Faculteit der Economische Wetenschappen en Econometrie

Serie Research Memoranda

Modelling Interactions between Economic Development and Environmental change: a Policy Life-cycle Interpretation

F. Brouwer
P. Nijkamp

Research Memorandum 1990-69
December 1990

vrije Universiteit amsterdam

1. INTRODUCTION

Human activities have always had an impact on the quantity and quality of (renewable and non-renewable) natural resources. Natural resources may include among others, surface water, groundwater, air, soil, forests, wetlands, grassland, and are therefore of considerable importance for production activities and economic development. The extraction and the use of such resources have often led to environmental degradation, not only in the past decades, but also in the long history of mankind. A city like London for example, suffered from air pollution problems already during the thirteenth century due to the burning of soft coal. Deforestation of land which was planned to be used for new settlements or agricultural development, has in many countries resulted in land degradation effects like soil erosion; this was already observed locally in several parts of Europe during the Middle Ages. Over the years, man was also able to undertake the cultivation of rural and natural areas, establish new urban centres, industries and infrastructural networks, and migrate to other places when these areas became degraded by human interference. This attitude of using natural resources without due regard to environmental implications and this simple adaptation and mitigation mechanism of leaving areas as they got degraded (the so-called 'cowboy economy'; see Boulding, 1966), is evidently nowadays causing conflicts in both society and environment. The intensity of conflicts is increasing because of:

- the rapid increase in population over the past two hundred years and the resulting increase in the demand for agricultural products, energy and other resources. World population increase was relatively low, and the total population was rather stable until the eighteenth century and then increased progressively until the 1970s, from about 900 million in 1800 to about 4,400 million people in 1980 (Grigg, 1987);
- an increasing part of the population that is living in urban areas, a situation which is among others due to the large-scale industrialization process of modern society. By the year 1920, about 100 million people lived in urban centres, which has increased tenfold to a present level of 1 billion. By the year 1940, about 1 per cent of the global population lived in cities of more than 1 million inhabitants, and by the year 1980 about 10 per cent of the global population lived in such cities. Largest increases have taken place in Third World countries (WCED, 1987);
- an increase in industrial development and the related need for improvements of services, infrastructure and communication networks, which does not only cause environmental pollution (e.g. of air, water and soil), but also leads to dramatic changes in landscapes; and
- a high pressure on land use caused by competitive uses, which leads to intensification of land use, and often results into soil degradation and a decline in ecological sustainability in general.

Modern society is therefore having a major interest in proper assessments and projections of the interactions between economic activities and environmental consequences, as well as of the extent to which environmental conditions may either provide opportunities or limits to (or control of) economic development. Various modelling efforts have been developed and explored over the past few decades to improve our quantitative insights into the links between economic activities and environmental impacts.

The major purpose of this paper is (i) to review the main trends from the past decades in assessing the interactions between (socio-economic) development and environmental changes, and (ii) to propose some strategic future research directions in this area. In so doing, we will use as a general frame of reference, the so-called policy life-cycle hypothesis, which takes for granted that the political interest in new issues passes through various phases, ranging from awareness and agenda formation to policy strategies, solutions, and management. On the basis of this policy life-cycle idea we will try to review some of the major development trends in environmental modelling. Our review of the major modelling efforts undertaken over the past few decades will then give due attention to the following elements during the life-cycle of environmental policies:

- the extent to which an integrative approach has been used to assess the interactions among economic-ecological phenomena in the past decades;
- the choice of major policy issues addressed during the course of environmental policy development (what is important; where, when and to whom are the issues relevant); and
- the way in which temporal and spatial components of environmental-economic problems are incorporated in the analysis during the successive stages of environmental policies.

Based on this review, we will discuss some important research issues. The interactions among economic development and environmental transformations and their impacts on society will no doubt show a global change over the next decades, and we will focus on two issues that are of utmost importance:

(1) the projected change in global climate and related environmental transformations due to an increase in atmospheric greenhouse gases (mainly carbon dioxide, nitrous oxide, methane chlorofluorocarbons, and ozone); and
(2) the projected rapid change in technologies, mainly in biotechnology as well as information technology (which might save water, material and energy in human activities like agriculture, energy production as well as in industrial processes and transportation, but may also pose new kinds of risks that are still unknown).

The potential impacts of such changes on society and the environment will be further explored for one component that is of major importance for the interactions between development and environmental change, viz. the use of land, because of its strong supply-demand (or similarly, environmental-economic) interactions. We will illustrate this assessment with a presentation of some plausible scenarios for land use changes in Europe, including changes in socio-economic conditions and environmental transformations.

2. THE POLICY LIFE-CYCLE HYPOTHESIS OF ECONOMIC DEVELOPMENT AND ENVIRONMENTAL CHANGE

The societal interests in the interactions between economic development and environmental change (as reflected by critical environmental issues in policy formulation and research agendas) are characterized by up-swing and down-swing trends over time. The period of the 1960's for example, showed a major emphasis in most of the developed countries on rapid economic growth, while this was followed in the 1970's with an increasing awareness of the environmental implications of such developments. This resulted into an increasing societal awareness of the deteriorating effects of rapid and uncontrolled economic growth on the environment. The Stockholm Conference in 1972 for example, was addressing the global pollution effects caused, among others, by the rapid growth of industry, energy consumption, and the increasing application of chemical fertilizers and pesticides in agriculture. It was also the period that the Limits to Growth Report was published, which stressed the limits of the supply side of natural resources, and of the oil-crisis, reducing the supply of oil to countries like the U.S.A. and The Netherlands for political reasons and causing a strong increase in the price of oil in a relatively short period.

The major societal interest in the environmental effects of economic development resulted in many countries in the establishment of Ministries of the Environment during the early 1970's as well as in the emergence and popularity of environmental sciences, initially starting as a cross-disciplinary approach (e.g., environmental economics), but increasingly maturing to a new discipline with however, major inputs from and numerous links to other disciplines, including among others, economics, ecology, chemistry, psychology, engineering, climatology, hydrology, and geography.

Fluctuations over time in societal interest and awareness of critical economic-environmental interactions can in principle be described by means of the so-called policy life-cycle hypothesis. This hypothesis has for the first time been explored in the area of environmental management by the former Minister of the Environment in The Netherlands (Winsemius, 1986). This hypothesis is rather similar to the well advanced product development cycle in industrial management and organisational processes. Research activities on environmental phenomena can be approached in a similar way by means of the policy life-cycle hypothesis (Zoeteman, 1987). The environmental policy life-cycle idea consists of four main stages of development:

(1) Recognition and awareness in society (from research, environmental groups in the country or from abroad) about the nature and extent of an environmental issue. By the end of the 1960s and the early 1970s, the emissions of pollutants were a major environmental issue, although their potentially important long-term and broad-scale impacts on the environment were still largely unknown. An example of the scientific uncertainty (until the early 1980s) regarding the extent and order of magnitude of a given environmental problem is acidification of soils and lakes, which is characterized by its transboundary nature and time-delayed responses because of the buffering capacity of the soils. This first stage

might therefore also show a considerable disagreement on the extent to which these issues are to be taken serious. Identification of new problems is the major scientific contribution at this stage of the life-cycle.

(2) Policy formulation, which is a period characterised by an increasing consensus on the order of magnitude and seriousness of the issue and a growing political attention to formulate policies, and goals to aim at. This stage of policy formulation is therefore generally being supported by major scientific efforts, collecting information and installation of monitoring networks exploring the direction of solutions and policy options that are still available or might already be foreclosed, and assessing the costs to various parts of society (industry, consumers, and government). The analysis of major processes contributing to the problem is then the major scientific contribution to the exploration and formulation of policies.

(3) Policy implementation of proposed solutions for the issues. Although there might still be large scientific uncertainties on the extent of seriousness of the issue, there is a general consensus on the kind of policies and technical solution required. This stage is based on major efforts in policy implementation, including the introduction and implementation of revised standards, which might also require new technologies for achieving such goals. Simulation of the problem, including assessments of consequences of alternative development trends as well as a social cost-benefit or multi-objective analysis on formulated policies, are the major scientific contributions at this stage.

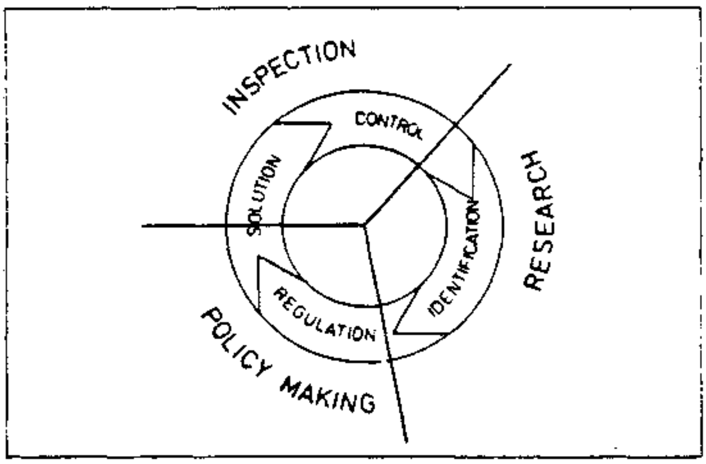

Figure 1. The contribution of research to the policy life-cycle (Source: Zoeteman, 1987)

(4) Management and control of the implemented policies, and control of environmental quality. This stage of the policy-life cycle would include the development of proper monitoring programs with advanced data processing and data presentation to enable management and control of environmental policies. In Europe, for example, a monitoring program was established by the United Nations Economic Commission of Europe (ECE) to collect information on among others, sulphur and nitrogen related emissions. Its objective is to monitor and evaluate the long-range transmissions of air pollutants in Europe. This monitoring program (called EMEP) covers most of the European countries.

Figure 1 shows an outline of the policy life-cycle hypothesis and the contribution of research achievements to policy making.

Some remarks on the societal interest of environmental-economic interfaces, and the changing role of scientific efforts during the various stages are in order here:

- First, the societal responses of environmental issues (in terms of a growing political awareness, formulation and implementation of policies and their management) do of course not necessarily fit completely in the four stages of the policy life-cycle; neither does each of the stages described follow smoothly a sequential order. The policy life-cycle approach is however considered to be a useful frame of reference to describe the various stages of development before environmental policies are implemented and the issues can be managed effectively.
- Second, the first stage is generally affected by achievements from scientific efforts, while the remaining stages will be supported by them as well. So, the importance and use of scientific assessments is not foreseen to be terminated at a certain stage, but should rather support the formulation of policies, and explore ways to implement policies and assess the effects of policy alternatives in a most effective and efficient way; in addition, they could also affect the priorities for monitoring (e.g., what should be measured, and where should the stations be placed). The scientific focus however will change during the various stages from the collection of information and state-of-the-art assessments to research on the management of these issues. The monitoring priorities for example, are to be based on an evaluation of their effectiveness and efficiency, since it incorporates decisions on what should be measured (in terms of achieving an optimal level of effectiveness) and where to place such measurement stations (in an efficient and effective way). Efficiency and effectiveness are both critical in monitoring programs since they do not only require to measure the items right (be efficient), but also to measure the right items (and be effective). An environmental issue could be managed efficiently, without reaching a level of effective management. Both considerations therefore require substantial scientific support.
- Third, the interactions between (socio-economic) development and environmental change may sometimes not attract the policy attention it deserves, and there are several principal reasons why this could be (Davies, 1987):

(a) the issue is difficult to understand since it involves the consideration of complex ecological factors as well as long-term and broad-scale impacts on society which are hard to understand. So, policies may have to be formulated and implemented based on much scientific debate and uncertainty of their potential impacts (on the environment), and also characterized by great uncertainty on the possible societal response to adaptation and mitigation; and

(b) there might be many political and administrative constraints on policy formulation and implementation, arising from national or local governments and supra-national authorities.

Such a mismatch of political attention in relation to the seriousness of environmental issues may largely affect the various stages of the policy life-cycle.

Nevertheless, the policy-life phenomenon provides an interesting frame of reference for understanding and interpreting the changing role of environmental research, so that it offers a testable analysis framework. In the following section we will hence try to summarize major environmental-economic modelling achievements in terms of both policy issues and fluctuating trends of societal interest in addressing such issues.

3. MODELLING ACHIEVEMENTS OVER THE PAST TWO DECADES

3.1 Introduction

Research efforts and political interests in environmental issues are closely related to each other, as was already emphasized in the previous section when discussing their main stages starting from awareness to management and control of a problem. The need to formulate environmental policies for example, certainly requires to be supported by research efforts, while the results from scientific achievements may also directly and indirectly influence the process of policy formulation and decision-making. The various stages in research directions on the interface between development and environmental change over the past few decades can be summarized as follows:

- a first stage that is merely addressing one-cause one-effect assessments; and
- a second stage that is addressing one-cause multiple-effects assessments.

3.2 The first development stage: one-cause one-effect assessments

The major recognition and environmental awareness from the late sixties were addressing the environmental impacts of socio-economic activities at a regional or national scale, including the impacts of industrial development and transportation (in terms of air pollution and noise) or the impacts of agricultural activities (in terms of leaching of phosphorus, and eutrophication of rivers and lakes).

The first attempts at environmental modelling in relation to economic development originate from that period when among others Isard and Leontief developed an input-output model to link the emissions of pollutants to the economic production sectors (see also Isard, 1968). This model could be seen as a single cause-effect regional assessment, such that the impacts of changing production levels (industry as the single sector) on the emissions (with fixed technical coefficients to link them to industrial activities) could be measured.

This first period of modelling efforts on the interface between development and environmental change was also influenced by an increasing awareness and recognition in society of the deteriorating effects of accelerating and unmanaged economic growth during the end of the 1960s.

The impacts of industrial development on the environment reached the stage of policy formulation by the early seventies, with policies implemented in many developed countries during the late seventies and early 1980s, while it is by the late 1980s reaching a stage of management and control through the numerous monitoring programs that measure amongst others emissions of sulphur and nitrogen oxides. This already indicates that it took approximately a 20 year period from societal awareness to a stage that policies enable the management and control of the issue concerned.

A similar example of a single cause-effect assessment concerns the environmental impacts of agricultural activities (such as the leaching of nutrients in soils and surface water). The application of chemical fertilizers and pesticides in agriculture increased rapidly after the 1950s, with nitrogen for example, affecting groundwater quality. The first modelling assessments on the environmental deterioration effects were prepared during the 1970s focusing on the impacts on water quality. One of the modelling achievements for example, was a multi-objective control assessment of phosphorus loadings in lakes (Duckstein et al., 1982), linking agricultural activities (in terms of the amount of phosphorus applied as a chemical fertilizer) and the resulting phosphorus loadings in water. Such assessments are aimed to achieve a balance between agricultural development and phosphorus loads in water. The late 1980s show the initialization of several monitoring programs on the environmental hazards in agriculture, and presently policies are formulated and implemented to reduce such hazards in terms of future land use planning (Brink, 1988).

3.3 The second development stage: one-cause multiple-effects assessments

As discussed in the section 3.2, the first stage of modelling environmental-economic phenomena was mainly focussing on one-cause and single-effect assessments. The 1970s however, showed an increasing need to include more complex issues in assessing interactions between development and environment. This trend was also reflected by an increasing recognition and awareness in society (the first stage of the policy life-cycle hypothesis). The formulation of environmental policies was also increasingly becoming important during that time, with a particular view on the miltidimensional nature of such problems (leading also to the popularity of multicriteria analysis; see Nijkamp, 1981).

An assessment of the management of water for the Netherlands may clarify the progress and present state of one-cause multiple-effects on environmental problems. A policy-oriented analysis on the management of available water resources in the Netherlands was completed by the early 1980s (Goeller et al., 1983). The overall objectives of this study called PAWN (Policy Analysis of Water Management for the Netherlands) were twofold:

(1) First, the development of a methodology to assess multiple consequences of water management policies.
(2) Second, the application of such a methodology in order to explore a set of water management alternatives on a national basis.

Linkages between water supply factors and socio-economic activities which require water are depicted in Figure 2.

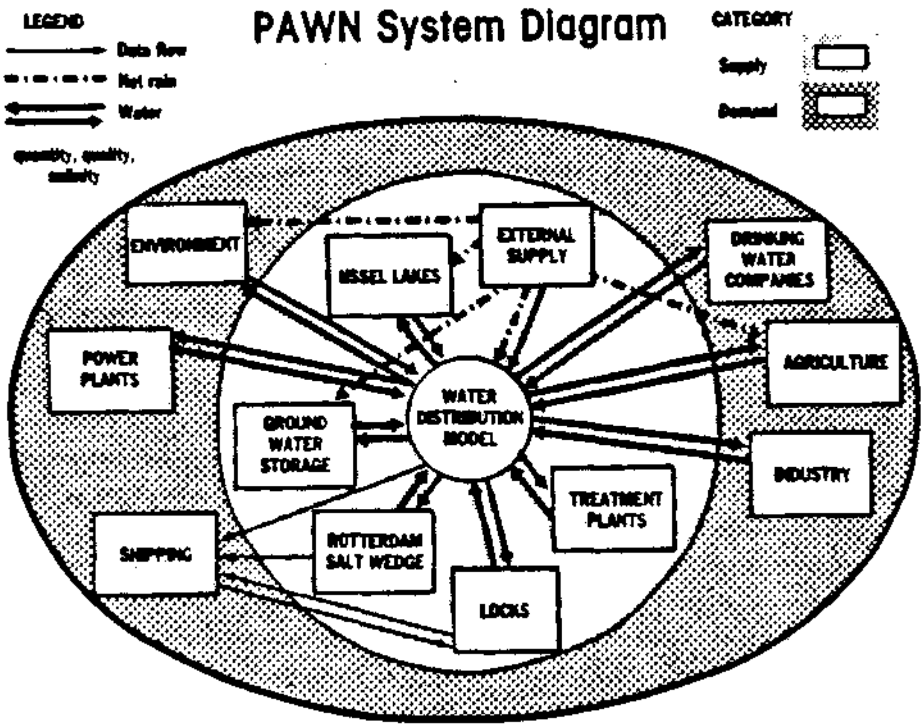

Figure 2. PAWN-system diagram (Source: Goeller et al., 1983)

The supply/demand balance of available water at a national basis is closely linked to a set of economic activities including among others water required for human consumption, industrial activities, agriculture, power plants and shipping. This supply/demand balance is then simulated on an annual basis with 36 periods of ten days, whilst supply/demand factors are distributed among 77 regions of the country.

Impacts of several water management policies are investigated in this model such as, for example, the losses (in monetary terms) to agriculture and shipping because of water shortages and/or water quality affected by salinization and eutrophication.

A detailed policy analysis for water management such as the one-cause multiple-effects assessment presented here is still difficult due to (i) the complexity of the system reflected also in the various scenario alternatives, and (ii) the uncertainty on the functioning of the system because of incomplete knowledge. It also shows that policy decisions on complex environmental issues such as the management and distribution of available water might only be based on incomplete scientific knowledge.

4. STRUCTURAL CHANGES IN ECONOMIC DEVELOPMENT AND ENVIRONMENTAL TRANSFORMATION

4.1 Introduction

Most assessments and projections of interactions between economic development and environmental change which have been undertaken over the past decades focussed on the regional or national scale, and covered a time horizon of one or two decades (see also Brouwer, 1987 for a state-of-the-art review of integrated environmental modelling). The question then remains whether such time and space scales are appropriate for emerging environmental issues that are observed on a global or continental scale, or for development trends that are of transboundary nature.

Major scientific improvements have been achieved over the past few decades in modelling the complex interactions between development and the environment. The scientific and policy focus followed relatively smoothly the four stages of the policy life-cycle from the identification to the control of environmental problems. Present trends in development (population, energy consumption, agriculture, forestry, as well as industry and transportation) and major societal transformations within the next few decades might of course induce a new policy life cycle of environmental issues not yet sufficiently explored until now.

Major transformations which are projected within the next few decades might initiate such a new policy life-cycle of environmental issues. "First, new technologies will transform the relationship of man to the natural world... The second major change differentiating tomorrow's world from today's is climatic change. Third,..., society enters an era of increasingly complex patterns of interdependence of the global economy and the world environment." (Stigliani et al., 1989).

Because of the invreasing interwovenness of economic development trends and environmental transformations (reflected in particular major improvements in technologies and in the global scale of climatic change), one might envisage a new cycle of interactions between development and the environment. In the following twe sections we will explore the importance of the two issues of climatic and technological evolution in more detail.

4.2 A scenario of projected climatic change in Europe

Various investigations have shown that a shift of climate is likely to occur on a global scale due to increased atmospheric concentrations of carbon dioxide and other greenhouse gases. For instance, the last 100 years have shown an increase in the global mean temperature in the range of 0.3 and 0.7°C. Recent estimates from simulation experiments with general circulation models for exemple, suggest a global mean temperature increase of between 1.5 and 4.5°C. However, the magnitude and order of variation as well as the changes over the seasons will vary with latitude. One of the additional characteristics of the changing climate is most likely the increasing frequency of extreme events. As an illustration it may suffice to mention that soil moisture (a critical characteristic for the availability of plants to grow)

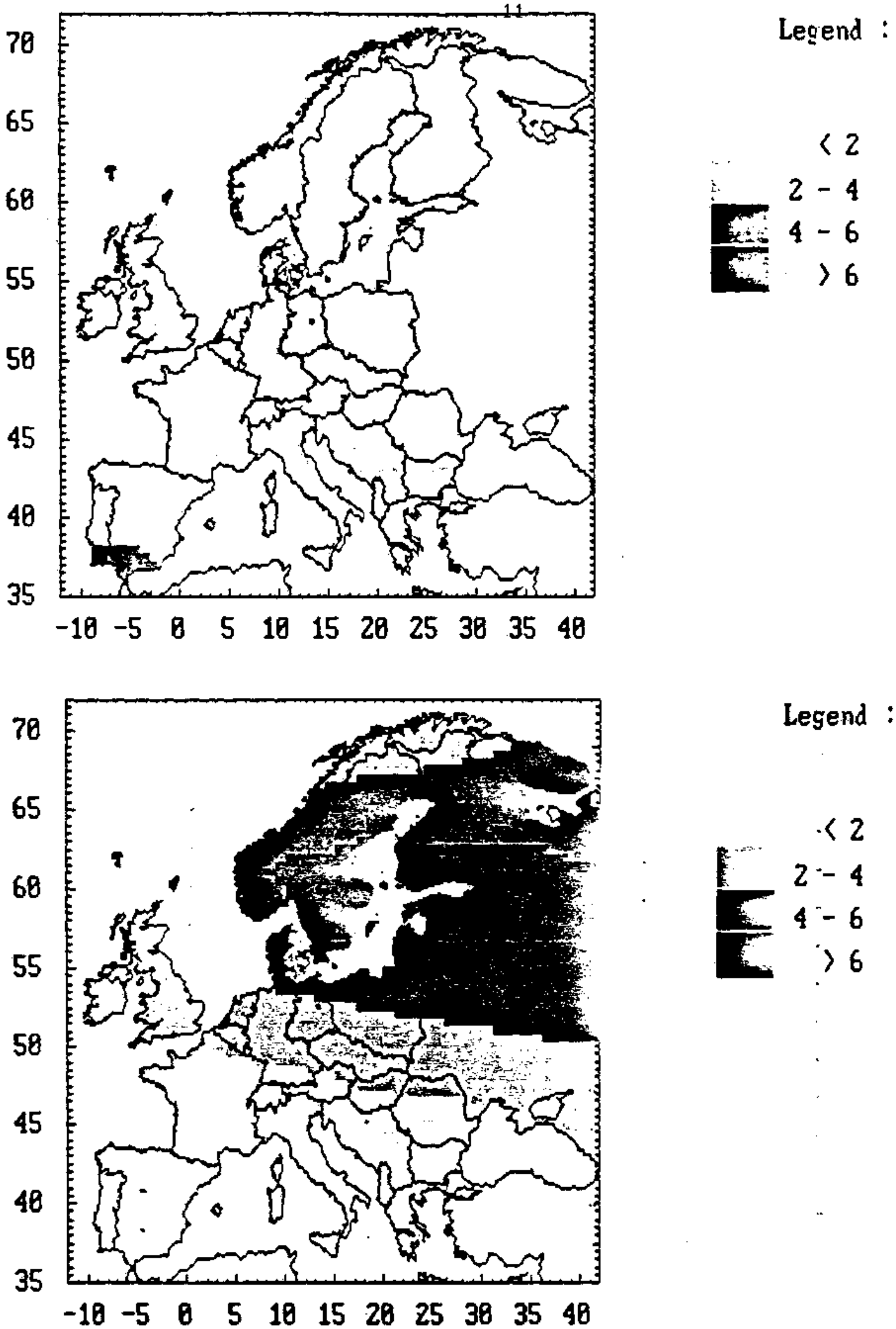

Figure 3. Projected changes of temperature in summer (top) and in winter (bottom) (in °C)

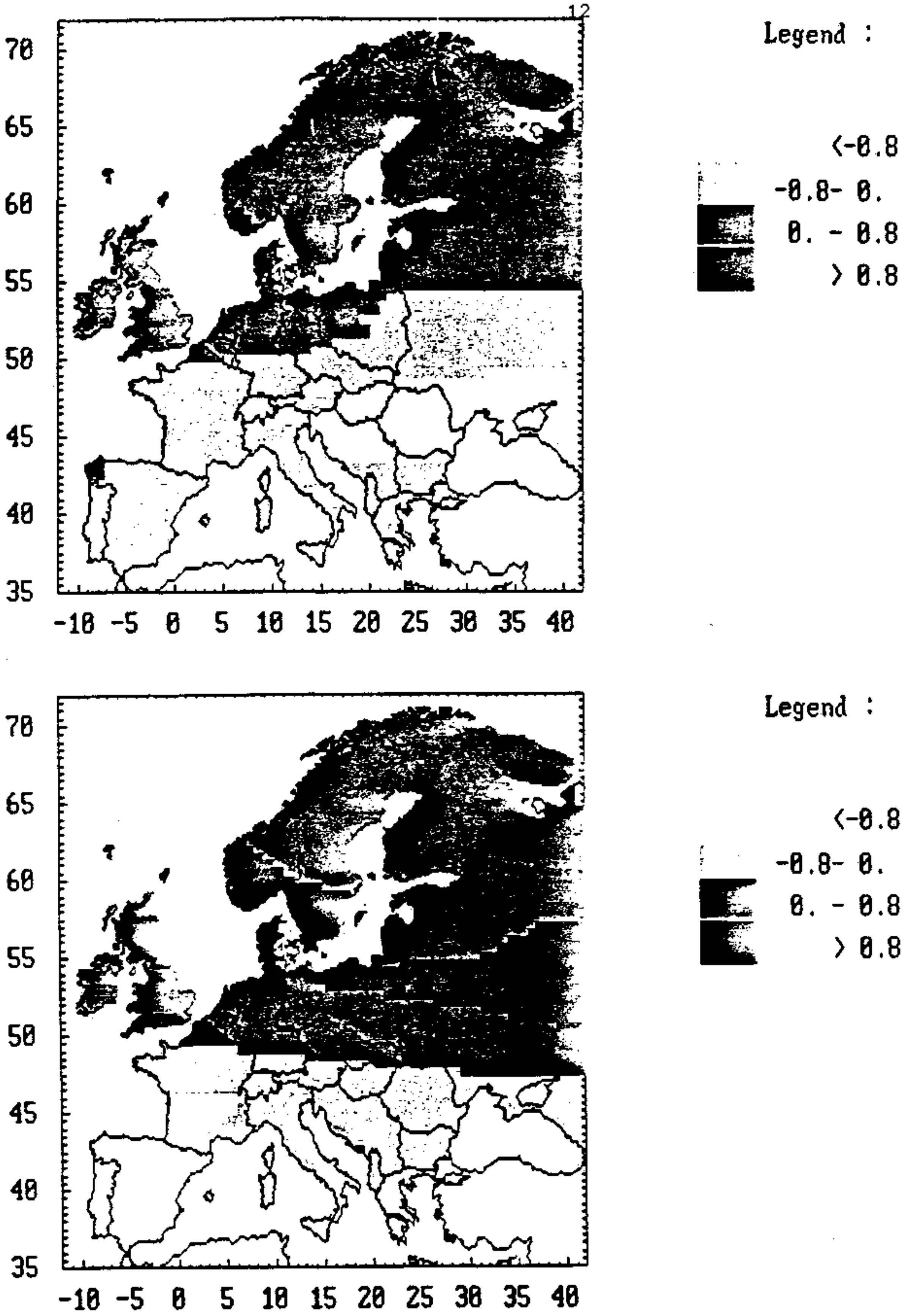

Figure 4. Projected changes of precipitation in summer (top) and in winter (bottom) (in mm/day)

during summer in the Mediterranean region may decrease by between 20% and 50% (Manabe and Wetherald, 1986). Soil wetness may however increase over large regions of Europe, particularly in middle and high latitudes. The occurrence of large amounts of soil moisture deficits will likely make water availability one of the major factors that are critical to the productivity of the land for agriculture and forestry.

Figures 3 and 4 depict a possible scenario for average seasonal temperature and precipitation changes in Europe, based on the consideration that atmospheric concentrations of CO_2 are double of present levels (Mitchell, 1983). A doubling of carbon dioxide concentrations compared to the pre-industrial levels may occur before the middle of the next century. This will however largely depend on development trends for energy consumption, as well as on the selection of the major fuel types. Energy consumption patterns as part of a development path which is based on the "business as usual" consideration will largely differ from an economic development path with moderate growth and major environmental concern.

Figure 3 shows projected changes of temperature (in °C) in summer and winter. Temperature changes are higher in southern Europe in summer, with an increase of more than 2°C, but higher in northern Europe in the winter period with an increase of over 6°C in some parts. Summer and winter scenarios (Figure 4) project an increased precipitation over the northern half of Europe, and less precipitation over much of southern Europe.

Such a scenario of climatic change will have a major impact on society. First, it will cause a global rise in the sea level; the areas that are most at risk are the coastal zones with important industrial and transportation facilities, with large urban zones and highly productive agricultural land (Hekstra, 1988). Also, the amount of water that is available for socio-economic activities (e.g. agriculture, urban consumption, waste water disposal) might change considerably both under wetter and drier conditions. (Brouwer and Falkenmark (1989) have examined the water availability changes in Europe as seen from the perspective of climatic change.) Agricultural activities might change drastically in response to such changes in global climate. There is clearly a potential in Europe for the northern crop boundaries to shift 5-7° in a northerly direction, and an associated limitation on crop growth in parts of the Mediterranean with the southerly boundary shifting 3-5° north. Large areas of land hitherto devoted to forestry (the northern boreal forests) would be able to be cleared for the cultivation of crops such as sugar beet, winter wheat, spring barley and potatoes (see also Figure 5).

While agricultural zones may shift due to a climatic change, it is also necessary to consider limitations on productivity resulting from soil degradation (due to erosion, salinization and loss of fertility) and adverse pollution loads.

In addition to the projected change in temperature and precipitation, various climate change scenarios take also for granted a resulting annual sea level rise of approximately 0.5 to 1 cm over the next several decades. This is especially important for salt intrusion (and its deterioration effects on soils and groundwater) in the coastal lowlands of Western Europe (The Netherlands, Belgium and France), and the Mediterranean coastal areas (Italy and Spain). One could imagine that the order of magnitude of scientific uncertainty as reflected here with

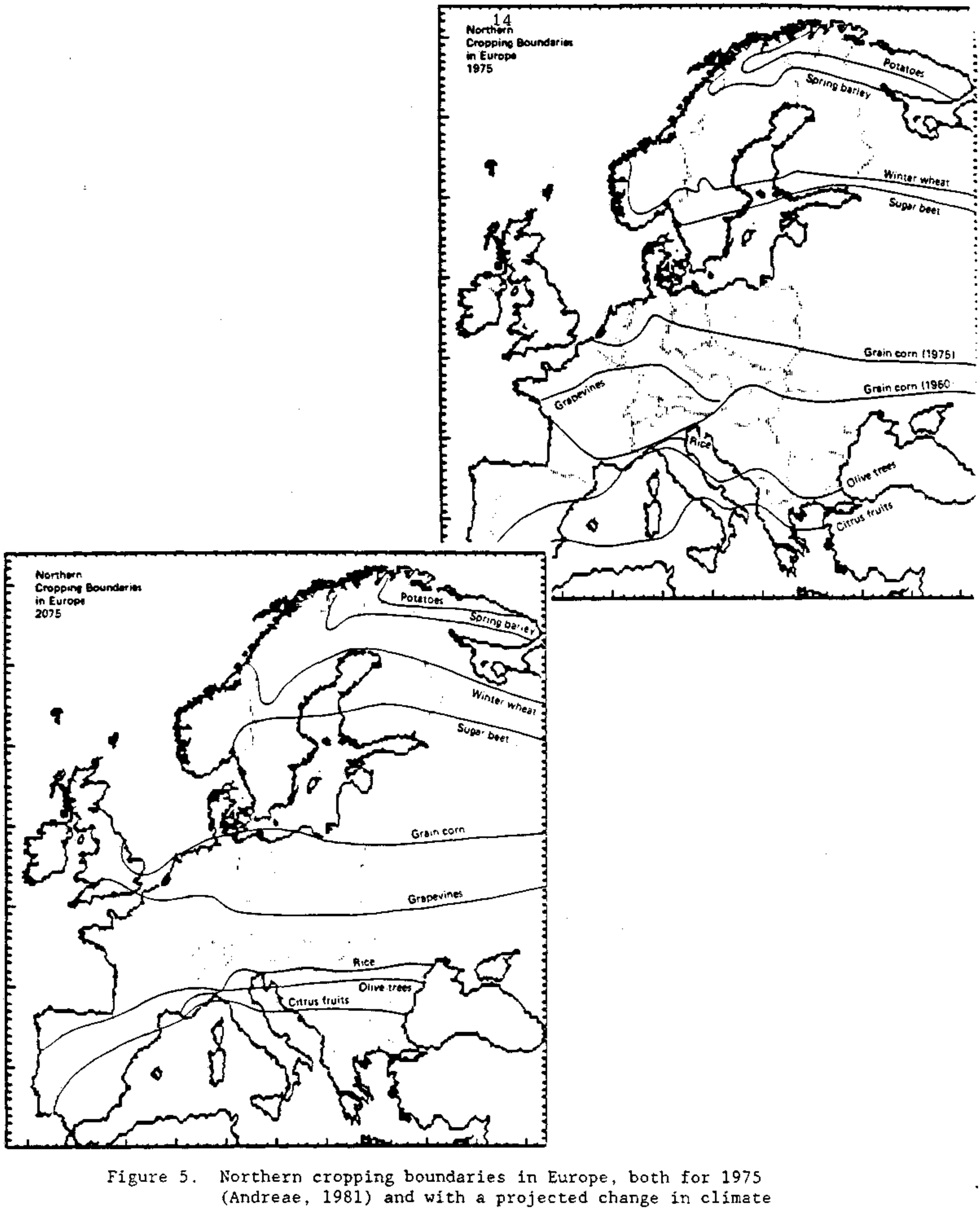

Figure 5. Northern cropping boundaries in Europe, both for 1975 (Andreae, 1981) and with a projected change in climate (Brouwer and Chadwick, 1988)

respect to the projected sea level rise (scenarios giving increases ranging from 40 and 160 cm), will raise serious difficulties in selecting and implementing proper policies for coastal protection, and even more so when the projected increase in the occurrence of extreme events (such as flooding) should also be taken into account.

4.3 New technologies

As a concise second illustration we will discuss technological progress in relation to land use (see also Nijkamp and Soeteman, 1988). Technological advances are important for land use changes as they may induce shifts in the critical limits for a range of crops currently used in European agriculture. The technological boundary of grain corn for example, has shifted its northern boundary by approximately 5° latitude in the past 25 years due to the selection by plant breeders, and yield varieties that can produce economic yields under shorter growing seasons.

Figure 5 shows the northern cropping boundaries both under present conditions and a scenario of climatic change. The major shift to the north of grain corn that has taken place between 1960 and 1975 was due to technological advances.

Progress in new technologies (biotechnology and information-technology) within the next decades could result in major shifts in continental land use patterns. A recent OTA report (OTA, 1985) made an assessment of annual production increase in agriculture both with present technologies and with wide application of new technologies. Annual production increase in the USA with present technologies is assessed to be 1%, which could be as much as 2% with new technologies. These two scenarios would have major implications for continental land use policies and options that would be available for the land that is foreseen to be set aside (e.g., use of agricultural land in a less intensive way, reforestation, production of cereals for bioethanol, and use for recreation purposes).

From a research perspective, the question emerges whether such drastic changes will contribute to an ecologically sustainable economic development, or whether such developments will do harm to the ecological basis of our society and hence in the long run also to economic development. Political and scientific awareness seems to be of critical importance here.

5. CONCLUSIONS

Environmental issues are gaining increasing importance in regional and national planning purposes, not only in terms of the formulation of environmental policies (e.g., the polluter pays, or the bubble concept), but also in exploring available options in order to prevent environmental deterioration effects of human activities and implement abatement policies where possible.

Environmental problems are moving away from relatively simple problems which are primarily affecting local scales, towards topics that are of major importance for whole continents or even the entire globe. The emergence of such a new series of environmental issues could also be reflected in terms of a new wave of the policy life-cycle hypothesis. Several of such issues are presently still in an exploratory phase to get a better understanding of their nature and order of magnitude of extent (e.g., depletion of the ozone layer, and the projected global warming). These issues will certainly require a series of global policies for abatement (such as the Montreal Protocol from 1988, which is a global convention on the reduction of the use of CFCs).

A new wave of the policy life-cycle with environmental issues that show impacts at a continental/global scale and might only be manifested in the 21st century, is also going to be supported by major scientific efforts at the interface between economic development trends and environmental change. Several initiatives are already underway (e.g., the International Geosphere Biosphere Program, and the International Federation of Institutes for Advanced Study). Major scientific achievements are to be foreseen within the next decade or two in order to formulate proper policies dealing with the broad-scale and long-term nature of environmental changes, based on strategic long-term environmental models.

REFERENCES

Andreae, B. (1981),
Farming, Development and Space,
Gruyter, Berlin.

Boulding, K.E. (1966),
The economics of the coming spaceship earth,
In H. Jarrett (ed.), Environmental Quality in a Growing Economy,
The John Hopkins Press, Baltimore, pp. 3-14.

Brink, N. (1988),
Research and monitoring on environmental hazards in agriculture,
paper presented at the IIASA Workshop on Land Use Changes in Europe,
Warsaw, Poland, September 5-9.

Brouwer, F. (1987),
Integrated Environmental Modelling: Design and Tools,
Kluwer Academic Publishers, Dordrecht.

Brouwer, F. and M. Chadwick (1988),
Future land use patterns in Europe,
Working Paper WP-88-040,
International Institute for Applied Systems Analysis,
Laxenburg, Austria.

Brouwer, F. and M. Falkenmark (1989),
Climate-induced water availability changes in Europe,
Environmental Monitoring and Assessment, 13, pp. 75-98.

Davies, B. (1987),
The practicalities of policy solutions,
In A. Chisholm and R. Dumsday (eds.),
Land Degradation: Problems and Policies,
Cambridge University Press, Cambridge, pp. 335-340.

Duckstein, L., Bogardi, I. and David, L. (1982),
Dual objective control of nutrient loading into a lake,
Water Resources Bulletin, volume 18 (1), pp. 21-26.

Goeller, B.F. et al. (1983),
Policy analysis of water management for the Netherlands,
Volume 1: Summary Report, R-2500/1-Neth,
Rand Corporation, Santa Monica.

Grigg, D. (1987),
The industrial revolution and land transformation,
In M.G. Wolman and F.G.A. Fournier (eds.),
Land Transformation in Agriculture,
SCOPE 32, John Wiley, New York, pp. 79-109.

Hekstra, G.P. (1988),
Climatic change and land use impact in Europe,
Paper presented at the IIASA Workshop on Land Use Changes in Europe, September 5-9, 1988, Warsaw, Poland.

Isard, W. (1968),
On the linkage of socio-economic and ecologic systems,
Papers of the Regional Science Association, vol. 21, pp. 79-99.

Manabe, S. and Wetherald, R.T. (1986),
Reduction in summer soil wetness induced by an increase in atmospheric carbon dioxide,
Science, vol. 232, pp. 626-628.

Mitchell, J.F.B. (1983),
The seasonal response of a general circulation model to changes in CO_2 and sea temperature,
Quarterly Journal Royal Meteorological Society, vol. 109, pp. 113-152.

Nijkamp, P. (1981),
Environmental Policy Analysis,
Wiley, New York, 1981.

Nijkamp, P. and F. Soeteman (1988),
Land Use, Economy and Ecology,
Futures, December 1988, pp. 621-634.

OTA (Office of Technology Assessment) (1985),
Technology, public policy and the changing structure of American agriculture,
OTA Report, Washington, D.C.

Stigliani, W.M., Brouwer, F.M., Munn, R.E., Shaw, R.W. and Antonovsky, M. (1989),
Future environments for Europe: some implications of alternative development paths,
The Science of the Total Environment, vol. 80 (1), pp. 1-102.

WCED (World Commission on Environment and Development) (1987),
Our Common Future,
Oxford University Press, Oxford.

Winsemius, P. (1986),
Gast in eigen huis: beschouwingen over milieumanagement,
Samson H.D. Tjeenk Willink, Alphen aan de Rijn (in Dutch).

Zoeteman, B.C.J. (1987),
Soil pollution: an appeal for a new awareness of earth's intoxication,
In W. van Duijvenboden and H.G. Waegeningh (eds.),
Vulnerability of Soil and Groundwater to Pollutants,
Proceedings and Information Vol. 38,
TNO Committee on Hydrological Research, pp. 17-27.