sites.

### *Group 2: The Eastern European countries*

Concerning the magnitude of production, these are still economically important nations. They may soon drop out of the group of developed countries, however, because of the transformation of their economic systems, the obvious efficiency problems of their economies as well as the disintegration of their politically isolated economic zones.

The majority of them are characterised by a below-average degree of environmental consciousness and, in comparison to the highly developed regions, by deficient environmental protection, i.e. by very great emission reduction potential as compared to the countries of the following groups.

Up to the beginning of this decade these states took a rather negative position towards climate policy resolutions, sometimes in agreement with the U.S. In the preliminary negotiations on UNCED most of the countries in this group pursued the goal of being exempt from the emission limits of the industrial countries as states with transitional economies and of laying claim to having the status of developing countries (Czakainski, 1992). For the time being, these nations will be ruled out as financial donors within the framework of global development aid.

As a result of the achieved level of national value added, with a high share of industrial production, in connection with deficient technical environmental protection, the countries of this second group number among the world's main emitters of $CO_2$, $SO_2$ and CFCs and thus share responsibility for many global environmental problems. At the end of the 80s, for example, roughly a third of all global $CO_2$ emissions came from Eastern Europe, including the then Soviet Union (RWI, 1993). According to initial assessments, air pollution problems, followed by water pollution, represent the largest burden from the past (Hughes, 1992).

In view of the current economic problems as well as those to be expected in the medium term in these nations, it is to be feared that without help from the outside the urgently necessary establishment and expansion of technical environmental protection (e.g. modernisation of power stations) and thus mobilisation of a substantial potential for reducing emissions of air pollutants will not take place.

### *Group 3: The newly industrialising countries*

These are countries for which the highest growth rates are expected in the coming years in comparison to the world average and even in relation to the highly developed nations (World Bank, 1992b). Since most of them are, at the same time, still characterised by high population growth rates and, in some cases, already have a high population density, they are especially important in the context of global change.

In the Pacific region of Asia this group of newly industrialising countries includes the four "old tigers", i.e. Korea, Taiwan, Hong Kong and Singapore as well as the "new tigers", Malaysia, Thailand and Indonesia; outside of this region the countries of Argentina, Brazil and Turkey, in particular, belong to this group (World Bank, 1989; IMF, 1989).

What is characteristic of these newly industrialising countries is that the proportion of directly productive investments in relation to national income – the most important criterion for an economic upswing – increased sharply in recent years, resulting in vertical diversification of the production structure combined with an overproportionate increase in interindustrial networks; with the exception of capital goods, this frequently enabled substitution for import products and resulted in exportable production surpluses. The export structure shifted away from intermediate goods produced at specific locations towards industrial articles that can be produced with standard technologies; in many cases it was even possible for countries to build up their own key sectors (Milton, 1990; World Bank, 1992b; UNDP, 1992).

In some cases environmental relief was able to be provided in the newly industrialising countries through the sectoral transformation just described. Of greater relevance, however, is the fact that the newly developing key areas (e.g. microelectronics) usually place high demands on the location and thus on environmental quality so that greater importance is gradually being attached to technical environmental protection, particularly for the newly industrialising countries in the Pacific seaboard of Asia.

Economic development in this group of countries led indirectly to substantial productivity increases in agriculture and thus to an expansion of the food base.

The main problems in these countries are those related to urbanisation, expansion of settlement areas, toxic industrial waste disposal as well as rapid increase in the volume of traffic.

### Group 4: The fuel-exporting countries

This a very heterogeneous group of countries whose oil and natural gas exports account for at least 50% of its exports of goods and services (World Bank, 1992a). They include, in particular, Algeria, Angola, Iraq, the Islamic Republic of Iran, the Congo, Libya, Nigeria, Oman, Saudi Arabia, Trinidad and Tobago, Venezuela and the United Arab Emirates. The major countries of interest here are the OPEC states, whose oil exports make up 75% of their export earnings on average (Schürmann, 1992).

These countries owe their affluence primarily to the great foreign exchange earnings they obtain from the export of a resource that is becoming increasingly scarce and is, up to now, hardly replaceable. In comparison to other exporters of raw materials, they have managed to push through advantageous prices via cartel strategies (OPEC Cartel). This is why they show little interest in measures to restrict and increase the price of consumption of fossil fuels. In their Vienna Communique (1991) they decisively spoke out against growth-limiting considerations and rejected the proposals for reduction of $CO_2$ emissions.

In these countries one frequently finds a concentration on the oil-processing and chemical industry which is not always oriented to the environmental standards of the highly developed countries. In many cases these countries are faced with the economic and environmental problem of "growth without development", at the expense of the environment. Some countries have, therefore, squandered their development opportunity and are slipping more and more into the group below.

### Group 5: The developing countries

This is, again, a very heterogeneous group of countries which are all still characterised by underdevelopment. In this situation they are both causal agents and victims of global environmental problems. Thus 36 states, particularly Pacific island states that hardly contribute to greenhouse gas emissions, but fear the negative consequences of climate change (rise in sea level) because of their island situation and geographical location, have joined together to form the Alliance of Small Island States (AOSIS). They call for an international climate fund and actively support the establishment of an international insurance system for climatic effects. Another group comprises the G-77 countries and China, whose main demand is for development aid and free technology transfer. China, India and Brazil, for example, often utilise the potential ecological threat posed by their situation as a means of leverage to push through their demands. The majority of them speak out against a substantial obligation to limit greenhouse gas emissions (see the Kuala Lumpur Declaration signed by 55 states prior to UNCED). This applies to both India and China, which possess the world's largest coal deposits.

In this group it is particularly the "least developed countries" that are faced with the biggest problems. They are not only increasingly cut off from the trend of world economic growth, but are also characterised by a kind of "development crisis" or "growth in poverty and its consequences" (Nohlen and Nuscheler, 1992a), i.e. by a considerable concentration of disease, illiteracy and malnutrition (Sachs, 1989; Nohlen and Nuscheler, 1992b) or a "vicious circle of poverty" (Stucken, 1966). Life in these countries is often a question of sheer survival, which usually means neglect of long-term oriented environmental protection considerations. The population is growing rapidly as life expectancy increases – though it is still lower than that in the countries of the first group, mainly because of the high birth rates. In the field of environment there is frequently a low degree of social and political consciousness and a lack of money for technical environmental protection. Since the administration does not function efficiently, control and implementation problems usually exist, even if the legal framework for environmental protection is expanded, thus making the application of institutional regulative instruments almost impossible. Frequently state-owned enterprises are generously exempted from environmental requirements.

The most pressing environmental problems in these countries are essentially contaminated water, inadequate sanitation facilities, overexploitation of soils, smoke from fireplaces in houses and emissions from the use of wood and coal (World Bank, 1992a). In contrast to the highly developed countries, a direct threat to human life and regional concentration of these problems prevail here – such as in the rapidly expanding big cities.

From a global point of view, the destruction of ecosystems requiring protection (e.g. tropical forests), caused by population growth and underdevelopment, soil degradation induced by maladapted agricultural technology as well as the danger of epidemics due to the catastrophic hygienic conditions play a great role. At the beginning of the next century the least developed countries will account for one-fourth of the global $CO_2$ deposition, primarily stemming from households, small businesses and transport (RWI, 1993).

Economic growth and development of trade relations within and between these five groups diverge significantly. In all likelihood this will continue to hold true for the future. For this reason, the causes of global change are also tending to move apart. One obvious development during the post-war period – especially in view of the spatial interlinkages between the flow of capital and goods – has been, for example, the formation of three gravitational centres, recently described as the *development triad*. Thus for some time now

- the relatively solid European trade block (12 EU countries, the 3 Scandinavian countries, Switzerland and Austria), currently expanding into the eastern part of Central Europe, as well as
- the three North American countries of Canada, the U.S. and Mexico (NAFTA) as the second block
- are increasingly being joined by a not yet very solid Asian block, including Japan, Korea, Taiwan, Hong Kong, Singapore, Malaysia, Thailand and Indonesia.

The extent to which China and India can catch up to this last block as potential newly industrialising countries is still open. Since they are both very highly populated countries striving for industrialisation and, in this process, making use of their enormous fossil fuel reserves, their development will be of significance to global change with regard to relevant emissions.

Today, however, there is widespread agreement that the three gravitational centres just described, including the newly industrialising countries, will be a major determining factor for world economic growth over the next ten to twenty years (World Bank, 1992b), and their growth will, to a great extent, have a decisive influence on the economic expansion of the other groups as a result of the existing economic dependencies. As demonstrated by development in recent years, a weakening of growth in these three large gravitational centres often leads to a relatively serious economic setback in the other groups. Thus in comparison to the 80s the currently emerging economic growth risks in important countries of this triad represents a rather gloomy medium-term outlook for the least developed countries, combined with the danger of a revival of protectionism. From an environmental policy point of view this poses a dilemma as declining growth rates incite resistance on the part of the economies of the highly developed countries against stricter environmental requirements and there is no relief for the environment induced by economic growth in the other groups. The latter applies above all to group 5, as will be shown below.

At present it is virtually impossible to venture a forecast for the difficult-to-classify new group of Eastern European countries (Borenzstein and Montiel, 1992; World Bank, 1992a). A certain degree of pessimism tends to prevail at the moment. This presents a problem in that this group of countries numbers among the major emitters of globally harmful substances (at the end of the 80s, for example, one-third of all global $CO_2$ emissions) and emissions could be drastically reduced via modernisation of antiquated real capital – such as to increase the efficiency of power stations. Whereas 2.2 t of carbon was emitted in Western Europe and Japan per capita and annum in 1989, the corresponding figures for Eastern Europe were 2.9 t, for the former USSR even 3.7 t ($CO_2$ figures: *3.67). While merely 4.2 gigajoules (GJ) of fuel and a little less than 1.3 GJ of electric power were consumed to manufacture products having a value of US$ 1000 in Japan at that time, the Eastern European states required nearly eight times as much energy to achieve the same production output (RWI, 1993). Therefore, if it were possible to bring these countries up to the level of efficiency and environmental standards that has been reached in Japan or Western Europe – and only then will necessary modernisation of the antiquated real capital stock take place – this might already lead to significant ecological relief.

The latter would be tied to several consequences for the least developed countries and thus for global change as well, though major distinctions have to be made within this group as far as the current level and trends of development are concerned (World Bank, 1991 and 1992a; UNDP, 1992). Starting from the status at the end of the 80s, the largest portion of truly poor countries with an annual income of less than US$ 370 was in Southeast Asia as well as Black Africa, where half the population fell into this category as compared to 20% in East Asia and Latin America (World Development Report, 1990, 1991 and 1992; Walton 1990; Summers, 1992; UNDP, 1992). This means that even today over a billion people have to live on less than a dollar a day – a standard of living that Western Europe and United States had reached, statistically speaking, about 200 years ago (Thomas, 1992; World Bank, 1991 and 1992). Rural areas are hardest hit by poverty, which explains the massive migration to cities and in its wake the accelerated process of urbanisation.

As far as the decline of poverty is concerned, obvious progress has been made in recent years – when viewing these countries in their entirety – and, contrary to some claims, the 80s were by no means the frequently quoted "lost decade" (Karaosmanoglu, 1991). Over the last 25 years the majority of countries of the former Third World have, indeed, been able to record positive development – based on per capita income, expansion of food production (Osten-Sacken, 1992), increase in life expectancy as well as the lowering of infant mortality (Summers, 1992; World Bank, 1991 and 1992a). If one ignores Bangladesh, Laos, Nepal, Pakistan, the Philippines, Sri Lanka and Afghanistan, this particularly applies to the poor countries in South and East Asia (Walton, 1990; Summers, 1992; World Bank, 1991 and 1992a). The above-average growth in the rapidly industrialising countries of Korea, Thailand, Malaysia and Indonesia in comparison to all developing countries is especially striking here. If the forecasts of the World Bank turn out to be accurate, therefore, then the share of world poverty in Asia, where roughly half of the world's 5 billion people live today, could definitely drop from 72% (1985) to approximately 53% by the year 2000 (World Bank, 1990).

A fact that cannot be ignored, however, is the advent of ecological problems in Asia in view of the high population growth – roughly 35% are younger than 15 years of age – as well as of the already high population density, particularly in the wake of this expected population and economic growth (see 2.1). Thus approx. 354 people currently use a square kilometre of arable land in Asia (excluding Pakistan), as compared with 55 people in Latin America, 58 in the region south of the Sahara and 116 in the Near East and North Africa. In Bangladesh the figure is over 1000 inhabitants per square kilometre of arable land (Karaosmanoglu, 1991). Regional differences within these countries were not taken into account here, though they may become increasingly significant in the future. This is especially true if one takes into consideration future population development – growth from 3.1 to 5.1 billion – in this region. It is expected today that by the year 2025 more than 50 cities will have over 4 million inhabitants, as compared to roughly 20 at present (Karaosmanoglu, 1991). In Bangladesh the population density may rise to the almost inconceivable figure of 1700 inhabitants per square kilometre (World Bank, 1992a; in comparison to the Ruhr area with a figure of just under 1200 inhabitants per square kilometre at the end of 80s; KVR, 1989).

In spite of future economic prospects that sound positive to many developing countries, there will, in all probability, be no decisive changes in the existing North-South Development Divide over the next few years. One-fourth of all developing countries even run the risk of experiencing a decline in development (Thomas, 1991). At the end of the 80s, for example, there were already 40 countries that had fallen below the level of development they had reached 25 years ago. This figure will possibly increase in coming years rather than decrease. A source of worry can be found in several countries of Latin America, but particularly in Black Africa[4], where an almost uncheckable development disaster seems to be imminent south of the Sahara (Walton, 1990; Broeckh, 1992). In the mid-80s nearly half a billion people lived here, with a gross national product only corresponding to that of Belgium with its 10 million inhabitants (Landell-Mills et al., 1989). At the end of the 80s some of these African countries had a per capita income that was less than what it was at the time they became independent over thirty years ago; in many of these countries even the daily supply of calories per capita declined (Easterly, 1991).

For this reason the World Bank also assumes that the proportion of poverty in Africa may increase from 16% in 1985 – a figure already corresponding to 85 million people – to roughly 32% by the year 2000. Another cause for worry is that food production will, in many cases, not be able to keep pace with population growth. Should the population "nightmare scenario" worked up by the UN Economic Commission at the beginning of the 80s turn out to be accurate, one would have to reckon with a doubling of the population in Black Africa every 23 years (Landell-Mills et al., 1989). What is depressing about these figures is that it would still be possible to cope with such a growth in population, as far as the food base is concerned. Thus according to the calculations of experts in large sections of Africa, there would still be sufficient land available to achieve the growth in African agriculture necessary to feed the population (presumably 4%), even with conventional agricultural technology, given adequate development of the transport infrastructure, solution of logistical problems, including stockkeeping, and liberalisation of the price and sale systems (Ali and Pitkin,

[4] The term Black Africa refers, as a rule, to the countries south of the Sahara, excluding South Africa.

1991). It would only be problematic in Nigeria, Ethiopia and Kenya (FAO, 1984). However, all signs indicate that this potential cannot be utilised.

This failure in combatting poverty in Black Africa is attributed, in particular, to neglect of the agricultural sector. The situation has been additionally aggravated by insufficient investment in schooling, a problematic industrialisation strategy in past years, a worsening of the *"terms of trade"* in the second half of the 80s (Nsouli, 1989; Summers, 1992), rising budget deficits, frequently accompanied by a relatively high proportion of military expenditures (Hewitt, 1991), a growing foreign debt burden (Summers, 1992), a deterioration of those institutions responsible for maintaining political and economic stability as well as a spread of armed conflicts (Walton, 1990; Summers, 1992). In part, a series of drought periods in the 70s and 80s played an important role, mostly affecting East and South Africa.

Particularly among the group of *"least developed countries"*, it is strikingly evident that environmental destruction is often the cause and consequence of poverty and the development crisis. If one takes into account, for example, that the relevant environmental consciousness of individuals, society or politicians for taking ecological action is co-determined by factors related to development, or that population development moves inversely to prosperity development, then it becomes evident that economic development can also trigger positive environmental impact. A regionalised analysis of world economic growth development is indispensable with regard to research into causes as well as regarding the aspect of recommendations for action.

### *The sectoral structure of world economic growth*

From a scientific point of view, there have been, even at the national level, very few satisfactory answers so far to the question concerning the extent to which the perceptible change in sectoral structure, particularly in industry, can contribute to increasing or reducing environmental stress. In Germany analyses in this field have mostly been conducted on the reporting of structural transformation (Graskamp et al., 1992); at the international level, however, such analyses are rare. Especially with respect to the thesis that the transformation of an industrial society into a service society is bound up with "free ecological benefits", differing views still exist. There are different reasons for this.

First of all, even in the highly developed nations it is by no means certain that there is an uninterrupted trend towards service economies. More recent forecasts for Germany, for example, definitely indicate a phase of slight "re-industrialisation" (RWI, 1993). From a global point of view, however, further industrialisation will be inevitable. Moreover, it must be taken into consideration that, under certain conditions, many areas in the tertiary sector (service sector) may be linked to significant environmental stress. This includes major service sectors, such as transport or tourism. The possible relief effect through intersectoral structural change can, however, be offset by possible stress effects of intrasectoral change. This is then the case, for example, when the networking of different production stages becomes more complex and induces additional traffic along with a globalisation of markets and an internationalisation of production. Regional relief effects (e.g. environmental relief of the Ruhr area through decline of the coal and steel industry) may therefore be accompanied by national or global stress effects.

### *The role of the primary sector*

Special importance must be attached to the role played by the agricultural, forestry and fishery sectors in global environmental change. This importance is, in part, already expressed in the chapters on water, soils and forests, but it cannot be treated exhaustively in this Report. The future task of the Council will consist of analysing the role of the primary sector in further Reports. This analysis should include the basic principles currently being worked up by the Enquete Commission for Protection of the Earth's Atmosphere.

Both in developing countries and in the more highly developed nations the primary sector is closely tied to global changes. In the former the main sources of concern are the expansion of farmland, pasture land and irrigation areas at the expense of other ecosystems as well as the overexploitation of pastures and forests. In the case of the latter countries, problems are caused by the mechanisation and use of chemicals linked to intensive farming methods. In both cases three overriding questions can be formulated with regard to sustainability.

1. To what extent will sustainability and productivity of cultivated farmland, pastures and forest areas be impaired by the use strategies applied in different regions and by their socioeconomic control?

2. To what extent do changes in the physical and chemical climate influence the usability and productivity of the cultivated farmland, pastures and forest areas (key phrase regarding 1 and 2: Sustainable Land Use)?

3. To what extent are the cultivated farmland, pastures and forest areas sources of stress for neighbouring (terrestrial and aquatic) ecosystems as well as for the ground water and atmosphere (key phrase: Environmentally Sound Land Use)?

Productivity is significantly reduced by the degradation processes described in the chapter on soils. In regions with a high precipitation level, for example, the temporary exposure of the soil surface resulting from harvesting, grazing or fire considerably accelerates erosion by water. This process is reinforced if such activities are accompanied by soil compaction. In regions with strong winds or storms, as is frequently the case in arid regions, degradation of soil cover leads to wind erosion. Examples of this can be found in all parts of the world, though there are great regional differences. Negative factors in the more highly developed countries include the trend toward large sections of farmland and the uniform cultivation associated with them, the use of extremely heavy machines, non-adapted cultivation methods and a shift from crop rotation to monocultures. Examples of such factors in the developing countries are uncontrolled expansion of farmland and pastures at the expense of forests, overgrazing of grasslands with little productivity as well as the use of inappropriate cultivation techniques.

Chemical degradation consists of, first of all, depletion of nutrients in agricultural and forestry ecosystems. It results from leaching, burning and export of biomass. This form of degradation frequently occurs in the developing countries as money for fertilisers is often not available. The opposite is true of many highly developed countries, where overfertilisation leads to stress on neighbouring systems. In particular, dissolved ($NO_3^-$) and gaseous ($NH_3$, $NO_X$, $N_2O$) nitrogen compounds must be mentioned here (see 1.4). In industrial countries and urban agglomerations additional local and regional stress stems from acids, toxic substances like heavy metals and organic substances that are toxic for people and ecosystems. These kinds of soil degradation along with the homogenisation of plant stands resulting from increasing intensive farming methods and ranging up to genetically uniform sorts lead to a reduction in biodiversity. The related decrease in stability and renewability of ecosystems can then only be reached with an increased utilisation of energy, fertilisers and pesticides. Efforts must be undertaken here to optimise land use with the aim of reducing the input of energy and material.

In contrast to natural and forestry ecosystems with long turnover periods, agricultural ecosystems are more adaptable with respect to the expected climate change. By selecting existing species and types of plants, growing new types and applying suitable forms of cultivation, it is possible to react to change flexibly. There are limits to the possible adjustments, however. As far as provision of nutrients and water supply are concerned, marginal locations can only be maintained through amelioration or irrigation measures, though they frequently have to be abandoned for economic reasons.

The rise in $CO_2$ concentration may signify fertilisation for agriculture. Since the other yield-producing factors are optimised in agriculture, significant effects can be expected here. The extent to which natural ecosystems react to this (growth, shift of species) is still extensively an unknown factor, a situation which also applies to the world’s forests (see 1.5).

The specific features of agriculture can only be assessed with regard to environmental policy against the background of a spatially defined natural balance (see 1.5) (SRU, 1985). In view of the importance and sensitivity of ecosystems in the tropics, the region with the largest population growth, this fact must be given special attention.

Agriculture and forestry are not only affected by global environmental changes but are also causal agents. They contribute to the emission of trace gases through deforestation (see 1.5.1) and the transformation of land use (see 1.4), through release of methane from rice farming and the stomachs of ruminants, through release of $CO_2$ stemming from decomposition of organic substances in the soil as well as through release of nitrous oxide from greatly fertilised agroecosystems (see 1.4). The substances deposited from ecosystems used for agriculture and forestry may pollute ground water and surface water bodies in dissolved form (nitrate, pesticides, heavy metals) or settle in particle form in rivers, lakes or shallow seas. These neighbouring systems may undergo great change in their characteristics in this way.

From these examples it is not only evident that identical economic activities under diverging natural conditions must be assessed differently with regard to their global effects (destruction of tropical forest, desertification, etc.) (Guppy, 1984), but it also becomes clear that many global environmental effects are a consequence of maladapted agricultural technology. Thus, defined on the basis of area, the scope for agriculture use of the Earth's surface is limited, though substantial opportunities still exist as far as biological, technical and organisational progress is concerned (Revelle, 1976).

### *The role of the secondary sector*

The elaborations on agriculture showed how important a differentiating analysis or a simultaneous consideration of regional aspects are. This also applies to the environmentally significant secondary or industrial sector, for which high growth rates are expected in the developing countries. Such a development is linked to high investment needs, which – in the event that sufficient funds are available – make it possible to implement integrated environmental protection. It is assumed, for example, that new equipment will provide for more than half the industrial production in the developing countries in roughly ten years and will, for all practical purposes, be responsible for the entire production in twenty years. In contrast to the industrial countries, therefore, the influence exerted on new investment will be more important than retrofitting existing facilities.

In the developing countries there will be an expansion in power generation which, according to recent studies of the World Bank (World Bank, 1992a), however, could certainly be achieved without any significant increase in pollutant emissions, provided that consistent reforms to increase efficiency are implemented, measures to lower pollution are taken and the necessary funds are provided. The efficiency of power generation still varies greatly, depending on fuel use and country groups. In the case of coal in 1990, for example, the figure for OECD countries was 38.2%, in Western Europe 40.5% and in Japan 44.2% while only 28% was reached in Eastern Europe, 29% in Africa, 31.4% in Latin America and 32.4% in China (RWI, 1993). The divergences in the utilisation of gas are even higher, and are also high in the case of oil.

If one defines the negative environmental impact stemming from the individual economic sectors via selected pollutant indicators (e.g. their proportions of the total $SO_2$, $NO_X$ and $CO_2$ emissions as well as the accumulation of sewage and waste), ten sectors stand out in Germany, as well as in other countries. They consist of energy and water supply, mining, oil processing, non-ferrous metal production, the chemical industry, the iron and steel producing industry, cellulose, paper and cardboard production, foundries, wood processing and the non-metallic mineral sector (Graskamp et al., 1992). It can be demonstrated that these sectors have contributed significantly to pollution of air and water as well as to waste accumulation and were, therefore, the starting point for environmental policy measures. Should it turn out in the course of time that these sectors – especially with respect to their production volume – decline in absolute or relative importance, one certainly could refer to a environmental relief effect caused by structural change.

On balance such relief has, indeed, taken place in most highly developed countries because of the development-related structural transformation and has been particularly visible regionally (such as in the Ruhr area). Generally, however, the relief effect achieved through lowering of the sectoral emission coefficients has, thus far, been greater than those of the structural change effects. "Additive" environmental protection in the form of *"end-of-the-pipe solutions"* played a special role in this context. However, it necessarily involved an additional cost expenditure for the operator. In the case of production-integrated environmental protection, on the other hand, it is possible to keep the costs for reduction of emissions minimal or even to lower manufacturing costs via optimisation of the process flow (Lipphardt, 1989). In the future it can expected that integrated environmental protection or the environmental relief effect brought about through structural change will play an increasing role.

For the developing countries comprehensive studies on these issues are still rare. It is coming to light, however, that greater industrialisation there is connected with three problems in particular (World Bank, 1992a):

- Short-term increase in emissions in existing industrial enterprises with low environmental technology standards,
- expansion of industrial cities, leading to aggravation of local and regional pollution as well as urbanisation problems as industrialisation attracts people, and
- changes within the industrial structure, away from activities that result in moderate pollution (manufacture of textiles, wood products and food processing), and towards other activities with higher pollution potential (metal and chemical industry, paper production).

Also of importance for global environmental change are the interactions between sectoral and regional development tendencies of the individual country groups. The economic structure of a region or nation is not only decisively influenced by the growth of the observed unit itself, but above all by the type and development of interregional or international division of labour. Within the framework of the international division of labour, which is in turn co-determined by economic and political power structures, basic institutional conditions (e.g. world economic order, trade agreements or contractual creation of economic zones, etc.), protectionist measures of the large economic blocks, etc., specialisation processes result which have an effect on the environment of these countries as well as on the global environmental conditions. These questions are becoming more and more important in connection with the discussion over the basic institutional conditions of world trade (UNDP, 1992; World Bank, 1992b) and touch upon, in particular, the current debate within the scope of the Uruguay Round and reform of the General Agreement on Tariffs and Trade (GATT).

Reference will be made here to several interrelations. For example, global environmental problems may arise if export of “dirty industries” to the least developed countries takes place in connection with the structural transformation in the highly developed countries. This may occur via direct geographical transfer (of a production site, for example) or via increased investments in developing countries, and becomes problematic if these countries are less suitable for such developments because of their environmental circumstances and basic institutional conditions (problem of control and implementation shortcomings). Thus, thanks to the restrictive requirements of environmental legislation, higher environmental standards and fewer implementation deficiencies, chemical production (e.g. of products of the chlorine complex) in Germany may proceed in a much more environmentally sound way than in Brazil, where in 1984/85, for example, extremely high immission values were recorded with grave consequences for the local population in Cubatao near Sao Paulo due to the spatial overlapping of emissions from production plants of the steel, chemical fertiliser, petrochemical and cement industries – where particularly state-owned enterprises played an unpleasant role (World Bank, 1992a).

World trade and its basic conditions may also have an effect on the global environmental situation (Siebert, 1974; Bender, 1976; Walter, 1975; Gronych, 1980). An empirical and theoretical-analytical examination of this complex structure is still at an initial stage and should be intensified. The specific role of multinational enterprises in technology transfer, for example, as well as the negative reactions of the increased protectionism of industrial countries must be looked at more closely.

The question of how to assess international division of labour with regard to global change is being given more and more attention. Some empirical analyses in this context are already available. They are directed at, among other things, “exported environmental stress” via environmentally sensitive goods. In a comparison of 109 countries at the end of the 80s this resulted in an average level of “exported environmental stress” in environmentally intensive sectors for Germany, an extremely above-average level for the Soviet Union and Brazil and a significantly below-average figure for Japan and most newly industrialising countries (Low and Yeats, 1992). On the basis of this research work, one can also detect, with some caution, a trend towards transferring environmentally problematic production sectors to the less developed nations. In some cases it is referred to as “industrial emigration”, in the course of which “dirty industries” are shifted to the least developed countries as a reaction to the shortage of environmental assets in the highly developed nations (Low and Yeats, 1992). Whether this was primarily a result of wage cost differences or of geographically relevant environmental protection regulations cannot be said definitively at present. This is also indicated by more recent studies for Germany (DIW/RWI, 1993). In any case, problems would arise if structural development of the least developed countries were to result solely on the basis of comparative cost advantages in “dirty industries” (Siebert, 1991).

This discussion is steering attention to the question of the ecological effects of world trade institutions (Kulessa, 1992), a topic which GATT is already concerned with and which focusses on “free trade and environmental protection” (Kulessa, 1992; Klepper, 1992; Petersmann, 1991). There is a prevailing fear that liberalisation of trade brings about negative regional and global welfare and environmental effects. Regional welfare effects may occur when – for reasons of market price or exchange rate developments and foreign exchange needs – the least developed countries have to export goods whose overall social and economic costs are higher than the social or economic value of the imports made possible by foreign exchange revenues (El-Shagi, 1991). Depending on the respective price elasticity, the more highly developed countries may be able to pass on part of the environmental costs to other countries, while conversely the least developed countries may be “forced” in the short or medium term to dispense with strict environmental protection in order to maintain their trade position.

### *The role of the tertiary sector*

The service sector in the highly developed countries will decisively shape global economic activity in coming decades. It is, therefore, all the more astonishing that even now little knowledge is available on the environmental implications of this trend at the national level. Partly this has to do with the heterogeneity of this sector, which ranges from trade and transport, insurance, consulting, federations, the educational and health system, non-profit organisations to the public sector. It is also due to substantial data deficiencies, a fact which particularly applies to the global level. For this reason one should initially remain cautious, as already emphasised in the introduction, with the hypothesis that development of the service sector has a positive environmental impact.

This becomes quite evident from a global point of view if one looks at two examples from this sector, transport and tourism involving long-distance travel. Both have gained increasing significance in recent years. As a result of shorter working hours, longer annual holidays and the rising number of old age pensioners, consumer travel activity on the part of many people is growing with simultaneously increasing income. In Spain, for example, the number of tourists rose by 50%, from 25 to 38 million annually, from 1986 to 1988. In Italy the flow of tourists during the same period jumped by 40%, from 25 to 35 million, and in Greece by more than 100%, from 7 to 16 million (Schneider, 1990). The causal factor behind this process is the desire for recreation as well as satisfaction of certain interests, such as viewing cultural and natural monuments. The recreational activities first mentioned are usually oriented to a specific infrastructure (hotel buildings, sports facilities, beaches, hiking paths, etc.) while the desire to experience nature, countryside, animals living in the wild as well as to see historical monuments plays an important role for the second category (Klockow and Matthes, 1990). As a rule, recreation-oriented mass tourism is concentrated in certain regions and places, sometimes resulting in profound alterations of the landscape because of the infrastructural preparations and the leisure-time activities themselves. Conversely, mass tourism reacts sensitively to information about deterioration of the landscape or of the quality of water and air. The reactions of tourists for whom the quality of the landscape or nature experience is the decisive criterion for their trip are even more sensitive.

This demonstrates the ambivalence involved in an assessment of long-distance tourism with regard to environmental aspects. On the one hand, it is the cause of severe environmental damage, which then takes on global proportions when it is accompanied by large-scale transport movements and destruction of the habitats of plants and animals. On the other hand, specific forms (ecotourism in Costa Rica and Indonesia) and the related economic effects may become the reason for increased interest in the conservation of primeval areas and biodiversity. Should greater environmental consciousness, i.e. an increasingly critical attitude on the part of the recreation-seekers as well as greater sensitivity to environmental damage, develop in the course of time, positive environmental effects may, indeed, result from such tourism. Therefore, it appears very important to examine and assess touristic activities with a discriminating eye, a task for a later Report.

### Effects

The previous sections made it clear that the economic subsystem represents a complex structure of interlinkages whose global environmental effects not only depend on its global input, production and emission or waste volume (world economy as a highly aggregated variable), but also on its regional and sectoral aspects. Furthermore, it became apparent that a sociopolitical concern lies behind economic activities, calling for exhaustion of all expansion options for several reasons (overcoming hunger and poverty, human striving for material independence and security, social security within an institutional framework, facilitation of distribution tasks to be performed), which will make any kind of problem-solving especially difficult. Finally, it was shown that poverty and environmental stress are mutually reinforcing, particularly in the least developed countries, and, there at least temporarily, economic development as well as environmental relief go hand in hand.

The material growth expected for these reasons must be examined with respect to the following aspects (Hartje, 1992):

- Implications for the ecosystem respectively restrictions on the resource side as well as limiting constraints imposed by sinks;
- estimation of the costs of practised environmental protection and actions not taken and of the benefits of environmental protection.

As far as the first complex of issues is concerned, the following factors, which may also mutually reinforce each other, play the most important role (Goodland, 1992):

- limitations in the production of biomass,
- risk of climate collapse,
- thinning of the ozone layer,
- soil degradation,
- loss of biodiversity as well as
- water pollution and water scarcity, above all important from a regional point of view.

The individual components are dealt with in detail below.

### *Limitations in the production of biomass*

For nourishment human beings require biomass, which in the view of advocates of a “bottleneck hypothesis” (Vitousek et al., 1986; Daly, 1992) is not indefinitely reproducible. Currently 40% of the net primary production of terrestrial photosynthesis is consumed by the human economy, and there is a danger that potential biomass production is even declining on a long-term basis due to desertification, decrease in arable land, fire clearing, erosion, etc. In view of population growth, one can assume in any case that 80% of the existing reserves will be exhausted in roughly thirty to forty years, and soon thereafter 100%. In this context, therefore, reference is made, in almost classical fashion, to an input component and a kind of ecological carrying capacity is defined, in particular for the acceptable number of people. For the most part it will impossible to influence this ecological carrying capacity.

Bottleneck hypotheses concerning biomass production appeared frequently in the course of history – one merely has to think of the ideas of Thomas Robert Malthus (1766 to 1834) – only to be questioned again by actual developments. The primary reason for questioning them was less the expansion of arable land than biological, organisational and technical progress in the area of agriculture production. In the view of many experts, lack of technology in semiarid regions represents a serious problem even today (Nelson, 1991). Scope for expansion of biomass production may be created by the application of low-cost techniques of moisture conservation – such as the combination of contour farming, which creates a comb pattern on the soil surface, and planting vetiver grass in the contours or the formation of stone rows. It has also been shown in recent years that many Asiatic nations turned from food importers into surplus producers through cultivation of high-yield sorts of rice or other types of grain requiring irrigation (Barghouti and Moigne, 1991). In Nigeria new methods of soil conservation were successfully introduced in cassava production, a significant feat in view of the 600 million people who subsist on this agricultural product (Blake, 1992). These and other examples do not yet provide sufficient proof to refute the biomass bottleneck hypothesis. They do demonstrate, however, that there is a chance for a less radical version allowing for the possibility of a broader food base in the developing countries.

### *The risk of a climate collapse*

Whereas population development, in particular, along with limited arable land is of central importance as a causal agent in the bottleneck components just described, the focus of the question regarding world climate is clearly on the consequences of a certain economic (throughput) growth, with special attention given to the limited absorption or assimilation capacity of our global ecosystem for certain harmful substances, i.e. the sink problem. The section on "Assessment" will go into detail concerning the question of whether this sink problem is adequate to make statements about the existing perspectives of growth.

The greenhouse gases altered by human societies are carbon dioxide ($CO_2$), methane ($CH_4$), ozone ($O_3$) and nitrous oxide ($N_2O$) as well as the chlorofluorohydrocarbons (CFCs). In the view of the Council, the critical absorption capacity has already been exceeded and there is need for action in view of the expected consequences.

Those responsible for the rise in $CO_2$ are known. It is known that, given current development trends, in the year 2000 roughly 35% of all $CO_2$ emissions will stem from Eastern Europe, approx. 25% from the developing countries and about 40% from the highly developed economies, the primary causal agents being households and small consumers in the least developed countries, power generation and industry in general in Eastern Europe and generation of electricity plus transport in the highly developed nations (RWI, 1993). Agricultural emissions contribute to the increased greenhouse effect worldwide with 15–17% (Armbruster and Weber, 1991; Burdick, 1991; Ashford, 1991).

The regional consequences are more difficult to ascertain. Already the determination of the direct effects for the environment in the event of a rise in the sea level is disputed, while the implications of expected shifts of climatic zones are even more difficult to predict. Special problems are posed by the translation of these effects into economic variables, i.e. into DM or dollars. In most cases, the problematic avoidance cost approach is used to calculate economic costs, ranging from 0.04% to 1% of the worldwide GDP (World Bank, 1992a; Masuhr et al., 1992). In any case there is further need for research here.

Problems also exist in connection with the damage cost approach. It requires above all pronounced regionalisation of the consequences. Only in this way is it possible to determine regional damage (losses of crops, income losses, reductions in productivity, etc.). In addition, there may not only be injured parties – such as in the case of a shift in climatic zones – but also beneficiaries. A balancing can hardly be permitted here, however. The question of how to assess migration effects is also open. They may take on large proportions, though many reasons indicate that highly populated developing countries will be especially affected. Finally, if one wishes to make a comparison with the results of the national accounting, a willingness-to-pay analysis would have to be employed (Junkernheinrich and Klemmer, 1992).

Since future consequences are involved here, the question arises as to the rate (discount rate) to be used to convert future net earnings into their present value. Cline (1992 and 1993) recommends a 2% discount rate, while other authors prefer a rate adjusted for inflation of 10% per annum. The lower the discount rate, the greater the possibility of a consistent climate protection policy. The Council does not consider an apodictic establishment of a certain amount of damage or avoidance costs to be useful; it holds the view, however, that the available analyses of consequences are adequate for justifying political action to cope with the climate problem.

### *The thinning of the ozone layer*

Increased UV-B radiation as a consequence of the thinning of the ozone layer is primarily caused by chlorine-containing CFC fragments in the stratosphere. Estimates of the quantitative extent of this damage still differ, however (see 1.1.2). Whether substitutes for CFCs, e.g. R 134a, cause global environmental problems is still a subject of controversy. Critics point out that they possess a high greenhouse potential. Welfare estimates, which would have to employ the damage cost approach or even the willingness to pay, are not yet available.

### *Soil degradation and decline in biodiversity*

Whereas, in many cases, treatment of the latter three effect and bottleneck components led in many cases to attempts at estimation or even valuation, the discussion revolving around the magnitude of global soil degradation, the hereby induced drop in productivity in agriculture as well as the erosion, salinisation and desertification effects is still open. Sometimes annual soil loss rates of between 10 and 100 tons per hectare are spoken of, or annual salinisation or waterlogging of possibly 6 million hectares (Pimental et al., 1987; Goodland, 1992). It is estimated that the annual deforestation rate in the last decade was 0.9%, attributable to a great extent to agriculture; due to its higher population density and its population development, Asia with 1.2% recorded a higher deforestation rate than Black Africa with 0.8% (World Bank, 1992a). Nevertheless, Africa's forests declined by roughly 8% during the 80s. The World Bank estimates the losses in land productivity on tropical soils at 0.5% to 1.5% of the GNP of these countries (World Bank, 1992a). It is even more difficult to determine the effects of losses in biodiversity. Attempts at quantification, as carried out by Hampicke for the "old" West German states (the "Bundesländer" that existed prior to reunification), for example, are not yet available at the global level.

### *Water pollution and water shortage*

In many recent studies water pollution and water scarcity are underlined as serious global environmental problems. This is controversial, however, because it is not possible to determine the extent to which regional stress and bottleneck effects have a global influence, if one ignores the migration reactions they trigger. It is a fact, however, that this pollution or scarcity is, directly and indirectly, a consequence of economic conditions, and here the interplay of population development, population density, underdevelopment and environmental stress must be emphasised. Particularly poverty and underdevelopment lead to shortcomings in water supply and treatment and even to wasteful consumption of water sometimes – in the case of free water supply or subsidised prices, for example.

The effects induced by this situation are considerable, though still primarily of a regional nature. Water pollution could, however, become a global issue. Roughly 1.7 billion people have no sanitary facilities, thus fostering the occurrence of diarrhoea – approx. 900 million cases per year (World Bank, 1992a) – as well as the large-scale spread of cholera, typhus and paratyphus. According to estimates of the World Bank, over 2 million cases of death and billions of cases of illness every year must be attributed to water pollution; in some cases water shortage leads to restrictions of economic activities (World Bank, 1992a), i.e. water is becoming a regional limitational factor. On the basis of the customary standard parameter of 1000 cubic metres of renewable water resources per capita, for example, water scarcity already prevails in 22 countries of the Earth and another 22 appear threatened. The majority of these countries are concentrated in the Near East, North Africa and the sub-Sahara region (World Bank, 1992a). Attempts at a monetary valuation of this damage are still rare.

## Assessment

The above statements have made it plain that the subsystem economy is, just like population development, centrally responsible for global environmental change and that the form of economic activity employed up to now has, globally speaking, reached a critical point which holds no promise for "sustainable development". In other words: if a decisive change in course is not effected, human society runs the danger of using up its "natural capital" at the expense of coming generations. In this respect the Council is also of the conviction that substantial restructuring of the economic subsystem has to take place, and no one knows whether it can be managed. It is possible that the economic system is more adaptable than the social system and that the main problems must be seen in the resistance to social adjustment. Increased environmental consciousness, improvement of social learning ability and environmentally sound individual and social behaviour are required to a high degree.

The primary task of this first Report, as has already been explained in detail, is to analyse the interactions between human activities and global environmental aspects. The question as to the conclusions to be drawn from this analysis and political recommendations will be answered in more detail by the Council in a later Report. Nevertheless, some basic aspects will be addressed at this point.

### In which direction are economic activities to be influenced?

If one initially attempts to find an answer to the first question in relation to the rough guideline of "sustainable economic development", then there is extensive agreement that the previous goal of material-intensive growth in throughput has to be changed. If a reduction in the scope of global economic growth, exacerbating social tensions, is to be avoided – if only in the interest of development on the part of the developing countries – a trend towards increased resource efficiency and waste reduction must be brought about, the latter via waste avoidance or via closed cycles in the economy. Many even talk about the necessity of an "efficiency revolution", which they define as dematerialisation of production, reduction in element flows, ecological product design and, in particular, increased energy productivity. This will require exhaustion of all (possible technical) potential for savings as well as an active structural policy, which is intended to effect a decoupling of income growth and environmental degradation via an "ecological structural transformation".

Sometimes there is also a demand for a "sufficiency revolution", i.e. a new "simple" lifestyle manifested in the renunciation of growing consumption or in reduced consumption of energy-intensive goods. It becomes apparent here that concrete formulation of the guiding principle involves some profound normative stipulations – such as the definition of the "appropriateness" of certain consumption activities, the definition of terms like "wastefulness" and recognition of the notion of saving resources for its own sake. These questions are still the subject of much controversy so that the Council would first like to dispense with taking a position.

There is, however, agreement that options exist regarding the treatment of renewable resources. That is, if there are limits to the carrying capacity of ecosystems which – if they are not observed – will lead to unacceptable ecological consequential costs (like climate catastrophe) or a collapse of the efficiency of these ecosystems (such as reduced cleaning capacity of running waters or declining yield capacity of soils due to degradation) and thus go against the interests of future generations, then one can stipulate maximum degrees of use or emissions and ensure that the economy meets these targets. A prime example is the Climate Convention of the Rio de Janeiro Conference, which provides for determination of a maximum emission quantity for $CO_2$ in Section 2 and thus describes a minimum secondary condition to be met that is relevant for future economic development. Therefore, the Council is of the view that it is up to politicians to implement this aspect of sustainable economic development as quickly as possible. This leads to the question of implementation strategies, which will be dealt with later.

### What kind of environmental information system will be required to cope with this task?

If one accepts the thesis that sustainable economic development can, in part, be defined on the basis of the limited disposal capacity of ecosystems or, even better, on the basis of conservation of the efficiency of ecosystems, i.e. conservation of renewable resources, conclusions can be drawn concerning development of an economically oriented environmental information system. The conclusion must then not only be globally oriented, but provide for, in particular, an accounting of environmental assets. Sustainable then means conservation of "real ecological capital". Just as a society is well advised to renounce reduction of its "real people-made capital" (real assets of the national economy), since it would otherwise live from its substance, it must also maintain its real ecological capital in its long-term interest. This requires an accounting of assets, however. In this respect the Council explicitly supports current efforts to develop an environmental-economic national accounting approach. On the other hand, it demands that this approach should not only concentrate on the correction of the flow variables (such as costs or turnover), ecological concerns (so-called ecological national product) as well as development of national systems of accounting, but should go over to undertaking global accounting of assets. In a later Report this topic will be taken up again, while taking into consideration current ongoing work, e.g. of the German Environmental Economic Council at the Federal Office of Statistics and corresponding UN bodies.

### What must be done to overcome the North-South Affluence Divide in the world?

The Conference of Rio de Janeiro showed further that environment and development are two closely linked topics. In other words: not only must the interests of nature or future generations be taken into account, but also the interests of those suffering now. This must be effected via financial transactions and technology transfer. This means that changes also have to be made with regard to development aid. The Council thus advocates an increase of such means and funds and holds the position that a percentage of the GNP on the order of 1% for development aid appears desirable in view of the worldwide disparity in affluence. The assistance for Eastern Europe provided by Germany should either be entirely or partially included here since many of these countries are in a difficult economic situation (frequently comparable to that of the developing countries) and renewal of the facilities there, often operating with low resource efficiency, also has a positive global environmental impact. However, there is also potential for greater efficiency of the development aid itself. It would, for example, be possible to distribute the funds to the above described countries that also take into account development aspects on a quota basis so that a call for tenders could take place among these groups – at least for part of the quoted funds – in which importance is placed on the consideration for environmental policy concerns. In addition, a tropical forest fund would have to be set up on the basis of a worldwide cooperation agreement and financially supported primarily by the highly developed industrial nations (Scheube, 1993).

### *Is there any scope at all for growth?*

Answering this important question poses some difficulties. Even the world models can only provide limited information here. They deal more with the problems expected in the event that the present form of economic activity is retained or it is applied to all countries of the globe. However, they are not able to forecast technical progress or substitution processes themselves. There are some indications that we are reaching limits or have already exceeded them, though a precise demarcation of the limits is difficult. Even the hypothesis formulated by several economists (such as Georgescu-Roegen, 1971 and 1976), according to which any global economic growth has to end in the long run in a kind of "sea of entropy", i.e. a state of "material disorder", because of the second law of thermodynamics, requires differentiated analysis (Nicolis and Prigogine, 1977 and 1989; Haken, 1978; Kafka, 1989).

Nevertheless, the question of whether the energy or sink problem has a growth-limiting aspect must be taken seriously. An attempt at providing an initial explanatory answer will be made here. It is, indeed, true that anthropogenic energy production both plays a decisive role and became the medium ensuring economic growth and was sometimes even its *engine of growth*. Though human beings were still extensively integrated into the natural process of photosynthesis up to the beginning of industrialisation, they have today unhitched themselves from this process to a great extent with an anthropogenic energy generation of roughly 11 terawatts per year (Seifritz, 1993). This took place, for the most part, through the constant tapping of new fossil energy reserves. Every form of economic growth or of the commodity production, distribution and use processes connected with growth was and is linked to use or transformation of natural resources. While, in the case of many resources, it was possible to constantly fall back on further reserves via substitution processes, dependence on energy production has even increased. And all recent attempts to disengage energy consumption from economic growth have not significantly changed the situation. In the highly developed countries expensive work has been replaced by energy-intensive processes. For this reason people burn today more fossil fuels per day than have been created in 1000 years (BMFT – Federal Ministry of Research and Technology, 1992b).

Anthropogenically generated energy itself is not consumed in this process, but is only transformed from a higher to a lower state (energy extraction). Thus this form of economic growth, which has dominated up to now and as it has taken place in the four previous *"Kontradieff cycles"*, can justifiably be called "throughput growth". Such throughput growth is, indeed, problematic if

- the energy reserves come to an end and substitution for this limitational factor is not possible, and/or
- the disposal capacity for the "waste" of this form of economic activity is exhausted or can no longer be increased without endangering humanity.

As far as this "waste" is concerned, it is not the waste heat that becomes a special problem, but $CO_2$ deposition in the Earth's atmosphere. In other words: it is not the exhaustion of the finite reserves of fossil fuels that becomes a limitational factor, but the sink problem related to $CO_2$. Namely, there are now 5.8 billion people burning roughly 5.9 billion tons of carbon into 22 billion tons of carbon dioxide every year. As was shown above, however, such deposition is connected with ecological risks which can no longer be accepted.

Fundamentally, limitation of this deposition is only possible if

- economic growth is disengaged from energy consumption,
- economic growth itself can be limited,
- a new carbon-free energy system is available or
- new technical means for climate-neutral use of fossil fuels are developed.

Disengagement of energy consumption from economic growth scarcely appears possible today, though there is scope for relative disengagement. In view of worldwide population growth and the related additional need for energy, a short-term increase in energy efficiency may not be sufficient to limit $CO_2$ deposition to the required extent so that many advocate a policy of limited growth in connection with the exhaustion of all possible means for increasing energy efficiency as well as saving energy. Another reason for doing so, in the view of the supporters of such a policy, is that it hardly appears possible in the short term to fall back completely on carbon-free energy systems. They would include renewable energy sources (water, wind, biomass), water power, photovoltaics or nuclear fusion. Their future perspectives are still uncertain and/or are dependent on large inputs of capital and time.

Are then state-compelled saving of energy, exhaustion of all technical potential for increasing energy efficiency as well as energy avoidance or limitation of growth the only possible means available in the short term? This question, which is answered in the affirmative by many, must be handled more cautiously in the view of the Council. Until now there have been few economic incentives for a basic change in our present economic structure, the development of relative prices even suggested energy-intensive methods of production and consumption, the $CO_2$ sink problem was scarcely price-effective due to a lack of property rights regulating the disposal of and the search for carbon-free energy systems hardly appeared necessary, at least from an individual economic point of view. In this respect great importance is attached to the instruments provided for by national and international environmental policy.

Before looking at this point in more detail, it must be underlined that the basic possibility of a strategy for a permanent $CO_2$ disposal site also exists. At least it cannot be ruled out, as recent studies indicate (Seifritz, 1993). Alternative solutions include a people-made $CO_2$ disposal site, deep-sea disposal or terrestrial dry ice disposal sites. The question of the various possibilities is not to be discussed here; what is important is that theoretical solutions exist that might grant us a pause to set up an operable carbon-free energy system. So far, however, economic incentives for looking more closely into development and implementation of such ideas have been lacking. Therefore, a procedure is required which is not one-sided in giving the economy instructions as to what to do, but functions as an improvement of the overall social and global search processes.

## Need for action

### *Political concept*

This brings us back to the basic question addressed above, i.e. how to transform the economy into a path promising "sustainable development". Must this path be stipulated by the state and then implemented or it is enough to set a framework and to leave the answering of the question to a social search process? If the latter strategy is preferred, the state's efforts must concentrate on improvement of the organisation of the search process, with great importance being attached to the market economy as such an organisation of the search process. It cannot be overlooked, however, that we are faced with a complex of questions here, the answers to which are very controversial in some cases. There is a mixture of ideological positions and diverging assessments of the efficiency of the market. It is also a fact that in reality there is not only market failure but also political failure. Even the opinion-forming process within the Council on this topic has not been concluded.

In somewhat exaggerated terms, however, one can already distinguish between two political directions, as far as the above mentioned strategic conclusions are concerned (Klemmer, 1993):

1. A political approach which – frequently in reference to model analyses – attempts to arrive at an explicit modification of the development path striven for and, in most cases, assigns this operationalisation task to the state, while the exploitation of all resource-saving and cycle-closing options for their own sake is frequently elevated to the status of an objective in itself and exemplary economic procedures are demanded to this end, in particular by the more highly developed countries. For this purpose there is a wish to exert influence on the economic structure via the explicit and selective application of all "command and control" instruments provided by the institutional law, of economic incentives (particularly charges and environmental taxes) as well as of planning law, and to steer this economy away from an economic structure based on high resource and disposal requirements as well as high risks and towards economic activity favouring a resource-saving, risk-reducing and cycle-based concept. Because it has recently become apparent that the "command and control" approach in many countries has, to a great extent, reached the end of its tether, there is greater support for a general increase in the costs of resource use and waste disposal. Basically this involves an interventionist economic and social policy oriented to what is technically feasible as well as to the "appropriateness" of consumption. The latter implies, in an extreme case, an intervention into consumer freedom that goes far beyond individual interventions (such as a ban on drug consumption and CFC-containing products).

2. A second political approach renounces quantified specification of a guiding principle to be striven for and leaves successful adaptation to ecological shortage up to the economic units themselves. The state is then only assigned the task of specifying the "scarcity" and setting the basic conditions. The idea behind this is that the future is ascertainable only to a limited extent and nobody knows enough about future needs, risks and possible ways of taking action. In other words: the task to be performed is seen as the efficient organisation of a search process whose result itself is still unknown. In this approach the state is primarily responsible for ensuring that all consequential costs of individual action are price-effective (i.e. internalised), while leaving individuals sufficient scope for speedy adjustment to this scarcity information. Whenever there is a danger of overuse and creation of consequential costs that are socially no longer acceptable because of the collective, non-excludable characteristics (lack of an exclusion principle, free rider problem) of an environmental asset (such as the Earth's atmosphere as a $CO_2$ sink), the state must stipulate the maximum usable quantity based on natural science findings.

Internalisation of all consequential costs appears to be an especially important task. Only it creates that "ecological truth" of prices which, as a rule, cannot be reached by imposing state levies. In most cases changes in important framework conditions, such as tightening of the liability law, allocation of property rights or elimination of a problematic subsidy are sufficient for this internalisation. In other words: whenever there is no explicit market failure (such as in the case of the tropical forest as a non-excludable, collective good), it usually suffices to strive for a situation in which the prices that are formed by themselves express ecological scarcity better. This is somewhat different (ignoring the Pigouvian tax for the moment) from the strategy of generally making resource use or waste accumulation more expensive via state-imposed resource or energy taxes or waste levies in order to force the economy to constantly increase efficiency. There is always the danger, however, that because this interventionism has to take group interests or elections into consideration, it will become ecologically inefficient and economically too expensive. This second political approach can also be termed an approach based on the *"Ordnungspolitik"*, the German institutional policy concept which aims at forming the legal und institutional framework of an economy.

When a decision is made as to which of the two approaches one should lean towards, one must not only take into account aspects of the *"Ordnungspolitik"*, but also the fact that important special features prevail at the global level. There has been a lack of a kind of "world government" that establishes the "command and control" policy and is able to enforce compliance with it. Worldwide charges are also difficult to implement since such action intervenes in the revenue autonomy of nations. In addition, price elasticity diverges depending on the respective average income. The allocation of such supplied funds will always be controversial because of the different interests and because conventions are required (internationally agreed standards). To this extent, great importance will have to be attached to solutions that ensure autonomy for taking action and attempt to provide for an environmental orientation via economic incentives.

If one takes the path of a global organisation of the search process, then agreement must be reached on important basic conditions. They are:

### Allocation of clear property rights to natural resources

Many natural resources are common property that are available for common use or belong to the state, which does not want to, or in many cases cannot, assert its property rights. Experience shows that in such cases there is always a danger of uncontrolled overuse or misuse (common property). Here nationalisation is frequently mentioned as the main cause for the advance of overexploitation of natural resources, forest depletion or soil degradation and reference is made to the positive experience with the transfer of clear rights of utilisation (such as in Costa Rica, New Zealand, Thailand and Kenya) or with the creation of formal legal norms for common soil property, as in Burkina Faso (World Bank, 1992a). Acquisition of property rights to parts of the tropical forest to be protected, for example, can also be effected via conservation organisations that finance themselves internationally through donations or membership fees (*"debt-for-nature swaps"*).

However, property rights may also involve rights to utilisation environmental assets that have not had any clearly defined "owner" up to now. This is the case, for example, when scope for utilisation (in this case policy about quantities as well), e.g. of the Earth's atmosphere for $CO_2$ deposition, is to be defined and subsequently allocated in accordance with property rights. This requires an international agreement on maximum emission level and on initial allocation of rights to this level. This will be dealt with later.

### Elimination of subsidies

It is becoming increasingly evident that widespread subsidisation of resource use, even in the highly industrialised countries, not only costs the developing countries, including Eastern Europe, an estimated US$ 230 billion annually (World Bank, 1992a) but also sends problematic signals regarding environmental policy. Water is, in some cases, provided free of charge, energy utilisation is cheap, the fees for logging do not cover the costs of afforestation and subsidisation of pesticides sometimes runs up to 80%. In relation to consumption which would result from internalisation of all costs, this induces "wasting of resources" and makes the setting up of self-supporting supply and disposal facilities difficult. In other words, it must be ensured that all ecological consequential costs are internalised. Without such internalisation allocation of property rights becomes a problem.

### Tightening of the liability law

A great portion of environmental risks to date has resulted from the fact that no compensation was possible through claims for transnational damages. Therefore, a tightening of the liability law may not only have a compensatory effect, but also a preventive effect on the basis of its features. In other words: allocation of property rights is only acceptable if damage to environmental assets of other nations can be legally prosecuted and prophylactically effective compensation can be demanded.

### Clear definition of assets requiring protection

There are assets which are of global importance or have the characteristics of non-excludable, collective goods (implementation of principle of exclusion not possible). In this case other measures are required to solve the problem. First of all, however, a clear definition is necessary: thus this Report emphasised many times the necessity of specifying global environmental assets so as to place them under special protection. Allocation of property rights is often not enough to implement this demand for protection; then planning law must be applied. Experience gained from the highly developed countries shows that regional planning is frequently less able to initiate development processes, but can have a more significant impact on conservation (resource protection, planning environmental protection). It cannot be overlooked, however, that this instrument requires a state which is capable of taking action and has the necessary power to ensure compliance with regional planning specifications.

## Priorities for taking action

A policy with such a framework allocates important tasks to the state or to the international community of nations. This will be described in more detail on the basis of three problem areas that are to be tackled with priority or require solving.

## *Coping with the climate problem*

The UN Conference on Environment and Development led to a convention which can be translated into a quantity target regarding the reduction of $CO_2$ emissions via interpretation of Section 2 of the "Climate Convention". The German Government was supposed to continue the discussion that started there and furnish instrumental considerations, i.e. steer the discussion away from the *Whether* and towards the *How*. The primary question is then how the scope for use of the Earth's atmosphere for a climatically tolerable deposition of $CO_2$, as indirectly defined in the Climate Convention, can be allocated to the different nations or parties interested in use and how these rights of use should be handled.

In the view of the Council, one should take advantage of the opportunity offered by the above described path of a global search process via allocation of property rights, i.e. installing a new market. $CO_2$ is a "harmful" substance which does not require solution of the regionalisation problem (determination of geographical emission-immission interlinkages), but represents a mass flow that permits a great segmentation of rights of use because of its "divisibility" and guarantees functioning markets in view of the large number of plant operators (or countries as owners) (Kölle, 1992; Heister and Michaelis, 1990; Grubb, 1990). An initial allocation of property rights regarding the maximum $CO_2$ emission level, indirectly predefined via Section 2 of the Climate Convention, should be oriented to the current population or the population of a past reference year. This appears to be a "fair rule" that might be generally accepted. In view of their low degree of industrialisation, it would, in particular, almost automatically guarantee most developing countries a scope for development defined on the basis of property rights that have not yet been utilised. The argument that the highly industrialised nations could "buy off" the scope for development of poor countries by "buying" the rights of use can be countered with appropriate precautions and the objection that the temporary leasing of rights (combined with escalation clauses) should be more interesting for the developing countries. Moreover, the presentation of utilisable rights of use may act as an investment premium and accelerate the industrialisation process without increasing global $CO_2$ deposition. In addition, in the highly developed countries investments can be "bought off" via capital transfers serving the purpose of renewal of inefficient energy production plants (such as in Eastern Europe). In any case rapid ecological efficiency would be ensured with a global minimisation of costs. Finally, an orientation of initial allocation to the current population (or to a past base year) would also furnish an indirect incentive for developing countries to exert greater influence on their demographic processes.

## *Conservation of the tropical forests*

A second focal point of action for global environmental protection policy concerns protection of tropical forests. This will presumably require other instrumental conclusions than in the example just described of a $CO_2$ reduction policy. Based on their functions for world climate and conservation of species, tropical forests have the character of a global non-excludable, collective good that should be conserved in the interest of the entire world population. Because of the non-excludable, public features, this interest is not expressed in individual demand activities; demand must, therefore, be organised. Only in this way do the global benefits come to economic fruition and can the "costs" be reimbursed to the countries connected with tropical forest protection. These costs have the nature of opportunity costs, i.e. of disadvantages resulting from the renunciation of use (such as renunciation of use of tropical wood or use of forest areas as pasture). To this extent, one must consider whether a cooperation agreement should be concluded to set up a global tropical forest fund financed by the world's population – on the basis of population level and average income, for example. Acquisition of such rights of use of the tropical forests could be effected by auctioning off certificates of obligation in order to minimise the financing burden (Scheube, 1993). Their holders (private or public forest owners) are bound either not to use the forest areas at all or only in an environmentally acceptable manner. Compliance with these obligations could be monitored via remote satellite sensing.

## *Securing the food base*

Agriculture or the securing of the food base in the developing countries represents a third focus of action. The starting point is the realisation that even a successful population policy will not be able to slow down rapid population growth in the short and medium term. Thus this expansion has the nature of an incorrectable basic condition, with the largest portion taking place in the developing countries. In the case of unproductive land use, not only is the cultivated area expanded at the expense of forests and grasslands, or rural emigration promoted, the poverty and hunger problem is also intensified. There is a need here for consulting, finance and technology transfer. The objective should be to develop and implement adapted forms of land use as well as to create domestic markets, e.g. by promoting expansion of the food, beverage and tobacco industry.

## Research needs

For a long time the area of global environmental research was dominated by the natural sciences, which pointed out the consequential effects of population development and of many forms of our economic activity. In the analysis of causes in environmental economic research the central question right from the beginning was whether a market or a political failure was responsible or what role is played by institutional influencing factors. In addition, interest soon developed in transformation of cause-and-effect research into economic variables (estimation of consequential costs) and adequate consideration of intergenerational equity. These complexes of issues can, by no means, be regarded as answered sufficiently.

In the meantime, however, there is extensive agreement on the need for action, which raises the question of the options available for taking action as well as the starting points and instruments of a national/international environmental policy. As a consequence, discussion over the guiding principle has recently ignited again, interest is directed particularly at institutional aspects and research is conducted on conceptual questions regarding global environmental policy.

In view of the current status of environmental-economic research, there is still significant need for research on the following questions.

### *Assessment of consequential costs and analysis of causes*

- Applicability of willingness-to-pay analysis or damage cost and damage avoidance costs approach to global analyses of the costs related to the absence of environmental protection
- Adequate consideration of divergent preference structures with respect to space and time
- Definition and assessment of global non-excludable, public goods
- Development of global accounting of assets in order to assess “ecological real capital”
- Global environmental and development impacts of current institutions of world economic order
- Global environmental aspects of sectoral and regional structural transformation of the world economy, including geographical transfer of environmentally intensive economic sectors

### *Basic research for political recommendations*

- Operationalisation of the term *“sustainable development”* from an economic point of view
- The significance of an increase in resource efficiency as well as closing of cycles within the framework of environmental policy targets
- Basic conditions for environmental policy at the international level, particularly applicability of “command and control” policy framework, of liability law and of economic instruments within the scope of a global environmental policy
- Economic instruments of global climate protection policy – certificates versus taxes
- Conceptual and instrumental implications of certain environmental assets (protection of the seas, protection of the soils, protection of water, etc.)
- Securing of food base in developing countries – agricultural policy conclusions

### *System of indicators*

Development of a system of indicators to record the variables that are able to illustrate global change from the point of view of cause and effect aspects entails the solving of several questions:

- solution of the regionalisation problem
- solution of the criteria problem
- solution of the indicator problem
- determination of critical thresholds

As far as the first problem is concerned, the method preferred up to now has been to fall back on the *"Länder"* (federal state) level. From the point of view of political responsibility this is certainly a suitable observation unit. Within the scope of this Report, however, it became apparent that a need for regionalisation exists in many places. It was shown, for example, that smaller geographical units are required for environmentally relevant factors which can only be transported or changed at high cost. A typical example of this is the area of water because a development-limiting component in this connection already exists in many countries. This applies similarly to the designation of globally relevant nature reserves. The 1992 World Development Report attempts to designate areas having priority for conservation (World Bank, 1992a; Mittermeier, 1992; Myers, 1988 and 1990).

The drawing up of a list of criteria should be less oriented to the available data material than to the hypotheses regarding global cause-and-effect relations. After that one would have to examine how the required detailed information can be procured or substitute information can be illustrated by means of auxiliary indicators.

The question of the formation of indicators concerns the frequently expressed desire for compaction of specific information. This would require standardisation and weighting of the individual criteria. Since few possibilities are available for constructing an overall indicator taking into account all environmental aspects, development of partial indicators will certainly be more important.

Any formation of indicators compels a classification in the end. This implies a search for critical thresholds, leading to political action in the event they are exceeded or not reached. In this context one must examine the extent to which globally relevant thresholds can be determined or still require further differentiation.

## 2.3 Increases in transport

### Summary

Transport is a major factor influencing patterns of global change. It ensures a regional and international distribution of labour, stimulates sales potential and thus, amongst other things, creates the conditions required for lower-cost, large-scale forms of production. At the same time it contributes to the creation of large economic blocks. For many years people particularly emphasised these positive effects and promoted them by consciously expanding transport routes. However, since then it has also been acknowledged that transport is among the primary causes of pollution. It is a major source of air pollutants, takes up large amounts of land and has a negative impact on the countryside. Over and beyond this many people suffer as a result of traffic noise, while their lives are endangered and the environment harmed by the various forms of transport operations, while the disposal of vehicles poses substantial waste problems. In the following section, the Council will concentrate on those aspects of transport which are of global significance. In this context it will deal with the issue of emissions above all and – amongst the traditional forms of transport – with road traffic.

Transport reflects the capacity of people, commodities and information to *overcome space and distance*. Leaving aside the expansion of the traffic networks for the time being, the transport of people and of freight are of particular significance for the environment. In this context *mobility* can be defined as the ability to move in space. To a large extent, the degree of mobility is a function of the quality of infrastructural traffic facilities and of the

means of transport provision available (speed, capacity for networking etc.), the level of use of transport routes (roads, railways, etc.), the cost of transport (per kilometre per person, per item or per unit of weight), the methods of production in the economy (as in the desire for more just-in-time transport and a lower vertical range of manufacture), economic development, disposable income and available time. In this situation the desire for greater mobility can be a dependent variable (traffic as a consequence of economic development or as a result of changes affecting the organisation of production), but also an independent variable (the desire for greater mobility as a result of consumer "demand"). Most transport operations are still functional in nature, but as incomes rise and increased leisure time is available, there is a growing desire for mobility in itself.

Given the requirements of transport and environmental policy, attention needs to be focussed not only on the development trends with regard to the number of vehicles and the levels of use of the various means of transport, but also on the relationship between the quantity of traffic (as measured in passengers or tonnes), the transport capacity (as measured in passenger or tonne-kilometres) and the actual distance covered (as measured in the number of kilometres per vehicle). In order to obtain a preliminary impression of the trends in global development, one can chart the development of the number of vehicles according to country and country group and establish the resulting trends (Table 20).

One can see that, in the case of *road traffic* with its relatively *high emission levels*, marked increases in the numbers of vehicles can generally be expected, with an exponential rise in some regions (e.g. Asia excluding Japan) (Fig. 14). It is true that by the end of the century two-thirds of all the cars in the world will still be in the highly developed industrial nations in North America, Western Europe and Japan should these patterns persist. Nevertheless, the proportion in the rest of the world will be clearly rising, particularly in the newly industrialising countries. This pattern has already become quite evident as far as lorries are concerned. However, it is safe to assume that the age structure of vehicles in the different parts of the world differs. In the developing countries older types of vehicles with higher emission levels predominate.

## Causes

Transport and economic development are closely interrelated and interdependent. For example, economic growth generally produces increased levels of traffic, while – conversely – the construction and maintenance of roads, railways and other transport services form vital elements in the growth-oriented infrastructural policies adopted in developing countries – policies which aim to help overcome the basic obstacles to development. The comparatively low levels of financing expenditure, planning and construction work involved in road building (as compared with the expansion of railway networks) has favoured road transport – or in large countries air traffic. A further determinant here is the fact that modern railway systems require relatively high levels of qualification and equipment and very often do not function effectively under the specific conditions existing in tropical climates. As a consequence, road and air traffic have particularly gained in importance in the majority of developing countries. Unlike the situation in the developed countries, the potential for influencing or changing the distribution of transport among the various types of carrier (*"modal split"*) is often slight here. In this respect the scope for instituting environmental policies is severely restricted.

In the context of environmental problems, attention must not only be focussed on the numbers of vehicles in use but also on the trends underlying the development of the *levels of traffic* of the different means of transport as well as the interrelations between level of traffic (measured in numbers of people and tonnes), transport capacity (measured in passenger- and tonne-kilometres) and the actual distance travelled (measured in kilometres per vehicle). The level of freight traffic is decisively influenced by the magnitude of commercial production of these commodities – although it must be said that the level of freight traffic is not expanding as fast as goods production in developed countries, a pattern whose cause can be found in sectoral structural change. The proportion of heavy, homogeneous bulk goods, which generally dominate in non-consumer sectors, is gradually decreasing. The level of passenger traffic is also influenced by the real net output. But the scale and geographical distribution of population development constitute a further decisive factor here. In this respect a large proportion of future passenger traffic in developing countries must be regarded as a variable independent of economic growth, being largely autonomous of external factors and difficult to influence.

Table 20: Growth in numbers of automobiles and lorries *(from IEA, 1991 and RWI, 1993)*

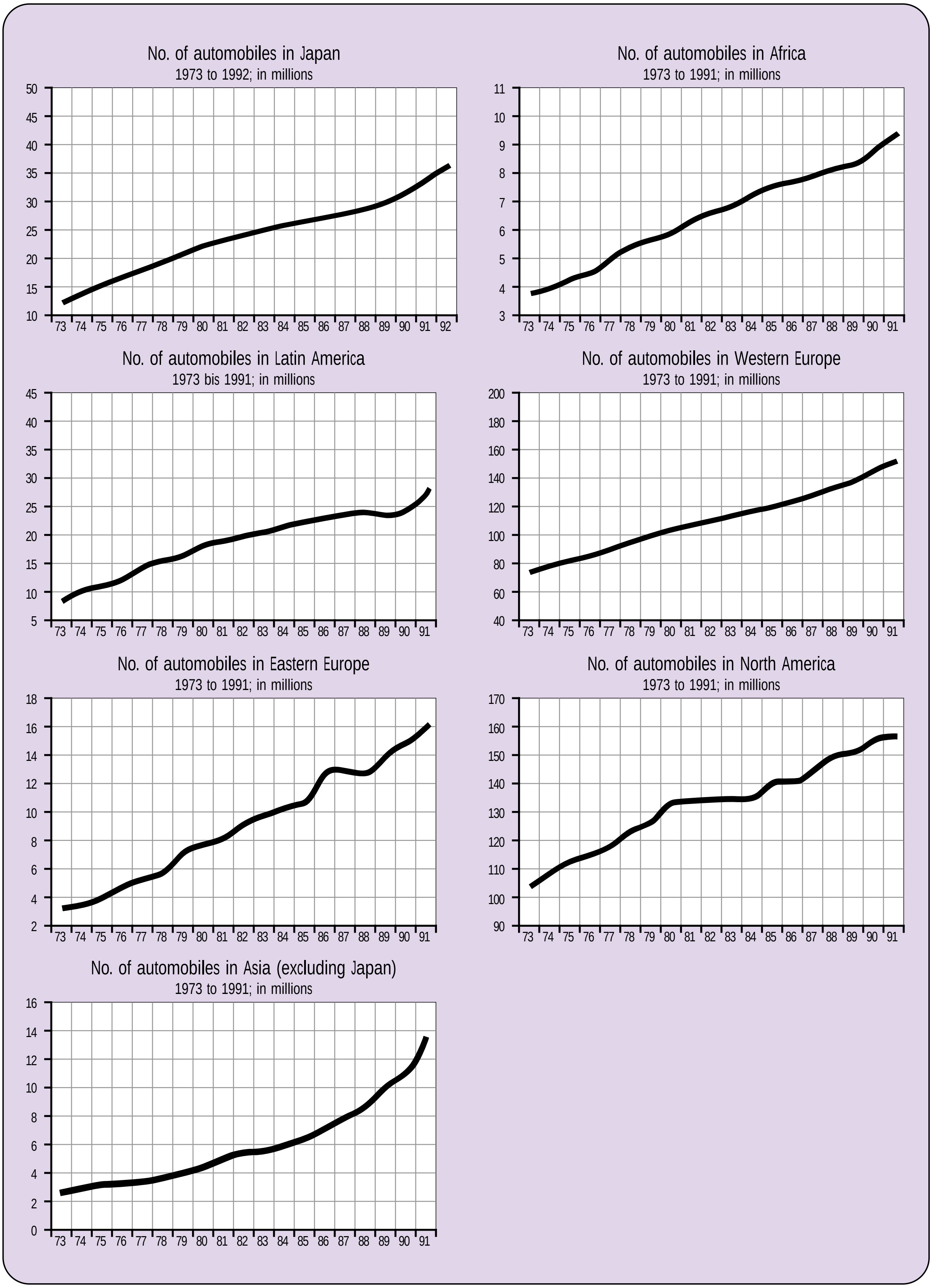
| | Automobiles | | | | |
|---|---|---|---|---|---|
| | Million vehicles in | | Variation in % from | Share of total vehicles in % | |
| | 1990 | 2000 | 1990 – 2000 | 1990 | 2000 |
| OECD | | | | | |
| North America | 158.15 | 189.72 | 19.96 | 36.95 | 31.54 |
| West Europe | 146.76 | 212.31 | 44.67 | 34.29 | 35.29 |
| Pacific | 9.57 | 12.37 | 29.23 | 2.24 | 2.06 |
| Japan | 32.62 | 46.21 | 41.65 | 7.63 | 7.68 |
| Non-OECD | | | | | |
| Asia | 11.32 | 17.78 | 57.10 | 2.64 | 2.94 |
| Near East | 6.32 | 10.09 | 59.69 | 1.48 | 1.68 |
| Africa | 9.03 | 14.66 | 62.23 | 2.11 | 2.44 |
| Latin America | 25.69 | 46.82 | 82.25 | 6.00 | 7.78 |
| East Europe | 15.29 | 30.25 | 97.77 | 3.57 | 5.03 |
| former USSR | 13.23 | 21.42 | 61.94 | 3.09 | 3.56 |
| World | 427.98 | 601.63 | 40.57 | 100.00 | 100.00 |

| | Lorries | | | | |
|---|---|---|---|---|---|
| | Million vehicles in | | Variation in % from | Share of totel vehicles in % | |
| | 1990 | 2000 | 1990 – 2000 | 1990 | 2000 |
| OECD | | | | | |
| North America | 46.65 | 55.35 | 18.65 | 36.02 | 28.83 |
| West Europe | 18.82 | 29.87 | 58.70 | 14.53 | 15.56 |
| Pacific | 2.54 | 3.79 | 49.45 | 1.96 | 1.98 |
| Japan | 21.65 | 27.96 | 29.18 | 16.71 | 14.56 |
| Non-OECD | | | | | |
| Asia | 11.11 | 22.18 | 99.68 | 8.58 | 11.55 |
| Near East | 3.23 | 10.94 | 238.54 | 2.49 | 5.70 |
| Africa | 4.36 | 8.18 | 87.84 | 3.37 | 4.26 |
| Latin America | 9.35 | 15.80 | 69.00 | 7.22 | 8.23 |
| East Europe | 2.43 | 4.11 | 69.58 | 1.87 | 2.14 |
| former USSR | 9.39 | 13.81 | 47.13 | 7.25 | 7.19 |
| World | 129.53 | 191.99 | 48.25 | 100.00 | 100.00 |

The transport capacity is even more significant in explaining the patterns of global environmental change than the levels of traffic. Through the globalisation of consumer and purchasing markets, internationalisation of production and more complex division of labour, the average shipment distance for almost all forms of transport has substantially increased in recent years. Consequently, transport capacity has generally increased more rapidly than the actual level of traffic. This trend towards growing mobility in passenger transport has been primarily favoured by greater levels of affluence in the developed countries. This has produced an above-average rise in the number of kilometres travelled per person as compared to the development of real income, particularly with respect to individual passenger traffic. It can be assumed that the developing countries will also follow this trend, although urban traffic (local transport) is still the dominant form here.

Of particular importance for the environment is the development of distance travelled via the respective means of transport. If the individual vehicle is seen as the critical source of environmentally relevant effects (noise, emission of pollutants, waste problems, etc.), then the development in the number of vehicles and the average distance travelled by each must be taken into account. If the average size and capacity use of individual vehicles is increasing, then rising traffic levels need not necessarily be accompanied by greater distance travelled per vehicle. In the more highly develo-

Figure 14: Development of automobile numbers for different groups of countries *(RWI, 1993)*



ped countries, the distance travelled (kilometres travelled per year) in the freight sector rose to a lesser extent than did the supply of goods (volume per year in tonnes). This is mainly explained by a result of increasing average loads, greater efficiency in the logistical coordination of the various means of transport and partly by the expansion of the transport infrastructure (reduction of shipment distances) (Klemmer, 1991). The reverse trend can be observed for passenger transport, however. Not only did transport capacity (passenger kilometres) in this sector increase more than the volume of traffic, there was also an increase in distance travelled, reflecting greater mobility on the part of individuals. In West Germany at the end of the 80s, the latter figure was about 17,500 km per person per year, with an upward tendency (BMV, 1991).

For the most part it is likely that the trends outlined above will also occur in developing countries. However, the absence of adequate rail services will restrict the transport options available in these regions, i.e. traffic will find its way primarily onto the roads. Population developments will further aggravate this situation. Bearing in mind the fact that there were 325 cars for every 1000 people in Western Europe in 1990 (North America 553), whereas there were only 13 in Africa and 3 in Asia (RWI, 1993), then one can easily imagine how the patterns of traffic levels might develop if the same trends continue to prevail. As can be seen in Table 20, recent estimates (RWI, 1993) suggest that there will be approximately 602 million cars and 192 million lorries on the roads in the year 2000 – which would mean an increase of almost 41% for cars (compared to figures for 1990) and of over 48% for lorries (compared to 1989). It should not be forgotten here that forecasts for transport and traffic levels usually prove to be too low rather than too high.

The qualitative and quantitative impact of traffic on the ecosphere and anthroposphere is mainly determined by the *use of different means transport*. In general it can be said that road and rail traffic, inland and ocean shipping and air transport form the main alternatives here. Positive and negative effects are triggered in the production, use and disposal of the operating equipment and of the components of the transport infrastructure – these effects varying between the different modes of transport. The following characteristics of the individual means of transport are of global relevance:

- *Road transport:*
  High networking capacity, set up to meet specific needs, lower capacity than railway and waterways for transport of bulk commodities, generally higher average speed, networks can be partially expanded more easily and more quickly than with other forms of transport, less capital is needed because partial networks can be developed, little sensitivity to climatic influences, low maintenance requirements, relatively high need for land ("land requirements"), segmentation effects, highest producer of environmentally significant emissions amongst the modes of transport.

- *Rail transport:*
  Less easily networked (based on junction points), high levels of capital required, generally long development periods, high levels of concentration and collectivisation, similarly high need for adjoining land, restricted applicability as a result of increased demands on service staff and greater proneness to breakdowns depending on climatic conditions, high capacity for transport of bulk commodities but generally lower speed, lower levels of environmentally significant emissions.

- *Ocean and inland shipping:*
  Well suited for the transport of bulk commodities, low capacity for networking, low speed, high capacity for concentration, restricted applicability due to dependence on natural conditions, including climatic conditions, high capital needs for expansion of artificial waterway systems (canals), little impact on levels of climatically significant emissions.

- *Air traffic:*
  Difficult to network, less capacity for transport of bulk commodities, capacity for relatively quick expansion, high speed over long distances, restricted and purely localised land requirements, sensitive to specific climatic conditions, high maintenance requirements, high levels of environmentally significant gas emissions.

Any decisions relating to the economically efficient and ecologically acceptable mix of transport carriers can only be made by analysing the prevailing conditions in the region in question. It is possible to create a *typology for the differing regions* on the basis of the following criteria:

(1) *Geographical location*
Relative proximity to a major centre of economic activity or location near globally important traffic routes can be a factor in the selection of the transport carrier (Meyer-Schwickerath, 1989).

(2) *Factors influencing demand for transport*
In freight traffic the economic development and the sectoral economic structure with the affinities between specific types of freight and means of transport, in passenger transport the distribution and expansion of the population, the population density and the level of disposable income are all factors influencing demand for transport.

(3) *The institutional infrastructure and the financial provision needed to achieve short-term flexibility in the use of transport*
Inefficiency in the area of administration and financial constrictions resulting from the absence of operative capital markets and high levels of foreign debt impede the application of complex and elaborate transport networks and the exploitation of environmentally acceptable forms of technology (Meyer-Schwickerath, 1989; World Bank, 1992a).

Based on these criteria the following groups of countries can be identified:

### The highly developed countries or global centres of economic gravity

This category is characterised by relatively slight restrictions in its transport carrier use alternatives as a result of the natural circumstances (Criterion 1), by its active integration into all major global transport networks, by increasingly individualised and differentiated requirements vis-à-vis the speed, reliability and frequency of transport services, by a dispersed settlement structure, and by high per capita income levels and the resulting strong preferences for road and air freight and passenger transport. It also possesses an operationally effective institutional infrastructure and considerable potential for the continued development of environmentally acceptable transport systems. Given this high level of transport use and the positive and negative effects associated with this in these countries, and the further probable shift in favour of forms of transport with a comparatively severe impact on the global environment (air traffic), there is a particularly urgent need to create *effective incentives* in these countries. These would serve to stimulate ways of comparing environmentally significant forms of transport use with the actual economic costs, thus enabling the creation of economically efficient and ecologically compatible transport carrier combinations, on the one hand, and providing additional incentives for increasing the degree of environmental acceptability of the components used within these transport systems, on the other.

### The Eastern European countries

These countries are characterised by only few natural restrictions on the choice of transport carrier (Criterion 1), by a relatively favourable location for gaining access to global transport networks – a result of their proximity to the EU countries –, and by a probable significant change in the *"modal split"* since the rigorous promotion of the railway systems came to an end. Moreover, these countries can expect to undergo sectoral structural change which will result in a reduction in the proportion of bulk commodities and an increase in the level of individual motorised forms of transport in the air and on the roads – a situation which will come about as a consequence of the convergence between settlement patterns and income levels. Action needs to be taken in these countries, given their inadequate institutional infrastructures and the low level of environmental protection technology. Due to the projected increases in traffic volume and a similar shift in usage towards environmentally less acceptable forms of transport, these countries particularly need to reduce emission levels and further expand their institutional framework for dealing with the increase in traffic.

### Newly industrialising countries

These countries have one thing in common in particular, their economic development (Criterion 2). Sectoral structural change from labour-intensive industries producing bulk commodities to differentiated and capital-intensive sectors will also generate a shift in demand in these countries towards individually utilised forms of transport. Natural regional restrictions on the choice of transport will be of particular significance for railway systems. In these countries with their large unspoiled areas the construction of axis-like lines for land-based transport systems may serve as a kind of "gateway" to the establishment of large communities. In order to prevent such a development the expansion of air services will probably be actively promoted there. These countries are already integrated into the main global transport systems, so that their share of international trade will continue to expand and it should also prove easier for them to implement environmentally acceptable technologies. There are great variations in the institutional infrastructures within these countries. Whereas some of the Asian countries have relatively stable political systems and a tight administrative organisation, the potential for reducing the negative impact of traffic in South American countries in this group is limited by inadequate institutional conditions. In these countries transport use will have to be adjusted to comply with the natural restrictions, although attempts from the outside to impose a particular solution may well meet with opposition and claims of infringement upon the country's national sovereignty (see the dispute between Brazil and the USA on the financial arrangements for a road construction fund; Kennedy, 1993). This problem is particularly evident in these countries because the types of transport available are limited, while several options are usually open in highly developed countries. Moreover, the projected increase in the negative effects of traffic needs to be countered by further improvements in the technology available for an environmentally more acceptable solution.

### *Developing countries with considerable potential for increased traffic*

There are good reasons for making a further distinction in relation to this heterogeneous category of developing countries, one which is based on the classification criteria specified above. The potential for increases in traffic volume in each country and the associated impact of such increases can be seen as constituting generally valid indicators. It is reasonable to assume the existence of considerable potential if the country in question can gain access to the major global transport routes relatively quickly and at little cost, for example because the country is located near one of these routes or because it has access to natural transport facilities such as seaports (Criterion 1). For the most part transport activities are still concentrated in urban areas. The level of development of the local institutional infrastructure is also of decisive importance, as deficiencies in the organisation of the country's administration, insufficient technical expertise and shortfalls in financial resources – the latter two factors being the consequences of inadequate educational institutions and capital markets – can restrict the development of efficient multimodal transport systems (Criterion 3) (see reports on case studies in Egypt: Soliman, 1991; Hafez Fahmy Aly, 1989). If the existing potential could be exploited in these countries, then an increase in transport capacity on the same scale as in the newly industrialising countries could occur. In order not to curb the positive economic effects associated with this, it makes sense to make this development environmentally more acceptable through transfer of environmentally acceptable technology.

### *Developing countries with little potential for increased traffic*

These countries are characterised by the following features: they currently have a low standard of transport provision; they are a considerable distance from the major global traffic routes; their natural circumstances and lack of financial and human resources result in severe restrictions in the use of transport methods; inadequate institutional structures due to political instability; rapid population growth; and they have high levels of population density as well as shortages of natural resources and developing economies (Criteria 1 & 3). The influence of these countries on global transport developments is likely to be slight.

These basic distinctions need to be refined when applied to the individual regions. For example, there are very substantial differences between the development of transport in the major cities and in the rural areas of developing countries (World Bank, 1992a). The varying regional requirements and potential effects must be taken into account when evaluating individual means of transport.

## Effects

The effects of traffic on the environment have been investigated and evaluated on numerous occasions (SRU, 1978; SRU, 1987). In general a distinction is drawn between those effects

- which are produced by the expansion and maintenance of transport infrastructure, and those
- which occur as the result of transport operations themselves.

In the first category the *direct effects* include

- "land consumption",
- local influence on soil characteristics through surface sealing, compaction, etc.,
- fragmentation of the environment (e.g. of biotopes),
- changes to the regional microclimates (barrier effects), and
- impairment of the landscape.

These are complemented by the *indirect environmental* effects:

- the controversial traffic-inducing effect ("he who sows streets will harvest traffic"),
- the environmentally significant effects on the *"modal split"*.

The second category (*effects of traffic and transport*) generally includes

- traffic emissions significant for the climate,
- the deposition of pollutants in air, water and land,
- traffic noise and vibration,
- the waste problems associated with the disposal of vehicles (disposal of used engine oil, tyres, cooling fluids, scrap cars, etc.),
- the consequences of accidents which occur during the transport of (hazardous) goods/substances.

Many of the effects listed here can only partly be classified as environmentally significant effects on a global scale. The causes of these and their remedies affect above all the governments of individual countries or their regional authorities. However, the situation is different

- where global effects can be observed and
- international coordination is necessary to solve problems associated with local development trends.

As far as the first category is concerned, the *climatically significant traffic emissions* are currently considered the most important. Here the Council sees a primary need to take direct action, particularly in the light of the debate on climate protection. This applies especially to $CO_2$ levels in the atmosphere.

It is likely that by the year 2000 about a fifth of all $CO_2$ emissions in the world will be produced by traffic, with emissions resulting from the generation of electricity and from traffic providing the largest increases in the period between 1986 and 2000 (48% and 42% respectively, RWI, 1993). If the expected regional distribution of traffic emissions is analysed, then it becomes clear that the proportion stemming from the highly developed countries will decline, but they will still be responsible for over half of the $CO_2$ emissions at the end of the century. Along with Eastern Europe they will generate about three quarters of all the emissions, with the developing countries only accounting for a quarter. The situation is different when it comes to CO and $NO_X$ emissions. In the first case the proportion generated by the member countries of the OECD will decline significantly, in the case of $NO_X$ only slightly.

Transport services are major sources of these emissions. In this context, the developments in passenger travel deserve particularly close scrutiny, as factors like the desire for increased mobility and the growth of the world's population will aggravate the situation. Transport services in the passenger traffic sector, as measured in kilometres per person, are still strongly concentrated in the highly developed industrial states, although the developing countries are already showing marked increases in this area.

Besides road and rail traffic, air traffic is also important from a global point of view. The harmful substances released from aircraft have a much longer atmospheric lifetime than at the Earth's surface, a result of the height at which they are introduced. In addition, water vapour emissions need to be taken into account. If the existing relationship between economic growth and air transport is sustained, then there will be a substantial rise in the amount of fuel used and a corresponding increase in the level of climatically significant emissions. This development will apply particularly to the member countries of the OECD.

## Assessment / Need for action

If, as has been the case in this Report, analysis of the global environmental effects of traffic is restricted for the most part to the subject of harmful emissions, particularly $CO_2$ emissions due to the urgent necessity of climate protection policy, then data relating to the regional distribution of $CO_2$ emissions shows quite clearly that the part played by traffic in highly developed countries and in Eastern Europe is of primary significance.

A reduction in the levels of traffic-related $CO_2$ emissions could be achieved initially by

- reducing fuel consumption of vehicles,
- reducing the distance travelled and vehicle capacity, and
- altering the distribution of transportation distance and capacity among the various means of transport (changes to *"modal split"*).

The potential provided by possible *changes to the "modal split"* should be fully exploited, but its significance should not be exaggerated. It is counterbalanced by forms of disperse settlement structures which have emerged above all in the post-war period. This can hardly be influenced in the short and medium term, as it has been developed with less regard to junction-based transport, and more as a consequence of the general accessibility provided by road networks and individual transport. In addition, the superiority of cars – in respect of their greater convenience and adaptability to individual requirements – frequently plays a significant role. Moreover, on specific routes and at certain times the environmentally more acceptable railway system can only cope with limited additional demand. A more serious problem, however, is the fact that the railways systems in many developing countries are either in poor condition or non-existent. In many cases the natural waterways offer a viable alternative. But – as with the railway systems – the financial resources needed for the maintenance and expansion of harbours and requisite facilities are lacking in many cases.

In the light of the above, any long-term considerations will need to be accompanied by a number of short-term efforts, particularly to *reduce fuel consumption* and to restrict the transport distance and vehicle capacity. This applies particularly to passenger and freight traffic on the roads. If one looks at the still considerable discrepancies between the amounts of fuel used per vehicle per year, then it becomes clear that there is still room for further reductions even in the highly developed countries. It must be assumed that these countries are capable of exploiting and putting these progressive environmental technologies into practice. Efforts are therefore required at a political level to reduce the average international level of fuel consumption decisively, e.g. to a level of less than 6 litres per 100 kilometres. This cannot be achieved without tackling questions as to the implementation strategies for achieving this on an international basis, with respect to reference factors such as fleet or vehicle.

One long-term means of reducing the *volume of traffic* might be provided by a regionally differentiated toll system for road users, the operation of which could be agreed by the countries involved (Ewers, 1991). Such *"road pricing"* schemes would not only allow the external costs of traffic to be internalised more effectively, but they would also allow greater scope for regionally differentiated options to be taken into account, something which would serve the interests of the developing countries. Furthermore, they would facilitate greater equalisation of the beneficiary and cost unit structure in line with the theory of "fiscal equivalence" (Klemmer, 1991). This approach promises a better solution to the problems associated with local traffic in particular and to produce a more rapid reduction in the levels of traffic emissions in urban areas. Experience gained internationally from previous attempts to enforce regionally developed traffic schemes (e.g. the *Area Licensing System* in Singapore, *Electronic Road Pricing* in Hong Kong) has shown that these produce markedly reduced emission levels (for an evaluation of some of these approaches, see Frank and Münch, 1993).

An even more attractive approach would be to link traffic-related emission issues with similar emission problems in other sectors and other regions and to carry out cost-benefit analyses in the process. In the context of the $CO_2$ problem, for example, such an approach would have to link together the reduction of emissions produced by the generation of electricity and by road and air traffic – taking regional concerns into account.

Such a programme might be based on a *standard fleet solution* in conjunction with a *global certification strategy* (Klemmer, 1993; RWI, 1993). The central idea here is as follows. Car manufacturers would sell their new cars along with a permit to drive them for a maximum distance (e.g. 150,000 kilometres). Once this distance has been exceeded, the permit to use the vehicle would automatically expire unless the owner has applied for a further permit for a set number of kilometres. If this permit is expensive, then the owner might be tempted to reduce his annual mileage so that the initial permit lasts for the whole of the new car's operational life. That would provide an incentive for drivers to use other forms of transport, to reduce the number of kilometres they drive each year or to use the car more economically.

Based on the level of fuel consumption per 100 kilometres, one could calculate the projected level of fuel consumption for the licensed distance and thus the level of $CO_2$ emissions expected for this full distance – even for a company's complete fleet of cars. In order to sell a car, a car manufacturer would have to acquire "emission permits" (certificates) on the national or international market. If the cost of these certificates were to rise, then numerous economic sectors would have an incentive to try and find production methods resulting in lower $CO_2$ emission levels. The car manufacturers, who would have to buy these emission permits for their whole fleets of cars, would find the development of cars with lower fuel consumption levels a worthwhile venture. This could instigate a research process which would be welcome from an environmental point of view.

Such an approach would be more efficient than a scheme involving taxes or charges. Given the low price elasticity in the demand for fuel, the likely resistance from parts of the population and regional redistribution effects, a general reluctance to set or increase related tax levels can be expected. As a result the ecological efficiency of imposing taxes or charges would be reduced. It is also quite obvious that the developing countries will be looking to increase traffic as a means of solving their economic problems. They will therefore be reticent when it comes to raising taxes on oil products, not least if road traffic represents the sole means of transport in the short and medium term, and if regional distribution effects are expected in view of the large areas concerned. If the certificate-based scheme were to create a market, whose benefits tended to aid developing countries, then one might assume that these countries would support the scheme. This would apply particularly if the initial allocations of global rights were linked to the size of national populations. In this context the Council recommends that this proposal be incorporated into the international debate, where it would be necessary – amongst other things – to discuss the specific circumstances in individual countries and to establish the conditions and control mechanisms under which such a scheme could be implemented and administered.

### Research needs

Beyond the numerous research projects currently being run elsewhere, studies need to be conducted to determine the extent and effects of global pollution produced by air traffic.

## 2.4 The human dimension of global environmental change: psychosocial factors

### Short description

Many of the global changes that are currently causing so much anxiety and which led politicians and environmentalists from all over the world to meet in Rio de Janeiro in 1992 are the direct or indirect effects of human action. The rapid rise in $CO_2$, one of the greenhouse gases, is the direct result of fossil fuel combustion, e.g. to heat and cool houses and factories, to power automobiles or industrial production. Many of these activities and behaviours are linked to economic behaviour, and especially to industrial production. But not everything that leads to global environmental change can be reduced to the economic level. Everyday activities also contribute to global change, be they quirks of habit or explicitly intended behaviour guided by values and attitudes.

Human action must therefore be analysed for the relative impact it has on regional and global systems. In addition, investigations need to be carried out in order to identify which forms of behaviour with harmful effects on the environment can be changed by means of which strategies and measures.

Global environmental changes must be understood as resulting from the interplay between people and their environment. This shows clearly that environment is a *relational* term, i.e. it is always related to one particular species.

For the human species this has two implications:

(1) Environment is necessarily a correlate of human *perception* (or, more generally, human cognition). This means that people do not relate to a world "as such", but to their own specific environment, i.e. to the world as they perceive and comprehend it. This applies both to the sphere of everyday life and to humans' scientific understanding of their environment.

(2) Environment is necessarily a correlate of human *action*. Environmental circumstances can be a *cause* or stimulus, but changing them can also be the *objective* and the purpose of action, using *resources* (e.g. tools) that human beings have wrested from their environment. The relevance of environment for human action thus has three aspects: it can be a cause, an objective or a means for human action.

Changes in the environment were long considered by humans to be "natural" processes, i.e. occurring independently of human action. The notion of environment as something that is changed, polluted or destroyed through human behaviour has only become part of popular awareness in the recent past.

As is the case for any action, we can distinguish between *intentional* and *non-intentional* effects. For example, compared to the "good", rational intention of increased yield through the use of pesticides, the decimation and ultimately the extinction of particular species is seen as the non-intentional side-effect or after-effect. The global environmental changes which are now recognised as posing a potential threat to humanity are partially the unintentional effects of human actions.

However, we are now learning to think in terms of networked systems, and are better able to include side effects or after-effects into our calculations from the outset, i.e. to understand them as effects that are potentially of equal importance within a networked system. Thinking in terms of networked systems is very difficult, as research has shown, and demands a certain amount of effort before it can be learnt. Not until we are capable of thinking systematically in this way, however, will we gain insight into our *responsibility for side- and after-effects*. Corresponding to this insight is the necessity to develop a new code of *environmental ethics*.

Comprehending global environmental change as resulting from the interaction between people and their environment means, on the one hand, that human action is the cause for such changes, but also that such action is affected by these same changes and can be a reaction to them (or in anticipation of possible effects). People are thus the causal agents, the persons affected and the potential managers of global change. If human behaviour is both cause and effect of the "environmental crisis" or "threatening global changes", then the logical conclusion is that we are dealing with a crisis of People-Environment interactions, or, more precisely, with *maladjusted behaviour*.

Reducing the extent, the intensity or the speed of global environmental changes (and their negative consequences for the human species, for animals and for plants), or steering them into a sustainable future, implies a change in human behaviour vis-à-vis our environment, and assumes environmentally oriented education and upbringing. Developing "environmental awareness" or environmentally relevant values is not sufficient. Instead, it is necessary to know more about the multiple conditions for environmentally relevant behaviour and the possibilities for altering behaviour, if adequate political, economic, social and technical strategies are to be initiated and implemented.

The analysis of global change therefore represents an enormous challenge for the human sciences, especially the social and behavioural sciences (e.g. psychology, sociology, economics and cultural anthropology). Research in the social and behavioural sciences has barely approached the problem of global change. The few examples of relevant research are case studies for the most part, and generally refer to smaller spatial units (regional, possibly national). The time spans considered so far have also been too short. There barely exists any crosscultural or even comparative cultural research on global environmental change. Interdisciplinary research within the social and behavioural sciences, or between the social and natural sciences is still at a weak stage of development. The social and behavioural sciences are therefore called upon to investigate more precisely and to explain

- which social changes could be capable of influencing the type and extent of changes to the ecosphere,
- what role is played by individual and collective human action for global change and what causes are at the root of such action patterns,
- how people perceive and evaluate global environmental change,
- how they react adaptively or act preventively in response to perceived or anticipated changes in their environment,
- how changes within the anthroposphere render people less vulnerable to global change, and
- how such changes in behaviour can be motivated and stimulated through political and administrative measures.

The intention here is not to present a *"state of the art"* Report, in order to then formulate recommendations for action in the political and research fields. The main emphasis of this section is rather to develop a conceptual framework and to draw attention to findings of particular relevance. The initial perspective is predominantly psychological in nature, thus emphasising the behaviour of individuals and small groups. Explaining and evaluating the available data in a comprehensive fashion must be reserved until later Reports produced by the Council. The twin fields of "risk perception and acceptance" and "environmentally relevant value orientations" should be dealt with in some detail however, since some research findings are already available here. Research recommendations refer above all to eradicating the deficits in each of the social and behavioural sciences, to the necessity of genuinely transdisciplinary approaches within the social and behavioural sciences, to the development of research approaches that combine the natural and the social sciences and to the research funding structures that are necessary to achieve this.

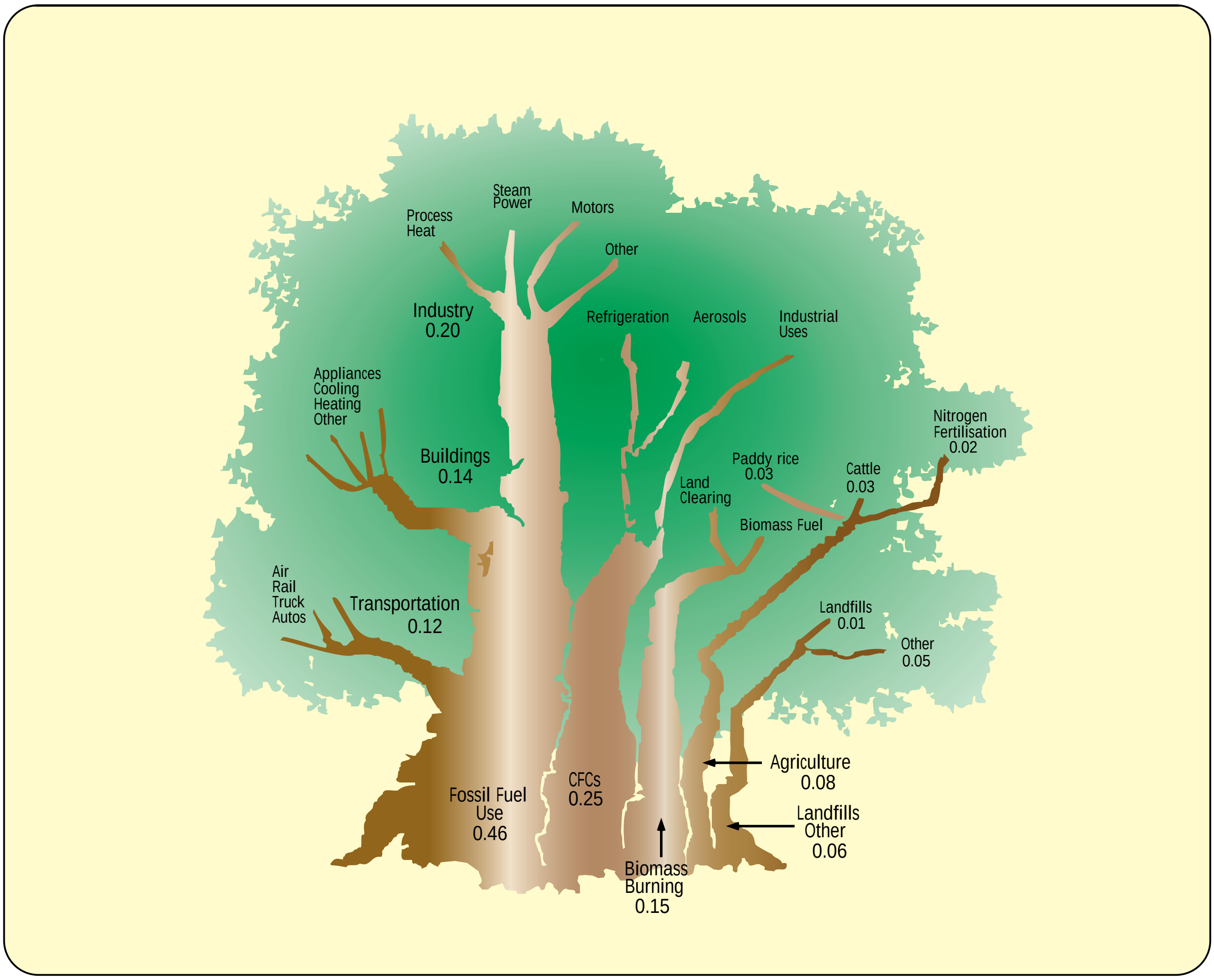
Recommendations for political action are derived from knowledge gained from environmental research within the social and behavioural sciences, and are directed at the necessity for preventive action in the light of various plausible scenarios involving considerable potential risk.

## Causes

Very many human activities connected with land use, mining of mineral resources, consumption of raw materials or energy, industrial production or mobility can be seen as *direct causes* of global environmental change. The *driving forces* behind such activities are population growth and distribution, economic growth, technological development, political and economic structures, but also individual perceptions, attitudes, value orientations, motives and needs (which *indirectly* affect the global environment). Needs are determined and influenced by cultural, historical, economic, technological and psychological variables, which in turn define the framework within which human activities develop, i.e. they facilitate or restrict such activities.

Perception, values, motives, etc., and the behaviour patterns associated with them, are important causal factors contributing to global environmental change, not only separately, but also through their interplay with other driving forces. Whether or not individuals invest their higher incomes in more foreign travel, bigger cars or in their own further education, for example, can depend on the dominant value system, but also on the social norms within their own groups or on the effectiveness of commercial advertising, and may accordingly have different effects on the global environment. Explaining the contribution of human activities and their multiple determinations to the various aspects of global change is an important aim of the *"Human Dimensions"* programme (Jacobson and Price, 1990; Stern et al., 1992). This kind of research is only possible if it is interdisciplinary in nature.

Figure 15: Relative contributions of human activities to greenhouse warming *(from Stern et al., 1992)*




If perception, values, motives etc. are to be studied as possible determinants of environmentally relevant action, it is first necessary to identify those behavioural patterns that have a major bearing on the environment, and to determine their precise significance for global environmental change. The question, in other words, is to what extent which behavioural patterns contribute to what environmental changes. For some global changes (e.g. anthropogenic greenhouse gases), estimates are already available (Fig. 15), while for others the behavioural causes have rarely been researched or quantified.

Knowing the relative importance of particular types of behaviour for particular global changes is important for the management of research, for developing scenarios of future development but also for intervening at the right time and place. If we know, for example, that only one third of the energy consumed in Germany is consumed by private households and two thirds by industry, public facilities and transportation, then investigating the conditions of *consumer behaviour* and how it can be altered will only address part of the behavioural problem in question. However, if there is a high potential and corresponding motivation to save energy on the part of private households, as figures published by the US Department of Energy in 1989 show (a third of all savings between 1972 and 1986 occurred in this sector, against only 10% in the transportation sector), then it would be absurd (and uneconomical) not to exploit such a potential (Kempton et al., 1992).

In discussing the causes and effects of global environmental change, it makes sense to make the following analytical distinctions:

(1) A distinction must be made between different *typical kinds* of behaviour with respect to their relevance for global environmental changes: *first and final investments* (e.g. insulation of housing) or the alteration of *everyday behaviour* (e.g. lowering room temperature) are not only effective to differing degrees for the aim in view (saving of fossil fuels, reduction of $CO_2$ emissions), but also involve different "costs" for the individual (first and final financial investment as against the daily expenditure of time, effort and money or the renunciation of comfort). A distinction must also be made between measures which change behaviour in the *short term* (e.g. price policies) and those aimed at changing value orientations and attitudes, something which can only occur over the *long term* (e.g. environmental education measures).

(2) Environmentally relevant behaviour occurs at different *levels* of individual and social action (from individual behaviour through to social behaviour on the level of families, companies, communities or countries, up to the level of national and international organisations). These must be viewed separately, but also in terms of their multiple interactions. Perception, knowledge, values etc. each have special weight at each of these levels. The analysis of behaviour that directly affects the environment (and the conditions for such behaviour) is therefore just as important as the analysis of the contribution that individuals make to collective patterns of behaviour (election behaviour, participation in "Green" movements). More empirical research is needed in order to recognise and identify their respective significance for global environmental change or for the management and prevention of same.

(3) Human beings perform different *roles* and *functions* within environmentally relevant processes. They are all *consumers,* some of them are *producers,* while others again are *policymakers* at various levels of strategic and tactical decision-making. Of particular importance in this regard is the role in the various mass media of journalists and other *multipliers* of opinions and values relating to environmentally relevant topics.

Establishing the determinants of behaviour which causes global environmental change, and the determinants for the effects of global change on behaviour is carried out in a similar manner: in other words, *behaviour in not only a function of its conditions, but also of its effects,* and this in a double sense:

- Many reactions to environmental stimuli are not only adaptations of behaviour to a relatively unchanged environment, but are changes in the environment itself. In this way, the stimulus will be different for subsequent behaviour, and so on.

- Depending on the extent to which behaviour is reinforced or not by its own consequences, the probability of such behaviour recurring will increase or decrease.

In both cases, the effect produced then acts as a different cause for subsequent behaviour: if insects infesting grain crops gain the upper hand, this will trigger the use of insecticides, for example. The result of such action is the decimation not only of insect pests, but also the species of birds that live on them. The perception and assessment of this situation can then lead on to other types of behaviour.

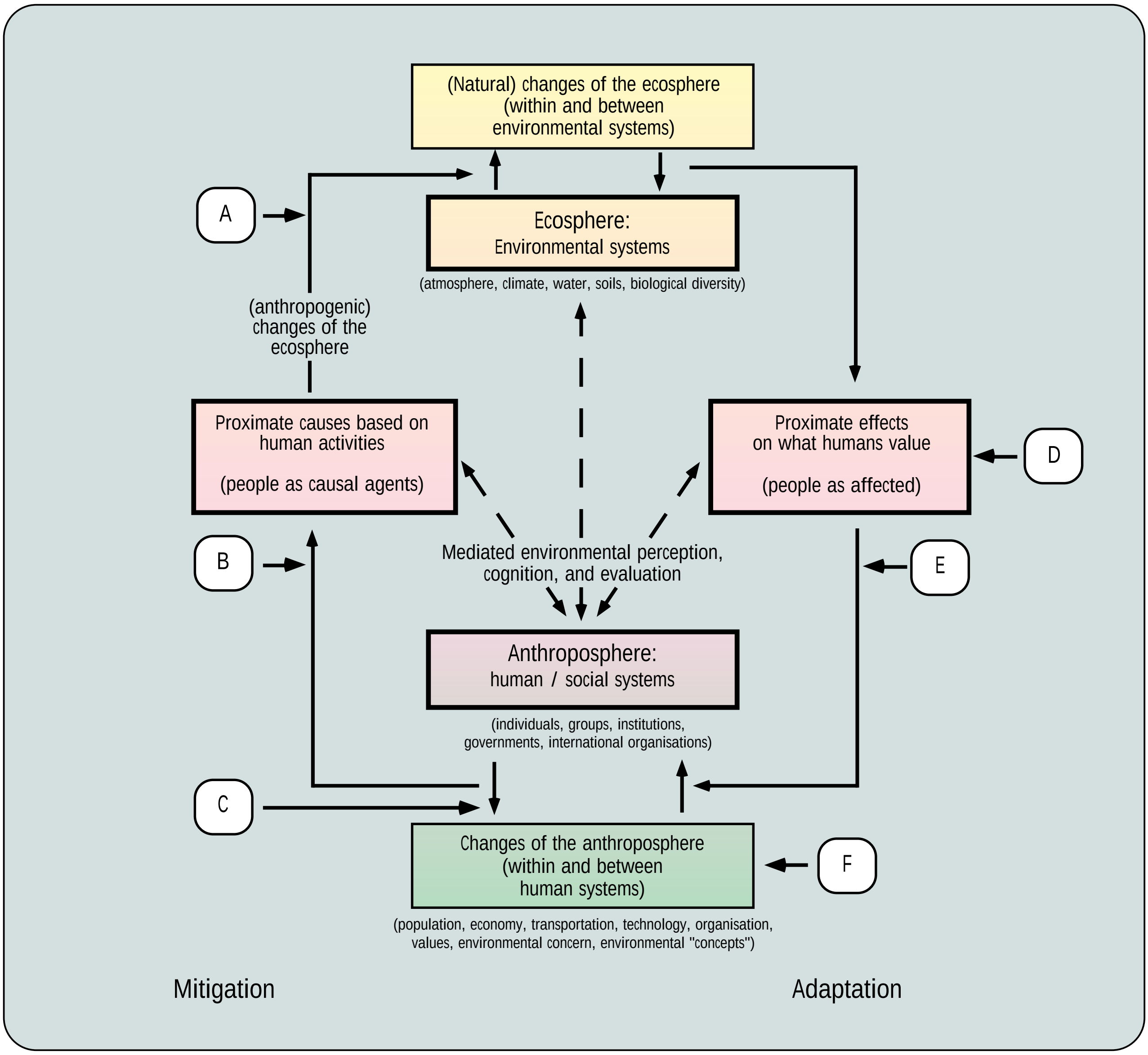
The conditions that critically influence such action sequences are dealt with jointly in the section entitled "determinants of behaviour".

## Consequences

The observation of perception, knowledge, values and actions are just as important when the issue is the *consequences* of global environmental changes. Consideration must also be given to the fact that people are not only capable of reacting to environmental changes that have already occurred, but can also act in response to anticipated change. Another factor that must be taken into consideration is that global environmental changes are not experienced by an inactive, rigid society, but that this society is often in (very rapid) movement and can transform itself independently of environmental changes, or can even transform these very changes when they are anticipated (people have built dams or emigrated in response to an expected rise in sea level). Nevertheless, global environmental changes and their specific local and regional effects signify "stress", and those most affected are often those who have done the least to cause them. It is therefore all the more important to know how such environmental stressors are perceived and evaluated, and how human beings and societies can react to them.

Reactions to global environmental changes can occur as *adaptation* to existing or anticipated changes. This does not influence the environmental changes themselves, but are an attempt to limit the effects of these changes on human life and welfare, and on the things that people value most. On the other hand, the response may serve the avoidance or *mitigation* of such changes, in order to prevent, limit or delay undesirable global changes. Such action can occur at different points in the network constituted by the ecosphere and the anthroposphere (Stern et al., 1992) (Fig. 16).

Figure 16: Diagram of potential measures to manage global environmental change *(based on Stern et al., 1992)*




Two basic types of measures can be distinguished:

1. Mitigation: This group of potential measures (A-C) is aimed at intervening on the human causes side, thus mitigating effects on the ecosphere by avoidance, reduction, or delay of anthropogenic impacts. It includes actions which
   (A) compensate for negative effects of human behaviour directly in the ecosphere (correctional measures, e.g. renaturation of damaged areas),
   (B) prevent the occurrence of such effects (preventive measures, e.g. regulations to reduce emissions), or
   (C) influence human/social systems directly (e.g. development of alternative technologies, stimulating or changing of environmental concern, facilitation of a value change).
2. Adaptation: The second group of potential measures (D-F) concerns interventions with regard to the impact of global environmental change upon the anthroposphere, above all in a sense of adaptation to already manifested or anticipated changes of the environment. This includes
   (D) actions to prevent negative environmental impacts on humans (e.g. construction of dams, use of sun protection against ultraviolet radiation, development of drought-resistant crop strains),
   (E) curative measures treating damages already manifest or imminent (e.g. evacuation from areas threatened by flood, insurances against damage), or
   (F) measures to preventively reduce the vulnerability of the human/social system against global environmental change (e.g. diversification of agricultural systems in-

Behaviour in anticipation of environmental changes is particularly important. It can prevent global environmental changes, sometimes before the role played by human action is understood in detail. Such behaviour also provides an opportunity to prepare human society for the possible consequences of global changes and to increase its capacity to cope with them (being prepared in advance for droughts, rising sea level, increased UV-B radiation, and so on).

The effects of global environmental change raise a considerable number of research issues in the social and behavioural sciences. Important problems include:

- Differing perception and assessment of global changes by lay people and experts, by politicians and scientists, by rich and poor. The main reason for these disparities is the gradual, creeping nature of global changes and the fact that these processes are rarely visible, with the result that the relationship between cause and effect cannot be immediately recognised.
- Changing patterns of individual and collective behaviour which cause damage to the environment, either directly through specific types of behaviour as starting points, or indirectly through changes in global values and persuasions, as well as through individual values and attitudes.
- The effects of transforming values and attitudinal changes on the general climate of opinion, on lifestyles and consumption patterns, on electoral behaviour, the development of environmental movements and other non-governmental organisations, and on the rejection of or support for environmental programmes.

Predicting the effects on human behaviour of global changes that may not occur until far off in the future is a difficult enterprise and dogged by a high degree of uncertainty, since little is known about

- the future (regional) state of the ecosphere,
- the social, economic and political structures that those affected will be living under,
- the perceptions, values and motives of future generations,
- the effects of global environmental changes on what these generations value most, and about
- the manner and the extent to which human societies respond preventively to anticipated global changes, or reactively to changes that have already occurred.

Nevertheless, some of the determinants of behaviour presented below will also be valid for future generations as well. The significance they will have within the ecosphere-anthroposphere causal system is uncertain, however.

## Determinants of behaviour

The following section deals with some fields of research and intervention that are important for understanding the interaction between ecosphere and anthroposphere.

### *Environment as a social construct*

An important premiss for all fields of research and intervention is that environment is understood and treated as a “social construct”. This means, firstly, that environment is a subjective correlate of human perception and human behaviour. The perceived or experienced environment is often more important, i.e. of greater relevance for action, than the objectively measureable environment (whereby perception is always selective and from a particular perspective, i.e. is guided by roles and hypotheses).

As a correlate of human perception, thoughts, feelings and actions, environmental conditions are experienced through different *meanings* (valences) as attractive or repulsive, as harmless or dangerous. Such interpreted meanings are not inherent properties of the things, the places or the conditions in question, but a correlate of human capacities, desires, needs, moods and aims. Accordingly, some meanings will vary from one moment to the next (the radiantly beautiful apple is recognised as being “irradiated’), while others will endure for a whole lifetime (e.g. a fascination for the sea or the mountains).

Some meanings are acquired through experience, others are learned or acquired through parents, teachers or through the media (books, magazines, films, etc.), through rules and bans, or simply through particular labels (e.g. as beautiful or edible, ugly or inedible, prestigious or "impossible"). Which meanings are actually acquired depends, for example, not only on gender roles, socioeconomic status, personality features or age, but on the sociocultural, political-economic context.

Environmental meanings are not perceived directly, but are conveyed through social communication, in direct, interpersonal contact, or through the media. The manner in which the environment, environmental problems or the "environmental crisis" are discussed and treated by experts, political parties, journalists, representatives of business or consumers, or by people on the street, determines the *environmental discourse* within a society (see box on environmental discourse), and is an important component in the social or societal construction of environment.

To speak of *environment as a social construction* (Graumann and Kruse, 1990) is to borrow a concept from the sociology of knowledge (Berger and Luckmann, 1966), corresponding to the concept of social representation in social psychology (Moscovici, 1977 and 1981), that is used to refer to collective, socially shared stocks of knowledge, values and practices.

Social constructions of environment show variations even between neighbouring societies, thus demonstrating cultural specificity (Douglas and Wildavsky, 1982; Johnson and Covello, 1987). A pertinent and politically relevant example is the different conception, assessment and handling of "waldsterben", or forest decline, in Germany and France (Kruse, 1989; Roqueplo, 1988). The treatment of seal deaths, food contamination or changes in global climate generally follows national patterns of meaning and evaluation that are also politically relevant as a result. Anyone active at the international level must be aware of these patterns in order to get a grip on the problems of global change, which of course are always experienced locally and nationally.

## Box 16: Environmental discourse

An important element in the social construction of environment is *environmental discourse*.

There is a major difference between describing a nature reserve as "overgrown" or "unspoilt", speaking of "rubbish tips" or "waste disposal parks", of "toxic waste" or "hazardous waste", between "waste incineration" or "thermal treatment of residual materials", or describing an accident as a "catastrophe" or an "incident".

Present-day environmental discourse uses vocabulary that is centred above all on crisis and risk, and increasingly highlights personal involvement (Nothdurft, 1992; von Prittwitz, 1992).

The social representation of, and verbal discourse about the environment are important variables in the relationship that people have to their environment, and play an important but little-researched role in the development and/or transformation of attitudes and behaviour towards global environmental change. Other factors must also be taken into account if human activities are to be understood as the cause of global change, or if one wishes to influence adaptive reactions or measures aimed at preventing or mitigating global change.

Sustainable development is only possible through "ecologically responsible behaviour" (Lipsey, 1977), i.e. behaviour that is suitable for counteracting environmental degradation and preserving resources. It is plainly evident that this can involve many different forms of behaviour on the part of individuals or of billions of people – in our culture, for example, these include waste avoidance, recycling, applying advanced technologies to reduce air and water pollution, agricultural methods that are environmentally sound, energy and water saving, or the reduction of private car use.

In the public and political spheres, but also amongst some scientists, there is a widespread belief that all these forms of behaviour are based on a common attitude or set of values (e.g. having a clean, intact environment), often termed "environmental awareness". Were this the case, then efforts for worldwide improvement of this environmental awareness would be the best way to develop environmentally responsible action. Comprehensive information aimed at improving knowledge, and appeals geared towards the promotion of pro-environmental attitudes are paramount in this respect. However, social psychological research has long since shown that values and attitudes, on the one hand, and behaviour, on the other, are only weakly linked. Other conditions influencing action must therefore be taken into account.

Other social groups consider that the problem of resource preservation can be solved better with the help of technological developments, or that the behaviour of consumers and producers should be controlled above all through price instruments and financial incentives. Such strategies, if they are deployed exclusively or one-sidedly are less successful than assumed, however, because they are often based on politically unrealistic assumptions that are also psychologically naive on occasion. All such measures are ultimately aimed at long-term and stable changes in behaviour, in other words at the transformation of anti-environmental to pro-environmental behaviour.

It is necessary here to take into account that both pro- and anti-environmental behaviour are dependent on many factors, whereby the weighting of each for particular types of behaviour varies from one person to another depending on the ecological, cultural, economic and technological context in each case. Comprehensive empirical determination of these differences has so far been attempted for only a few behavioural patterns and contexts, e.g. for energy saving. Even though global environmental changes are the result of a different set of conditions, research into energy saving during the 70s can still provide some valuable conclusions.

Without wanting to attach preference to any specific model for conceptualising environmentally related behaviour – of which many have been developed (Fietkau and Kessel, 1981; Stern and Oskamp, 1987) – the aim here is to outline a framework containing some important variables that can influence environmentally relevant action on the part of people.

Important factors influencing the development, alteration and stabilisation of behaviour are

- perception and evaluation of environmental circumstances,
- knowledge and information processing pertinent to the environment,
- attitudes and value orientations,
- incentives to act (motivational and reinforcement factors),
- opportunities and offers to act,
- perceptible consequences of behaviour (feedback).

These factors interact and interrelate in a multitude of different ways, roughly outlined as follows: environmentally relevant behaviour (pro- and anti-environmental) is dependent on incentives that motivate individuals or collectives to behave in a certain way (e.g. financial incentives, social prestige), on opportunities to act (existence of public transport as an alternative to personal transport, or of recycling containers for separation of waste), and on attitudes and values capable of influencing both action and the acquisition of knowledge and other information processes. Perceiving the consequences of behaviour (e.g. in the form of a report on energy saving within the household) can also affect attitudes, but also the input and processing of further information.

The psychosocial factors and processes of relevance to the behavioural causes of global environmental changes and to the reaction to the effects are dealt with in more detail in the sections that follow.

### *Cognition (perception and evaluation) of global environmental conditions and changes*

People lack the requisite sense organs for detecting many environmental conditions and changes, which therefore do not become evident to human perception. The ozone hole cannot be seen, heard or smelt (problems of absolute threshold). Other changes can be so minimal that they are below the threshold of "just noticeable differences", or cannot be perceived because the time lag between environmental interference and the noticeable effects is very large. A mean temperature rise of 0.5°C over several centuries cannot be filtered out as a "signal" from the "noise" of general temperature variation. This applies in a similar way to the time lag between the immediate benefit of anti-environmental behaviour and the long-term damage or cost for the individual or for society (see below on the *commons dilemma*). The time lag problem is further compounded by the problem of geographical (and social) distance between those causing and those affected by environmental changes, for example when natural assets are systematically depleted in the industrialised North and people far away in the developing world have to suffer the consequences of such interference (Pawlik, 1991). Where there is a lack of direct experience, it is replaced by *indirect experience*. Communication of the latter occurs through the medium of family communication, with those having similar convictions, with colleagues, but above all through the (mass) media.

This invisibility and exclusion from experience of many environmental problems, the considerable temporal and spatial distance between the cause and manifestation of global changes, but also the uncertainty regarding global effects and their signals, all raise a number of issues: How are environmental states perceived, represented, assessed and evaluated in the first place? What consequences does this have for the way we handle such environmental conditions (decisions, everyday action, emotional reactions)? How do perceptions differ between lay people and experts? What role is played by media reporting and the debate between experts that is conducted there?

Answers to many of these questions can be provided by the cognitive sciences, by environmental psychology and sociology, but also by geographical research into natural disasters. However, these fields have only just begun to grapple with some of the specific problems of global environmental change.

What aspects of environmental problems can be identified which make people sit up and take notice, and which are perhaps of critical importance for the modification of behaviour? Problems in the immediate vicinity that can be directly experienced (noticeable air pollution and contamination of drinking water), or rather the abstract and distant problems of global warming? What significance has the interrelationship of these problems with the four traditional elements, fire, earth, air and water? Must one's own health or standard of living be at risk first, or do people also react when plant and animal species are threatened with extinction? And how do people react to the sheer variety and complexity of environmental problems? Initial conclusions produced by a large-scale survey of schoolchildren aged between 14 and 19 (Lehmann and Gerds, 1991) showed, for example, that the ozone hole and climatic change are felt to be the environmental problems most urgently in need of attention, but that these have *virtually no relevance for the interviewee's own actions*. Environmental problems that are geographically close at hand produce less reaction than those more distant. This is paralleled by the finding, frequently reported in other studies as well, that environmental problems in one's own neighbourhood are classed as less serious in comparison to those in other areas. Lehmann and Gerds clearly state, however, that even threats to one's own standard of living or health do not necessarily result in action, and that perceived environmental problems lead to greater communication with others, but not to changed consumer behaviour.

Three-quarters of all Americans have heard about the greenhouse effect; their perception and understanding of the causes and consequences deviates sharply from that of the scientists, however. The correlations between objectively measureable environmental conditions and reality as perceived by human beings are generally low (Kempton, 1991). Climatic changes are not noticed, at best the weather and its extremities. The unusually hot summer of 1992 or the mild winters of recent years are assessed using standards derived either from one's own actual or supposed experience or as (superficial) knowledge gleaned from the media. People's memory of their own experience is generally vulnerable to inaccuracies that can distort judgement, however.

In order to make sense of unusual or inexplicable phenomena we normally try to find causes, whereby there is a tendency to put forward *monocausal* explanations. Changes in the weather were often ascribed during the 60s to nuclear testing, and today to the greenhouse effect. This type of cognitive economy does not do justice to the complexity of observed behaviour, which is characterised by network structures, non-transparency and momentum. Studies on *networked thinking* (Dörner, 1989) have shown the difficulties involved in dealing with complex systems, but also possibilities for training this skill.

Other cognitive strategies that individuals use in order to assess complex and unpredictable events, besides the tendency to use monocausal explanations, involve *heuristics of judgement* (Kahnemann et al., 1982). These are often seen as "mistakes" in information processing, but should be interpreted instead as "rules of thumb" which "reduce complex problems to simpler judgemental operations" and which are mostly used "automatically and without reflection" (Hewstone et al., 1988).

(1) Applying *"representativeness heuristics"* leads to excessive importance being attached to phenomena or properties which appear typical for a class of events, without the *a priori* probability of an event or the size of the sample from which a certain event originates being taken into consideration. This results in slow changes being overlooked, and coincidental events, such as the hot summer of 1992, being assigned too much significance, and seen instead as an indicator for the greenhouse effect.

(2) *"Availability heuristics"* refers to the tendency to over-estimate the frequency of new or especially dramatic events that have attracted a great deal of attention and media coverage. Events are available and evident if they are shown in a particularly vivid and lively fashion. The finding obtained by research into energy saving, namely that investments in energy-saving appliances are encouraged more through recommendations by friends and acquaintances than through objective information through the media, can be explained by the greater availability of personally transmitted information.

(3) The *presentation*, or *framing of a problem* influences the formation of judgement. One and the same option, e.g. an investment, can be accepted more easily if the avoidance of financial loss rather than the same financial gain is stressed.

### *Perception and acceptance of risk*

These findings on cognitive strategies and the fallibility of evaluative processes obtain special relevance when applied to the perception, communication and acceptance of risk. Global warming and the progressive depletion of the ozone layer are risks that are assessed in different ways by scientists, but even more so by politicians, members of certain parties or interest groups, and finally by lay people, with all the consequences this has for preventive and adaptive action.

There is now a substantial number of studies and empirically based theory on the perception and acceptance of risk by human beings. However, these mostly relate to technological developments (nuclear energy, new chemicals, etc.). Gradual processes, such as global environmental changes, have been virtually absent so far as subjects of risk perception research (Fischhoff and Furby, 1983; Jungermann et al. 1991).

Available research findings can be summarised as follows (Slovic, 1987): people are more likely to accept risks that they incur voluntarily than risks which they perceive as externally imposed (e.g. driving a car vs. nuclear energy). This often results in an over-estimation of one's own capabilities or capacities (*self-serving bias*). Risks which are considered to be unknown or uncontrollable are perceived as posing a threat, whereas risks that are thought to be controllable and/or to have known effects are felt to be much less threatening. Estimating the probability of risks and damages actually occurring is obviously a difficult thing to do, and leads to typical "mistakes" being made: rarely occurring and latent threats are over-estimated, and real threats that occur frequently or even permanently are under-estimated.

Differences between the assessment of risks by lay people and experts are consistently found: lay people base their assessments on a much broader notion of risk – "intuitively", so to speak, whereas "experts" ground their analyses of risk exclusively on "objective" figures about potential direct consequences (e.g. mortality rates). The layman's broader concept of risk is frequently described as "irrational"; but it must be taken seriously, especially since the criteria used by "experts" are often "contaminated" by politically defined limits and requirements, or by economic considerations (Fischhoff, 1990).

Global environmental changes play an ambivalent role as far as the voluntary nature of accepted risk is concerned, since the causal agents are both the individuals themselves, with their specific behaviour towards the environment, as well as other agencies (e.g. industry) that can be controlled by the individual to only a limited extent. Given the creeping and often unnoticeable way in which the effects of global environmental change develop, the tendency would be towards an overestimation of one's own capacities and towards an assumption that one is not involved personally. The low level of awareness and controllability of global environmental changes, however, would suggest a high potential threat. Because anticipated global changes are not discrete accidents or catastrophes (receiving short-lived but intensive media coverage, as in the case of nuclear or chemical accidents, for example), but are gradual processes instead, then calculations based on probability of occurrence are unsuitable as a means for estimating the level of risk.

The perception and assessment of anticipated environmental changes must be seen as an important prerequisite for all subsequent action aimed at managing and coping with these changes. Given the new quality of global threats compared to those risks that have already been researched, it is absolutely imperative that the relevant risk perception research be conducted with reference to this global dimension, especially since we can assume culturally specific differences in the social construction of risk (e.g. Bayerische Rück, 1993).

### The role of the media

Global environmental changes are not immediately perceptible. Of critical importance, therefore, is information which can contribute to a better understanding of global problems, their causes and their consequences, and to the growth of knowledge in this sphere. Such information is normally sought for through face-to-face communication. This is especially so in situations of general uncertainty, where rumours are often rife. The media play an important role as communicators of “second-hand” information and in the social construction of global change and its associated risks. Media are important filters in the handling of natural scientific findings. This process extends from actual publication of information to a state where, in the form of public opinion, it can have its full effect (as individual cognition of environmental problems, as influence, directly exercised or mediated through electoral or consumer behaviour, on political and economic decision-makers, as committed involvement in environmental initiatives or consumer boycotts, etc.). In the draft programmes on *“Human Dimensions”*, studies on media-conveyed information about global environmental problems, and the effect this has on audiences, is given high priority. Some findings can be gained from the risk research field (Dunwoody and Peters, 1993), others from the research tradition on attitudinal change, e.g. in the energy field.

The role of the media is multifacetted:

(1) Their task is to take abstract facts and processes with which the audience still has no direct experience of its own, and which cannot otherwise be seen (environmental change being a good example) and to illustrate these facts and processes so that people can understand them. An important factor in this context is *visualisation*. Each one of us was able to “see” the Chernobyl cloud, or the ozone hole growing. Computer animation is an important didactic tool for portraying exponential growth, for example, or for illustrating global changes over long periods of time, i.e. for generating an awareness for global changes, and winning or maintaining public attention in them. What needs to be clarified, however, are the conditions under which, and for which recipients, such presentations are adequate, and where they render harmless or over-dramatise environmental problems instead.

(2) The *type of presentation* has a number of different effects, some of them well known, on media consumers. This is the case with quantitative understanding, but also with the positioning of pro and contra arguments in controversial issues. The importance of *“framing”* was already mentioned in this connection: i.e. the presentation of gains and losses, the chances of survival and the risk of death, are processed differently by media consumers despite objectively identical content. What is also important is linguistic presentation, the terminology and semantic associations that are chosen; this issue has been the focus of intensive research into media reporting about technological risks, especially in connection with the Chernobyl disaster. The language policy consciously deployed by official authorities and associations in press statements, advertisements and television features is one means of dramatising or playing down risks.

    This more or less conscious deployment of expressive means to arouse fear or to make risks appear harmless, the fanning or stifling of emotions, is of major importance for the processing of information, and especially for the consequences this has for action. Emotional involvement, as various studies have shown, is a necessary precondition for concrete implementation of pro-environmental values and attitudes (Lantermann et al., 1992). Feelings that are too intensive, however, e.g. fear and anxiety, can have the reverse (“boomerang”) effect: people will stick their head in the sand or will ignore information about risks (the dangers of smoking, for example), will behave contrary to their genuine attitudes, or will fall into resignation. Reactions of this kind are found more frequently when the complexity of the problem prevents appropriate reactions from becoming apparent, or where there is a lack of suitable options. This subjectively experienced *loss of control*, which can be the consequence of particular environmental perceptions or information, or the cause of reactions such as the denial of environmental problems, the tendency to perceive one's own environment as "safe", or even the development of environmental diseases, is a phenomenon that must be taken seriously.

(3) The *expert debates* conducted in the media, which produce "second-hand non-experience", as Beck (1992) has pointedly expressed it, is especially relevant to the global environment problem. The general public is confronted again and again with contradictory information. This can lead to *"cognitive dissonance"* (Festinger, 1957), the non-compatibility of competing standpoints that the individual may find difficult to bear. Even though there is an unmistakeable trend in society towards "expertocracy" and towards everyday life becoming a subject for scientific investigation, conducting such debates in public can lead to a loss of credibility in experts and in those people who rely on experts, politicians being a case in point. Because the credibility of the person communicating is just as important as his or her authority and reputation for the message to be received and acted upon, this factor must be given greater attention. (This is also true for the German Advisory Council on Global Change).

### *Values / Attitudes ("Environmental Awareness")*

According to survey findings, "environmental awareness" among the population has shown a definite increase over recent years. This general trend is evident in the Member States of the European Union at least (Wasmer, 1990; Schuster 1992; Hofrichter and Reif, 1990) and in the United States of America (Milavsky, 19991), whereby one must presume substantial variations between cultural circles, nations and regions.

At EU level, 85% of those interviewed in 1992 viewed environmental protection as being an "immediate and pressing problem" (11% more than in 1988). This growth occurred in virtually all Member States, although to differing extents. 69% of interviewees assigned equal weight to economic growth and environmental protection, with only 4% assigning priority to the former. 92% of interviewees expressed concern about the disappearance of plant and animal species and of biotopes, about the destruction of the ozone layer and the disappearance of the tropical rainforests (Commission of the European Communities, 1992). This confirms the general tendency that "general" changes in the environment are assessed as being more serious than the personal threat at local level.

Within a European comparison, the Federal Republic of Germany counts among those nations with a highly developed environmental awareness (Hofrichter and Reif, 1990; Commission of the European Communities, 1992). Here, too, however, one can assume regional variations, especially when comparing the population in the new federal states with that in the old. In the years 1990/91 there was a definite decline in the level of fears relating to environmental problems, while other themes, such as the economic situation in the eastern states, became the foremost concern over the same period (Schuster, 1992). If the economic problems that are currently developing for the entire Federal Republic continue over a protracted period, then a similar situation can well develop in the "old" federal states as well.

When asked about the environmental changes that they fear most, Germans are worried about climatic problems in particular: the prime concerns amongst west Germans are the ozone hole (37%) and air pollution (36%), followed by waste disposal problems (20%) and climate change (18%). East Germans are most worried about waste problems (41%) and air pollution (37%), but the ozone hole (34%) and climate change (25%) also play an important role, landing on places three and six respectively (Institut für Praxisorientierte Sozialforschung, 1992).

Looking at the long-term trends as determined by opinion research in recent years, there was a clear increase in environmental awareness in the years 1986/87, which the consensus interprets as being the result of the reactor catastrophe in Chernobyl at that time. Whether this change in environmental awareness, which has since remained at a high level, is also a result of the *concentration* of environmental disasters in 1986 (the Sandoz catastrophe and numerous other accidents in the chemicals industry), is still an open question. Schuster (1992), in any case, interprets the *"Chernobyl effect"* as confirmation of findings obtained from risk research: a rare but spectacular accident with a large number of victims obviously leads to the potential risk being assessed as high.

Findings obtained in environmentally related attitudinal research are often linked to the value theory concept of materialism/post-materialism (Inglehart, 1977, 1989 and 1991), according to which these changes in environmental awareness are merely *symptoms* for the much wider process of change from a materialist value orientation (emphasis on economic and physical security) to a post-materialist value orientation (emphasis on self-realisation and quality of life). Inglehart sees the root cause of this “cultural transformation” in cohort-specific socialisation: the hitherto unknown level of economic security that the post-war generations in western industrialised nations find themselves with is a crucial factor contributing to the growth of post-materialist values.

Correlations between environmental awareness and Inglehart’s (somewhat controversial) thesis are repeatedly the subject of reports. Wasmer (1990), for example, confirms a clear relationship between post-materialism and the perception of environmental stresses. This interrelationship is most clearly apparent in connection with stresses that have low visibility – a dominant characteristic of global environmental changes as well. Furthermore, connections with environmental awareness can be established for other factors as well, such as school education. Level of education always appears to have a greater influence when the phenomena in question cannot be directly perceived.

Any conclusive assessment about the possible interrelations between a general transformation of values and environmental awareness would be premature given the lack of longitudinal data (especially from developing countries). A large-scale *monitoring* project involving 40 countries from all five continents and 70% of the world population (on the basis of the World Values Survey of 1990) could help in the long term, however, to make up for this data deficit (Inglehart, 1991).

Instructive and publicity-effective though the results of opinion research to date may be (only a small selection was presented here), they still need to be viewed with some methodological scepticism: published figures are typically based on answers to only one question, posed in very different contexts. Formulation and positioning of the question, the more or less powerful suggestiveness of instructions, choice of wording, prescribed alternatives and interviewer behaviour are all sources of possible error.

Caution is also advised when interpreting such highly aggregated data: firstly, they mostly obscure the substantial variability of individual patterns of perception and attitude, and hence conflicts of values within the population. Secondly, the correlation between public opinion (i.e. general values), individual values and, at the end of the chain, environmentally relevant behaviour is much weaker than is generally assumed. Correlations between generally held values and individuals’ reports on their own behaviour are no higher than between 0.1 and 0.2 in most cases, while the correlation with actually observed behaviour is even lower. There is still a requirement for methodologically less suspect research into attitudes on environmental issues. This research should be based on theoretically and empirically well-founded constructs, and must do justice to the global nature of environmental change in terms of both content and methodology.

### *Motivation and incentives*

Values and attitudes, but also knowledge of environmental problems, only become relevant for action when individuals are correspondingly motivated to do or not to do something. Environmentally oriented behaviour serves firstly to satisfy the need (or better: the requirement) for food, shelter, but also security (often termed “basic needs”, to distinguish them from “higher order” needs such as recognition and self-realisation). However, to identify and influence the motivational preconditions for pro-environmental action, it is necessary to be acquainted with the motives that we know have contributed to a major extent (as “side effects”) to anti-environmental behaviour. These motives, in summary, are the striving for individual comfort, immediate gratification, and avoidance of displeasure – or egocentric motives in general: such motives, and the behavioural patterns associated with them are not “wrong” or immoral per se, but they become a problem when directed at a resource in which everybody must or should have a share.

There is a paradigm that obtains special relevance at this juncture, namely the *“commons dilemma”* (Hardin, 1968). In the literature it is also referred to as the “commons trap”, the “socio-ecological dilemma” (Spada and Ernst, 1992), the “social trap” (Platt, 1973) or the “freerider” problem (Olson, 1965). This paradigm is often applied in economic and in social psychological research where the issue is the use of finite (renewable and non-renewable) resources (e.g. fish stocks, intact landscape) or the pollution and degrading of environment (e.g. through waste disposal or contaminants). The essence of the dilemma is that individual (short-term) interests (hedonism, personal comfort) which lead to excessive use of resources collide sooner or later with the interests of the community or the future interests of the individual himself. Something that initially appears desirable and enjoyable for the individual (e.g. unlimited consumption, use of one's own car, increased use of fertilisers), will sooner or later be to the detriment of the society to which the individual belongs, or may affect only future generations. This means in effect that a few enjoy the spoils while the majority are left empty-handed and footing the bill.

Despite being brought up from an early age to accept delayed gratification, many people appear unwilling to make any sacrifices whatsoever when it comes to their own behaviour vis-à-vis the environment. Many appear to be guided by such maxims as "enjoy now, pay later" and "après nous le deluge", rather than by the thought of environmental catastrophes or by a concern for the generations that will succeed us. Consumers are often prepared to spend more money for the sake of short-term individual gains (in enjoyment and comfort), risking social and environmental costs but not acknowledging them. The relationship here between rising costs and falling demand is obviously not quite as straightforward as some economic models would have us believe.

Besides individual motives and values, human behaviour is also influenced by *social values* (social norms within the reference group). Behaviour that damages the environment (fast driving, sophisticated packaging) usually has a higher prestige value and is effectively "rewarded" by the social group or by society as well, whereas pro-environmental behaviour is barely acknowledged and recognised (i.e. socially reinforced), but tends to be negatively labelled instead.

Breaking down such "social traps" and promoting individual behaviour that serves the public good is an important precondition for the development and stabilisation of behaviour that is environmentally sound. Research has identified various conditions that counteract egocentric and exploitative behaviour and promote altruistic behaviour instead. These involve above all the knowledge of systemic interrelations within the environment, and the environmental consequences of one's own action, but also trust in knowledge and the willingness of others to cooperate in preserving a given resource (Spada and Ernst, 1992). A whole series of other principles relevant to learning and motivation must also be given consideration in this respect.

One will find few people whose well-developed environmental awareness suffices and who will give up of their own accord, i.e. *with intrinsic motivation*, a specific behaviour that is acknowledged as harmful but also subjectively satisfying, and who will replace this behaviour by another. This is all the less likely to occur if the behaviour in question is automatic and bound up with a long history of socialisation.

Stronger *incentives for behaviour* are needed before an initially uncomfortable, time-consuming, cognitively more demanding behaviour is taken up. This occurs through the use of "reinforcers" as behavioural consequences intended to increase the probability of pro-environmental behaviour, and reduce the probability of behaviour that causes harm to the environment, e.g. by making non-returnable bottles and parking space more expensive or by lowering the prices for public transport.

"Rewards" need not always be financial in nature, although material gains in our society seem to be the most powerful incentives. *Social recognition* by relevant reference groups (neighbours, friends) can also have a motivating effect.

*Feedback* which informs the recipient about the positive effects of appropriate, or the negative effects of inappropriate behaviour is experienced as a kind of cognitive reinforcement. Feedback in terms of a specific criterion (e.g. energy saving in comparison with the previous year or the community average) can motivate an individual to achieve a desirable objective that the individual sets himself and which is perhaps even reinforced through his publicly committing himself. One problem with such reinforcement strategies, however, is that the change in behaviour often lasts for as long as it continues to be rewarded, i.e. is externally supported. For such behaviour to become stabilised it is necessary to build up intrinsic motivation via such extrinsic motivation and education about environmental interrelationships.

## *Opportunities, possibilities and contexts for action*

What is often lacking for pro-environmental behaviour to become established are *possibilities for action*, firstly in the sense of a lack of competence and skill: some people do not know what they are supposed to do, others cannot perform a certain kind of behaviour (e.g. riding a bicycle) because they have never learnt or can no longer learn how to do it. In addition, there is often a lack of *opportunities for action*, e.g. low-packaging products, energy-saving household appliances, water-saving devices, or short-distance public transportation that must be available before motorists will leave their car behind. It makes little sense to call on people to save money by avoiding waste when there is no opportunity for individuals to save on waste disposal charges.

The *context* of action also encompasses the *social environment* in which new behaviour is to be learnt or become effective. Good neighbourhood contacts (social networks) provide the opportunity for social compensation and social control (Hormuth and Katzenstein, 1990), and especially the chance to develop cooperative relations and solidaristic behaviour (Diekmann and Preisendörfer, 1992; Neuman, 1986).

When planning opportunities and incentives for action, careful consideration must be given to the question whether it makes sense to strive for a change in everyday behaviour (e.g. reduction of private automobile use) in order to reduce $CO_2$ output, or to promote first and final investments (e.g. buying an energy-saving car). Some social scientists (Stern and Gardner, 1981) argue that the environmental relevance and the energy-saving potential of everyday behaviour is often over-valued in relation to the significance of larger, first and final investments in the household. For very many environmental problems, however, it is absolutely essential that consumer habits and everyday routine actions be changed (e.g. avoidance of waste). Cutting down on consumption on a daily basis demands that habits change, and must therefore be supported if necessary by (intermittent) reinforcement. Investments in energy-saving technology, on the other hand, require a first and final decision. It has been well confirmed that a single decision for relatively costly investments is influenced above all by economic factors, whereas environmentally related values and norms are more likely to apply in the case of behaviour that is relatively easy to perform (e.g. doing the shopping or sorting waste) (Diekmann and Preisendörfer, 1992).

### Strategies for behavioural change

So far we have been dealing, mainly at the conceptual and categorical level, with the determinants of environmentally relevant behaviour as causes, but also as consequences of global environmental change. To round off this analysis, some important strategies and interventional approaches for modifying behaviour which were developed in response to the first energy crisis in the early 70s (especially in the USA) are presented. During that particular period, oil became scarce and energy prices rose, thus exerting a major effect on behaviour (investments in energy-saving cars, heat insulation on buildings, changeover to other forms of energy, e.g. from gas to coal). Nevertheless, it soon became apparent that market forces alone do not suffice to alter the energy-consuming behaviour of the population to any adequate degree.

The "new" global environment crisis is of a different quality. Today, too, attention is focussed on the consumption of energy, not because energy is scarce and expensive, but because emissions through the consumption of fossil fuels are one of the main causes of the greenhouse effect. What was considered a mere "side effect" of energy consumption in the 70s is now a key focus of attention as one of the main causes of anthropogenic climate change, namely $CO_2$ emissions through the use of fossil fuels. There is sufficient energy available, prices are low, so that there are basically no major extrinsic incentives that could motivate similar behavioural change (Kempton et al., 1992).

A number of programmes have been developed for changing environmentally harmful and energy-intensive behaviour. These have been applied and subsequently evaluated, especially in the USA, whereby evaluation takes into account not only the determinants already specified, but also a large number of other factors that are known to be significant conditions or transmission factors for behavioural change – the human system is no less complex than the natural system. The human system comprises *individual* factors (e.g. cognitive abilities, or demographic variables such as age, gender and socioeconomic status), *interpersonal* factors (social norms, social contacts) and *contextual* factors (place of residence, size of household, property of technical appliances, etc.).

The most important types of intervention strategy are (Kempton et al., 1992; Stern, 1992a):

(1) *Information, education, feedback*

Information and education occur through the mass media, but also through brochures, advertising, schoolbooks and other educational material. Many studies have confirmed that pure communication of information has very little effect in relative terms, unless certain fundamental principles of information presentation are complied with (Dennis et al., 1990; Stern and Aronson, 1984). This is especially the case when other behaviour stimuli such as high energy prices do not exist. Changes to attitudes and behaviour are more likely to develop when information is communicated in a precise, easily understood, personally relevant and lively form, and conforms with basic principles for optimal presentation of alternatives (losses vs. gains).

More effective than pure information is concrete *feedback* about one's own successes. The perceived consequences of pro-environmental behaviour can then trigger off changes in attitudes and values, which themselves influence behaviour. Feedback is particularly effective when prices and environmental awareness are high, and people are already motivated to change their behaviour. Information has little effect when prices are low and environmental awareness is less developed; a high level of motivation, on the other hand, can compensate for the latter and improve effectiveness. Motivation can be reinforced by self-commitment to pro-environmental, energy-saving behaviour, especially when this commitment is made publicly.

What is also more effective occasionally is "learning from models", for example when well-known personages demonstrate pro-environmental behaviour (the Minister regularly rides to work on his bicycle). The credibility of the communicator or information source has also proved to be a very significant variable. Energy information provided by utility companies had less effect than the same information from consumer advisory centres or local community groups. Information from friends and acquaintances, or "word of mouth" propaganda in local groups has a greater bearing on behavioural change than information through the media, however comprehensive and objective the latter may be. In smaller, somewhat more experimental studies, the *"foot-in-the-door"* approach has proved its effectiveness. The reason for this success is the knowledge that a person is more liable to take on a larger obligation in the future (e.g. to separate waste into four separate bins) if he or she has already consented to a minor, but related obligation. Achieving an initially small change in behaviour – whatever the extrinsic motivation or incentive – can be the stepping stone to a more substantial involvement and commitment. It follows from this that one should not "over-do it" when behavioural changes are necessary, but that a step-by-step approach is called for instead.

Deploying information strategies is a complex task. However, applying some well-confirmed findings from the fields of cognition and communications research could make such approaches more successful than they have been to date.

(2) *Incentives for action*

Applying positive and negative incentives for action, e.g. granting rebates to people buying energy-saving cars, or imposing an energy surcharge, is a widespread and effective strategy all in all, especially when the issue is the introduction of "new" forms of behaviour. Incentives are all the more effective when they have direct relevance for the behaviour in question. A low electricity bill at the end of the year is less effective in encouraging permanent energy-conservation behaviour than a bonus at the end of the month. Making electricity bills bigger by putting up prices despite lower consumption levels is counter-productive, however, since consumers think more in terms of monetary units than in kilowatt hours (Kempton and Montgomery, 1982) and could therefore feel as if they are being punished for their efforts to conserve energy.

Households react more positively to the granting of a bonus than to the granting of a loan, even if the net benefit is the same (Stern, 1992b). One survey conducted more recently in Germany (Karger et al., 1992) showed that interviewees were more liable to accept the costs involved in protecting the environment if they themselves have some control over those costs (buying an energy-saving appliance), than they are líkely to accept compulsory levies or taxes imposed by the state. Even though the costs are an important incentive for changing behaviour, such campaigns can be made even more effective by taking non-monetary factors into account.

(3) *Non-monetary strategies*

Money is not the only driving force behind behavioural changes. Non-monetary strategies can also succeed in this aim. This is particularly relevant for the problems of global change in the 90s, and perhaps in the more distant future as well, at a time when energy prices no longer indicate energy shortage. The importance of personal preferences (people prefer to invest in storm windows rather than in wall insulation), of group structures and social networks, of personal values and attitudes and the fact that people will often fail to react until the crisis or catastrophe is upon them – all this demands that further schemes be developed with the aim of modifying behaviour.

All in all, it can be stated that no single strategy, but rather a combination of different strategies is most effective. These must be planned with the specific situations and target groups in mind, and must also integrate above all the cultural, technological, economic, political and legal context.

**Box 17: Follow-up issues of the UN Conference on Environment and Development in the field of psychosocial factors**

The relevant chapters from the social and behavioural scientific perspective are Chapters 23 to 32. These describe in detail the role of those social groups who are particularly affected by global environmental change and who are seen as especially relevant actors for environment and development (children, youth, women, indigenous people).

Measures are proposed for promoting participation of the following groups and organisations: women (Chapter 24), children and youth (Chapter 25), indigenous people and their communities (Chapter 26), non-governmental organisations (Chapter 27), local authorities (Chapter 28), workers and their trade unions (Chapter 29), business and industry (Chapter 30), the scientific and technological community (Chapter 31) and farmers/rural populations (Chapter 32).

## Assessment

For sustainable development it is necessary that every single individual, above all those who have responsibility for the actions of others or who perform functions as multipliers – politicians, leading people in the economy, employers and workers' representatives, but also journalists and teachers – meets some basic requirements:

(1) There is a necessity for insight into the *systemic nature of the environment* – at local, regional and global level – and in the fact that this system is severely changed by human activities, with negative consequences for the ecosphere and the anthroposphere.

(2) A further necessary requirement is knowledge of the *systemic nature of human action*, the cause, individually and cumulatively, for many global environmental changes and which itself is affected by the latter in many respects – through adaptive reaction or as preventive action. Human action is the result of manifold conditions (multivariability) that are causally interlinked (multicausality), and can have numerous different effects (multi-effectivity). Through its interdependencies on natural and cultural determinants, human action exhibits such a high degree of variability that simple, predictable correlations are rarely encountered.

(3) In planning measures for *modifying* what is essentially *maladjusted* behaviour on the part of individuals and societies, the following significant factors must be taken into account:

– perception and assessment of global environmental changes
– environmentally relevant knowledge and information processing
– attitudes and values
– incentives for action
– opportunities and offers for action
– perceivable consequences of action

Because many global environmental problems cannot be seen or experienced directly, the way in which they are *communicated* at the everyday level, through the media or through educational schemes, becomes all the more important.

To achieve constant growth in awareness, consideration must be given to various social scientific findings on the communication and processing of information. For example, the effect of informational and educational campaigns is much lower than is often assumed, especially when basic principles of information processing, such as the message itself and the role played by various features of the communicator, are not complied with.

The role played by attitudes and values in connection with pro-environmental behaviour is generally overrated. This is particularly the case for global environmental values. The better attitudes are comprehended, the more reliably they can be used to forecast pro-environmental behaviour. Exerting influence on attitudes and knowledge must therefore be supplemented by measures to stimulate motivation, whereby consideration should be given not only to monetary incentives, but also to the importance of social recognition. The role of feedback about one's own behaviour must also be taken into account.

Integrating existing knowledge and enabling the acquisition of further knowledge (through research, interventional measures, as well as their systematic evaluation) provides an important foundation for environmental, economic, labour market and education policies that are aimed at sustainable development and which attach greater importance to the prevention of global environmental changes than to merely adaptive strategies.

## Need for action

Environmental policies that appreciate the seriousness of the threats posed by global environmental changes, not only for those now living but above all for future generations, must try to engender an awareness amongst the population for these threats and for the demands on present generations that ensue from this. What is required is a "generational contract", a "solidarity pact" that attends to the predictable and/or possible interests of future generations. This demands the conservation, i.e. responsible consumption of renewable and non-renewable resources, the reduction of environmental degradation and destruction, and the preservation of biodiversity.

The political sphere, in particular, must not only convey these principles to the population through appropriate forms of communication, but above all must establish them firmly as objectives of political action in the various programmes directed at the modification of individual or collective behaviour. A radical change of values is necessary: the conservation of nature for nature's sake and as the essential basis for the survival of future generations must qualify and moderate the dominant orientation towards growth and profit. Precautionary and preventive action are called for, despite and because of the lack of certainty about the future of our planet. Delay of gratification is necessary, even if the "reward" for our sacrifice will benefit future generations only.

To promote this change of values, the development of environmental awareness and especially pro-environmental behaviour, politics must make use of scientific knowledge from those scientific disciplines that can contribute to the analysis of societal values and the changing of values, of the values and attitudes held by individuals and how these can be influenced (environmental psychology, sociology and education, ethics, and environmentally oriented economics). Even giving attention to existing knowledge about the modification of environmentally relevant attitudes and behaviours will open up sufficient space in which politics can be active: glossy brochures, advertisements and television spots by themselves have little effect if the ultimate requirement is to achieve permanent change in behaviour, and acceptance for environmental measures. Taking into consideration information processing strategies, risk perception and acceptance, the significance of behavioural incentives and opportunities for action, not to mention the social context, could help to make some environmentally meaningful measures a greater success. Developing specific schemes for communicating information and for intervening could be the task of an interdisciplinary *task force*.

## Research needs

Global environmental changes are complex processes that need to be understood as interactions between the ecosphere and the anthroposphere. The consequence is that they cannot be analysed, neither in the natural nor in the social sciences, from the perspective and on the theoretical and methodological foundations of a single discipline alone. Research within the social and behavioural sciences on global environmental change is still in its infancy. It is mostly confined to specific disciplines and relates only to the local level, perhaps to the national level, and this within narrow time horizons. There is an almost total lack of multidisciplinary and multinational approaches. The vertical organisation of our universities according to strictly separate disciplines, and the tendency towards specialisation in ever-narrower fields is detrimental to the analysis of complex global environmental problems. There are few large-scale, internationally networked projects, and cooperation between the social and the natural sciences is still a rare phenomenon (see the Report by the Science Council on environmental research due to appear in 1993).

In contrast to natural scientific research into the environment, the social sciences do not receive any explicit funding in Germany for research into environmental topics. There is no specific research programme with the requisite funding in sight. At the EU level, there is now a research programme within the Third Framework Programme (1990–1994) in the environment field. The sub-programme on “socioeconomic environment research” is supported with ECU 15 million. A fourth research support programme dealing with the problems of “Global Change” is to be established for the period 1994–98. In the USA, less than 5% of the Global Change research programme is dedicated to the Human Dimensions field.

In 1990, on the basis of a Framework for Research on the Human Dimensions of Global Environmental Change (Jacobson and Price, 1990), the International Social Science Council (ISSC) drew up the Human Dimensions of Global Environmental Change Programme (HDGEC, now shortened to HDP). The principal aims of the HDP are to provide material and immaterial support to social and behavioural science research on global environmental change (see box below).
If the causes and effects of global environmental change are to be investigated fully, the above considerations generate the following research demands:

**Box 18: Human Dimensions of Global Environmental Change Programme (HDP)**

The ISSC programme focusses on seven fields:
1) Social dimensions of resource use
2) Perception and assessment of global environmental conditions and change
3) Impacts on local, national and international social and political structures and institutions
4) Land use
5) Energy production and consumption
6) Industrial growth
7) Environmental security and sustainable development

- Analysis of People-Environment issues from a *monodisciplinary* perspective in the various social and behavioural sciences, especially where this has not yet occurred to an adequate extent. Technical objects, environment that is constructed, shaped or cultivated by human beings, must no longer be the preserve of the natural and engineering sciences. The important issue here is to develop concepts and methods that are appropriate to the analysis of the various modalities of People-Environment interactions.

- Support and funding for *transdisciplinary research approaches within the social sciences*. The first step here would be to establish stronger links between the approaches of the various disciplines in the study of individual and societal action. This is important in that the behaviour immediately relevant for global environmental change traverses the traditional disciplines. Demographic and economic change, for example, must be analysed together, as must legal and economic conditional frameworks. Cultural, social and psychological variables must be investigated by an approach that can integrate all three types in its analysis. This requires (larger) multidisciplinary teams. Social scientific and behavioural research must be conducted at all levels (local, regional, global) and on the basis of different temporal perspectives (historical, present-day, prospective; cross-sectional and longitudinal).

- Development of dialogue and *cooperation between the natural and social sciences*. The classical separation between the two scientific cultures can no longer be upheld given the pressing environmental problems we face. Since the crisis of nature emanates from a crisis of culture, sustainable development can only be achieved through a change in culture, in society, through individual and collective awareness and action by the members of society.

  Closer cooperation between the natural and social sciences is the logical and necessary consequence of the growth in knowledge concerning the interdependency of humanity and nature. The need for such cooperation has now been recognised, also by scientists themselves, who repeatedly come up against the boundaries of their particular specialities when attempting to find solutions to global problems, due to the traditional vertical structure of universities. The main reason why there is little or no "border traffic" between disciplines is that scientific workers within a particular natural or social science do not know what information and methods another disciplines can provide that could be useful in approaching their respective issues. Problem-centred (large-scale) research establishments may represent a certain structural surmounting of the barriers between disciplines, but so far there have only been initial approaches that still require major funding (such as the *Umweltforschungszentrum* [Environmental Research Centre] in Leipzig/Halle, or the *Potsdam-Institut für Klimafolgenforschung* [Potsdam Institute for Climate Impact Research], PIK). The recent establishment of the *Terrestrial Ecosystem Research Network* (TERN) serves the aim of transdisciplinary communication.

  Examples for activities aimed at enabling or facilitating cooperation between previously disparate research establishments and disciplines include:

  - the *Scientific Committee on Problems of the Environment* (SCOPE) of the *International Council of Scientific Unions* (ICSU), up to a third of whose reports, on *environmental impact assessment* or the greenhouse effect, for example, originate from social scientists,
  - the *Intergovernmental Panel on Climate Change* (IPCC), with its studies on alternative political reactions to climate change, which are similarly produced through joint research by natural and social scientists, and
  - the *Bergen Conference* (1990), whose Report entitled *"Sustainable Development, Science and Policy"* (NAVF, 1990) contains an analysis of sustainable development that is recognisably the product of a multidisciplinary enterprise.

  One is well advised in these and future initiatives to attach different weightings to the respective contributions of the natural and social sciences towards solving global environmental problems, depending on the task involved. If one takes the main questions which la Rivière (1991) considers important (1. How does the Earth System function? 2. How can forecasting be improved? 3. How can environmental decision-making be scientifically based?), then one can identify a decline in natural scientific and an increase in social scientific involvement as one moves from 1 to 3, despite the basic interaction between the two.

- Methods and indicators for *"social monitoring"* need to be developed on a Europe-wide and international basis, comparable to those used in *"environmental monitoring"*. Relevant social and behavioural data must be collected continuously and/or periodically, at as low an aggregation level as possible (e.g. tourist behaviour).

  There are a number of national or European surveys (e.g. "Eurobarometer") for ascertaining values and attitudes in the population, but as a rule these fail to record internationally comparable parameters, or to record all the variables of relevance here. Good examples for the kind of initiative needed are the following:

  - An initial project aimed at recording data on perception and cognition is planned within the *Human Dimensions of Global Environmental Change Programme* (HDP) under the auspices of the *International Social Science Council* (ISSC) (Miller and Jacobson, 1992):
  - Further initiatives are organised in the USA by CIESIN (Consortium for International Earth Science Information Network).

**Box 19: Global Omnibus Environmental Survey (GOES)**

GOES (Global Omnibus Environmental Survey) will collect data on a periodic basis (every five years) on environmental knowledge, environmental attitudes and self-reported behaviour in different countries in the world. With the help of such data the attempt will be made to unravel the relationships between knowledge, attitudes and self-reported behaviour. Other issues which can be investigated include media use and the direct experience of environment, in order to examine the influence of cultural traditions on the development of environmentally relevant attitudes. The countries participating, in addition to the USA, the EU Member States and Japan, are Bangladesh, Brazil, China, India, Indonesia, Korea, Mexico, Nigeria and Pakistan, as well as Russia and other eastern European countries.

This survey thus embraces more than two-thirds of the world's population, more than 84% of all GNPs and more than 70% of all greenhouse gas emissions.

  - UNESCO is endeavouring at the international level, as part of the MAB Programme, to institute standardised monitoring of biosphere reserves, including social scientific indicators. The UNESCO biosphere reserves can function as a first field of practice worldwide, since they are not only designated as large-scale conservation zones, but should also be used as areas where research can be carried out.

- In addition, *case studies* are needed on similar problems in different countries, in order to conduct the relevant comparative studies. A prime example of such work is the *Critical Zones Project*: a multinational team is concentrating its attention on 12 areas threatened by rapidly increasing environmental destruction. The project aims, for example, to compare the social perception of environmental changes and the implementation of environmental policies.

  Another example is the joint *"Land cover/land use changes project"* being carried out by IGBP and HDP. The aim here is to develop a global "land cover/land use changes model" on the basis of regional case studies (Miller and Jacobson, 1992).

- National initiatives in the international political sphere, and especially the demand of the industrialised nations that development aid be linked to environmental and social improvements, require well-founded knowledge about the natural and sociocultural circumstances in these countries.

  To promote such knowledge, two things are needed:

  - Relevant research must be stimulated and supported in the respective countries, e.g.

    – through *training programmes* for training and continuing training of researchers from countries in which there is still little or no research of this kind. This applies above all to countries in the Third World. The START Programme (Global Change System for Analysis, Research and Training) initiated by the IGBP, WCRP and HDP is one example for such activities.

    – through participation of appropriately trained research teams in *large-scale multinational projects*.

  - Research involving *cultural comparisons* must be given support, mainly in order to become familiar with the perspective of partner countries in relation to (global) environmental problems, and to integrate this knowledge into appropriate aid measures

- Support (and demand) for *evaluation research* are also important. Measures must be systematically evaluated, be they in the field of environmental education or within the framework of specific economic and political programmes aimed at promoting environmentally and socially acceptable behaviour, from consumer behaviour to industrial production. Evaluation should not be limited to the question whether objectives were achieved or not, but above all must also integrate (undesired or unintended) side-effects into the analysis.

- Important prerequisites for multidisciplinary and multinational research are corresponding institutional *structures* and appropriate financial and technical facilities (good social scientific research, being labour-intensive, is expensive!). In addition, support instruments as well as structures and processes for expert opinions appropriate for the new quality of these research projects need to be developed. Here, too, the corresponding institutional preconditions must be created, along the lines of the "national centers for research" proposed by the National Research Council for the USA (Stern et al., 1992).

All these measures should be implemented at the national and, more importantly, the international level in order to do justice to the global character of environmental changes.

# E Global change: A tentative synopsis

## The principal trends, their interactions and the ensuing dynamics

The members of the Council were chosen to represent the specialised areas of greatest relevance to the analysis of global environmental change. This offers both opportunity and obligation for a holistic analysis of the present crisis of the Earth System. *Multidisciplinarity* alone, achieved most effectively by a suitable arrangement of contributions in a reader, will not suffice: the complexity, i.e. the interwoven dynamics of global change must be reflected in a network perspective where insights gained in various fields of science act as reciprocal inputs and outputs. From this approach genuine *interdisciplinarity* can emerge and subsequently develop into an *expert system.*

## Choice of analysis

There are two fundamentally different ways to tackle the synoptic task:

1. Modelling the coupled ecosphere-anthroposphere system on the basis of a comprehensive and detailed description of the relevant system variables, sources and sinks, internal interactions and external driving forces.

   In the ideal case these efforts lead through formalisation to a mathematical dynamic system that permits predictions to be made about the further development of the complex under observation – at least in the statistical sense –, given suitable initialisation and integration in time.

   The Earth System can be described on different spatio-temporal scales by means of a hierarchy of models with different degrees of aggregation. The first steps along the strenuous path to the corresponding integrated models are presently being made, with the consequence that politicians cannot expect reliable data in the short run. In the long run, however, only complex models of this type will be able to provide a quantitative understanding of the overall system. The Council will follow this promising development with great interest over the next few years, offering every possible support and integrating important results into its own analyses where so required.

2. Empirical-phenomenological systems analysis (determination of principal trends, synergy effects, neuralgic points, feedback loops, etc.) on the basis of combined expert knowledge and, where information is heterogeneous and/or sparsely available, intuition.

   This means attempting to describe the interrelations within the Earth System in a dynamic model without prior recourse to formal reconstruction. The primary objective of this approach is the identification of the most important developments within global change and their interplay. In other words, attention is focussed on the dynamics of mutually interacting cooperative phenomena.

A *qualitative* analysis of this kind stays clear of the danger of trying to arrive at accurate conclusions with a mass of inaccurate data at hand; it is, therefore, the Council's first choice.

## Description of the instrument used

A specific type of diagrammatic representation of the global network of interrelations is chosen as a methodological tool assisting the holistic analysis. This is to be justified by the fact that a geometrical representation of interactions often appears more confusing than an algebraic one (e.g. in the form of a matrix), but illustrates more clearly the direct and indirect connectivity of the system's components.

The network of interrelations should be constructed as follows:

*1st step:*
Decomposition of the coupled ecosphere-anthroposphere system into its 10 major components, along the lines of the basic structure of this report. In the corresponding graphical representation (Fig. 17), each of the main compartments is

assigned a specific colour to facilitate the identification of cause-effect relations in the fully developed diagram (see below).

*2nd step:*
Determination of the key trends of direct or indirect significance for global change. These trends are symbolised by ellipses positioned at a suitable place within the main compartments or, if cross-sectional in nature – between them (Fig. 18). The diagram can be made as detailed as desired by using different sized ellipses depending on the impact accorded to the development in question.

*3rd step:*
Identification of mutual influencing of global trends. Interactions can occur both within and between the main compartments. Each effect exerted by one trend on another is symbolised by a line connecting the relevant ellipses and bearing the colour of the "causal" compartment. In the case of cross-sectional phenomena, the colour is determined according to the proximity to the neighbouring sub-systems.

The type of influencing is taken into account and differentiated according to three rules (Fig. 19):
(i) "Trend A reinforces Trend B"
(ii) "Trend B attenuates A"
(iii) "Trend C has an as yet unknown net effect on Trend D"

The analysis can be extended by including the "self-reinforcement" and "self-attenuation" mechanisms (Fig. 19):
(iv) "Trend A reinforces itself"
(v) "Trend B attenuates itself"

Just as ellipses of differing sizes can be used to mark the momentum of trends, the connecting lines can be of different line thicknesses or line patterns in order to signify the strength of the interaction.

Taking into account no more than the most obvious phenomena and interdependencies, the result is highly complex, demonstrating the intellectual challenge implied by a rigidly systems-based approach. Figure 20 provides an introduction to the synoptic perspective: the "hologram" of global change is shown in an initial stage as defined by the particular network pattern associated with the trend "increased greenhouse effect".

There is another aspect which argues against the Council presenting a complete description of the network of interrelations in the first Report – the fact that the identification of the trends and their interactions represents an enormous scientific challenge. In this process the most recent research findings from various disciplines will have to be taken into account; the instrument needs time to mature. However, the Council considers this approach fundamental for organising and accumulating the collective knowledge of its members in a transdisciplinary manner appropriate for the system being analysed. The global network of interrelations could serve as a "general map" for setting the direction to the Council's future work.

## Possible areas of application

Generally speaking, the approach described above is suitable for the application of qualitative systems analysis as practised in the fields of theoretical ecology, operations research or control theory. With the aid of such procedures, as well as through direct inspection, a great deal of significant information can be obtained from the network of interrelations. Some possibilities are outlined below:

- *Cluster analysis*
  How homogeneous is this network of trends and compartments? Does the overall complex decompose into independent sub-clusters? Are there "bottlenecks", "short circuits", "flashpoints" or "transmission belts"?

- *Feedback analysis*
  Which "reinforcement and attenuation loops" can be identified? Where do polarisations and/or equilibrium tendencies manifest themselves through antagonistic trends or restoring forces?

Figure 17: Global network of interrelations – Basic structure

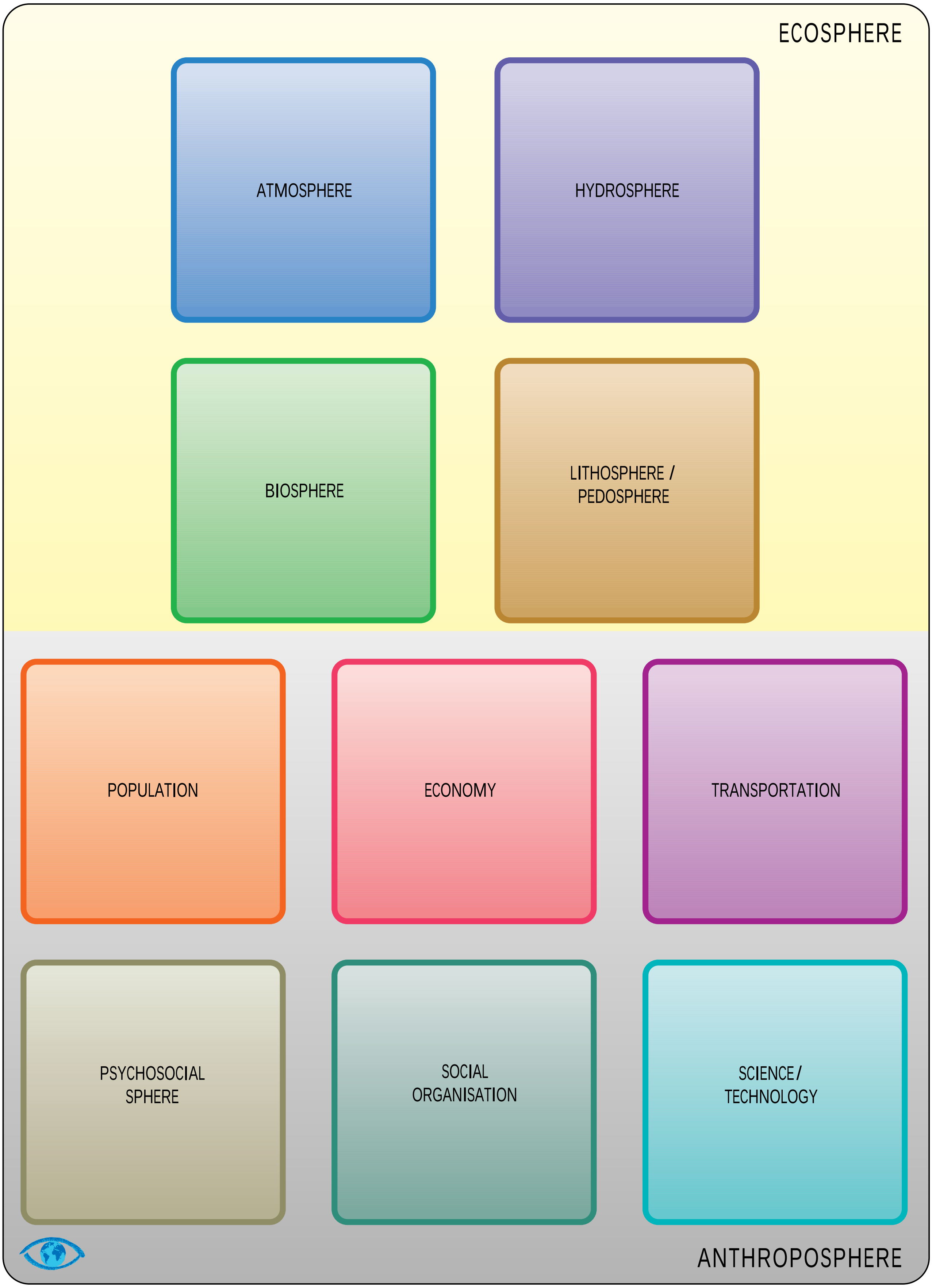
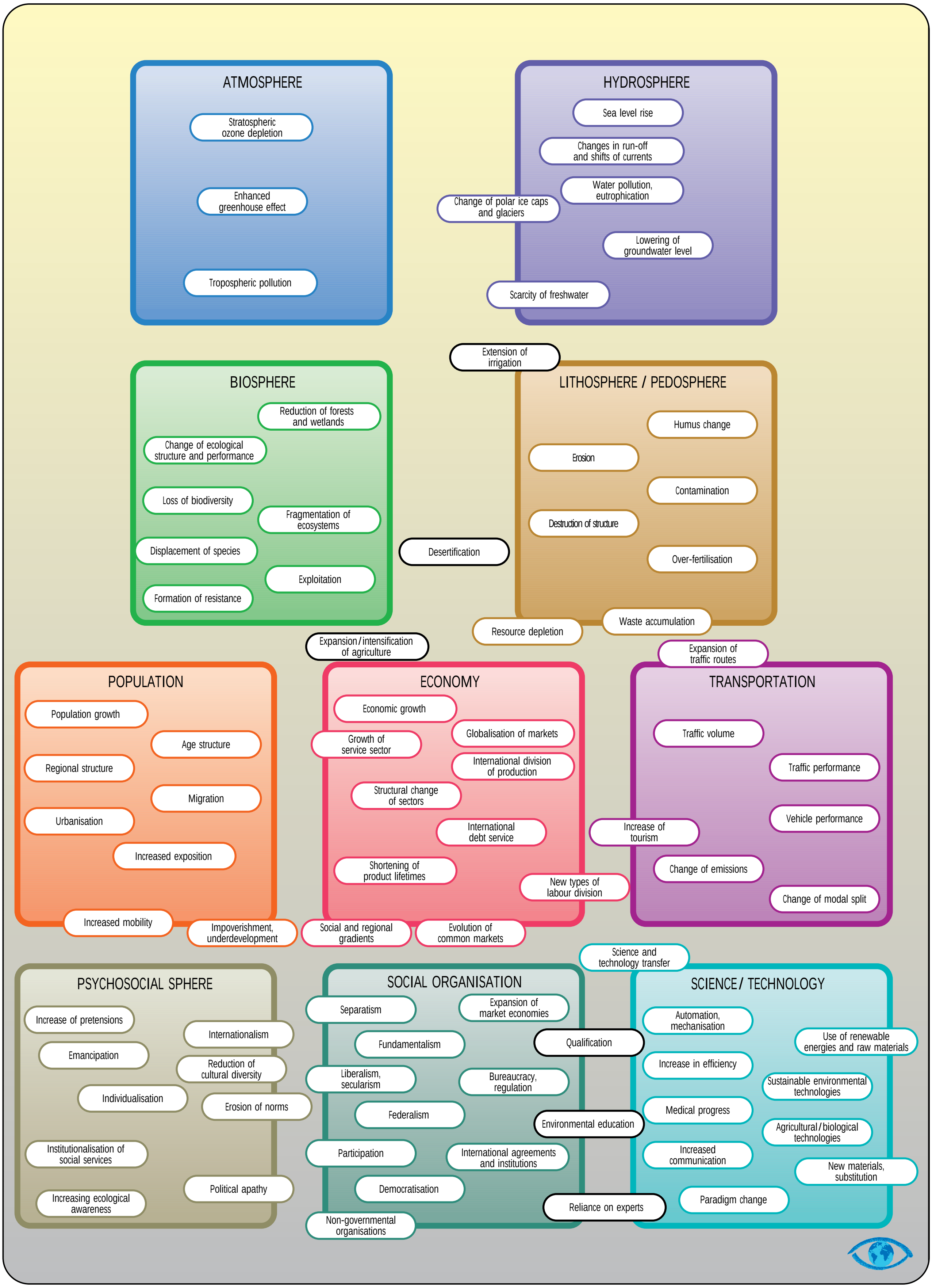


Figure 18: Global network of interrelations – Major trends in global environmental change



- *Synergy analysis*
  Which different influences on a particular trend are not just superimposed on each other but act in non-linear combination?

- *Sensitivity analysis*
  Which trends relate to especially fragile components of the eco- or anthroposphere? Where rapid development and high vulnerability coincide, serious problems in the present or future have to be expected.

The network of interrelations can also be used to identify research deficiencies (see, for example, the interactions marked with questionmarks), or to offer a survey of the international process of environment conventions (environment and development problems "ripe for" or "in need of" conventions can be labelled accordingly on the hologram by means of special symbols).

Figure 19: Rules for constructing the diagram "global network of interrelations"

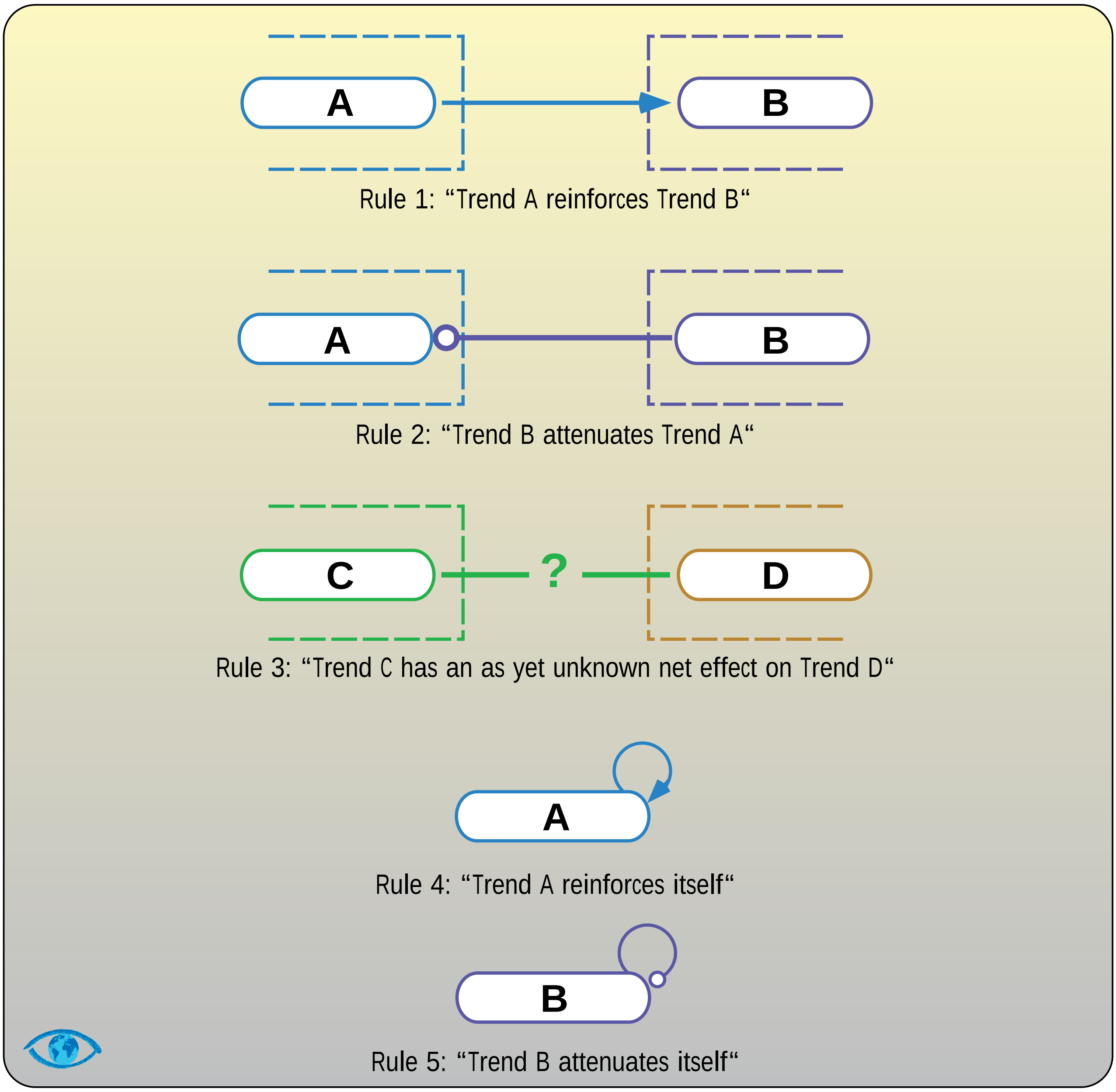
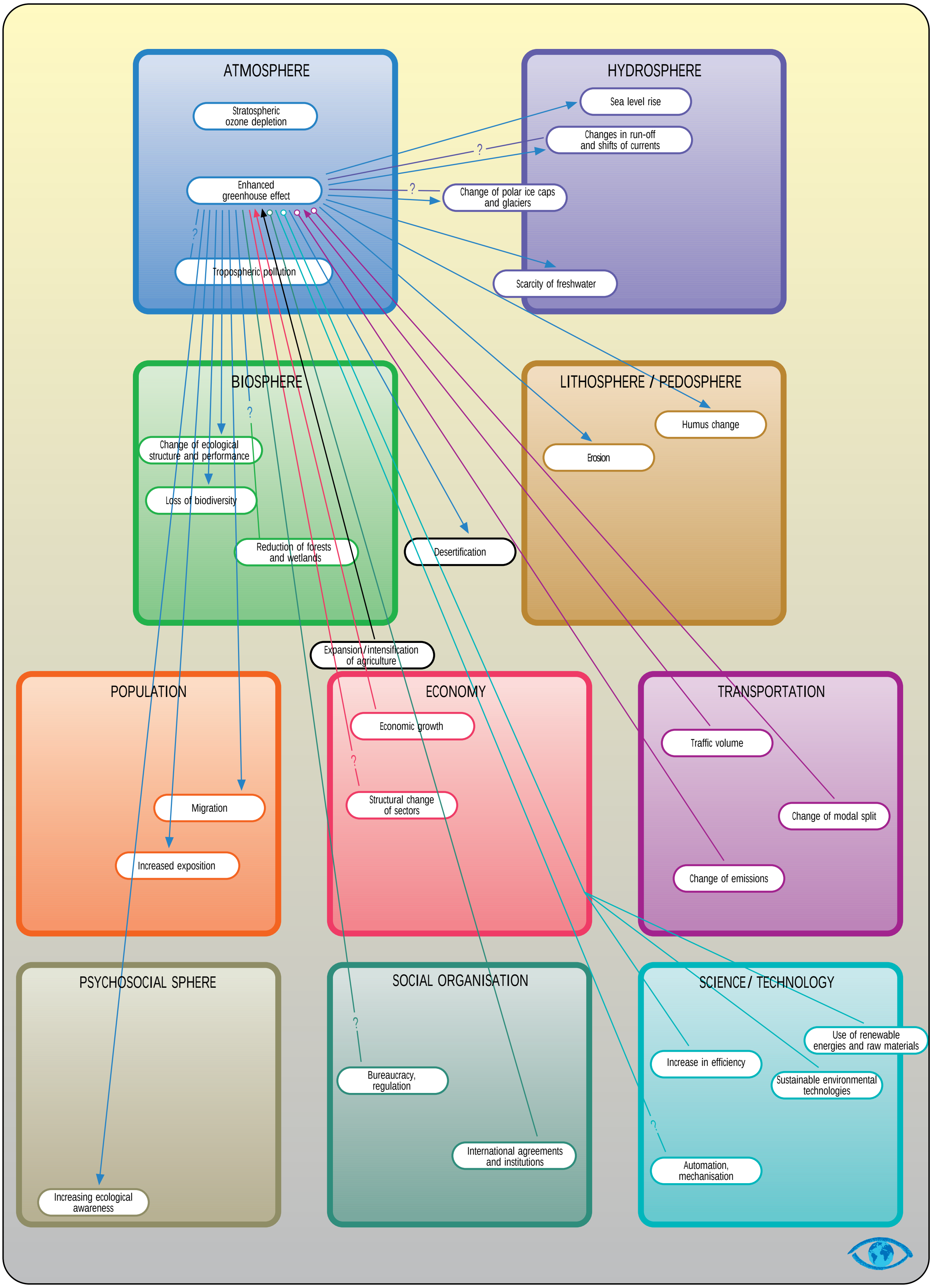


Figure 20: Example of the partial global network of interrelations for the enhanced greenhouse effect



The instrument can also be supplemented by a *regional* or *historical* dimension:

In the former case, the network of interrelations can zoom in on industrialised or developing countries, or on different continents. This would not only qualify the "Eurocentric perspectives" that have been difficult to avoid so far, but would also throw light on the conflicts of interest and tensions around the world which are the main obstacles to precautionary policies on issues of environment and development.

In the second case one can try to reconstruct, by means of "historical snapshots" (e.g. for the years 1800, 1900, 1930, 1960, 1990), the network of interrelations as it has developed through history. This stroboscopic technique will facilitate the identification of the long-term driving forces of global change.

Finally, in analogy to a quantitative model, the hologram can be turned into a *dynamic* prescription: in other words, it could be used as a qualitative automaton. Two possibilities will be specified:

- *Iteration*
  Global change is being shaped by the interplay of all (developmental) tendencies. By summing up trends and interactions, and carrying out a subsequent "balance-sheet analysis" of all influences, synergisms and antagonisms, an attempt can be made to predict the state of the Earth System in the not-too-distant future.

- *Crash scenarios*
  Sensitivity and/or stability of the global system can be tested through qualitative "gedanken experiments": massive perturbations or stimuli, e.g. doubling of the world's population or technological breakthroughs ("geoengineering", revolutionary concepts for exploiting solar energy) are fed into the network and kept track of as they interact with the system.

The limitations and the possibilities of the holistic approach presented above need exploring over the next few years. The Council believes that the effort is justified: the dimension of the problems demands a search for new and unconventional solutions.

# F Recommendations

## Recommendations for research and political action

The reactions in the political arena and among wide sections of the public to global environmental changes and their anthropogenic causes are still ambiguous. For many years they were plagued by mistrust towards the often contradictory statements of experts. The demand for scientific proofs and "reliable" forecasts dominated discussions. Since the 1992 UN Conference on Environment and Development in Rio de Janeiro, however, a general consensus has evolved that, given the growing environmental risks, certain preventive strategies and reductionary measures have to be implemented as soon as possible, even if the scientific basis for evaluating the success of such measures has not yet been fully developed.

The Council shares this view and recommends some measures in this Report which require immediate implementation. However, it refers also to the risks that could develop from measures that have not yet been assessed for their long-term effects or side-effects. It therefore recommends that the current and commencing measures for reducing global environmental problems be critically accompanied by appropriate research programmes, and that future global environmental policies with a long-term perspective be prepared and supported in the same way. This requires, in turn, a new concept for interdisciplinary cooperation and international networking of research. The Council, taking into account the expertise produced by the German "Wissenschaftsrat" on environmental research, will develop proposals in this regard, as already commenced with in this first Report, but above all in future reports.

## Research

Global change confronts research worldwide with tasks of a completely new character. The current organisation of research is not adequate to the challenge being faced. The complexity of the problems must be responded to with *interdisciplinarity*, and the global nature of the processes involved requires *international networking* of research programmes. Interdisciplinarity within global environmental research has mainly been conceived of to date as the bundling of similar (natural science) disciplines dedicated to the joint study of a sub-problem, such as explaining ozone depletion in the stratosphere. There are already some informal research links across national boundaries and across several such sub-problems, although the efforts involved are mostly directed at specific fields. The modification of behaviour towards nature is a challenge, above all for the social sciences, to study the interactions between the ecosphere and the anthroposphere in greater detail and to provide guidelines for environmental policymaking and action. Separate disciplines and even groups of disciplines will find it difficult, indeed impossible, to provide answers to the central issues within this decade if they continue to work in isolation from each other. Recommendations from research are absolutely essential, however, for political action to be taken in the present. For this reason, the various disciplines within the natural and social sciences should research jointly into global problems from a defined basis, and funding should be provided in a coordinated way.

In addition to the various research recommendations made in the respective chapters above, the Council wishes to stress research particularly related to the following issues:

- Understanding the interlinkages between the ecosphere and the anthroposphere by means of modelling, global monitoring programmes and process studies.
- Decoupling of the carbon, nitrogen and sulphur cycles.
- Long-term effects of the altered nitrogen and carbon cycles on primeval ecosystems and agricultural production.
- Availability of water under conditions of growing population and regionally differing anthropogenic climate change.
- Regionally specific strategies for achieving the aims defined in the "Convention on Climate Change" and the "Convention on Biological Diversity".

- Creation and preservation of environmentally stable landscapes guarding the cultural heritage.
- Possibilities for a worldwide reduction of population growth and slowing of trends towards migration and urbanisation.
- Increasing awareness among human beings in the different cultures for global environmental problems and for possible ways of modifying their environmentally harmful behaviour.
- Global environmental aspects of major structural changes in the world economy.
- Transfer of environmentally sound technologies, i.e. development of models and programmes for appropriate transfer for different groups of countries.
- Assessment of effects on environment and development caused by present institutions of the world economic order.
- Assessment of global commons, especially taking the needs of future generations into consideration.
- Further development of instruments for protecting the (global) commons, differentiated according to the particular problems that exist.
- Establishing environmental indicators and global environmental accounting for estimating “real environmental capital” as the basis for policies aiming at sustainable development.
- Analysis of social conflicts and the development of strategies for dealing with environmental problems.
- Importance of the media for the assessment of global environmental problems.

As already mentioned, all these themes require an interdisciplinary approach with corresponding structuring. The Council illustrates this with the example of climate change, and refers to the United Nations Framework Convention on Climate Change agreed on 12th June 1992. The specified research themes can also assist in the implementation of other conventions.

### *The example of the “Convention on Climate Change”*

The ultimate objective of the Convention on Climate Change, namely “stabilization of greenhouse gas concentrations”, is equivalent to a reduction in the use of fossil fuels. Implementing this objective requires research that can be provided either by the natural or social sciences alone, or in combination. Two examples for questions that can be answered without the natural sciences having to be involved are:

- How can reductions in $CO_2$ emissions best be achieved in individual countries (e.g. through emission certificates, taxes, regulations)?
- What forms of international agreements for reducing global environmental stress are particularly effective while respecting the sovereignty of states?

By contrast, all the sciences are called for to achieve the three sub-conditions to the ultimate objective of the Convention on Climate Change:

The *first* sub-condition demands stabilisation of greenhouse gas concentrations within a period that allows ecosystems to retain their natural adaptability to climate change. For the time being it is not possible to put a figure on this objective. For example, we do not know how quickly and to what extent vegetation zones can shift location.

The *second* sub-condition sets a standard for achieving stabilisation of greenhouse gas concentrations in such a way that the production of food for human consumption is not endangered by anthropogenic climate change. Here, two important questions need answering:

- How can agriculture be carried on in the industrialised world while preserving soil fertility, even in periods of rapid climate change?
- How can agriculture in the humid and semi-arid tropics be adapted to natural variability and anthropogenic climate change in such a way that it feeds the population, avoids erosion and limits urbanisation, and at the same time contributes to the preservation of biodiversity?

The *third* sub-condition demands that anthropogenic climate change occur so slowly that sustainable economic development is still possible. Research needs here relate to the conditional framework of economic systems which enable sustainable development. Another important component in this context is research on opportunities for guiding people towards due consideration for the environment within economic decision-making processes.

### *What consequences are derived for research in Germany from the necessary implementation of the Conventions?*

The answer to this question relates primarily to the structure of the research programmes and research institutions. Given the powerful interlinkages that exist within the Earth System, research must also be organised according to network principles. Groups comprised of high-level specialists from other disciplines should be formed around existing core departments that combine a high standard of scientific work, equipment and facilities, in order to jointly address one of the themes mentioned above, making use of the tools and facilities offered by the core department. For each major theme it is necessary to draw a balance between data acquisition, the generation of global data, modelling and validation of findings derived from modelling.

Such networking is being planned or already exists in some areas of the natural sciences, but the social sciences are still lagging behind. Because financial constraints will prevent individual countries from achieving “state of the art” research results in all fields, networking with other European countries will certainly be needed. Cooperation with developing countries in research on global environmental change is also a must. This makes it easier to organise the adaptation of national to international research programmes. Designing such programmes requires greater cooperation than has been the case up to now. National competence must be strengthened in previously weak research fields in order to be in a position to make recommendations for political action.

## Political action

It is not an easy task, given the manifold interactions in and between the ecosphere and the anthroposphere, to formulate priorities for political action. Despite the severity and urgency that some of the global change problems involve, concerted action by many countries is prevented because of the lack of international agreements and gaps in understanding and information. The attempt to define priorities is therefore made on the basis of only a few *criteria*:

- the severity and rapidly growing magnitude of the problems in question,
- opportunities for a global strategy,
- the special contribution that can be made by Germany.

As far as the first criterion, *severity* and *rapidity*, is concerned, the most serious global problems and major global trends in the estimation of the Council are:

- **Growth of the World’s Population**
  This problem is very difficult to influence in the short term, but is a determining factor of global environmental change in the long term. Population growth is closely bound up with the problem of poverty, thus rendering the abatement of poverty an important task alongside family planning, improvement of the position of women in society, and training.

- **Long-term changes in the composition of the atmosphere**
  The most important aspects here are:
  – the anthropogenic increase in the concentration of greenhouse gases (particularly carbon dioxide, methane and nitrous oxides),
  – the increasing levels of synthetic substances in the atmosphere (particularly chlorofluorocarbons),
  – climate change caused by increasing levels of trace gases,
  – effects of global climate change such as shifts of vegetation zones, sea level rise, decline of available water resources,
  – reactions of human beings to anticipated and existing climate change.

- **Loss of biodiversity**
  The habitats of many plant and animal species are being destroyed through deforestation of tropical forests, expanding settlements, emission of pollutants into air and water, and through intensivation of agriculture in the industrialised countries. Biodiversity generally acts to stabilise ecosystems, but it is not well known at what point the loss of species causes irreversible damage to ecosystems.

- **Degradation and loss of soils**
  Soils are the “skin” of the Earth and the basis for nutrition, but are often over-exploited and finally eroded by growing population. Even marginal lands are used for agricultural production and in many cases rapidly destroyed, while others are degraded by pollutants. The total area of utilisable land in the world is continously declining.

What all these major global trends have in common is accelerated growth and long-term effects, with time scales in the order of decades, indeed centuries. Nevertheless, quick steps on a small scale can be very important for the long-term reduction of harmful or destructive effects. The major trends are not independent of each other. For instance, population growth accelerates the degradation of land, which increases the level of long-lived greenhouse gases in the atmosphere, which in turn speeds up, via climate change, the loss of biodiversity, etc.

As far as the second criterion, *strategic capacity*, is concerned, there are no standard answers. For the reduction of emissions of long-lived greenhouse gases the Framework Convention on Climate Change was formulated and accepted by 154 nations, which will actually become binding in international law and which is due for implementation, subsequent to the Conference of signatory states planned for spring 1995 in Germany, on the basis of initial implementation protocols. By contrast, there is still no convincing action as regards reducing the current annual increase of 1.7% in the world population. The Convention on Biological Diversity is further away from implementation than the Climate Convention. The Convention for the Prevention of Desertification, the drawing up of which has been commissioned by the United Nations and which is due to be signed in 1994, will probably contain few measures for soil protection. Important changes in land functions and appropriate countermeasures must similarly be given consideration; there is, however, no international forum for concluding such agreements. The Convention for the Protection of Forests demanded by the Council could make an important contribution to the preservation of soils and their quality.

With regard to the third criterion, the *special contribution of Germany*, there is considerable variation in the possibilities and leverage points for contributing to the amelioration of the major trends mentioned. Given overproportionate responsibility for the altered composition of the atmosphere, overproportionate efforts to implement the Climate Convention are called for. Even though population growth in Germany (and other highly developed countries) is very low, even declining, Germans are under an obligation, in view of the severe threats posed by global population growth, to contribute towards the institutionalisation of population policies in a manner appropriate to the respective conditional frameworks through international cooperation, advice and financial support. If this is not done, Germany’s efforts to reduce the emission of greenhouse gases would be rendered worthless by population growth in other regions of the world. The same applies with regard to the protection of water resources and soils. Only through productive and environmentally sound agricultural practices worked out with the developing countries in accordance with the principles laid down in the *World Soil Charter* and AGENDA 21 can the threat to soils and water resources be reduced. In this sense, Germany should use all its possibilities for technical cooperation and technology transfer. Its cooperation in implementing the Convention on Biological Diversity will be assessed in other countries according to the extent to which Germans succeed in raising the level of biodiversity in their own country.

Action principles for the mitigation of global environmental change are:

- giving consideration in all decision-making to the consequences for the entire Earth System,
- respecting the interrelationship of environment and development in all decision-making,
- enlarging the systems for economic analysis and assessment to include natural resources.

This first Report by the Council concentrates on describing global environmental change in terms of interlinkages. In the individual chapters we give specific recommendations for political measures and on research needs. A number of key issues, such as protection of global resources by using all opportunities of demand-side management, and the institutionalisation of dialogue and cooperation between industrialised and developing countries on global environmental policies, could not be treated as yet. Concluding this Report, the Council wishes to place particular emphasis on three proposals of a general nature to the Federal Government:

1) Increasing the percentage of GNP assigned to **development aid** from the current level of 0.4 %, via the Rio de Janeiro figure of 0.7% to a target level of 1.0%.

   This should comply with the United Nations' redefinition of the term "developing countries", put forward by Germany, in order to take account of the changes on the world political stage over recent years, especially the problems of economic and environmental adjustment in eastern Europe.

   The additional finance obtained from this increase in GNP percentage should particularly be used for eradicating poverty, for improving the position of women, and for improving family planning. Besides the transfer of financial resources, it is important to intensify technical cooperation with developing countries and to transfer and deploy environmentally sound technologies.

2) The following activities are proposed regarding the implementation of the instruments for the programmes discussed and partly decided upon at UNCED in Rio de Janeiro:

   - concerning the **global reduction of $CO_2$ emissions**, the Federal Government should contribute to the discussion on a global "certificate scheme", with the aim of implementing this solution internationally,
   - parallel to the reduction of $CO_2$ levels by this means, efforts should be concentrated on greater transfers for the **protection of the tropical forests**, because in this way subsidies can be paid to countries owning these resources in order to preserve them as a public good. This financing mechanism should be tied in order to facilitate the raising of funds.

3) **Increasing awareness among the population** for global environmental problems.

   Through improved information directed at target groups, and through suitable programmes for modifying environmental behaviour, all opportunities are to be used for demonstrating how human action is the cause and the effect of global environmental change.

The Council again emphasises the urgency of the global environmental problems described in this Report. The ensuing tasks must be tackled with absolute priority, even in difficult political and financial times at the national and the regional level.

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# H Appendix

## The German Adisory Council on Global Change

Prof. Dr. Hartmut Graßl, Hamburg (Chairman)
Prof. Dr. Horst Zimmermann, Marburg (Deputy Chairman)

Prof. Dr. Friedrich O. Beese, Munich
Prof. Dr. Gotthilf Hempel, Bremen
Prof. Dr. Lenelis Kruse-Graumann, Hagen
Prof. Dr. Paul Klemmer, Essen
Prof. Dr. Karin Labitzke, Berlin
Prof. Dr. Heidrun Mühle, Leipzig
Prof. Dr. Hans-Joachim Schellnhuber, Potsdam
Prof. Dr. Udo Ernst Simonis, Berlin
Prof. Dr. Hans-Willi Thoenes, Wuppertal
Prof. Dr. Paul Velsinger, Dortmund

### *Staff to the Council Members*

Dipl.-Ing. Sebastian Büttner, Berlin
Dipl.-Volksw. Oliver Fromm, Marburg
Dipl. Psych. Gerhard Hartmuth, Hagen
Dipl.-Ing. Benno Kier, Essen
Dipl.-Met. Birgit Köbbert, Berlin
Dr. Gerhard Lammel, Hamburg
Dipl.-Volksw. Wiebke Lass, Marburg
Dipl.-Ing. Roger Lienenkamp, Dortmund
Dr. Heike Schmidt, Bremen
Dr. Detlef Sprinz, Potsdam
Dipl.-Ing. Ralf Theisen, Dortmund (1.10.92 – 31.12.92)
Dipl.-Ök. Rüdiger Wink, Bochum
Dr. Ingo Wöhler, Göttingen

## The Secretariat of the Advisory Council*

Prof. Dr. Meinhard Schulz-Baldes (Director)
Dr. Marina Müller (Deputy Director)

Dipl.-Geoök. Holger Hoff
Vesna Karic
Ursula Liebert
Dr. Carsten Loose
Dipl.-Volksw. Barbara Schäfer
Martina Schneider-Kremer, M.A.

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# Joint decree on the establishment of the German Advisory Council on Global Change

### Article 1

In order to periodically assess global environmental change and its consequences and to help all institutions responsible for environmental policy as well as the public to form an opinion on these issues an advisory council on "Global Environmental Change" will be established with the Federal Government.

### Article 2

(1) The Council will annually submit a report to the Federal Government by the first of June giving an updated description of the state of global environmental change and its consequences, specifying quality, size and range of possible changes and giving an analysis of the latest results of research. In addition, the report should contain indications on how to avoid or correct maldevelopments. The report will be published by the Council.

(2) While preparing the reports the Council will allow for the Federal Government to give an opinion on central questions arising from this task.

(3) The Federal Government may ask the Council to prepare special reports and opinions on specified topics.

### Article 3

(1) The Council consists of up to twelve members with special knowledge and experience regarding to the task of the Council.

(2) The members of the Council will be jointly appointed by the two ministries in charge, that is the Federal Ministry for Research and Technology and the Federal Ministry for the Environment, Nature Conservation, and Reactor Safety, in agreement with the departments concerned for a period of four years. Reappointment is possible.

(3) Members can at any time hand in a written announcement of resignation from the Council.

(4) If a member resigns before the end of his or her term of office, a new member will be appointed for the retired member's term of office.

### Article 4

(1) The Council is only subject to the fulfillment of its task as established by this decree and otherwise independent in its activity.

(2) Members of the Council must neither belong to the Government or a legal corporation of the Federal Republic or of a *Land* nor to the public service of the Federal Republic, of a *Land* or of any other juristic person of the Public Law other than as university professor or as staff member of a scientific institute. Neither must they be representatives of an economic association or an employers' or employees' organization or be attached to these by the permanent execution of services and business in their favour. They must not have held any such position during the last year prior to their appointment as a member of the Council.

**Article 5**

(1) The Council elects from among its members in secret election a chairman and a vice-chairman for a period of four years. Re-election is possible.

(2) The Council will set up its own rules of procedure. These must be approved of by both ministries in charge.

(3) If there is a differing minority with regard to individual topics of the report then this minority opinion can be expressed in the report.

**Article 6**

In the execution of its work the Council will be supported by a Secretariat which will, for the time being, be located at the Alfred-Wegener-Institut (AWI) in Bremerhaven.

**Article 7**

Members of the Council as well as the staff of the Secretariat are bound to secrecy with regard to meetings and conference papers considered confidential by the Council. This obligation to secrecy is also valid with regard to information given to the Council and considered confidential.

**Article 8**

(1) Members of the Council will receive an all-inclusive compensation as well as a reimbursement of their travel expenses. The amount of the compensation will be fixed by the two ministries in charge in agreement with the Federal Ministry of Finance.

(2) The costs of the Council and its Secreteriat will be shared equally by the two ministries in charge.

Dr. Heinz Riesenhuber
Minister for Research and Technology

Prof. Dr. Klaus Töpfer
Minister for the Environment, Nature Conservation, and Nuclear Safety

May 1992

– Appendix to the Council Mandate –

## In explanation of the task of the Council under Article 2, par. 1

The task of the Council includes:

1. Summarizing and continuous reporting on current and acute problems in the field of global environmental change and its consequences, e.g. with regard to climate change, ozone depletion, tropical forests and sensible terrestric eco-systems, aquatic eco-systems and the cryosphere, biological diversity, socioeconomic consequences of global environmental change;

   Natural and anthropogenic causes (industrialization, agriculture, overpopulation, urbanization, etc.) should be considered, and special attention should be given to possible feedback effects (in order to avoid undesired reactions to measures taken).

2. Observation and evaluation of national and international research activities in the field of global environmental change (with special regard to monitoring programmes, the use and management of data, etc.).

3. Identification of deficiencies in research and coordination.

4. Suggestions on how to avoid and correct maldevelopments.

In its reporting the Council should also consider ethical aspects of global environmental change.