Environmental Issues Requiring International Action

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Preface

In October 1990 a symposium was held in Vienna on Environmental Protection and International Law. The symposium, which was jointly organized by the Austrian Ministry of Foreign Affairs, the Institute for International Law and International Relations of the University of Vienna, and the Austrian Institute for International Affairs in Laxenburg, covered a wide range of topics relating to the increasingly important problem of the development and international acceptance of laws designed to protect the environment taking into account the interests of both the developed and developing countries.

As an introduction to the discussion on these matters, Prof. Bo R. Döös, Deputy Director of IIASA, and Leader of the Environment Program, presented an analytical overview of those environmental issues which require international action. The present research report contains his contribution to the symposium.

At the same time, this overview reflects very closely the philosophy adopted in the design of IIASA's Environment Program which aims at providing the scientific knowledge base required for developing international policies for achieving environmental sustainability. It is thus sufficiently broad in scope to take into account the complex linkages between the main environmental problems and their relation to other global issues which have a bearing on global security and risk management.

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1. Introduction

Thirty years ago the world detected that the environment is not an inexhaustible resource. For example, through Rachel Carson's book (1962) it became clear, at least to a minor portion of the world population, that there is a limit to the stresses the environment can take without being seriously degraded. This late recognition of the vulnerability of the environment is quite remarkable considering the fact that some of the major environmental issues were identified by some scientists already in the late 1800s.

During the last three decades, however, considerable attention has been given both to identifying the causes of the growing stresses on the environment and to evaluating their long-term consequences, as well as to the development of response strategies. Considering the increasing concern for the various environmental issues demonstrated by the numerous meetings organized by the scientific community, international organizations, and governments, the extensive space the environment is given in the media, and the concern expressed by politicians, one would tend to believe that the prospects of sufficient protective action being taken would be promising. This seems, however, to be far from the truth; the stresses on the environment are becoming more and more pronounced. Comparatively little has been done with regard to the environmental problems which were recognized already in the 1960s, and since then new major threats have surfaced.

Clearly, there are many causes contributing to this destructive development, but there are a few which should be singled out as being particularly important, namely:

- The rapid increase in world population, particularly in the developing world. Since 1950 the population has increased from 2.5 billion to about 5 billion people, and it is expected to double again before the middle of the next century (see *Figure 1*).
- The technological and socioeconomic developments, with their increasing use of chemicals in industry and agriculture, resulting in extensive environmental degradation and toxification of air and water resources.
- The lack of understanding and imagination in industrialized countries with regard to the consequences of the ongoing and expected environmental degradation.
- The lack of financial resources for environmental protection in less developed countries. At present they seem to have no choice but to repeat the mistakes now being made by the industrialized countries.

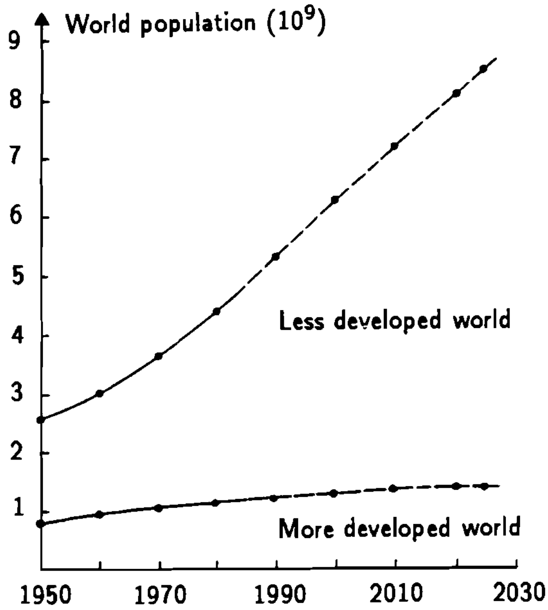


Figure 1. The expected increase in world population. (Source: United Nations, 1989.)

2. Major Environmental Issues and their Interaction

The major threats to the environment requiring international attention and action may conveniently be grouped into the following five problem areas (not in order of priority):

- Greenhouse gas induced climatic change.
- Destruction of the stratospheric ozone layer.
- Acidification of terrestrial and aquatic ecosystems.
- Degradation of land, including deforestation and desertification.
- Pollution and toxification of air, water, and soil.

They are all linked with each other in a complex way, both internally and through their causes. An attempt to illustrate some of these linkages is made in *Figure 2*. Although this figure gives a very simplified picture of the problem, it indicates clearly that in developing realistic and efficient response strategies, the individual environmental problems cannot be treated

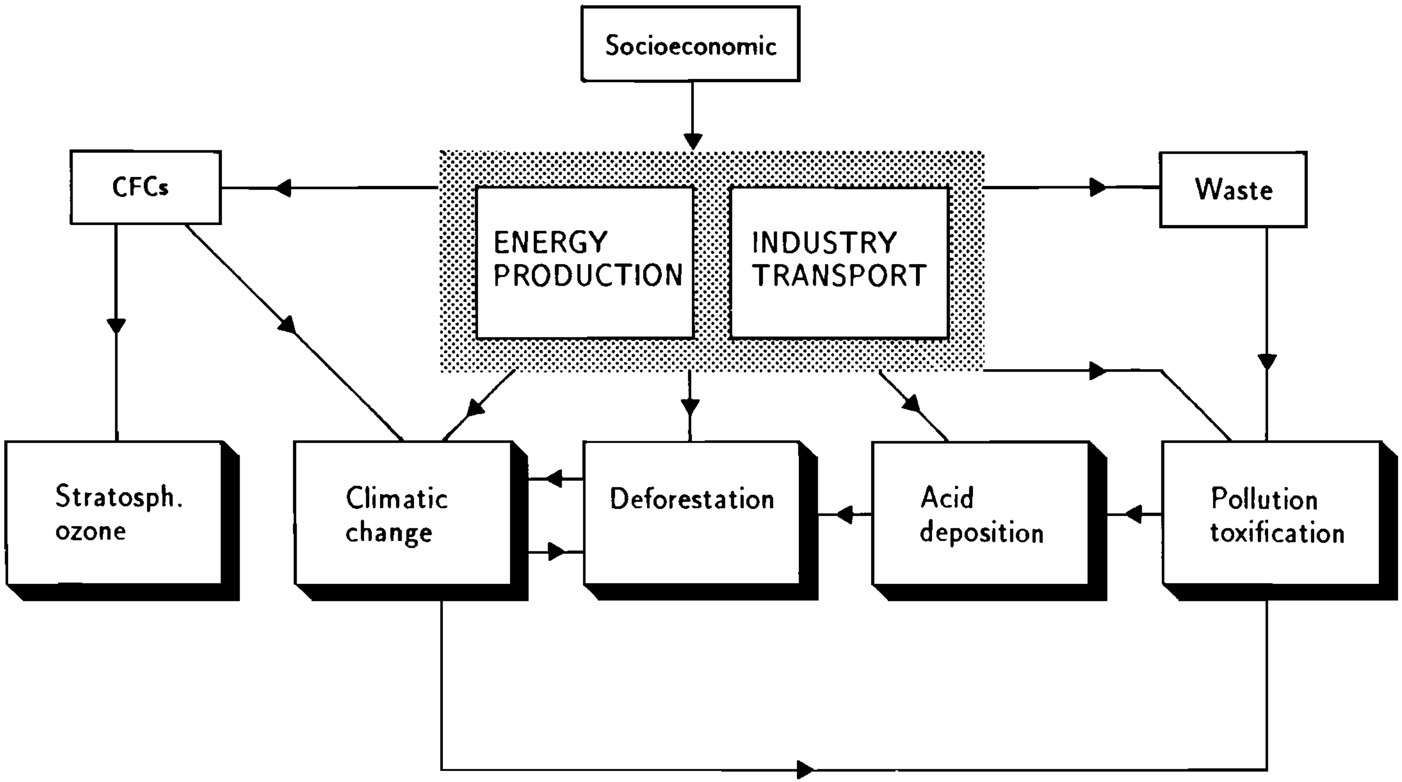


Figure 2. Schematic illustration of the main environmental issues and some of their causes and interconnections.

in isolation. The positive aspect of this is that almost any action taken to reduce the cause of one of the environmental problems, will, at the same time, have a positive effect with regard to one or more of the other main problems.

It obviously cannot be claimed that this list of threats to the environment is complete. For one thing, it should be recognized that the list is basically limited to the identification of the anthropogenic activities which have an immediate destructive effect on the environment. Thus, it does not include explicitly all the secondary and higher-order impacts of these activities. In particular, there are bound to be increasing problems related to the living world, e.g., the global life support system (agriculture, forests, water supply, etc.), the state of biological diversity, and human health.

3. The Evolutionary Process: From the Identification of a Threat to the Environment to Effective Response Strategies

In a very simplified way *Figure 3* illustrates the major steps in the complex process of identifying a potential threat to the environment to the adoption and implementation of internationally agreed response strategies which provide sufficient protection.

3.1 The identification and first observational indications

It should be noted that at the time when concern for the environment began some three decades ago, little or no attention had been given to four out of the five problems listed above. The concern was mainly focussed on the increasing pollution of air and water.

In spite of the fact that the greenhouse gas issue had been identified as a possible problem almost a century ago (Arrhenius, 1896), it was only in the mid-1970s that it was given any serious attention, and only less than ten years ago was it realized that, in addition to carbon dioxide, there are several other trace gases in the atmosphere which, taken together, have a comparable impact on the radiation balance of the atmosphere and thereby on the climate.

The acidification of soils and lakes was also identified in the last century (Smith, 1872) as a possible future problem, but was not given any attention until some observational evidence existed (Odén, 1968). The situation was

	ISSUES			
	Climatic change (global)	Strato-spheric ozone (global)	Acidifi-cation (Europe)	Defores-tation (global)
Identification of potential environmental problems	1896 (Arrhenius)	1974 (Molina-Rowland)	1872 (Smith)	1874 (Marsh)
First observational indications	1980s	1984 (Farman *et al.*, 1985)	1960s (Odén, 1968)	1960s (Richards 1967)
Scientific community major consensus: Positive / Neg.				
Development of response measures				
Public opinion Political base; Formulation of policy options				
Major political acceptance: National and International	Late 1980s	Late 1970s	Late 1980s	Early 1980s
First international conventions on preventive actions	1988 Toronto	1987 Montreal	1979 Genéve	—
International agreements and laws providing sufficient protection of the environment	?	1990 London	?	?

Figure 3. Schematic illustration of the complex and time consuming process of achieving sufficiently powerful and binding international agreements and laws for the protection of the environment.

similar for the decline of global forests and land degradation; it took more than a hundred years before it was recognized that response action was required (Marsh, 1874), and still very little is being done to improve the situation.

The problem of the depletion of the stratospheric ozone layer caused by the use of chlorofluorocarbons is much more recent. It was hypothesized less than twenty years ago by Molina and Rowland (1974), and about ten years later the *ozone hole* in Antarctica was discovered (Chubachi, 1984; Farman *et al.*, 1985).

Given this information, the following conclusions appear to be justified:

- Environmental problems seem to have a tendency to come as a surprise even if they have been identified at a very early stage. They have to be "redetected"!
- We cannot be completely confident that we are now aware of all possible serious threats to the environment. There may be several more lurking in the wings.

3.2 Achieving scientific consensus and major political acceptance

The first observational indication that an environmental problem is emerging, which could have severe consequences, is usually effective in attracting the attention of the scientific community. Attempts are made to obtain the data and to model the physical, chemical, and biological processes involved, and thereby make it possible to predict the future developments. The difficulties encountered here are that perfectly reliable projections cannot be achieved, partially due to the uncertainty of the future magnitude of the "driving forces" generated by the anthropogenic activities, and partially due to the fact that more or less realistic modeling assumptions need to be made. No doubt, there always exist different opinions about the validity of the assumptions made and the magnitude of these uncertainties and even about the practical value of these predictions. It is unlikely that a unified scientific consensus will be achieved.

Given this fact, together with the fact that appropriate response measures require financial resources, it is not surprising that attempts to reach major political acceptance about the need for actions can be slowed down. Two observations associated with this process can be made:

- The minority scientific opinion arguing that the knowledge base is insufficient and uncertain is often favored by governments in order to delay response action and thereby gain short-term economic advantages. This negative feedback process is indicated in *Figure 3*.
- There is a tendency to develop response actions for the various environmental problems in isolation from each other in spite of the fact that they are closely linked to each other.

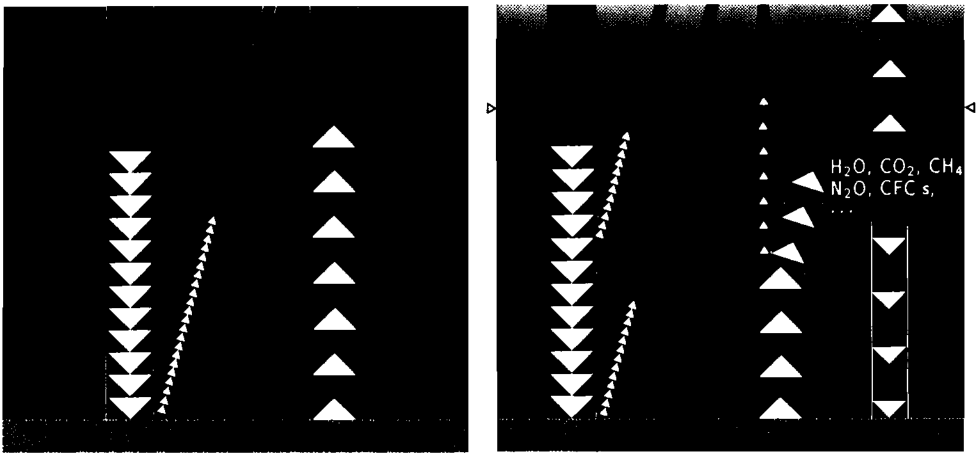
4. Global Climatic Change

In his paper published in 1896, Svante Arrhenius makes a reference to Fourier (1827), who had concluded that "the atmosphere acts like a hot house, because it lets through the light rays of the sun but retains the dark rays from the ground". Even if this is a simplification of the complex radiation budget of the earth, it provides the most important explanation of why the earth's surface temperature is as high as it is (see *Figure 4*). Arrhenius then carries out an extensive analysis of this problem, and the values he obtained of the warming for different values of an increased atmospheric concentration of carbon dioxide are very much in agreement with what is now being obtained by using very complex and comprehensive global general circulation models.

4.1 The greenhouse gases and their sources

Water vapor is the major atmospheric constituent influencing the radiative balance of the earth, but its concentration is not directly influenced by human activities. It is determined internally within the climate system, and it will increase in response to global warming and further enhance it. Water vapor is therefore not included in *Table 1*, which provides summarized information about the major greenhouse gases as well as their natural and anthropogenic sources. Ozone is another gas contributing to the greenhouse effect, but is not included in this summary because of uncertain observations. The numerical values of the emission rates of their individual sources are not given because of the large uncertainties in estimating production rates.

The variation with time of the radiative forcing of the anthropogenically emitted greenhouse gases is shown in *Figure 5* (WMO/UNEP, IPCC, 1990b).



Earth without atmosphere would not have a greenhouse effect.

A minor part of the incoming solar radiation is reflected at the earth's surface.

The net incoming radiation is balanced by the outgoing long-wave radiation.

This would result in a global mean surface temperature of −18°C.

The atmosphere with its radiatively active gases provides the greenhouse effect.

Parts of the incoming solar radiation is reflected by the atmosphere and the earth's surface.

The outgoing long-wave radiation from the earth's surface is partially absorbed and re-emitted by the greenhouse gases causing a warming of the lower atmosphere and the earth's surface.

This absorption of the long-wave radiation by the greenhouse gases yields a higher global mean surface temperature of +15°C.

Figure 4. A simplified diagram illustrating how the presence of the earth's atmosphere with its radiatively active gases (greenhouse gases) modifies the radiation balance of the earth, yielding a 33° C warmer global mean surface temperature.

4.2 The expected climatic change

Following considerable efforts by the scientific community there now exists a comparatively unified scientific opinion on climate change, as expressed by the Joint WMO/UNEP Intergovernmental Panel on Climatic Change (WMO/UNEP, IPCC, 1990a-d) and the Second World Climate Conference (SWCC, 1990a). Their findings are summarized below.

Table 1. Summary of the major trace gases contributing to the greenhouse effect.

	Carbon dioxide	Methane	CFC-11	CFC-12	Nitrous oxide
Atmospheric concentration:					
Pre-industrial	280 ppmv	0.8 ppmv	0	0	288 ppbv
Present (1990)	353 ppmv	1.72 ppmv	280 pptv	484 pptv	310 ppbv
Present change/year	1.8 ppmv	0.015 ppmv	9.5 pptv	17 pptv	0.8 ppbv
Atmospheric lifetime (years)	50-200	10	65	130	150
Natural sources	Oceans Land	Wetlands Termites Oceans Wild animals Lakes Tundra	–	–	Soils Oceans
Anthropogenic sources	Fossil fuel Deforestation Land use	Rice paddies Cattle Biomass burning Gas drilling Solid waste	Foams Aerosols Refrigeration Other	Refrigeration Aerosols Foams Other	Fossil fuel Cultivated soils Fertilizers Biomass burning
Contribution to radiative forcing of anthropogenically made greenhouse gases (1980–1990)	55%	15%	17%		6%

ppmv = parts per million volume
ppbv = parts per billion volume
pptv = parts per trillion volume
Source: WMO/UNEP, IPCC, 1990b.

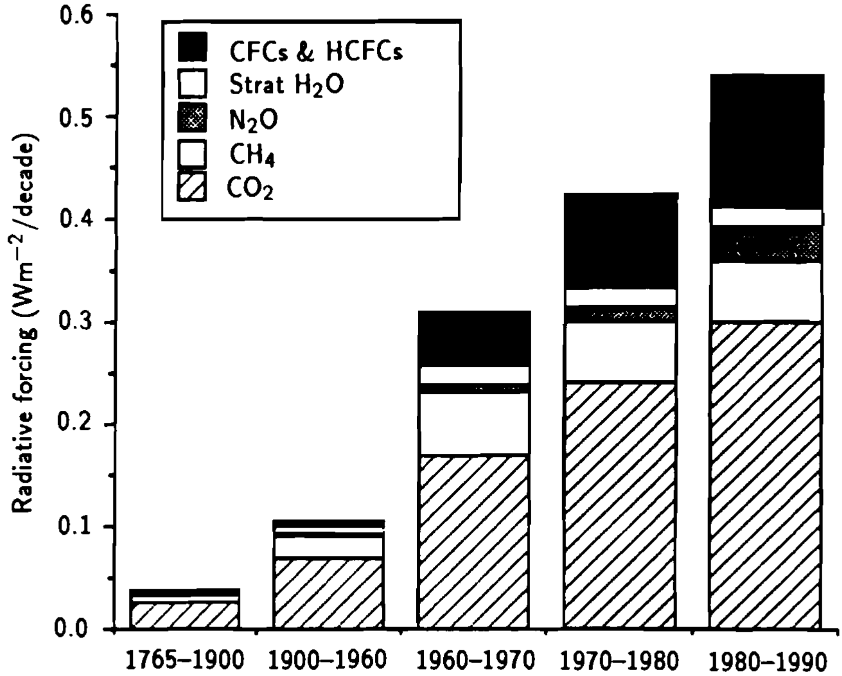


Figure 5. Decadal contributions to the increase in radiative forcing (Wm^{-2}) resulting from increases in greenhouse gas concentrations for periods between 1765 and 1990. The changes for the periods 1765-1900 and 1900-1960 are the total changes during these periods divided by the number of decades. (Source: WMO/UNEP, IPCC, 1990b).

With certainty it can be concluded that:

- There is a natural greenhouse effect which already keeps the earth warmer than it would be without an atmosphere. (This warming is about 33° C.)
- The increasing concentrations of the main greenhouse gases will enhance the greenhouse effect, resulting, on average, in an additional warming of the earth's surface.

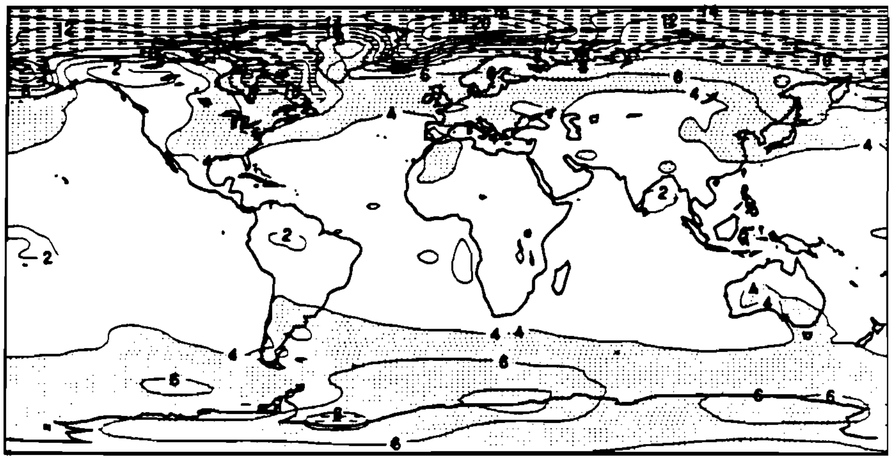


Figure 6. The change in surface air temperature due to a doubling of the atmospheric concentration of carbon dioxide for December-January-February as obtained by a high-resolution general circulation model. The dotted areas represent a temperature increase of 4 to 8° C, and the hatched area an increase between 8 and 20° C (Geophysical Fluid Dynamics Laboratory). (Source: WMO/UNEP, IPCC, 1990b).

With confidence it can be calculated that:

- Carbon dioxide has been responsible for over half of the enhanced greenhouse effect in the past, and is likely to continue to do so in the future.
- Atmospheric concentrations of the long-lived gases adjust only slowly to changes of emissions. The longer emissions continue at present-day rates, the greater the eventual reduction would have to be for concentrations to stabilize at a given level.
- Immediate reductions of over 60% of net emissions of long-lived gases from human activities would stabilize concentrations at today's levels.

It is predicted that:

- The global mean surface air temperature will increase by 2 to 5° C over the next century under the assumption of a ***business as usual*** scenario of emissions of greenhouse gases.[1] *Figure 6* shows the change in surface

[1]This scenario assumes that few or no steps are taken to limit greenhouse gas emissions.

air temperature resulting from a doubling of the atmospheric concentration of carbon dioxide for the Northern Hemisphere winter (December-January-February) as simulated by one of the high resolution general circulation models from the Geophysical Fluid Dynamics Laboratory (GFDL), Princeton, USA (WMO/UNEP, IPCC, 1990b). The result obtained with this model is similar to other model simulations of climatic change in the sense that the warming is more pronounced in higher latitudes and during the winter season. The magnitude of the warming obtained with the GFDL model is, however, somewhat more pronounced.
- The oceans delay the full effect of the warming. Thus, as concentrations of greenhouse gases increase, the temperature rise at any given time is between 50 and 80% of the committed temperature rise.

It is judged that:

- The global mean surface air temperature has increased by 0.3 to 0.6° C over the last 100 years, with 1990 being the warmest year, topping previous temperature records in 1988, 1987, and 1983 (Pearce, 1991); see *Figure 7.*
- The extent of the warming over the last century is broadly consistent with the predictions of climate models, but is also of the same magnitude as natural climate variability. The unequivocal detection of the enhanced greenhouse effect is not likely for a decade or more.

4.3 Consequences of a climatic change

Attempts to assess the various kinds of impacts a climatic change would have on human activities is initially dictated by the need to evaluate whether the consequences will be so severe that response action, preventive and/or adaptive, will have to be taken. In making such judgements, account needs to be taken of the fact that, simultaneously with the occurrence of a climate change, there will also be other developments which can have severe implications, e.g., the rapidly increasing world population and the accompanying increased demand on the global life support system (agriculture, forestry, and water resource management).

A detailed account of the present knowledge about the wide spectrum of consequences of a climatic change cannot be made here. A few points, however, deserve particular attention:

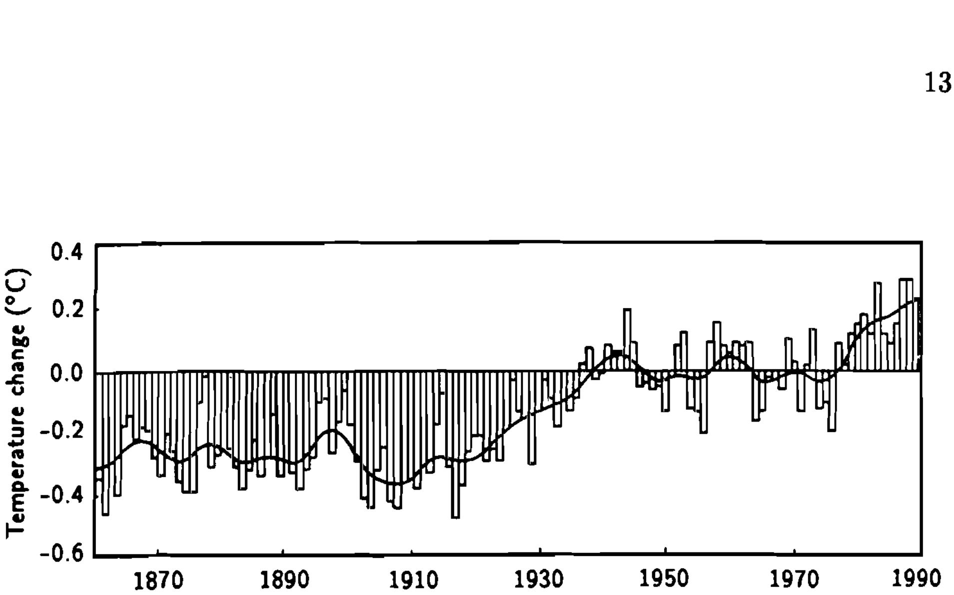


Figure 7. Global mean surface air temperature from 1861 to 1989, relative to the average, 1951–1980. (Source: WMO/UNEP, IPCC, 1990b). The 1990 temperature (not shown here) exceeded all previous years (Pearce, 1991).

Agriculture. Although it is clear that a climatic change will have an important influence on agriculture, it cannot yet be concluded whether the total global agricultural production potential will increase or decrease. One of the many reasons for this is the great uncertainty about the predicted future large-scale precipitation patterns.

Indeed, a net negative effect of a climatic change would have severe consequences in view of the fact that the world grain production per capita is expected to decease already in the 1990s owing to the increasing world population (see Section 7.4).

Forestry. In high latitudes where the temperature increase is expected to be particularly pronounced, the natural forests and especially the boreal forests are expected to decrease in size in view of their sensitivity to warmer temperatures. Although the boreal forests may, in some areas, be able to shift north into the current tundra zone, the net loss of the boreal forest area is expected to be about 30–40%. In low latitudes any change in the forests is likely to be more affected by future changes in precipitation.

Water resources. The present limited reliability upon the prediction of the future distributions of large-scale precipitation patterns is also a severe handicap in view of the many decisions that need to be taken for long-term water resource management. Some of the structures required (e.g., for

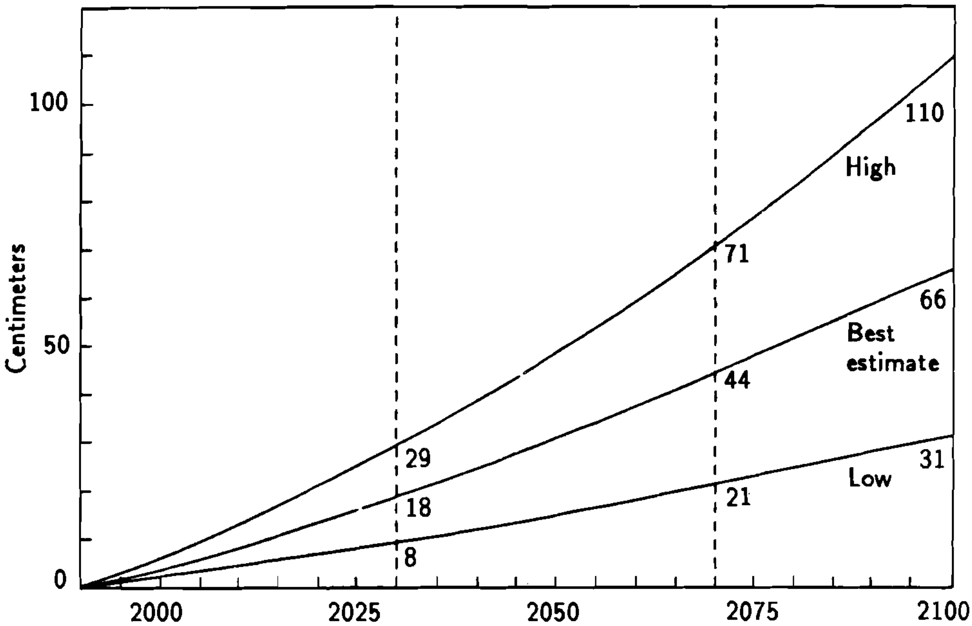


Figure 8. Global sea level rise, 1990–2100 for the policy scenario *business as usual.* (Source: WMO/UNEP, IPCC, 1990b.)

irrigation and hydropower) are designed to last several decades and require large financial commitments.

Although little is known about the regional hydrometeorological change, and it appears that many areas in the mid and high latitudes will have sufficient rainfall, it is feared that water availability will decrease in existing areas with marginal precipitation, e.g., in the Sahelian zone in Africa.

Sea level. Over the last century the sea level has risen by 10–20 cm. The predicted global warming will accelerate this process and the increase will be around 30–50 cm by 2050, which will threaten low islands and coastal zones (see *Figure 8*). A one meter rise by 2000 would make some island countries uninhabitable. Thus, millions of people in low-lying urban areas would be displaced, the salinity of estuaries would increase and threaten food production and otherwise impair water quality.

4.4 Response strategies

Considerable attention is already given to the formulation of response strategies, both with regard to preventive measures aimed at reducing the increase of the anthropogenic emissions of the greenhouse gases and thereby delaying a climatic change, as well as to measures aimed at adjusting to climatic change. The following points can be made relating to this aspect of the greenhouse gas issue:

- Numerous opportunities do exist to reduce emissions of greenhouse gases; several of these opportunities are promising because they can be motivated both from an economic point of view and, because they would be of benefit to other environmental problems (e.g., the ozone and the acidification issues).
- It should be recognized that any attempt to reduce the greenhouse effect will take considerable time. There are several factors that contribute to delaying the effect of response measures:

  (a) The time lag caused by the process of developing and reaching international agreement on emission reductions.
  (b) The time lag caused by the fact that promising new (or even existing) technologies do require considerable time before they are applied extensively.
  (c) The time lag caused by the long residence time of the major greenhouse gases.

  The delay caused by these factors, usually decades, is illustrated in a schematic way in *Figure 9.*
- Considering the very low consumption of fossil fuel per capita in many developing countries (less, or much less than 1 ton of carbon per capita compared with 2–5 tons of carbon per capita in most industrialized countries); the rapid increase in the population (from about 5 billion at present to about 10 billion by the middle of next century – the increase will mainly be concentrated in the developing world); and the need for development in the developing countries, simple calculations reveal that if it is possible to stabilize the concentration before it reaches twice the pre-industrial level ($2 \times 280 = 560$ ppmv), it will be necessary for the developed countries to reduce emissions of carbon dioxide by about 50%! Currently some developed countries (not the major contributors) plan to reduce present emissions by up to 20% before 2005, some will increase present emissions, and some are not in favor of any control.

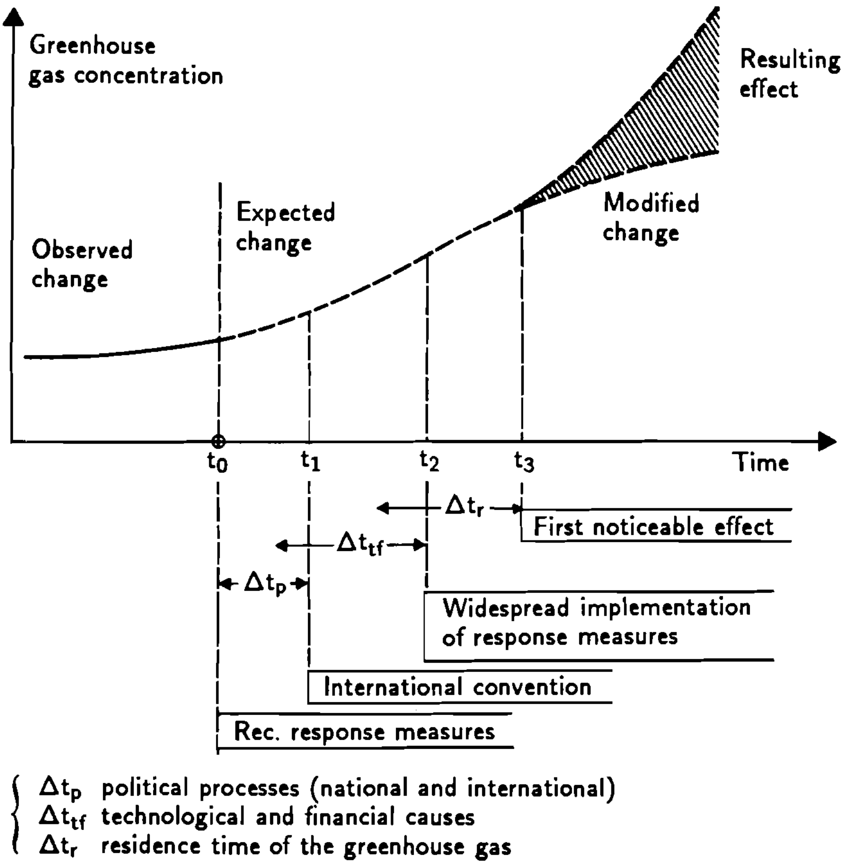


Figure 9. A schematic illustration of the factors that contribute to the decrease in the rate at which the greenhouse effect can be reduced.

5. The Depletion of Stratospheric Ozone

A schematic illustration of the ozone problem is given in *Figure 10*, showing how a reduction in the stratospheric ozone results in an increased transmission of ultraviolet radiation to the earth's surface. This first theory of the natural formation and destruction of ozone in the atmosphere was presented by Sidney Chapman (1930). In his theory the loss of ozone was explained by a reaction between an ozone molecule and a free oxygen atom. It was later realized that oxides of nitrogen catalyze the destruction of ozone in the

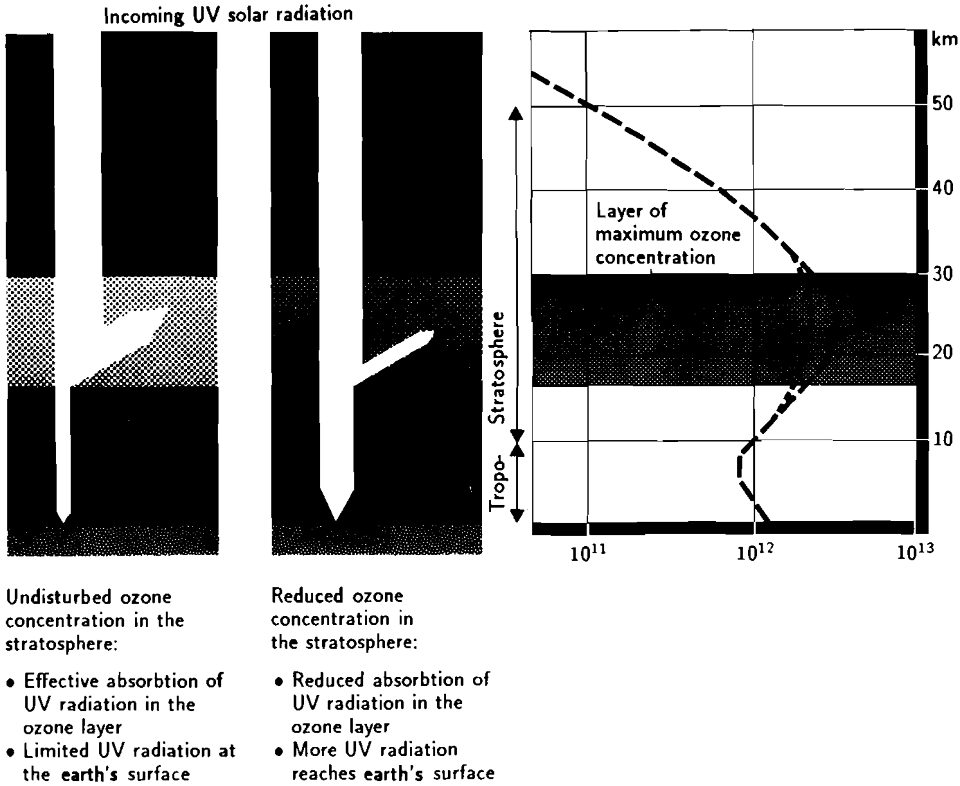


Figure 10. Schematic illustration of the ozone problem: How the increased atmospheric concentration of substances that deplete the ozone concentration in the stratosphere results in increased ultraviolet radiation at the earth's surface.

stratosphere, and it was argued that supersonic aircraft flying in the stratosphere would provide sufficient nitrogen oxides to pose a threat to the ozone layer.

The first hypothesis that chlorofluorocarbons (CFCs) would lead to a significant depletion of the ozone in the stratosphere and thereby reduce the protection of ultraviolet radiation was presented by Molina and Rowland (1974). Although their theory of the chemical reactions in the stratosphere was a significant step forward and provided a good base for the intense debate focused on the aerosol industry, it was not quite sufficient in explaining the detection of the *ozone hole* over Antarctica in 1984 (Chubachi, 1984;

Farman *et al.*, 1985). Actually the exceptionally low values of ozone had been registered earlier by instruments on satellites, but they were so low that they fell below the limit for realistic observations used in NASA's automatic data processing system and were therefore discarded. Following the evidence obtained by Farman *et al.*, using ground-based observing systems, the NASA scientists re-examined their data which showed that the hole extended over all of Antarctica.

5.1 Formation and destruction of ozone in the stratosphere

In this section an attempt is made to describe the most important elements of those chemical reactions that occur in the stratosphere and are responsible for the formation and destruction of ozone. Clearly this is bound to be a gross simplification of the stratospheric chemistry as it is presently known and simulated in computer models, but it may give an indication of how the balance between the natural formation and destruction of ozone is being disturbed by anthropogenically emitted chemicals (see *Figure 11*).

Formation of ozone. In 1930 Chapman put forward the idea that ozone is formed by the action of ultraviolet radiation (UV) on oxygen molecules (O_2) which are split up into highly active oxygen atoms (O). These free oxygen atoms then react with oxygen molecules resulting in ozone molecules (O_3) making use of another molecule for the absorption of the released energy in this reaction. It can be an oxygen or a nitrogen molecule which remains unchanged during this reaction.

Destruction of ozone. Chapman also provided an explanation of the natural loss of ozone: Through the action of ultraviolet radiation, ozone molecules (O_3) are split up into oxygen atoms (O) and oxygen molecules (O_2). This reaction is then followed by a combination of the free oxygen atoms (O) into oxygen molecules (O_2).

Research in this field has later revealed that there are several other processes which result in the depletion of the ozone layer. In particular, ozone loss is caused by the presence of catalysts which originate from the breakdown of gases emitted from the earth's surface. Some of these gases are of natural origin, e.g., chloromethane which comes from rotting plants, but most are synthetic compounds such as the various chlorofluorocarbons (see *Table 2*). An example of such a process caused by anthropogenic emissions of CFC-12, one of the many man-made, long-lived chlorofluorocarbons, is schematically illustrated in *Figure 11*.

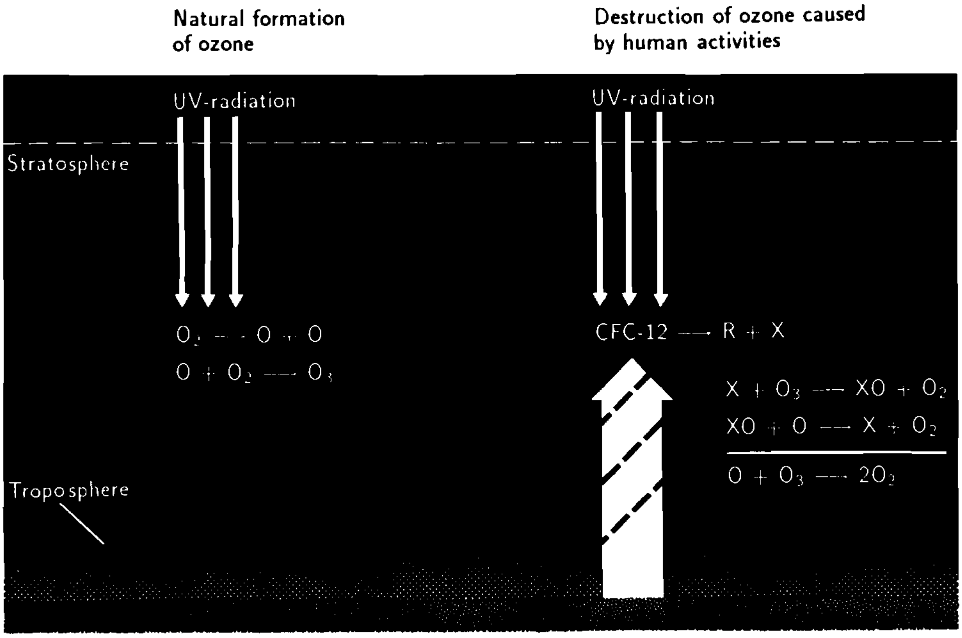


Figure 11. Schematic illustration of the natural formation of ozone in the stratosphere and an example of its depletion by anthropogenic emissions of CFC-12 (CF_2Cl_2). X represents a catalyst (Cl in this case) which re-emerges to trigger off a new cycle of reactions and R is CF_2Cl.

As indicated above, this account of the main processes resulting in the depletion of stratospheric ozone is very incomplete in relation to current knowledge. Present models of the atmospheric chemistry simulate about 160 chemical reactions involving some 40 reactive species. Still, it must be recognized that our knowledge is far from complete. It should be recalled that only seven years ago the discovery of the *ozone hole* came as a complete surprise. A possible reason for the effectiveness in the destruction of ozone is possibly that the presence of ice particles may accelerate some chemical reactions, so that the ozone destruction by chlorine would thereby be more effective (Solomon and Schoeberl, 1988).

As Rowland stated in 1989, the current lack of knowledge "casts severe doubts on any current predictions of ozone changes – the actual losses in the future are likely to be more severe". The latest measurements indicate

Table 2. Anthropogenic sources of atmospheric chlorine.

Name	Acronym	Formula	Ozone depletion potential[a]	Green-house potential[b]	Estimated world use 1985[c]
Tichlorofluoromethane	CFC-11	$CFCl_3$	1.0	0.32	341.5
Dichlorodifluoromethane	CFC-12	CF_2Cl_2	1.0	1.0	443.7
Trichlorotrifluoroethane	CFC-113	CCl_3CF_3	0.8	0.3–0.8	163.2
Dichlorotetrafluoroethane	CFC-114	$CClF_2CClF_2$	1.0	0.5–1.5	15.0
Chloropentafluoroethane	CFC-115	$CClF_2CF_3$	0.6	1–3	15.0
Bromochlorodifluoromethane	Halon 1211	$CClBrF_2$	3.0	–	10.8
Bromotrifluoromethane	Halon 1301	$CBrF_3$	10.0	1.7	10.8
Dibromotetrafluoroethane	Halon 2402	$C_2F_4Br_2$	–	6.0	> 1
Carbon tetrachloride	–	CCl_4	1.2	–	122.3
Methyl chloroform	–	CH_3Cl_3	0.15	–	544.6
Chlorodifluoromethane	HCFC-22	$CHClF_2$	0.05	0.07	109.0

[a]The ozone depletion potential is compared to CFC-11 with a value of 1.0.
[b]The greenhouse potential is compared to CFC-12 with a value of 1.0.
[c]The values are given in thousands of metric tons.
Source: Van Hook *et al.*, 1989.

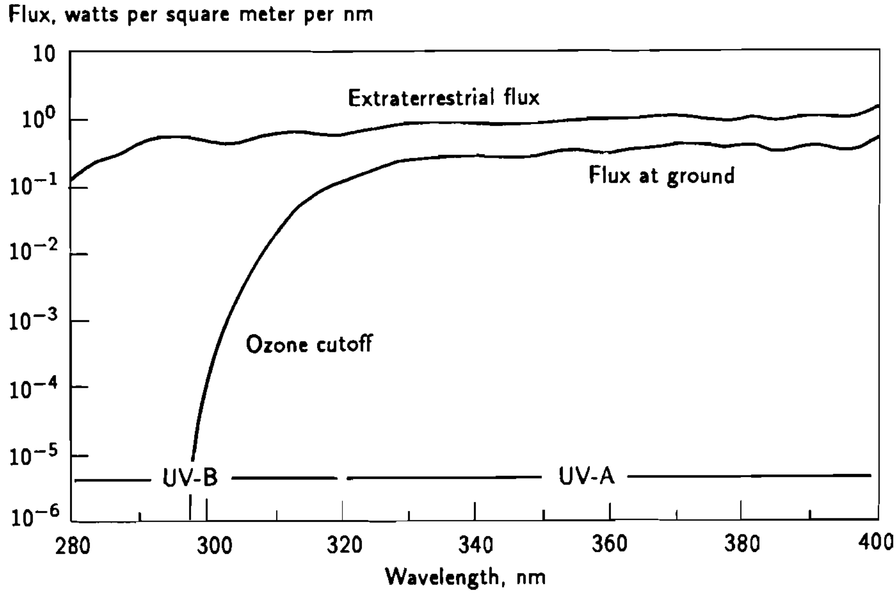


Figure 12. A comparison of the solar flux at the top of the atmosphere within the ultraviolet spectrum with the solar flux at the earth's surface. The figure illustrates the condition of an undisturbed stratospheric ozone layer. With less ozone in the stratosphere the *ozone cutoff* would be at a shorter wave-length. (Source: Van Hook *et al.*, 1989.)

just that (Climate Alert, 1991). The global average for the decrease of atmospheric ozone is now reported to be 2.3% per decade.

5.2 Impacts on ultraviolet radiation and associated consequences for human health

The ozone and oxygen in the earth's atmosphere are very effective in absorbing the sun's ultraviolet radiation, and it is ozone that is entirely responsible for the absorption in the UV-B baud which ranges from 280–320 nm (see *Figure 12*). Consequently a reduction in the amount of ozone, which is at its maximum in the lower stratosphere, would result in an increase in UV-B radiation at the earth's surface. At 300 nm, a one percent drop in ozone would result in about a ten percent increase of radiation at the surface.

The reason why attention is given to UV-B radiation and its expected increase at the earth's surface is that this part of the ultraviolet radiation has the strongest impact on human health. In particular, the risk of skin cancer can be expected to increase substantially with an increasing intensity of UV-B radiation, and the body's autoimmune system also may be affected (Van Hook *et al.*, 1989).

Skin cancer. Although there is a well-founded concern that there will be a general increase in the occurrence of skin cancer owing to the expected increase of UV-B radiation, the most serious worry is attached to melanoma. It is at present the most common form of fatal skin cancer, it kills three times as many people per year than any other form of skin cancer. What is characteristic of this skin cancer is that the location of the melanomas on the body is seldom in well exposed places for solar radiation, but in underexposed areas (back calf, back of ear).

According to the estimates made by scientists at the US Environmental Protection Agency (Climate Alert, 1991), the acceleration in the depletion of ozone, resulting in increased UV-B radiation, would result in 12 million additional cases of skin cancer in the USA by the year 2030. The previous estimate, based on a lower value of the ozone depletion, was only half a million cases.

Photoimmunology. According to recent studies there are indications that the body's autoimmune system is being changed by UV-B radiation. It is also hypothesized that increased UV-B radiation may suppress the body's intrinsic capacity to immunologically reject tumor growth and development.

5.3 International agreement on CFC phaseout

The stratospheric ozone issue is the "youngest" of the environmental problems discussed in this report. Nevertheless it appears that this will be the environmental problem for which an international agreement providing sufficient protection can be reached. The short, but intensive, history of the international negotiations has been described by Benedick (1991) who himself played an important role in this process. The only point I want to make here is the remarkable fact that governments were able to make an important decision aimed at reducing one of the serious threats to the environment in spite of the fact that scientific certainty is still lacking. This decision took place in June 1990 in England, when 93 nations agreed to a complete a phaseout of chlorofluorocarbons. Industrial countries would be required to achieve this by 2000 and developing countries by 2010.

5.4 Ozone in the troposphere

While the ozone concentration is decreasing in the stratosphere causing harmful ultraviolet radiation at the earth's surface, at the same time it is increasing in the lower layers of the troposphere, also due to anthropogenic activities, causing other harmful effects. In the troposphere, ozone is produced by reactions involving hydrocarbons and oxides of nitrogen. During the last few decades the concentration has considerably increased in the Northern Hemisphere (Crutzen and Graedel, 1986). Regionally it now frequently reaches very high concentrations (well above phytotoxic levels) causing numerous problems, e.g., damage to crops, forest decline, decreased lung function, eye irritation, and corrosion of works of art.

No doubt efforts are being made to define regulatory measures for the reduction of the tropospheric ozone concentration. Such attempts are, however, difficult to accomplish in view of the complexity of the processes involving many chemical compounds.

6. The Acidification of Terrestrial and Aquatic Ecosystems

There is a basic difference between the acidification problem and the two environmental problems discussed above. Both the greenhouse gas issue and the ozone problem are truly global issues. The emitted gases causing these two environmental problems have a very long life time and are therefore being mixed globally. Response actions to reduce the atmospheric concentrations of these gases, and thereby reduce their consequences for the environment, will thus require the cooperation of all nations.

The chemicals that are mainly responsible for the acidification problem have a considerably shorter life time in the atmosphere; they stay aloft only a few days, and are therefore traveling much shorter distances before returning to the earth. The region of their influence is only about 1000 km. The acidification problem is thus basically of regional character. Thus, the problems encountered in Europe require only cooperation and actions by European nations.

6.1 Recognition of the problem

The first observational evidence that an increase in the emissions of acidifying chemicals has an impact on the environment was provided by Odén

(1968), who discovered that the lakes in Sweden were acidifying and that damage was becoming apparent. Nevertheless, it took a long time before this environmental threat was taken seriously. Governments demonstrated a remarkable lack of motivation in their attempts to take appropriate action, and this is illustrated by various statements made in the years following Odén's revelation: "There is no acidification problem." "There is no long-range transport of sulfur dioxide ...It is a local problem and can be solved by tall stacks." "The long-range transport may be causing damage, but we cannot be sure reductions of emissions will help." "We need more research."

At least in Europe, where the problem is most pronounced, the governments are now beginning to recognize the need for major reductions in emissions. What has been achieved so far in decreasing emissions is, however, very little in relation to what is needed. Even if evidence is mounting that it might be cheaper to reduce emissions of acidifying pollution rather than to continue it, it is unlikely that reduction will be sufficient in view of the enormous cost of control.

In other parts of the world the acidification problem is slowly emerging, and can be expected to be of significant importance in view of the rapidly growing population and industrialization. So far, however, it has been given little or insufficient attention.

6.2 The chemicals causing the problem

In a very condensed form, *Table 3* presents some basic information about the pollutants which are responsible for the acidification problem, namely sulfur dioxide (SO_2), nitrogen oxides (NO and NO_2), and ammonia (NH_3).

Sulfur oxide is emitted into the atmosphere during the combustion of various kinds of fossil fuels, e.g., brown, hard, and derived coal, as well as crude oil and its different distillates. Originally most attention was given to sulfur, but it has subsequently become evident that the acidification problem has significantly increased due to the anthropogenic emission of nitric oxide (NO), nitrogen oxide (NO_2), and ammonia (NH_3). Clearly, the contributions from the individual sources to the acidification in different countries exhibit large differences from the average values given in *Table 3*, depending on the degree of industrial or agricultural activities, and to what extent high- and low-sulfur content fossil fuels are being used. This can be observed by comparing the values of the emissions of the various pollutants from the different countries in Europe given in *Table 4*. Ireland, with more farm animals than people, has a comparatively high per capita emission of ammonia, while the

Table 3. Some basic information about the gases that contribute to acidification in Europe (1989).

Gases	Main sources of emission	Transport distance before deposition	Emission in million tons	Contribution to acidification	Change from 1980 to 1989
Sulfur dioxide (SO_2)	Power plants coal and oil burning	100s km	41	60%	−22%
Nitrogen oxides (NO, NO_2)	Exhausts from traffic plants	100s to ~1000 km	22 (NO_2)	21%	+5%
Ammonia (NH_3)	Animal waste on farms and fertilizers	~10–100 km	9	19%	unknown

Sources: Alcamo *et al.*, 1990; Iversen *et al.*, 1990.

(former) German Democratic Republic, with its use of high-sulfur content coal, has comparatively high emissions of sulfur oxide.

The fact that the acidification problem is of a transboundary nature is illustrated in *Figures 13a* and *13b*. The figures show the contributions of various European countries to the deposition of sulfur dioxide and oxidized nitrogen in Austria, a country which receives considerably more of these pollutants than it "exports" (see *Table 5*). By comparing *Figures 13a* and *13b*, it can be seen that nitrogen oxides are, on average, carried longer distances by winds than sulfur oxide. The typical distances the different pollutants are transported by the winds are given in *Table 3*.

6.3 Impacts of the acidifying pollutants

The first observational evidence of the consequences of the acidifying pollution was the lowering of the pH-levels in lakes where it was causing damage to fisheries. Subsequently it has become evident that acidification is responsible for a wide range of impacts affecting all ecosystems and causing extensive economic losses.

Aquatic ecosystems. In extensive areas, both in Europe and North America, the acidity of lakes has increased radically. More than half of them have pH-values of less than 5 and are fishless. (The range of pH required for good

Table 4. Emissions of sulfur oxide, nitrogen oxides and ammonia in Europe (1989).

Country	Popu-lation[a]	Total emissions			Emissions per capita		
		SO_2[b]	NO_2[c]	NH_3[d]	SO_2[b]	NO_2[c]	NH_3[d]
Albania	2.9	50	9	24	17.2	3.1	8.3
Austria	7.5	104	207	85	13.9	27.6	11.3
Belgium	9.9	418	299	94	42.4	30.4	9.5
Bulgaria	8.9	1030	150	147	116.3	16.9	16.6
CSSR	13.5	2774	950	200	205.5	70.4	14.8
Denmark	5.1	254	252	125	49.8	49.4	24.5
Finland	4.8	278	282	43	57.9	58.8	9.0
France	53.9	1272	1761	841	23.6	32.7	15.6
FRG	61.6	1060	2729	380	17.2	44.3	6.2
GDR	16.7	5242	1005	242	313.9	60.2	14.5
Greece	9.6	500	746	112	52.1	77.7	11.7
Hungary	10.7	1084	249	151	101.3	23.3	14.1
Ireland	3.4	182	93	139	53.5	27.4	40.9
Italy	56.4	2410	1700	426	42.7	30.1	7.5
Luxembourg	0.36	12	16	6	33.3	44.4	16.7
Netherlands	14.1	254	552	199	18.0	39.1	14.1
Norway	4.1	66	226	41	16.1	55.1	10.0
Poland	35.6	3910	1480	478	109.8	41.6	13.4
Portugal	9.8	208	132	55	21.3	13.5	5.6
Rumania	22.2	1778	390	350	80.0	17.6	15.8
Spain	37.5	3118	950	273	83.1	25.3	7.3
Sweden	8.3	210	382	62	25.3	46.0	7.5
Switzerland	6.3	68	189	61	10.8	29.9	9.7
Turkey	44.4	398	175	699	9.0	3.9	15.7
UK	56.3	3552	2513	478	63.1	44.6	8.5
USSR	170.0	9318	4190	3180	54.8	24.6	18.7
Yugoslavia	22.3	1650	480	235	74.0	21.5	10.5
		41200	22107	9126	59.2	31.8	13.1
		Total values			Average values		

[a]In million.
[b]In kt sulfur oxide per year.
[c]In kt nitrogen oxide per year.
[d]In kt ammonia per year.
Sources: Alcamo *et al.*, 1990; Iversen *et al.*, 1990.

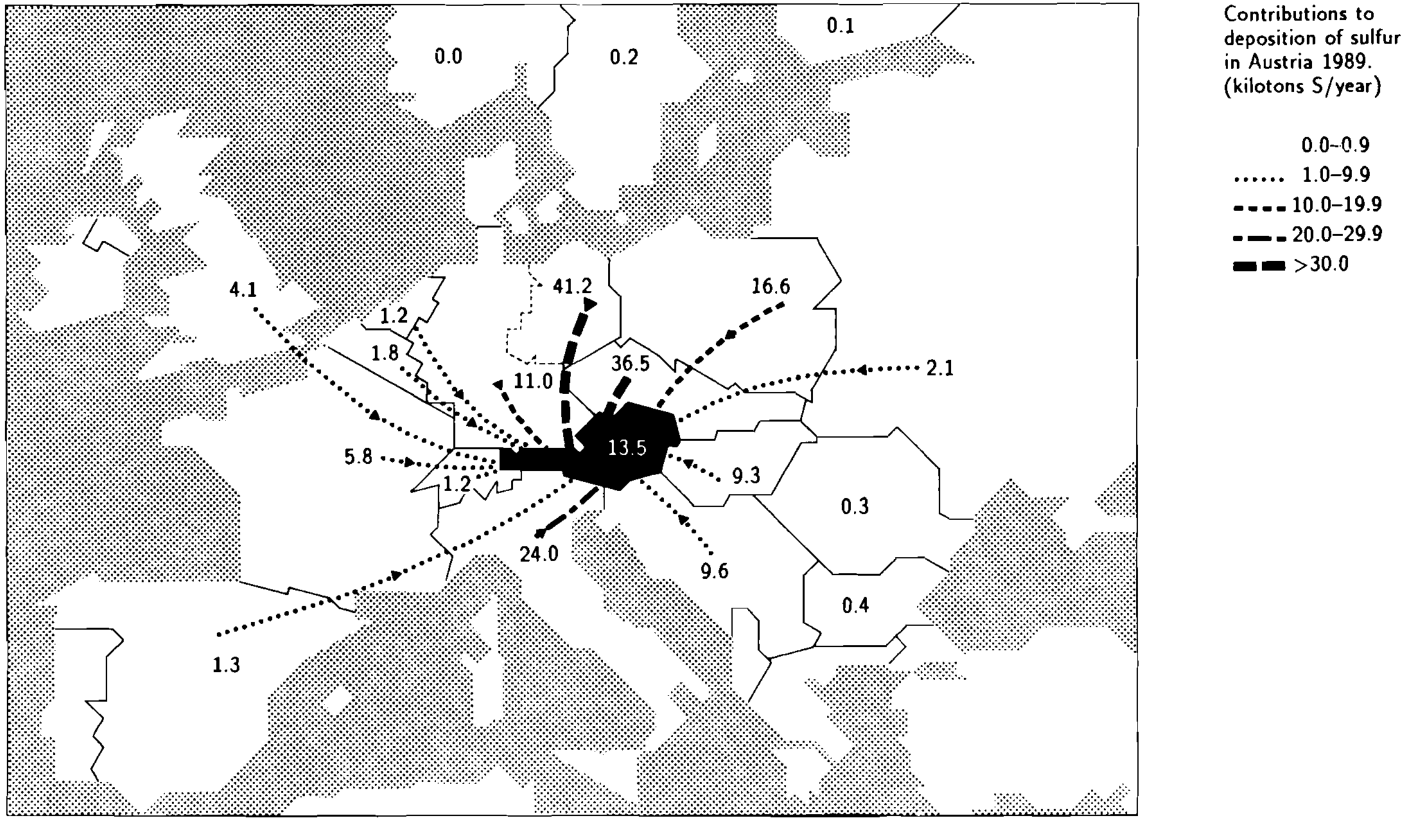


Figure 13a. Schematic illustration of the origin and transport of sulfur dioxide that is being deposited in Austria. The values of these air transports have been obtained using the Regional Acidification Information and Simulation (RAINS) model (Alcamo *et al.*, 1990).

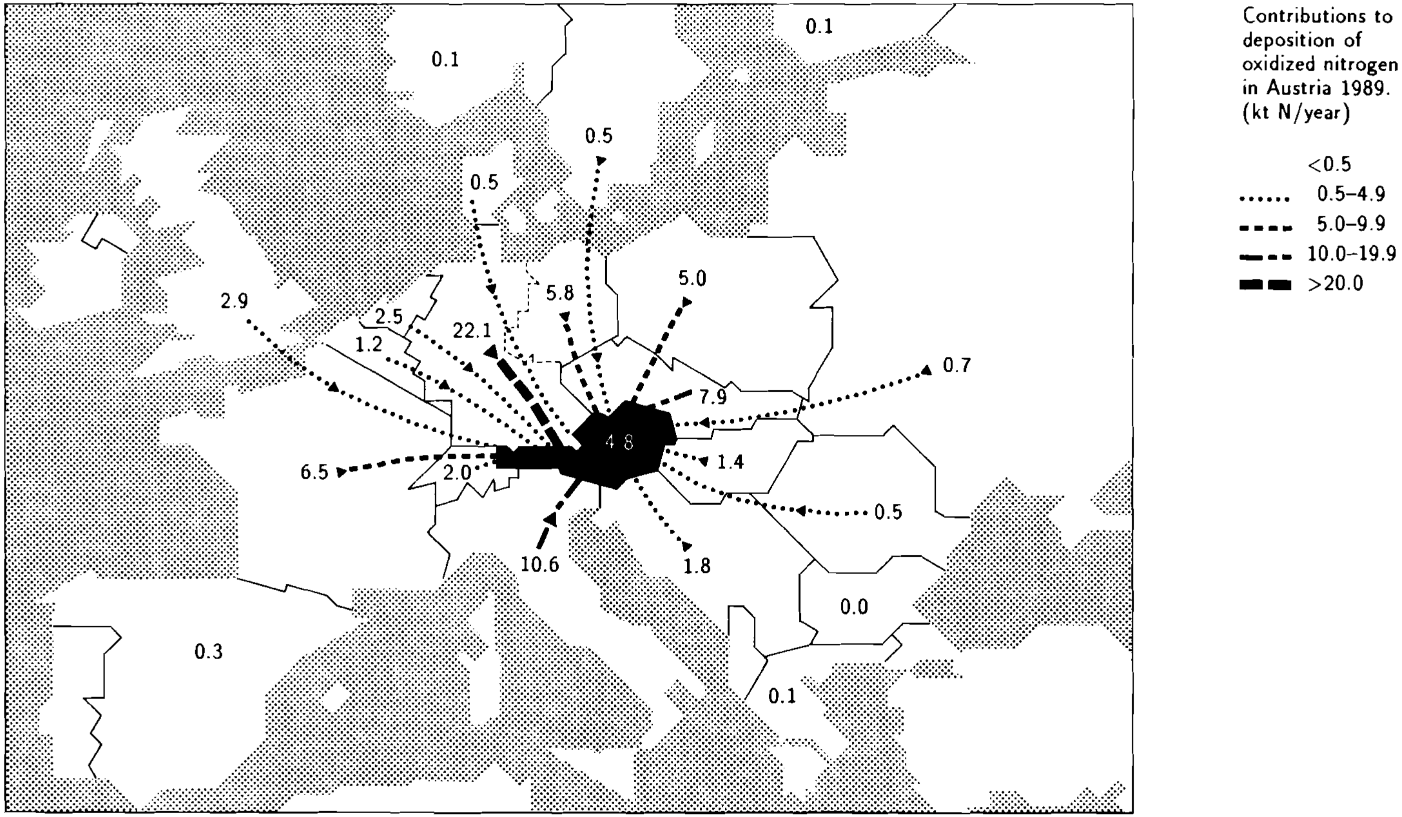


Figure 13b. Same as *Figure 13a*, but for oxidized nitrogen.

Table 5. "Import" and "export" of sulfur oxide and nitrogen oxides in Austria (1989).

	Deposition in Austria from emissions in:			Total emissions
	Austria	Other countries	Total	in Austria
Sulfur oxide (kt SO_2/yr)	27.0	372.8	399.8	104.0
Nitrogen oxides (kt NO_2/yr)	15.7	263.0	278.7	207.0

fishery is about 6 to 9.) In Norway, 1750 lakes have lost their entire fish population (Alcamo *et al.*, 1990).

Acidifying pollution has also affected the groundwater in many areas, e.g., in the Netherlands, North America, Sweden, and the FRG. This in turn has resulted in a substantial increase (10 to 100 times) in the concentrations of toxic heavy metals.

Forests. The ongoing damage to and loss of forests in Europe is a result of several complex, interactive processes caused by a wide range of pollutants, including the following (EPRI, 1985):

- Acidic deposition has several impacts on soil chemistry including leaching of nutrients and damage to the roots thereby reducing their ability to take up what nutrients are left in the soil.
- Acidic deposition also erodes the waxy protection layer on the leaves.
- Deposition levels of nitrogen up to the critical load cause growth increase by fertilization. But deposition levels above the critical load will have a negative impact and eventually lead to a disintegration of the forest (Hofmann *et al.*, 1990).
- Ozone-acid mist damages leaf tissues and disrupts photosynthesis and metabolic functions.
- The above mentioned anthropogenically induced stresses may work in combination with other stresses, such as climatic extremes, pests, and pathogens, and thereby enhance the negative effects.

Soil chemistry. The deposition of sulfur and nitrogen during the last decades has led to a substantial increase in the acidity of the soils which has many direct and indirect consequences (see *Figure 14*), e.g., nutrient deficiencies of forest ecosystems and leaching of sulfate and nitrate into the groundwater. It also intensifies processes leading to higher concentrations of toxic chemicals in the soil.

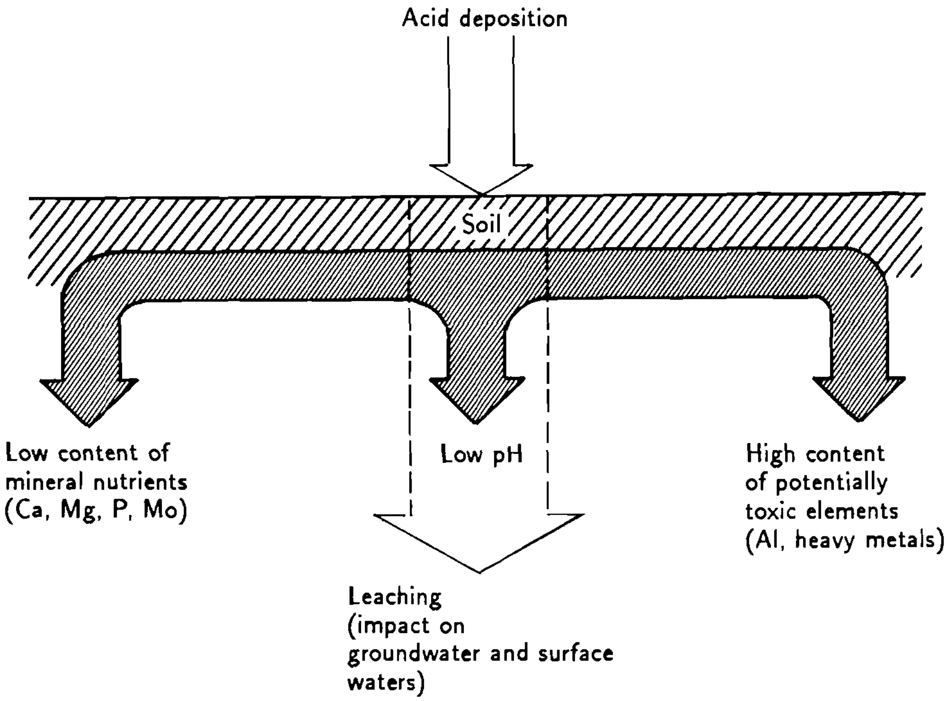


Figure 14. Effects of acid deposition on soil chemistry. (Source: Nilsson and Grennfelt, 1988.)

Corrosion of materials. Considerable damage is done to cultural and historical monuments and buildings by sulfur ad nitrogen dioxides and ozone. For example, many of the ancient buildings in Athens and Rome are deteriorating rapidly. Irreplaceable damage has also been caused by acid deposition on medieval glass windows, and extensive loss can be expected if no action is taken. Most of the corrosion is caused by local pollution, but the long-range transport of acidifying chemicals is certainly making things worse.

6.4 Critical load of pollution

The extent of any damage made by a pollutant is not only dependent on the amount of the pollutant deposited but also the sensitivity of the various ecosystems has to be taken into consideration. For example, for a given level of sulfur deposition, a pine tree in Scandinavia, with its highly sensitive ecosystem, would only be able to survive a few years. The same tree would, however, stay healthy if it grew in an area with a less sensitive ecosystem. This has led to the establishment of critical loads, defined as:

> "a quantitative estimate of exposure to one or more pollutants, below which harmful effects which are judged to be significant on specified elements of the environment do not occur according to present knowledge" (Nilsson and Grennfelt, 1988).

Figures 15a and *15b* show the deposition of sulfur in Europe in 1989, and the estimated critical load values respectively. By comparing these two maps it can easily be seen that the present values highly exceed the critical values in extensive areas, particularly in central and eastern Europe. It is within these areas that forests have already experienced, or will experience, forest damage.

6.5 International action

A first step in achieving international cooperative action was taken with the signing (1979) of the United Nations Economic Commission for Europe's International Convention on Transboundary Air Pollution (UN-ECE, 1985). Its target was an overall reduction in European sulfur emissions by about 30%.

In 1982, the signatories of this Convention met again at the Conference on Acidification of the Environment in Stockholm. The most important outcome of the meeting was that a concerted international control program was set up within the ECE.

Subsequently, at a ministers' meeting in early 1984 in Ottawa, Canada, 10 countries volunteered to reduce emissions of sulfur dioxide by 30% by 1993, relative to their 1980 levels. The original members of this so-called "30% Club" were: Austria, Canada, Denmark, the Federal Republic of Germany, Finland, France, the Netherlands, Norway, Sweden, and Switzerland. By 1985, the members of the 30% Club had increased to 21 countries. Among the countries that had not signed the Protocol at that time were two of Europe's largest SO_2 emitters, the UK and Poland (UN-ECE, 1988).

In 1989 the UN-ECE recommended that the RAINS-model, developed at the International Institute for Applied Systems Analysis (IIASA), should be adopted by all parties as the central technical support for the negotiations. This is a model which policy makers themselves can use and from which they can get quick answers to the many questions involved.

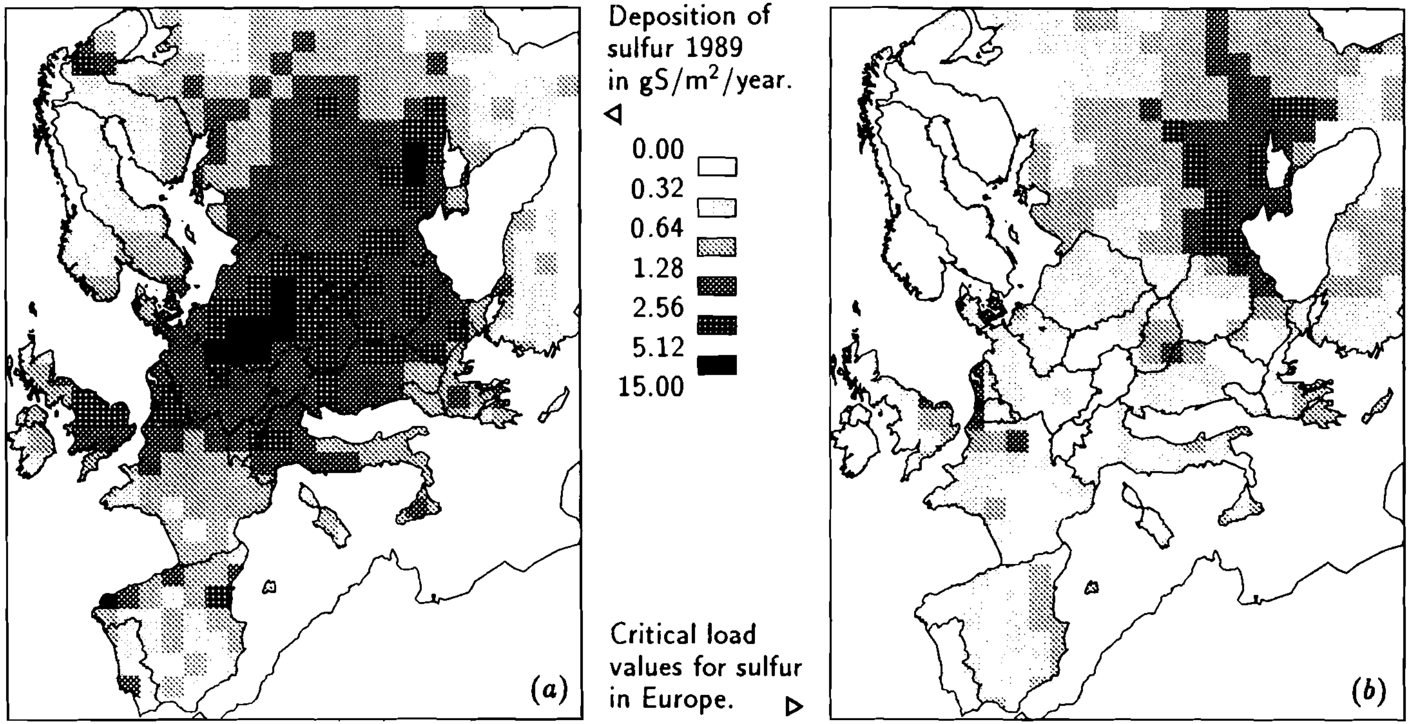


Figure 15. (*a*) Deposition of sulfur in Europe in 1989. (*b*) The estimated critical load values of sulfur for forest ecosystems. (Source: Chadwick and Kuylenstierna, 1990.)

In addition to simulating the air transport of the actual emissions and determining the geographical distribution of the acidifying pollutants, this model can be used to determine optimum control strategies. For example, given an environmental limit of deposition, the model can determine where emission should be reduced to minimize the cost of removal and still meet the target.

Current plans to reduce sulfur dioxide in Europe will result in a 46% reduction of these emissions in Western Europe and three percent in Eastern Europe, resulting in an overall reduction of 22%. In this context it should be mentioned that the effects of acid rain in Europe can only be stabilized by reducing the sulfur dioxide emissions by about 60–80%, and at the same time reducing significantly the emissions of nitrogen oxides and ammonia.

7. Deforestation and Degradation of Land

The problem of deforestation in the tropics and the degradation of global land areas are very closely connected, not only with other environmental issues, but also with such issues as socioeconomic development and relations between the industrialized and the developing worlds. The future management of these problems is of fundamental importance for the very basic question: Will the global life support system have sufficient capacity for the rapidly growing world population?

The deforestation problem was previously confined to the temperate latitudes, but since the second world war it has shifted to the tropics. The consequences of the accelerated clearing of forests will, however, not be confined to the low latitudes. It has become a problem of global concern, e.g., because it is causing an irreplaceable loss of biological diversity. According to the Interactive Council (1988), between 1990 and 2020, it is anticipated that an average of 50 animal and plant species will disappear every day in the tropics. Deforestation is also contributing substantially to the increasing atmospheric concentration of carbon dioxide and will thereby have an impact on the global climate.

On a local and regional scale deforestation will cause a wide range of environmental damage in addition to the rapid loss of an economically valuable natural resource. For example, deforestation will cause increased erosion of soils, a reduction of the capacity of the soils to hold water resulting in increased frequency and severity of floods, and a change of the regional climate caused by a change of the surface albedo.

Table 6. Estimates of the rate of tropical deforestation in 1000 km^2.

	FAO 1980	Meyers 1989	WRI 1990	FAO 1990
Closed forests	73	139	n.a.	n.a.
Total forests	113	220	160–200	170

Source: Houghton, 1990.

7.1 The magnitude of tropical deforestation

The information about the rate and extent of tropical deforestation before 1980 is both insufficient and uncertain. At that time, however, a major effort was made by the Food and Agriculture Organization and the United Nations Environment Programme (FAO/UNEP, 1981 and Lanly, 1982) to estimate the magnitude of the tropical forests and its decrease. About a decade later three other estimates were made by Meyers (1989), the World Resources Institute (WRI, 1990), and the FAO (1990a). The rates for deforestation obtained in these four estimates are given in *Table 6.*

The closed forests are generally larger and their canopies are dense enough to preclude the growth of grasses. The figures in *Table 6* for the total forests include also open forests or woodlands which have open canopies with grasses between trees.

Although there are still uncertainties in these recent estimates of deforestation, as reflected in the different values referring to the present situation (around 1990), it is apparent that the rate of deforestation has increased radically – by about 50% during the last decade. In view of the fact that very little is currently being done to reduce deforestation, it can be expected that in the next few decades the rate will most likely not be very much less than about 100,000 km^2/year for closed tropical forests and about 170,000 km^2/year for all tropical forests. Comparing these rates with estimates of the remaining tropical forest areas, 8,000,000 km^2 closed forest and 17,000,000 km^2 total forest, it can be expected that the main parts of the tropical forests will disappear by the middle of the next century.

7.2 Deforestation as a contributing factor to climatic change

Next to the combustion of fossil fuel, deforestation is the major source of anthropogenic emission of carbon dioxide. The current best estimates of the global emissions from these two sources are (WMO/UNEP, IPCC, 1990b):

fossil fuels account for 5.4 ± 0.5 billion tons of carbon per year and deforestation accounts for 1.6 ± 1.0 billion tons of carbon per year.

An attempt to map the distribution of the deforestation has been made by Houghton (1990) and is shown in *Figure 16.* Outside the tropics deforestation is comparatively low, but may increase because of the expected global climatic change and acidification.

Although there is a considerable range of uncertainty with regard to the estimated carbon dioxide emission caused by deforestation, there is no doubt that it represents a significant contribution to the increasing atmospheric concentration of carbon dioxide, and thereby to global climatic change. Consequently, the Intergovernmental Panel on Climatic Change (WMO/UNEP, IPCC, 1990a,c) has recommended that response strategies should include "sustainable forest management and afforestation."

Such kinds of recommendations no doubt make sense, but as long as no concrete and realistic plans exist for their implementation, they cannot be expected to lead to any improvement in the situation. In this connection it should be pointed out that existing suggestions with regard to reducing, or even solving the greenhouse gas issue by undertaking a massive reforestation program are more optimistic than realistic (Houghton, 1990). For example, the area available for reforestation is not as large as it is assumed to be – up to about 5 million km^2. Furthermore, it does not take into account ownership of the land, the cost of reforestation, or the ability of degraded lands to grow trees. In addition, the uptake of carbon through reforestation occurs less rapidly than the release associated with deforestation. Reforestation should not, under any circumstances, be regarded as an alternative to deforestation. As Houghton also points out, it makes little sense to attempt to reforest areas if deforestation and its causes have not been resolved.

7.3 Do we know the causes of tropical deforestation?

The severity of the tropical deforestation problem is not limited to its several harmful consequences, or to the fact that it is dramatically increasing in magnitude. The problem is also exacerbated by the fact that our knowledge about the driving forces of tropical deforestation is very limited, which, at present, makes it impossible to develop efficient response strategies. The only thing we can state with some confidence is that there are many factors behind tropical deforestation and that they are linked together as various causal chains and mechanisms (Nilsson 1989, 1990).

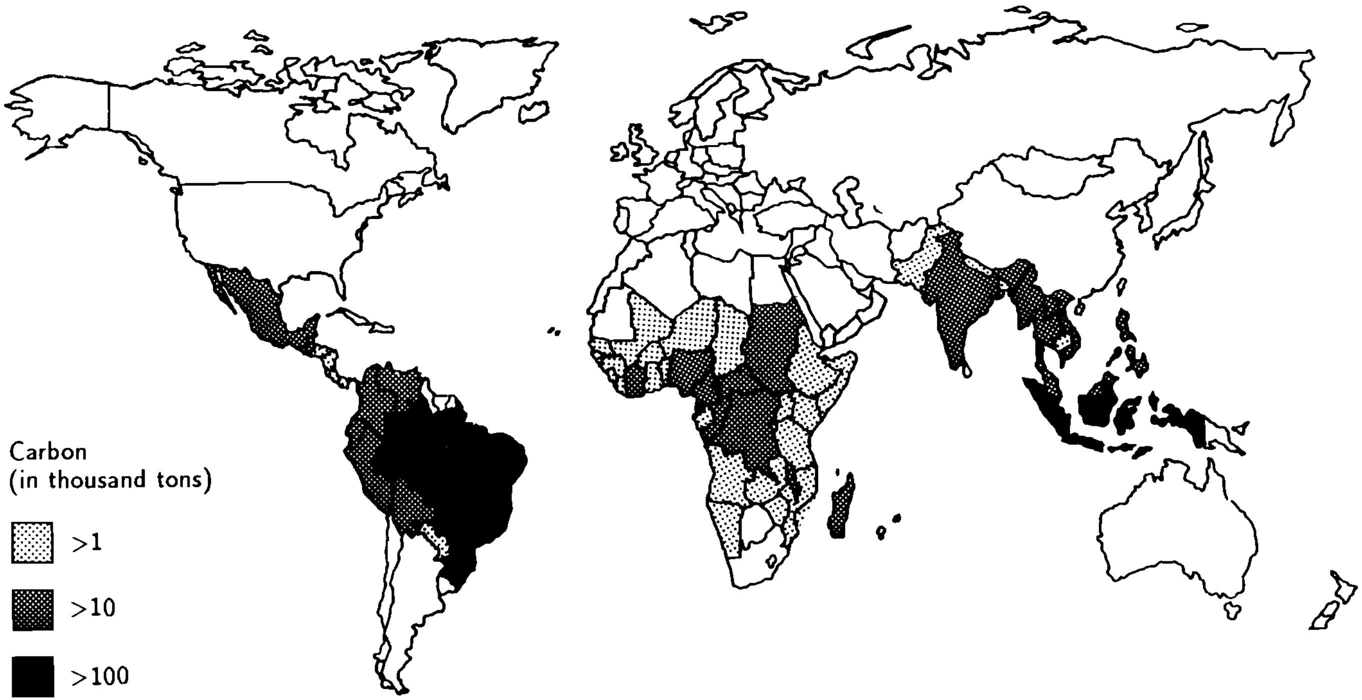


Figure 16. Carbon dioxide emissions from tropical deforestation in 1989, expressed in million tons carbon per year. (Source: Houghton, 1990.)

Palo and Salmi (1987) have produced a framework on how the various factors influencing deforestation interact with each other through a number of positive and negative processes, resulting in a vicious circle (see *Figure 17*).

In view of the above it can be concluded that, should it be possible to develop response strategies for an effective retardation of tropical deforestation, and should this be politically acceptable, a dedicated multi-disciplinary research effort must be initiated. This should include the following (Nilsson, 1990):

- Identification and quantification of the numerous socioeconomic factors, taking into account that the driving forces are specific to each of the main regions of the tropical forests.
- Production of consistent quantitative scenarios on future tropical deforestation for each region, taking into account that the driving forces are changing over time.
- Production of cost-benefit analyses (gains and losses) on the consequences of future tropical deforestation.
- Development of strategies for the control of deforestation in each region, and policy measures required for their implementation.

If such an effort could be accomplished, it would remove the main reason why so little has been achieved in reducing the tropical deforestation. Time for achieving such a knowledge base on the causes of tropical deforestation, required for political action, is beginning to run out if there is to be any possibility of saving any major portions of the remaining tropical forests.

7.4 The need for a global convention on forests

At present several legal instruments are in force which relate, either directly or indirectly, to forests. On a global level one agreement does exist on the cooperation and consultation between tropical timber producing and consuming members (The International Timber Agreement, Geneva 1983). There also exists a number of agreements operating on a global or a regional level for the protection of different aspects of natural resources conservation and management.

As has been emphasized by the Food and Agriculture Organization of the United Nations Committee on Forestry (FAO, 1990b), what is lacking is a proper framework at the global level, dealing with *all* types of forests and *all* aspects of forest management. In order to achieve this, an initiative has been taken by this FAO Committee for the development of an international

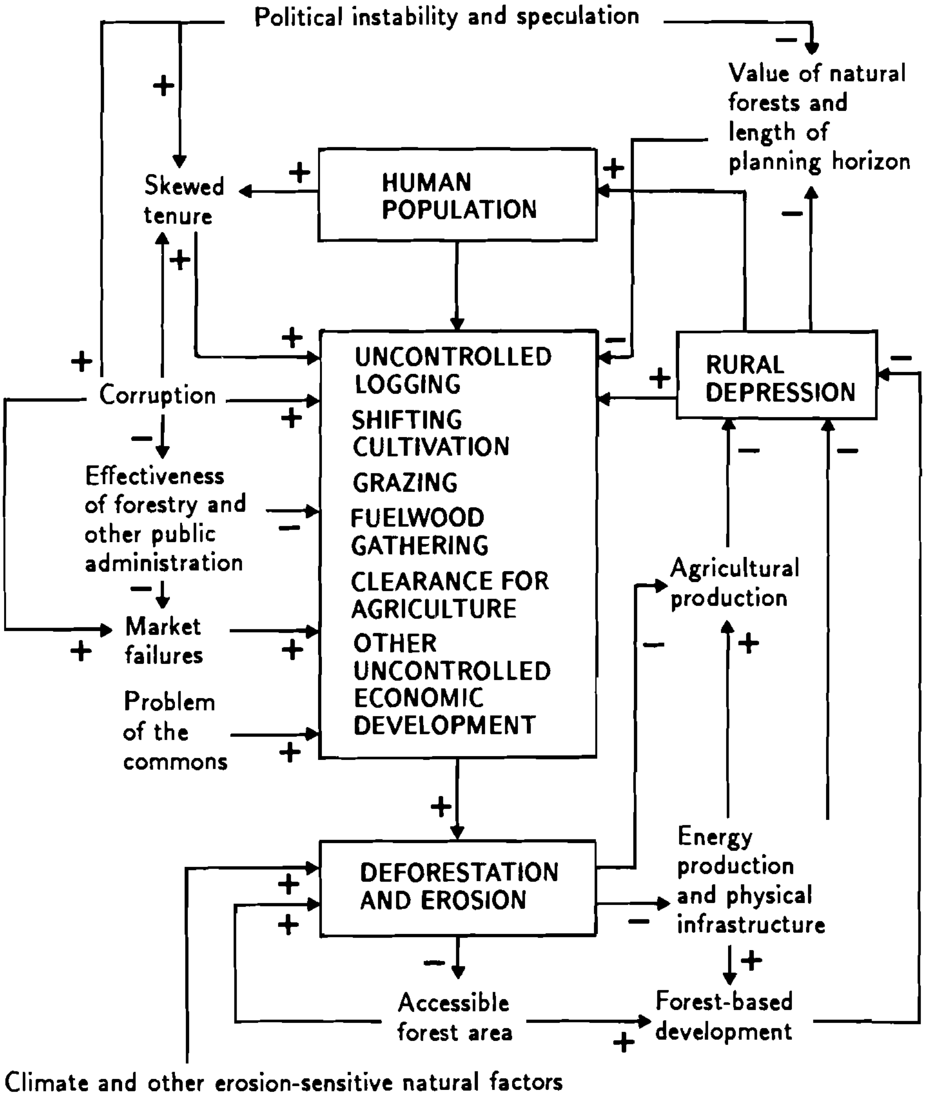


Figure 17. The vicious circle of population pressure, deforestation, and rural depression in the tropics. (Source: Palo and Salmi, 1987.)

convention on forests which should be resource-based and provide flexible, but well-defined principles and measures to:

- Harmonize ecological and socioeconomic approaches to the conservation, development and use of forest resources.
- Support effective forest management and afforestation, as well as other forms of integration of trees, in sustainable land uses contributing to environmental stability and land productivity.
- Assure an equitable flow of direct and indirect benefits from the forest to all parties, respecting local rights, abiding by national laws and policies, and accommodating regional and global environmental protection requirements.
- Apply compensation mechanisms to offset losses incurred by traditional users in reserving certain forests or modifying existing forest land use for environmental protection.
- Ensure coherence and complementarity with existing and planned legal instruments dealing with forests or closely-related issues, such as climate change and the maintenance of biological diversity.

The intention with such a convention is conceived primarily as a means to mobilize and harmonize action at local, national, and international levels by ensuring firm commitments and engaging and maintaining a dynamic process of cooperation.

7.5 Land degradation and its impact on food production

Due to several causes the world's cropland is beginning to be severely degraded at the same time as the demand for food is increasing rapidly because of the growing world population. Although the harvest per unit area (yield) has, on the average, increased during the last few decades, it is now beginning to level off with the consequence that global grain production per capita already shows a downward trend. This is the background to the statement made by Lester R. Brown (1990): "As we enter the nineties, the world has little to celebrate on the food front".

Some of the several causes of the degradation and erosion of land are acidification caused by emission of fossil fuels, increased run-off of precipitation and flooding caused by deforestation, water-logging, and salinization. An estimate of the consequences of land degradation on the yield potential has been published by the US Department of Commerce, and is shown in *Figure 18.*

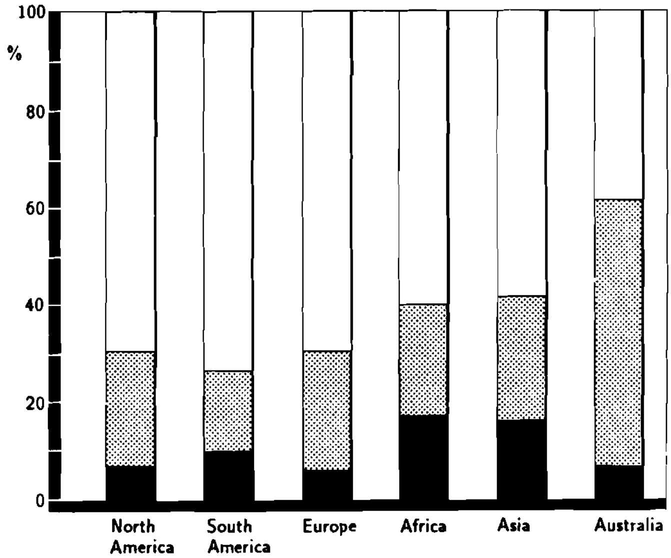


Figure 18. Estimated land erosion in the late 1970s. The black areas correspond to regions where the reduction of the yield potential is more than 50%, the grey areas correspond to reductions between 10 and 50%, and the white areas by less than 10%. (Source: Brown, 1990).

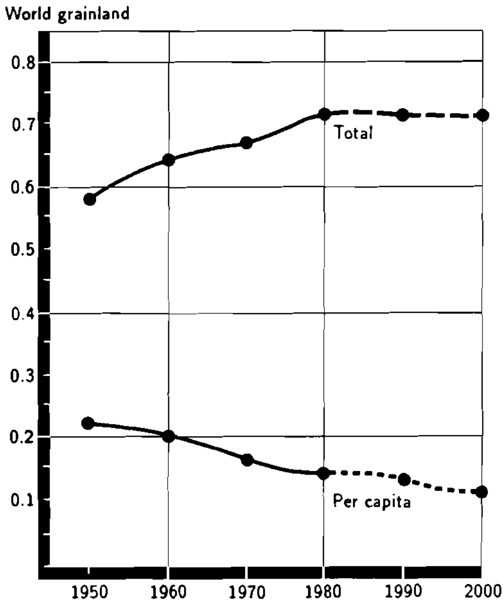


Figure 19. World grainland (in billions of hectares) and per capita (in hectares), 1950-1980, with projections to 2000. (Source: Brown, 1990).

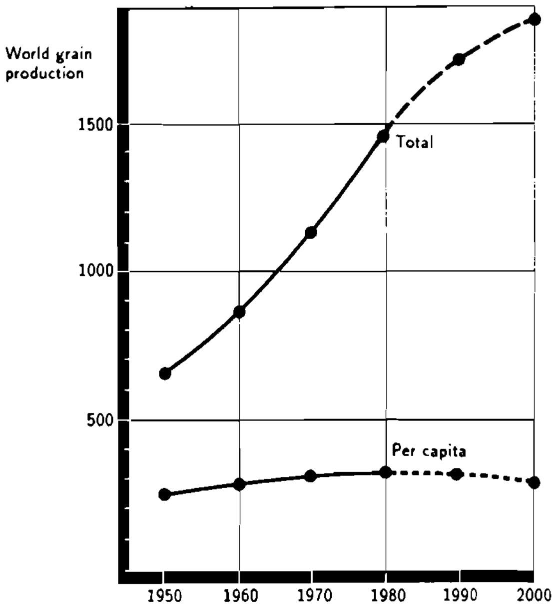


Figure 20. World total grain production (in million tons) and per capita (in kilograms), 1950-1980, with projections to 2000. (Source: Brown, 1990).

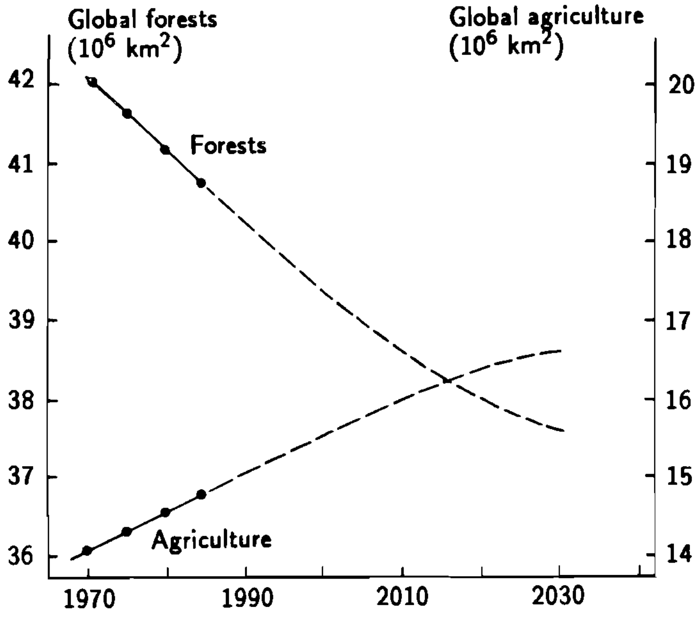


Figure 21. Variation with time of the areas of global forests and global agriculture assuming no significant retardation of the ongoing deforestation.

At the same time as land has been degraded and become less productive, new cropland has been added at a rate sufficient to offset the losses. The total grainland of the world is thus still increasing, but at a much slower rate. (It should be noted that the best land has already been taken.) The figures for the grainland area per capita, however, have been decreasing for the last several decades owing to the rapid increase in the world population (see *Figure 19*). Looking at the world grain production (see *Figure 20*) we find a similar tendency. Its total value is still increasing but is slowly leveling off. The variation with time of the per capita values is, however, somewhat different. The production per capita has been increasing slightly during the last decade, but around 1990 it began a downward trend.

There is also another aspect of the availability of land for agricultural production that is directly related to the problem of deforestation. A considerable portion (about 40% in 1980) of the tropical forests is being cleared to provide land for agricultural production to meet the demands of the rapidly growing population (see *Figure 21*). Indeed, this is one of the aspects which needs to be taken into account in the attempts to reduce or even reverse tropical deforestation.

8. Pollution and Toxification

In the early 1960s it became clear that the increasing use of chemicals in industrialized countries was causing environmental problems. Emissions of pollutants had become very visible and it had begun to be evident that they were responsible for damages to both aquatic and terrestrial ecosystems. The first harmful effects were identified at the single-species level. Through the rapid development of ecology at that time it was recognized, however, that the analysis of the impacts of the polluting chemicals must take into account the interaction between the various biological components at an ecosystem level. Somewhat later, following the recognition of the greenhouse, the acidification, and the ozone problems with their secondary effects, the magnitude and severity of chemical pollution was realized – requiring both national and international response actions.

It will not be possible here to discuss all the consequences of the innumerable chemicals that are now polluting the environment. There are, however, two aspects of this multifacet environmental issue that deserve special attention. One is concerned with the need for a more comprehensive picture of the flow of chemicals through the industrial economy and their point of entry

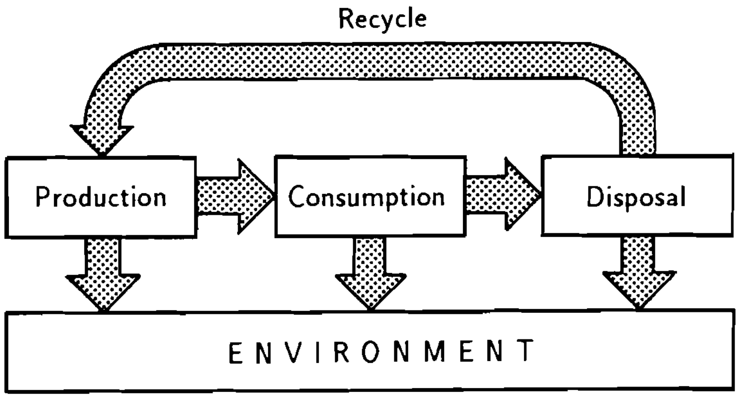


Figure 22. A schematic picture of the flow of chemicals through the industrial economy and points of exit to the environment. (Source: Stigliani, 1990).

into the environment. The other is concerned with recent research results indicating that ecological systems, which have accumulated chemicals for a long time, eventually become saturated and that this can lead to surprising environmental effects – the so-called *chemical time bomb* concept.

8.1 An emissions accounting system

To achieve a more systematic and efficient abatement of chemical pollution will require improved capability in tracing the sources of the emissions of the pollutants. An approach to achieve this is suggested by Stigliani (1990) which includes a) the establishment of an emissions accounting system of the stocks and flows of manufactured chemicals through the economy (see *Figure 22*), and b) the determination of the precise linkages between the flow of materials in society, and the points in this flow at which they are emitted to the environment.

For the establishment of such an accounting system (illustrated schematically in *Figure 23*) it is suggested that the following three emission-source categories are introduced:

(i) *Point-source emissions:* The emissions belonging to this category are usually highly concentrated and confined to specific locations. They include emissions from energy production and industrial emissions (sulfur, nitrogen oxides, heavy metals, polynuclear aromatic hydrocarbons, etc.). The limiting factor in diminishing industrial emissions is partially due to

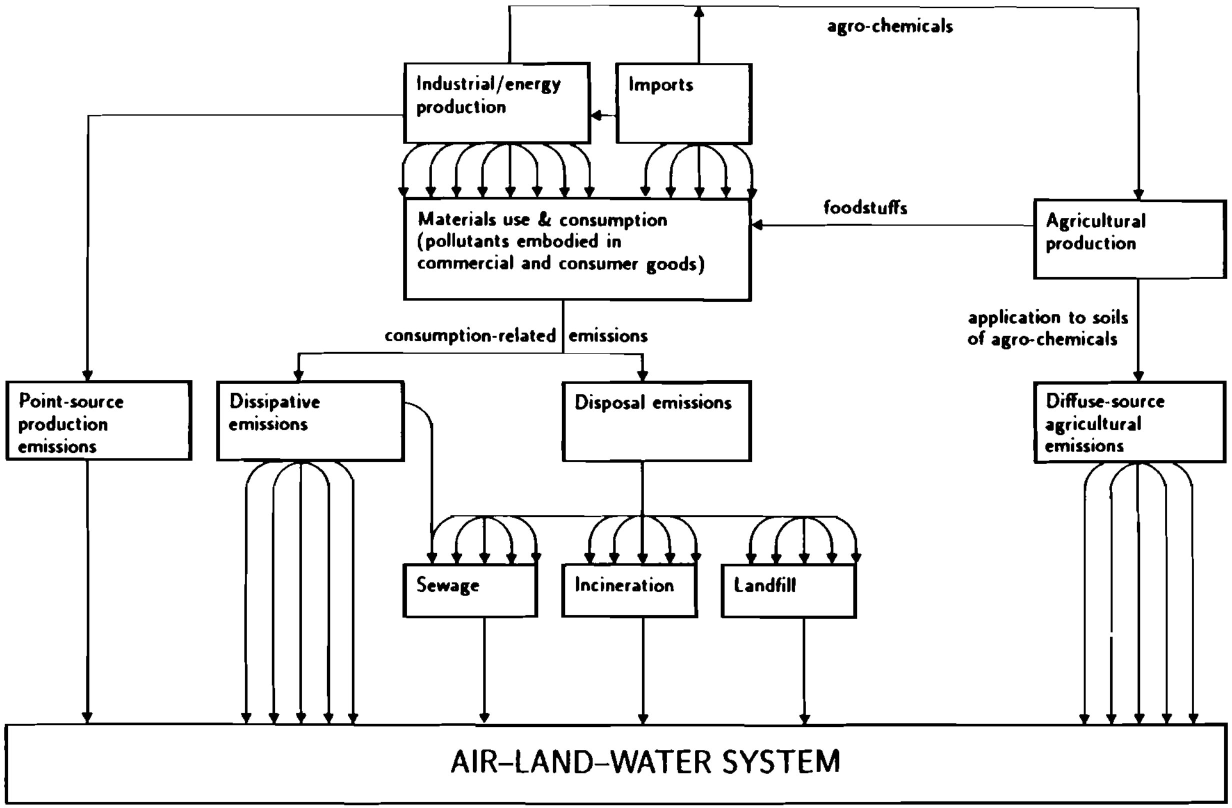


Figure 23. A schematic illustration of the pathways of the polluting chemicals before their entry into the environment, i.e., from point-source emissions, consumption-related emissions, and diffuse-source agricultural emissions. (Source: Stigliani, 1990.)

Table 7. Percentage of point source (P%)[a] and diffuse (D%) emissions in the Hudson-Raritan basin for some heavy metals, 1900, 1940, and 1980 (totals in metric tons).

	1900		1940		1980	
Chemical	Total	P%/D%	Total	P%/D%	Total	P%/D%
Arsenic	250	44/56	1,670	23/77	680	6/94
Cadmium	26	100/0	82	16/84	52	60/40
Chromium	700	64/36	1,590	10/90	880	16/84
Copper	730	72/28	1,400	38/62	1,120	28/72
Lead	1,680	95/5	12,200	17/83	9,640	1/99
Quicksilver	32	72/28	67	66/34	64	47/53
Zinc	1,780	18/82	8,650	6/94	7,870	2/98
Total	5,198	59/41	25,659	15/85	20,306	4/96

[a]P% includes point sources from industry and energy production.
Source: Adapted from Ayres *et al.*, 1988.

the lack of information about the generated wastes and partially due to technical and economic reasons.

(ii) *Diffuse source emissions* caused by agricultural production (synthetic chemicals in farm fertilizers and pesticides). These emissions are diffuse in nature and spatially dispersed, and their pathways are via runoff and erosion to surface waters, as well as seepage into groundwaters.

(iii) *Consumption related emissions* through dissipation and disposal. These emissions are concentrated in areas with high population density. They include chemicals occurring during the normal use of products, e.g., asbestos, lead from petrol, zinc from corrosion of paints and galvanized materials.

Studies carried out recently in the USA and in Western Europe (Ayres *et al.*, 1988, and Anderberg *et al.*, 1989) provide evidence that the point source emissions trend is on the decline, while the other two kinds of emissions have not declined appreciably.

As an example of this trend of decreasing point source emissions in relation to the diffuse source emissions *Table 7* gives the total values of emissions of seven heavy metals and the ratio of the emissions to diffuse agricultural diffusion in the Hudson-Raritan basin in 1900, 1940, and 1980.

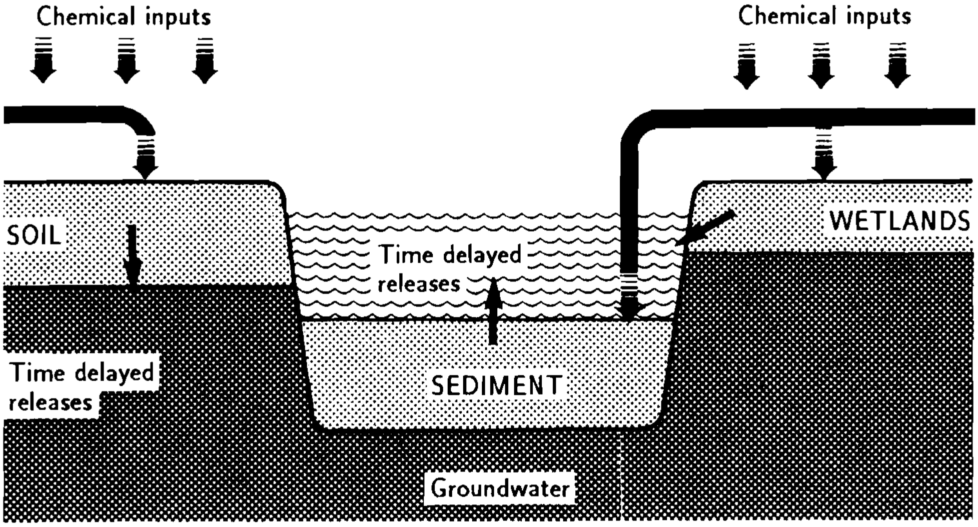


Figure 24. A schematic illustration of the pathways of chemical pollutants to ecological systems and the time-delayed releases, i.e., the *chemical time bomb* concept.

8.2 Chemical time bombs

In view of the amount of toxic chemicals (e.g., heavy metals, certain organic pesticides, and industrial chemicals) that have been widely dispersed in industrialized countries since the beginning of the industrial revolution it is remarkable that the contamination of the land–water systems (see *Figure 24*) has not caused more problems than have been experienced so far. A considerable part of the deposition of toxic heavy metals originates from sources several hundred kilometers away, illustrating the fact that contamination is not only confined to limited areas such as the vicinities of toxic waste dumps. They are emitted from stacks and are airborne before being removed by precipitation or dry deposition. About 5,000 tons of arsenic, 1,000 tons of cadmium, 85,000 tons of lead, and 45,000 tons of zinc enter and leave the atmosphere annually across Europe. Arsenic and cadmium are cancer producing, while lead has various other possible health impacts.

The reason why the harmful impacts from this substantial deposition of chemicals have so far been limited in extent is due to the fact that most ecosystems (e.g., soils, sediments, and wetlands) have the capability to store and immobilize toxic chemicals. The accumulation may occur over long

Table 8. Chemical/ecosystem interactions as potential time bombs.

Ecological system	Chemical stored	Threshold mechanism	Delayed effect
Forest soils	Acids (from deposition)	Depletion of buffering capacities	Acidification of soils and lakes; leaching of heavy metals
Agricultural soils	Phosphate fertilizer	Saturation of phosphate sorption capacities	Leaching of phosphate to aquatic systems (eutrophication)
Agricultural soils (abandoned)	Heavy metals (e.g., Cd)	Lowered sorption capacities on cessation of liming	Leaching of metals to water bodies; plant uptake
Coastal waters	[a]	Depletion of oxygen; generation of H_2S; mixing of deep water during storm events	Anoxia, fish kills
Estuary sediments	Heavy metals	Changes in redox potential; resuspension of sediments (sea level rise)	Release of metals; fish poisoning
Wetlands	Sulfur; heavy metals	Drying from climate change (causing exposure to air)	Release of sulfuric acid; heavy metals

[a]No chemicals stored *per se*, but "over-fertilization" of coastal waters from, for example, runoff of agricultural fertilizers can lead to sudden episodes of anoxia and H_2S generation.
Source: Stigliani *et al.*, 1989.

periods of time with little or no harmful environmental effects. However, any ecosystem has a limited capacity for storing chemicals. Consequently, sooner or later, and with very little warning, the ecosystem will have reached its maximum storage capacity and begins to leak, years or decades later. This will thus lead to a sudden and unexpected release of chemicals which can have devastating environmental effects (Stigliani 1988, 1991). Because the loading of the chemicals into the environment can occur long before effects are observed, the term *chemical time bomb* has been coined to describe such phenomena. In *Table 8*, six problem areas have been identified that may exhibit time bomb phenomena (Stigliani *et al.*, 1989).

The worst effects of chemical time bombs can probably be prevented, but only if countries choose to embark on an environmentally friendly pathway, which would include the following actions:

- Better early warning monitoring systems.
- Establishment of incidents registries, whose mission would be to record, analyze, and disseminate information on time bomb-like episodes.
- More rigorous standards for pre-market testing of potentially toxic substances.
- Establishment of source inventories and environmental pathways for each substance.
- Reductions in materials use through conservation and recycling.

9. Linkages Between the Various Environmental Problems and Other Global Issues

In this report it has been emphasized that the individual environmental problems are connected in a complex way and that this needs to be taken into account in the development of response actions to ensure environmental sustainability.

It is also true that the entire environmental issue is in turn linked with other issues which bear on global security and risk management. These include issues of population, technology, economics, and those of a political, humanitarian, and social nature.

Figure 25 illustrates some of the major factors arising from human development which are involved in global security. They include the driving forces such as population and life style which in turn includes technological development and social, political, and economic approaches to living. These driving forces have effects, in terms of greenhouse gas emissions, on both the natural environment and on the part of the environment that directly supports human life, especially food and the water supply. Disruption of these life support systems will have a destabilizing effect upon humanity leading to threats to economic, social, political, and military security.

Not only do the environmental changes themselves pose a threat to global security, but measures to forestall or ameliorate them, if improperly implemented, could also threaten world security. For example, if the developing countries perceive that measures to reduce the emissions of greenhouse gases will curtail their economic development, North-South tension will increase

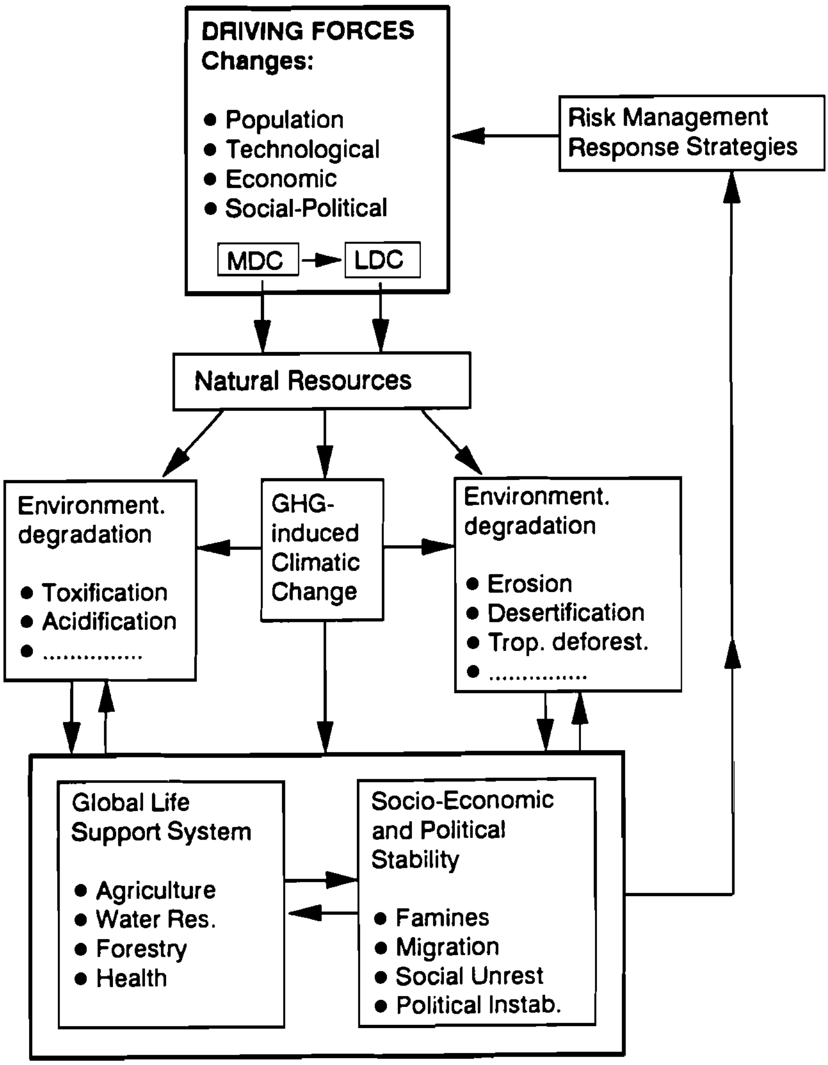


Figure 25. A simplified picture of the interaction between the major issues/system elements which bear on global security. Although all these elements are to a larger or lesser extent interconnected, they can be divided into three main categories: *Driving forces* – these include elements which basically can be considered to be targets for redirection, constraints or control. *Consequences* – these include elements which are being directly or indirectly influenced and may require the development of adjustment strategies. *Responses* – these include measures designed to modify the driving forces and thereby achieve global security.

and attempts to reduce climatic change and its consequences may well fail. Another example is that reforestation carried out to reduce the effects of climatic change may reduce the area of agricultural land and threaten food supplies.

It is essential, therefore, that the magnitude of the linkages among the various issues affecting global security be examined and an attempt made to quantify them, at least in an approximate way. The various feedbacks must also be examined in order that any measure taken to increase world security does not have an unexpected side-effect that in reality would decreases world security. It is also essential to establish the boundaries to human development that will ensure the security of food and water supplies.

A dedicated research effort aimed at studying such interactions between the various environmental problems and other global issues has been initiated at the International Institute for Applied Systems Analysis (IIASA) at the request of the Secretariat for the United Nations Conference on Environment and Development (UNCED). In very broad terms the conduct of the project will require:

- Examination and evaluation of the various forcing factors, such as technological and economic developments, as well as changes of the global population.
- Analysis of the linkages between the principal elements which bear on global security and risk management. The elements in question include those of an ecological, economic, humanitarian, social, political, and military nature.
- Identification of the outer limits or boundary conditions which may require that constraints or controls be placed on human activities that impinge upon these principal elements.
- Formulation of a series of practical proposals on improved and/or new measures to strengthen international cooperation in defining and monitoring global risks and controlling the human activities that give rise to them.

It would be pretentious and unrealistic to attempt to address all the relevant processes. It is important, however, that a framework is developed through which the most important linkages between the issues can be better understood. Initially efforts will be concentrated on the interactive processes which have a bearing on the future capacity of the global life support system and its possible shortcomings.

10. Is our Knowledge of Environmental Issues Sufficient to Take Response Measures?

No responsible scientist can claim that our present knowledge of environmental problems is complete, or even close to being complete. As a matter of fact, there is a tendency among scientists to emphasize the uncertainties of results caused by the need to introduce simplifying assumptions about the processes involved, and the incompleteness of observational information. Given this situation, it is no wonder that governments have had difficulties in recognizing how severe the individual threats to the environment are and how to assign priorities when dealing with them.

There is no doubt, however, that some progress has been made during the last few years. Both international organizations and some responsible governments have taken initiatives which aim at achieving an international scientific consensus about the major environmental problems and the implementation of response measures. In particular the role of the United Nations Environment Programme (UNEP) with regard to the ozone issue should be mentioned; this lead to the Montreal Protocol on Substances that Deplete the Ozone Layer, adopted in 1987 and sharpened in London in 1990 (see Section 5.3).

This, however, raises the question about why was it not possible to accomplish something similar at the Ministerial Conference following the Second World Climate Conference (SWCC, 1990b) on the greenhouse gas issue? It would be difficult to argue that the scientific base for this issue is less convincing than that for the ozone issue. Nevertheless, the results of this ministerial conference with representation from 137 countries was very meager indeed. In trying to answer this question of why nations have been able to respond so much more decisively with regard to the ozone issue as compared with the threat of a man-induced climatic change, one needs to take into account the fact that the CFCs are relatively easy to control. There are only a few manufacturers and alternatives can be found in most cases. The greenhouse-gas issue is more complex and response actions will require considerably larger financial commitments. It should also be recognized that the expected harmful health effects of an increase in UV radiation is taken more seriously by the public than a slow change of climate. Consequently, for the ozone issue, there exists a much more firm political base for decisive response action.

The *New Scientist* (Pearce, 1991) made the following comment: "Looking at the statement which followed [the Second World Climate Conference convened the week before] you would have thought the ministers had not even listened to the scientists". Maybe they did, maybe they didn't. But even if they did, the outcome of the ministerial conference would most likely not have given a more positive result in view of the fact that most of the position statements made by the governments had been prepared well in advance. No doubt it would have been more strategic to have the two conferences separated in time by at least a month.

As regards the acidification problem, it is interesting to note that, following several years of hesitation, at least in Europe, the nations have accepted that the scientific knowledge is sufficient for taking corrective action (see Sections 6.1 and 6.5). Following years of negotiations the European nations have agreed to reduce emissions of sulfur and nitrogen oxides. Agreements have thus been reached to lower these emissions according to the protocols of the UN Economic Commission for Europe Convention on Long-Range Transboundary Air Pollution. It is at the same time recognized that these commitments, in spite of the substantial cost involved (of the order of ten billion DM per year), are far from sufficient to stabilize the harmful effects of acid rain in Europe. The estimated costs for reducing sulfur dioxide alone is about four to six times as much. New initiatives are therefore being taken to explore the possibilities for further emission reduction, accepting that the present uniform percentage reduction by all signatory countries does not necessarily provide the most cost-effective strategy.

Returning to the basic question on whether it can be stated that our scientific knowledge is sufficient for taking response action with regard to the main environmental problems, a responsible answer may be summarized in the following way:

- Although it is impossible to state that we have complete knowledge of the main environmental problems and linkages between them, it is sufficient for taking action.
- If we wait until our knowledge has been significantly improved, too much valuable time would be lost. Improving our scientific understanding about the many processes involved is a very time-consuming process.
- It should also be recognized that even after a firm decision has been taken to reduce a threat to the environment, considerable time will elapse before there will be any significant effect (see, e.g., *Figure 9*).

- Some of the anthropogenically induced processes leading to the degradation of the environment will have irreversible effects, for example, the already ongoing extensive loss of biodiversity caused mainly (but not only) by deforestation.

In conclusion, we cannot expect to achieve complete international scientific consensus about the need for action. As expressed by Ullsten (1991), there will always be those who deny the environmental risks in their field. They may argue in the name of scientific prudence even when their real reason are short-term economic concerns.

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