SCENARIOS OF SOCIOECONOMIC DEVELOPMENT FOR STUDIES OF GLOBAL ENVIRONMENTAL CHANGE: A CRITICAL REVIEW

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Foreword

The Environment Program is devoted to investigating the interaction of human development activities and the environment. Its research is policy-oriented, interdisciplinary, international in scope, and heavily dependent upon collaboration with an external network of research scientists/institutes. The Program encompasses long time-horizons and large space-scales, and assumes that environmental discontinuities and surprises will happen.

An increasing number of international efforts explore various aspects of development-environment interactions under the common theme "Global Change." Some of the organizations involved in this research are: the International Geosphere-Biosphere Programme (IGBP), whose objective is to describe and understand the interacting physical, chemical, and biological processes that regulate the total Earth system; the Intergovernmental Panel on Climate Change (IPCC), which is responsible for organizing internationally agreed assessments of climatic change and the range of policy responses for limiting and adapting to climatic change; the World Climate Conference (WCC), which is aimed at providing a comprehensive account of the present state of knowledge (1990) on climatic change and variability and their impacts on natural and human ecosystems.

All these activities need scenarios of long-term, large-scale socioeconomic development as inputs to drive their environmental impact studies. I believe this document is a valuable compilation of analyses and source material that should serve as useful input to those studies.

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Leader
Environment Program

Preface

The problems of long-term, large-scale interactions between human activities and the environment have received increasing attention in recent years. The underlying natural science is being explored by the International Geosphere-Biosphere Programme and related national efforts (e.g., ICSU, 1988). Scholarship on the question of environmentally sustainable human development is advancing on many fronts (e.g., Clark and Munn, 1986). The policy debate is becoming more serious and significant (e.g., WCED, 1987).

Common to all these efforts is a need for *scenarios* of human development to use as reference cases in exploring the possible environmental implications of alternative patterns of future socioeconomic activity. Many modeling exercises and scenario-building efforts have been conducted that are of some use in meeting this need. Three difficulties nonetheless persist:

(1) Many existing efforts focus on single sectors (e.g., the UN Population projections) or single environmental variables (e.g., scenarios of chlorofluorocarbon production). Combining such sectoral studies for more broadly based scenarios of global change can easily lead to internal inconsistencies.

(2) Virtually all existing efforts are "surprise-free," devoid of the wars, depressions, plagues, and other "breakpoints" that have so influenced history.

(3) Despite the large amount of criticism that has been leveled at existing global scenarios of human development no critical literature has developed to help potential users apply these inevitably imperfect tools with a sophisticated awareness of their comparative advantages and pitfalls.

This study is an initial attempt to begin addressing some of these shortcomings. In brief, it:

(1) Critically *reviews* existing studies of global trends in population, agriculture, and energy with a view toward showing which studies are most useful for which sorts of studies of global environmental change and sustainable development.

(2) *Synthesizes* a single, internally consistent scenario of global changes in population, agriculture, and energy over the next century for use as a "conventional wisdom" reference case for such studies.

(3) *Creates* a number of "surprise-rich" scenarios of world development for use in exploring unconventional, but not impossible, patterns of human activities that might be useful for exploring the outer limits of global environmental change.

The work reported here was carried out as part of the project on Sustainable Development of the Biosphere at the International Institute for Applied Systems Analysis. The critical review of existing studies was begun as a study involving 18 visiting graduate students and project staff in the summer of 1985. Separate study teams reviewed the major modeling and forecasting studies available at the time, and sought to characterize their relative strengths and weaknesses for use in research and policy analyses of global environmental change. The synthetic effort was led by S. Anderberg of University of Lund and involved a number of other project collaborators. A condensed version of the results reported here has appeared in Darmstadter et al. (1987). Finally, the surprise-rich scenarios summarized here were initiated as part of a major study conducted with the Swedish Council for Planning and Coordiation of Research. An extended account of that study has been published as Svedin and Aniansson (1987). Since our original selection of models for review in 1985, several additional studies of global trends in population, agriculture, and energy have appeared.* By and large, however, these are merely updates of the studies reviewed here; their inclusion would not significantly alter our conclusions.

The results of IIASA's preliminary review of global change scenarios are presented here in some detail, in the hope that they may provide useful source material for the many groups around the world now formulating their own research and policy assessments of global change.

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WCED (UN World Commission on Environment and Development; the "Brundtland Commission"). 1987. Our common future. New York: Oxford University Press.

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* For example:
Alexandratos, Nikos (ed.). 1988. World agriculture: towards 2000. An FAO study. London: Belhaven Press.
United Nations. 1988. World demographic estimates and projections, 1950–2025. New York: United Nations.
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This report is a result of a joint effort by a large number of people and not only those whose names are listed in the table of contents. The material presented in Chapters 2, 3, and 4 are products of an intense three-month research program carried out under the auspices of IIASA's Young Scientists' Summer Program (YSSP) in 1985. Participants are listed as authors of these three chapters. Their work was organized and coordinated by the editors. We gratefully acknowledge the additional guidance and support for the YSSP group by Robert Ayres, Günther Fischer, Klaus Frohberg, Janos Hrabovszky, Robert Kates, Nathan Keyfitz, and Martin Parry.

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Chapter 1

Scenarios of Socioeconomic Development for Environmental Studies: An Overview

Ferenc L. Toth

In recent years we have witnessed increasing concern over the nature and consequences of long-term, large-scale interactions between socioeconomic development and the natural environment. The long history of human development has from time to time produced collisions with the natural environment. In most cases these collisions resulted in at least temporary degradation in the quality and services of local ecosystems. Environmental degradations in the past, however, tended to be limited in space (to a single watershed or bounded air basin), in time (days to a few years), and in the complexity of cause-effect linkages (single cause - apparent effects).

Over the past two decades the scales and character of development-environment interactions have changed drastically. There is an increasing concern over larger scale problems that affect multiple nations, continents, or the globe (e.g. acid deposition in Europe and North-America, accumulation of radiatively active gases in the atmosphere); longer term problems that persist multiple decades to centuries (contamination of ground water, disposal of radioactive wastes), and complex linkages that involve a number of sectors of the economic activity at various geographical locations and produce complex syndromes of environmental change throughout the globe.

There are now a number of studies underway to understand and manage these development-environment interactions. We have identified four major elements that we believe are necessary to address these issues in a policy-oriented context. These elements are outlined in the next section.

1. Elements of policy oriented studies of environment-development interactions*

Synoptic perspective

Environmental scientists study and report numerous threats to the environment that may considerably degrade the environmental potentials for development in large regions for relatively long periods of time. Examples include the increasing atmospheric concentration of carbon dioxide, depletion of the ozone layer, and toxic contamination of water supplies. Most studies have concentrated on the individual environmental problems. Most human activities, however, simultaneously affect many environmental problems (eg. energy production). Conversely, many of the individual environmental problems simultaneously impact the same basic ecological and economic functions (eg. forest growth). Studies of individual causes and effects are increasingly inadequate for policy makers who confront not discrete instances of pollution, but rather extremely complex and threatening "syndromes" of environmental and economic interdependence.

To illustrate this difference in the scientific and management perspective, Figure 1 presents a synoptic assessment of the impacts of various human activities and natural changes on the atmospheric environment. Scientists tend to look at the problems

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* Many of the ideas in this section are adapted from Toth and Clark (1987).

"columnwise", that is, a research project on acidification would normally look at "vegetations and soils", "petroleum combustion", "coal combustion", and selected industries as potential sources and contributors to the problem. Policy makers, however, look at the problems "row-wise", that is they are more likely to be interested in the environmental impacts and consequences of changes in specific development activities. Policy analysis thus needs to pay much more attention than is currently the case to responding to the "row-wise" interest of the policy and management community.

Bounding the problem in space and time

In order to provide useful policy analyses for the issues addressed by specific studies of environment-development interactions and to make full use of synoptic frameworks like the one presented above, great care must be taken to select the appropriate temporal and spatial scales.

Choosing the appropriate temporal scale means covering time horizons back in the past and out into the future sufficient to include at least one complete cycle of each important development action - environmental impact - social response loop of concern to a specific study. This requires studies of the time necessary for environmental effects to be realized on the natural science side, and for technological innovations, institutional restructuring, and other social responses to be implemented on the socioeconomic side. Critical attention must be paid to activity sectors with long lead-times, like forestry and electric utilities.

Choosing the appropriate spatial scale means covering regions big enough to include both causes of changes in different components of the atmospheric environment and effects of human activities for each source - valued component relationship incorporated in the overall framework. This requires analysis of the spatial dispersion of specific environmental impacts on the natural science side, and the economic, jurisdictional, and legislative boundaries of possible social responses on the socioeconomic side.

The linkages between the spatial and temporal aspects for atmospheric constituents are illustrated by Figure 2. The residence times of the gases represented in the upper-right corner are decades to centuries, long enough to get evenly spread throughout the global atmosphere. This gives the "greenhouse" syndrome its long-term, large-scale character. At the other extreme, the heavy hydrocarbons represented at the lower left corner drop out of the atmosphere in a matter of hours, normally traveling a few hundred kilometers or less from their sources. Thus visibility reduction and other environmental components associated with these chemicals tend to be acute, local problems.

Coping with surprise

The surveys of a set of long-term, large-scale projections (presented in this volume) in the areas of human population (Chapter 2), energy use (Chapter 3), and agricultural production (Chapter 4) show that most "future" studies postulate smooth trends or equilibrium conditions in interactions between development and environment and then seek to identify likely, possible, or even optimal ways to alter them. But history shows that discontinuities, thresholds, and - more generally - surprises are more the rule than the exception in such interactions, exerting a major influence on their outcomes.

The key to understanding the surprise issue is related to the problems of uncertainties and ignorance. For most environmental questions where scientific uncertainty is important, the policy analysis community has come to view its task as one of risk assessment and management. This approach has been highly successful for studies of local or relatively small regional problems. For the carbon dioxide - climate change issue and for other long-term large-scale environmental syndromes, the policy analysis community has, almost without exception, ignored the uncertainties and their implications altogether.

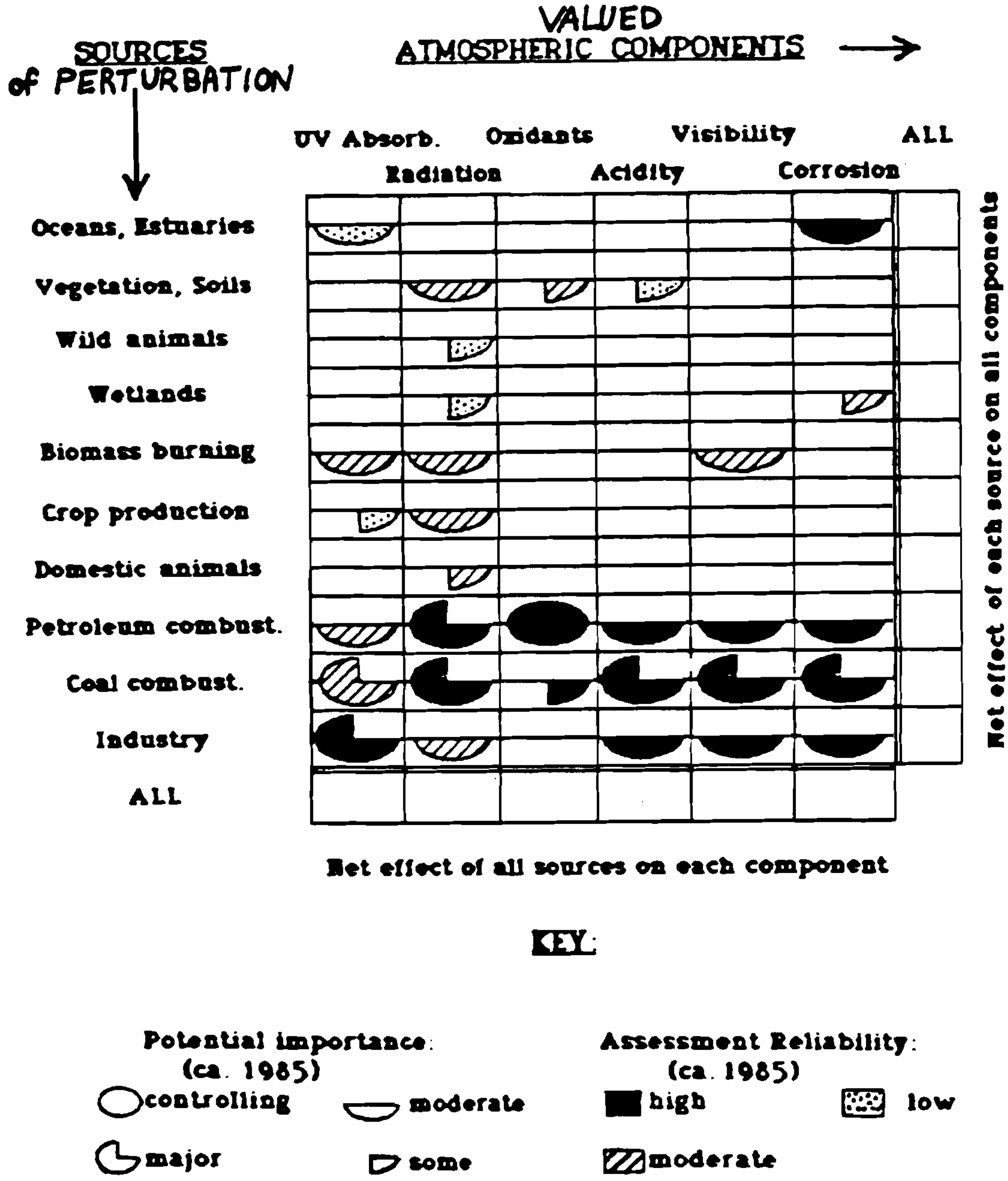

Figure 1 A synoptic assessment of impacts on the atmosphere, from Crutzen and Graedel (1986). Cell entries assess the relative impact of each source on each valued atmospheric component, and the relative scientific certainty of the assessment. Column totals would, in principle, represent the net effect all sources on each valued atmospheric component. Row totals would indicate the net effect of each source on all valued atmospheric components. These totals are envisioned as judgemental qualitative assessments rather than as literal quantitative summations.

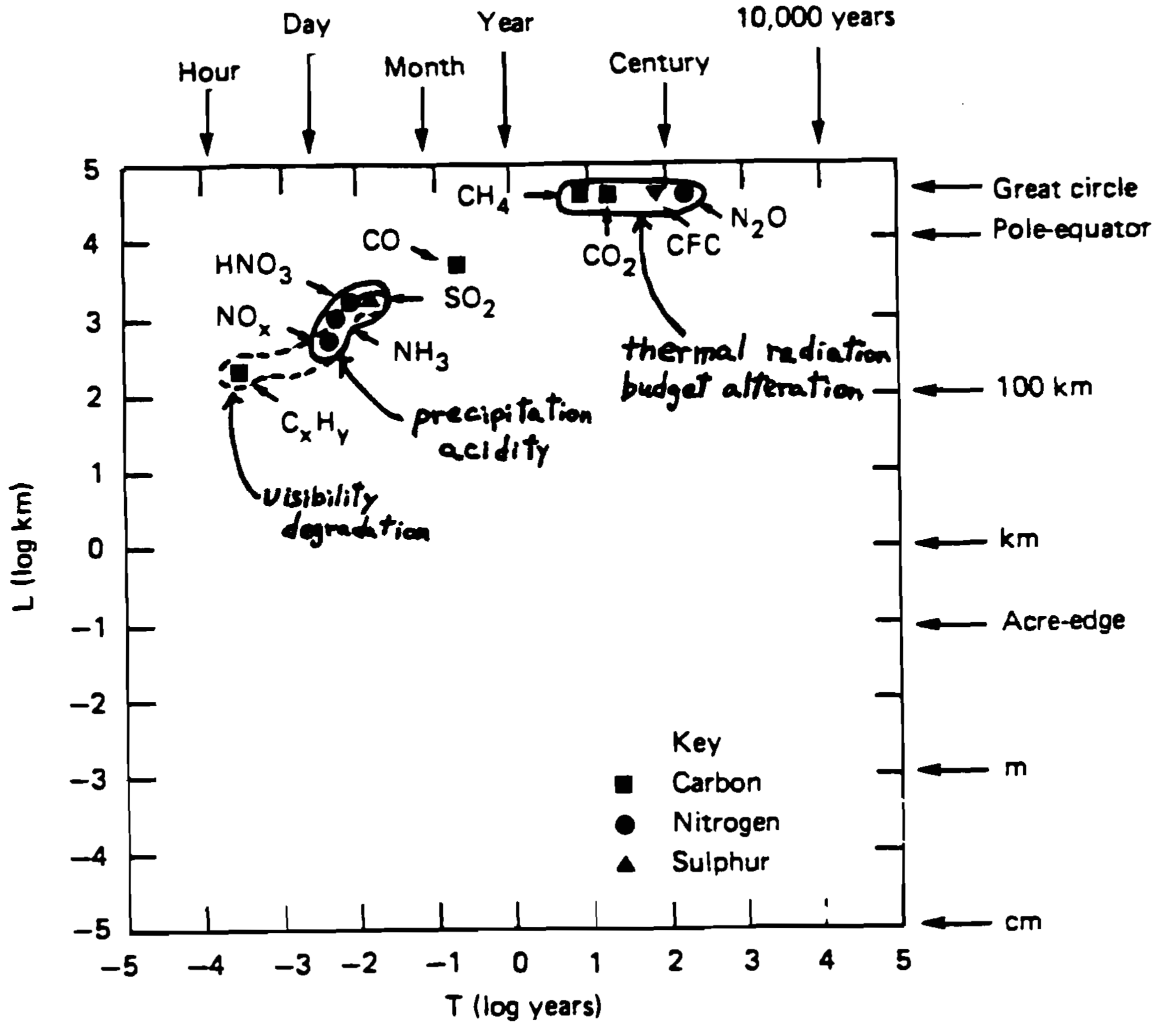

Figure 2 Characteristic scales of atmospheric determinants. The figure applies to the clean troposphere above the boundary layer. The abscissa indicates the amount of time required for the concentration of the listed chemicals to be reduced to 30% of their initial values through chemical reactions. The ordinate indicates the mean horizontal displacement likely to occur over that lifetime. Data are from Crutzen (1983).

Superimposed are characteristic scales of perturbations of the valued atmospheric components - thermal radiation budget alteration, precipitation acidity, and visibility degradation. These superpositions are plotted on the basis of known effects of atmospheric constituents on valued atmospheric components.

A crucial element of any meaningful effort to address these syndromes is to develop approaches to impact assessments that are able to manage uncertainties and surprises of three different kinds:

- surprises resulting from environmental properties that are likely to change discontinuously due to known thresholds, saturation or depletion phenomena, or other nonlinearities;
- uncertainties in assessments caused by "parametric ignorance" or lack of precise information;
- uncertainties in assessments because whole pathways and linkages of interaction were ignored in the analysis.

In each case, there are two sides of the surprise problem. First, there is a need to understand the sources of possible discontinuities in the investigated system on the natural science side. Second, studies also should account for the factors that might limit social response to the unexpected.

Management orientation

There are various angles from which the policy making community is interested in studies of the long-term, large-scale environmental syndromes. They include managers in sectors of the economy whose resource base or activity is affected by these syndromes, officials of international development agencies whose investments are threatened by future environmental changes, and planners of international organizations whose strategic planning choices must include environmental components. This requires a cross-fertilization between research and policy making, an effort both sides can gain from. Current channels of communication between the scientific and policy making communities are becoming increasingly inadequate. Decision makers cannot make full use of all the relevant scientific knowledge, while scientist are unable to determine which new knowledge would be of most value to the decision maker.

The synoptic perspective proposed earlier for studies of environmental syndromes requires methods capable of synthesizing large bodies of scientific knowledge already accumulated in studies of specific environment - development interactions. In recent years, two approaches have been used widely to carry out this kind of synthesis work: one involves building large computer models, while the other involves committees of experts. Both approaches have their own merits and shortcomings. There is a need to develop new tools that complement these existing synthesis methods.

One possible answer to this need is a structured effort that brings together policy people, scientists, and technologists to write and analyze scenarios via interactive formulation of and testing of alternative policies. The approach is called a Policy Exercise (see Brewer, 1986; Toth, 1986, 1988), being developed and tested in the program on "Sustainable Development of the Biosphere" of IIASA, the International Institute for Applied Systems Analysis.

A Policy Exercise is a structured process designed as an interface between academics and policymakers. Its function is to synthesize and assess knowledge accumulated in several relevant fields of science for policy purposes in the light of complex practical management problems. It is carried out in one or more periods of joint work involving scientists, policymakers, and a support staff. A period consists of three phases (preparations, workshop, evaluation) and can be repeated several times. The process includes scenario writing ("future histories", emphasizing non-conventional, surprise rich but still plausible futures) and scenario analyses via the interactive formulation and testing of alternative policies that respond to challenges in the scenario. These scenario-based activities take place in an organizational setting reflecting the institutional features of the addressed issues. Throughout the exercise, a wide variety of hard (mathematical and computer models) and soft methods are used.

2. Scenarios of socioeconomic development

In order to carry out assessments of possible future long-term, large-scale environmental problems, we need a set of plausible scenarios characterizing key components of socioeconomic development. Four such components have been identified as major sources of development-environment interactions: population growth, and associated increases in energy, agricultural and industrial production. The first three components are given primary attention in this study. We have not created scenarios for industry because, except for a few chemicals, there are no models or projections available at the spatial and temporal scales and appropriate resolutions requested for our study. The models and projections included in the assessments are summarized in Table 1.

Growing demand for goods and services by an increasing global population is the primary driving factor in the development-environment interaction. Thus, the number, geographical distribution and density, age structure, rural-urban distribution, level of education, and migration patterns of future population will indirectly affect what long-term and large-scale environmental stresses will arise in various parts of the world. Many environmental impacts, however, result not from people per se but from what people do. Of particular importance are the impacts of energy and agricultural production. The key difference between these two sectors is that, with a few exceptions, environmental impacts resulting from various forms and technologies of energy production do not directly effect the future of use and production by the same technology, whereas agriculture may suffer from detrimental impacts originated both inside and outside the sector.

There are profoundly different environmental impacts associated with various types of energy production and energy use. Therefore, we need for our development scenarios not only total energy projections but fractions of each major fuel types as well. The fuel types considered in scenarios reviewed here include oil and coal, gas, synfuels, biomass, hydro and solar energy, and nuclear energy.

Various types of agricultural activities and their resource base are affected by environmental impacts from other sectors and by their own management practices in different ways. The contribution by specific land-use types to present and future environmental stresses is also different. Besides total agricultural production, the following land use types and intensity indices are treated in the studies reviewed here: total cropland, dry cropland, irrigated cropland, grazing land, forests, other land, total fertilizer use, fertilizer per unit of cropland.

Instead of developing a set of new projections characterizing possible paths of socioeconomic development, we decided to undertake an assessment of already existing, recent, widely circulated, heavily referenced and used models and projections in the above three key areas. Major objectives for these assessments were:

- to provide a critical appraisal of how existing projections can be used methodologically;
- to explore what are these projections good for;
- to evaluate which study provides the best available tool for specific types of environmental studies.

The objective clearly was not to evaluate how good or bad the selected models and projections are per se but rather to assess how they can be used to characterize socioeconomic development as a driving force in studies of development-environment interactions.

The central criterion in the assessment was the ability of a study to describe relations between alternative development strategies, specific policies and actions, and characteristic paths of future development and indicators of environment in terms of possible or estimated impacts on a set of key valued environmental components (VECs). One such attempt to create an action-VEC matrix for energy production is presented in Chapter 3.

The aim for the assessment was to construct a summary and "user's guide" to direct potential users interested in environment related issues and to identify appropriate tools for specific questions. This includes an assessment of which model or projection can or cannot be used for particular questions as well as identifying structural constraints of these studies for dealing with some questions and not others. The key question in this respect is: How can one use these global studies/models as inputs to various environmental studies (e.g. long-term atmospheric studies) in a way that the user does not have to become an expert in modeling the related fields (e.g. in energy modeling in the case of climate and atmospheric impact studies). In general, what are the relevant inputs from population, energy, and agricultural models for a specific environmental study?

Time boundaries and temporal resolution

The long-term, large-scale nature of the environmental problems we are interested in here requires driving scenarios of socioeconomic development at the same scales. The time horizon of the models and projections considered in the assessment ranges from 2000 to 2150. Not surprisingly, population projections tend to cover the longest time into the future (at least 50 but typically 75 to 100 years), and agricultural models provide the shortest outlook in the future (no agricultural model extends beyond 2010). Accordingly, the temporal resolution of the long-term models is usually 25 years while that of the medium-term models is 5 years.

Our assessments show that only some of the population forecasts (Keyfitz, Frejka, WB) and two of the energy models (E&R, N&Y) cover the necessary time horizon to carry out long-term, large-scale environmental impact studies. It would be difficult to extend any of the agricultural studies to cover at least twice the length of their present time horizon because the assumptions underlying these models represent short-term concerns. The 25 year resolution of the longer-term projections seems to be appropriate for illustrating the broad patterns of change essential for these environmental studies.

Geographical scale and spatial resolution

All the models included in the assessment provide the required global coverage. Three agricultural studies, however, have special focus: AEZ and AT2000 on developing countries and RFF on the United States. Most population projections are broken down into countries and geopolitical regions and are aggregated into major geographical regions. Energy studies do not consider country-level disaggregation. Except for N&Y (treating the world as a single region), they provide projections for at least four major geopolitical regions. Criteria for grouping countries into regions and thus the composition of those regions are different for each study as they represent specific geographical, economic development, resource endowment, and political considerations.

Spatial resolution in the agricultural studies depends on the specific focus of the individual models. Those primarily concerned with agro-ecological issues (AEZ, AT2000) are broken down into hundreds to tens of thousands of smaller regions based on soil characteristics and climatic conditions. These small units are then aggregated into countries and larger regions. Agricultural studies focusing on economic aspects of agricultural development (MOIRA, FAP) provide less detailed ecological inventory of the resource base and their principal spatial units are countries, country groups based on political and economic integrations, or regional groups based on geographical location.

For studies of large-scale environmental changes, studies by Keyfitz, UN, and WB provide the best sources of information on population. Considering the level of spatial disaggregation, E&R, IIASA, and WEC are the most appropriate among the energy models (but the last two do not stretch long enough to cover the required time scale).

An appropriate combination of agricultural models that would provide both the necessary agro-ecological assessment and incorporate the most important underlying economic processes as well as cover an 80-100 year time horizon is yet to be developed.

Table 1. Overview of the models and projections included in the assessment

Short name	Title and reference	Temporal scale	Spatial scale and resolution
Population			
Keyfitz	Global population (1975-2075) and labor force (1975-2050) (Keyfitz et al., 1983)	2075	Global, 150 national territories, 9 regions
UN	World population prospects (United Nations, 1985)	2025	Global, 210 countries and areas, 8 regions, 24 subregions
Frejka	Long-term prospects for world population growth (Frejka, 1981)	2150	Global, 8 regions
WB	World population projections (World Bank, 1984)	2050 (2155)	Global, 185 countries and geopolitical regions
G2000	Global 2000 Report to the President (CEQ, 1980)	2000 (2100)	Global, 5 major regions, also 12 developing countries and 5 developed countries & minor regions
Energy			
IIASA	Energy in a finite world (Haefele et al., 1981)	2030	Global, 7 regions; 7 fuels
E & R	Global Energy (Edmonds and Reilly, 1985)	2050 (2100)	Global, 9 regions; 6 primary, 4 secondary + biomass, synfuels
N & Y	Paths of energy and carbon dioxide emissions (Nordhaus and Yohe, 1983)	2100	Global, 1 region; 2 aggregated: fossil, nonfossil
WEC	Energy 2000-2020 (Frisch, 1983)	2020	Global, 10 regions; 8 fuel types
IEA	World energy outlook (IEA, 1982)	1990	Global, 4 regions; 5 fuel types
G2000	Global 2000 Report to the President (CEQ, 1980)	2000	Global, U.S. and 4 regions; 5 fuel types

Table 1. (continued)

Short name	Title and reference	Temporal scale	Spatial scale and resolution
Agriculture			
AEZ	Agro-ecological zones project (FAO, 1978-1981)	-	Developing, 117 countries, 50,000 land units
AT2000	Agriculture toward 2000 (FAO, 1981)	2000	Global, 90 developing in detail, 34 developed aggregated
MOIRA	Model of international relations in agriculture (Linnemann, 1979)	2010	Global, 222 soil regions, 106 geographical units, 6 geographical regions
G2000	Global 2000 Report to the President (CEQ, 1980)	2000	Global, 3 major regions, also 7 countries and minor regions
FAP	IIASA Food and Agricultural Program (Parikh, 1981)	2000	Global, 18 country, 2 country-groups, 14 regional groups
RFF	Resources and environmental effects of U.S. agriculture (Crosson and Brubaker, 1982)	2010	US and rest of the world

Internal resolution

In order to carry out appropriate environmental assessments, the sectoral studies used as inputs should provide details on the composition and structure of each sector. As a rule-of-thumb, short-term models tend to be more detailed and, thus, contain more complex internal feedbacks within the sector they consider.

Each population forecast included in the assessment elaborates some details of future populations. Keyfitz focuses on labor force (based on labor force ages and participation ratios). The UN report contains information about birth rates and death rates, reproduction rates, and life expectancies. The WB report includes individual country data on fertility, three major age-groups (0-14, 15-64, 65 and over), and dependency ratios.

Region-specific data on possible development of the main energy sources is necessary to assess future environmental stresses arising from the energy sector. The internal resolution of the energy models included in the assessment covers 5-8 fuel types except for N&Y that considers only two aggregated fuels: fossil and non-fossil.

The agricultural models considered show a diverse picture with respect to their internal resolution. The studies focusing on agro-ecological conditions are primarily concerned with land-use types, major cropping systems (dry crops, irrigated crops), and major crop classes (cereals, seeds, etc.). The agro-economic models provide a higher level of disaggregation in agricultural commodities, and they also shed light on international trade of those commodities.

3. Conclusions

Results of the assessments show that individual sectoral models provide a better description of the internal dynamics and development patterns of these sectors than highly aggregated "world models". There is a considerable degree of freedom in the ways and directions each sector may develop relatively independently of what happens in other sectors, especially on the long-term. Constructing endogenous feedback loops describing linkages among variables of different economic sectors often result in obscure relationships.

This approach, however, raises the problem of constructing consistent summary scenarios. The proposed solution is to start with a collection of models and projections whose initial assumptions are well understood and documented. The next step is to combine results or versions of those projections that share a consistent set of assumptions. One such attempt to generate a comprehensive long-term, global development scenario based on "conventional wisdom" versions of the sectoral projections is presented in Chapter 5.

The assessments of sectoral models show that the models and projections describe a smooth transition between their starting values (today) and projected values (at the end of their projection horizon), and that the projected values of key variables in each sector fall into a well-bounded range. The environmental assessments and the analyses of possible human responses to the environmental impacts would offer little useful, if only these highly conventional, surprise-free socioeconomic development paths were used as inputs to them. Therefore, as a first step, a summary "conventional wisdom" reference scenario was developed based on the future sectoral developments as suggested by the studies included in the assessment (Chapter 5).

One of the objectives of the sectoral assessments was to identify possible sources of surprises in the future developments of each sector. The term "surprise" is used in a broad sense here. Events or future development patterns are considered to be surprising if they are profoundly diverted from the generally projected trends based on past histories and some widely accepted convenient assumptions and lie far beyond the high-low boundaries of conventional projections or they are qualitatively different. Thus, as a second step a selection of surprising development patterns identified as plausible surprises in the assessment work were used to define three different and highly surprising states of the world for 2075. A multinational interdisciplinary group of dedicated experts developed alternative "historical" paths to reach each specified future state over a hundred-year period mainly in forms of qualitative future histories (see Svedin and Aniansson, 1987).

The final step was to create a quantitative and consistent development path for each surprise-rich future history. The objectives of this effort were (i) to check the plausibility of the scenarios; (ii) to improve the internal consistency of the scenarios; and (iii) to provide an improved material for use in environmental assessments (Chapter 6). The specific social and political events in these future histories are not very important. It is rather the patterns of population development, energy and agricultural production, their structure and geographical distribution that might provide useful information for studies of global environmental change.

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Chapter 2

A Critical Review of Population Projections for the Study of Long-term, Large-scale Interactions between Development and Environment

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1. INTRODUCTION

1.1. Objectives and Goals

IIASA's Project on Sustainable Development of the Biosphere is designed to serve the needs of policy-makers and planners in government and industry who confront long-run trade-offs between development objectives and possible environmental constraints, in the face of significant scientific uncertainty and minimal social consensus. The goal of the Project is to develop a strategic perspective on the interactions of development and environment that will help to clarify key issues, to order the knowns and unknowns, and to illuminate possible "future histories" for sustainable development of the biosphere.

The project's plan of work is to assess the major published forecasts and future-oriented studies regarding long-term, global-scale human development; to use the information from those studies to construct a matrix of valued environmental components (VECs) and human actions affecting those components; and to use the matrix and our assessments of the major scenarios in Policy Exercises that will examine -- and perhaps try to construct a new -- plausible scenarios of future "collisions" between environment and development.

The studies selected for assessment were those we felt to be the most widely known, and the most widely used. In this paper we focus on major population forecasts. We seek to show where they agree and disagree, where they have uncertainties, what their assumptions are, and where discontinuities or surprises could make a difference in the outcomes they project.

Population is presumed to be the driving force in long-term, large-scale interactions between socioeconomic development and the natural environment, both in modifying the environment through energy use, agriculture, industrialization (in a word, development), and in terms of using the environment to meet human needs. We attempted to develop a VECs/actions matrix of population-environment interactions, but discovered that the approach we used inevitably led to population having mostly indirect environmental effects, the direct linkages occurring through agricultural and energy activities. Therefore no discussion of VECs/actions is presented here. Appendix 1 displays a partial catalogue of population-environment effects gleaned from papers presented at the Symposium on Population, Resources, and the Environment (Stockholm, 26 September - 3 October, 1973). This conference was held in preparation for the 1974 World Population Conference held in Bucharest, Rumania.

1.2. Method/Approach

Table 1.1 presents a list of the five major studies containing six projections of global population which were reviewed. These studies were selected because (1) they are used as inputs to global energy and agriculture models, or (2) they are judged by the demographic community to be major projections, or (3) both. The six projections vary in their time horizons from 2000 to 2155.

The projections were evaluated using the following criteria to assess their usefulness for long-term, large-scale environmental studies. We do not expect any single projection to meet all the criteria but expect this critical appraisal to illuminate where individual demographic studies can make important contributions to these kinds of environmental studies. The criteria are that the projections (should)

(1) be at an appropriate level of disaggregation so as not to obscure important differences between countries and regions of the world;

(2) have an appropriate time horizon to provide the long-term (100 year) information on population growth required by long-term environmental studies;

(3) be accepted by the demographic community as being a reasonable assessment of the future possibilities of world population;

(4) specify the rates and assumptions for each of the key parameters of fertility, mortality, and migration;

(5) possess error bands around the projections or at least provide variant projections; and

(6) be understandable to the policy maker who will ultimately be the user of the output of the projections (i.e., if a simple model of geometric increase provides information about the future to the same level of accuracy as a more highly specified model then this might be selected for use).

Section 2 presents a detailed description and evaluation of each of the projections which were examined, with accompanying summary tables and graphs. Wherever possible, the data have been re-aggregated into a scheme of eight regions developed for global environmental studies. (A list of the countries in each region is exhibited in Appendix 2.)

2. MODEL DESCRIPTION AND EVALUATION

2.1. Introduction

Accurate projections of future population growth require a valid theory of demographic change. This implies a theoretical understanding of the determinants of fertility, mortality, and migration. Keyfitz (1983) has reviewed the rich literature on theoretical explanations for changes in fertility, mortality, and migration. He points out that most theories have been developed by observing the past and concludes that one is left with no clear theoretical explanation on which to build a behavioral model to predict future populations. He states that this is primarily due to "[T]he recalcitrance of the data, and their unwillingness to distinguish between theories..." (Keyfitz, 1983:744).

In the absence of a causal theory, then, how are population projections made? Keyfitz (1983) provides a catalog of the techniques available for making population projections. These can be classified as (1) statistical methods, (2) mathematical methods, and (3) behavioral models based on causal theory. All have certain disadvantages and limitations for use in projecting future population size.

Table 1.1 Summary Information on Forecasts Evaluated in this study

Title, Author, Citation	Time Period of Projection & Spatial Scale of Resolution	Comments, Assumptions, Key Variables
Global Population (1975-2075) and Labor Force (1975-2050) Keyfitz, et al. 1983, Oak Ridge Associated Universities, Institute for Energy Analysis, ORAU/IEA-83-6(M)	• population to 2075 • labor force to 2050 • done for 150 main national territories and the world	• revision of Littman & Keyfitz, 1977 • predicts changes in fertility rates by assuming dates for achieving replacement level fertility and applying a linear interpolation back to starting point • used as input to Edmonds & Reilly (1985) and IIASA energy models (Haefele et al., 1981)
World Population Prospects Estimates and Projections as Assessed in 1982 United Nations, 1985, ST/ESA/SER.A/86	• population to 2025 • done for 210 countries, territories and areas and the world	• most widely cited source • revised regularly • produces three variant projections with the medium variant assumed to be the most "likely" • high and low variants should not be assumed to represent upper and lower bounds of uncertainty
Long-Term Prospects for World Population Growth Frejka, Tomas, 1981, Population and Development Review 7, No.3 (September) pp 489-511	• population to 2150 • done for 4 developed and 4 developing regions of the world	• revision of Frejka, 1973, where he first introduced notion of assuming future date for achieving replacement level fertility and linearly interpolating back to starting date to get fert. rates • presents 4 trajectories intended to represent upper and lower boundaries of population growth
World Development Report 1984, World Population Projections 1984 World Bank, 1984. N.Y.:Oxford University Press; Vu, M.T. 1984. Washington,D.C.:The World Bank	• 3 projections to 2050; 1 to 2155 • done for 185 countries with regional and world totals	• not very user accessible • makes projections to stationarity • emphasizes LDCs
Global 2000 Report to the President: Entering the 21st Century Vol.2, Technical Report and Vol.3, Documentation on the Government's Global Sectoral Models (Washington, D.C. GPO)	• population to 2000 • single trajectory to 2100 • done for 12 developing countries, 5 major regions, 4 minor regions and the world	• contains 2 projections, one prepared by the U.S. Census Bureau and one by the Community and Family Study Center of the Univ. of Chicago • assumes continued decline in fertility • uses WB rescheduled UN mortality estimates

2.1.1. The component method of projection

The models reviewed in this section all use the component projection method. A summary of this method, paraphrased from World Population Prospects (United Nations, 1985) is presented below.

First, age-sex-specific survival rates are successively applied to the base-year population in order to determine the number of survivors in each age at the end of each five-year period. These survival rates are based on national life tables, when applicable, or on model life tables.

Second, the number of births expected to take place during each five-year period is estimated. The expected age-specific fertility rate, which is derived from the assumed gross reproduction rate, is multiplied by the corresponding number of females in the reproductive age groups to yield the total number of births. Next, these births are distributed on the basis of an assumed sex ratio at birth. Finally, the numbers of survivors from these births at the end of each five-year period are calculated by applying the appropriate survival probabilities.

The third, and final, major step is to determine the net number of migrants that are to be added to or subtracted from the projected survivors. The assumed net numbers of migrants during the five-year period, classified by age and sex, are combined with the projected age and sex structure to produce the projected population at the end of the five-year period.

2.1.2. Sources of error and bias

Key assumptions for population projections using the component method, which can contribute sources of error to the projection, involve the four key parameters: (1) initial population size and age-sex structure; (2) fertility estimates; (3) mortality estimates; and (4) migration estimates.

Keyfitz et al. (1983) consider the uncertainty in the assumptions made for these different variables greatest in the fertility estimates. Hence, this is likely to contribute the largest source of error to projections of future population size.

Growth rates can also be calculated by assuming that growth will slow to replacement (net reproductive rate = 1) by a certain time. This has the advantage that one can easily assess the reasonableness of this assumption and its effect on future population size. In the developing countries, starting with estimates of 1975 population, postponement by one year of the time of replacement adds, on the average, 160 million people to the world population. For the developed countries, a similar postponement of time of replacement adds, on the average, 4.5 million people to the world population (Keyfitz et al., 1983:24).

A second source of error, sometimes called "jumping off" error, involves variability in initial estimates of population parameters for key developing countries. Ten countries designated as key include: China, India, Indonesia, Brazil, Bangladesh, Mexico, Philippines, Nigeria, Pakistan, and Thailand. These accounted for 52 percent of the world's population in 1975, and are projected to account for 54 percent in the year 2000. Errors in selecting the initial estimates for these key developing countries will contribute a small amount to the uncertainty of the final population projections. In the year 2000, a difference of 360 million people exists between the highest and lowest estimates prepared.

All the studies assume that its mortality rates make a small contribution to the uncertainty of the population projections. Mortality rates are determined essentially by extrapolating the consensus which exists in the demographic community, that present trends in decreasing rates of mortality will continue. The downtrends are forecast at a slightly faster rate for the developing countries than the developed countries.

All the studies assume that net migration is zero. On a global scale migration must of course net to zero; but because world population is often derived additively, it is possible for migration to affect world totals as well. Assumptions concerning migration are more important for assessing population growth in individual nations and regions than the world, but even here zero net is assumed because available data are usually so few and unreliable that accurate estimates cannot be made. Total population for the world can be obtained by adding estimates for individual countries or by a simple direct calculation for the total. An additive total will always be greater than a simple total because an arithmetic average is always greater than a geometric average. The additive procedure is superior to the simple procedure since it allows the relative numbers to shift toward the high end of the projection, as they do in the real world.

Looking at global figures often obscures the diversity of the world demographic situation. There is a large disparity in all demographic indicators between the developed and developing regions of the world. Considerable diversity also exists within developing regions of the world. The proportional contribution of the developing countries to world population growth is increasing.

A few developing countries have a large effect on the demographic indicators when viewed as an aggregate grouping. For example, the observed decline in the growth rate for developing countries from 2.6 percent to 2.0 percent during the period from 1965 - 1985 is reduced to a decline to 2.5 percent if China is excluded from the calculations. Differences in the population trends in individual countries and the eight major regions of the world (as defined by the United Nations) point to the need to examine future population on a national or at most regional scale of aggregation.

The component method cannot discriminate between inaccurate and accurate data; only the demographic analyst is in a position to determine whether the initial data are of suitable quality. The extent and accuracy of the initial population data are of primary importance in the production of accurate projections, especially for the short-term.

The knowledge gained from attempts to develop a causal theory of demographic change is incorporated into the models implicitly as casual theorizing and expert opinion concerning rates of change in the key parameters of fertility, mortality, and migration. In general, rates of change in these parameters are established in one of two ways: (1) extrapolation of past trends modified by judgement into the future, or (2) assuming a point in the future when replacement level fertility will be reached and deriving subsequent fertility rates via linear interpolation between that point in time back to the initial period or base year.

2.2. Keyfitz, et al.: Global Population (1975-2075) and Labor Force (1975-2050)

2.2.1. Introduction

This projection, developed by Nathan Keyfitz, Edward Allen, James Edmonds, Rayola Dougher, and Barbara Wright, was prepared in 1983 as a revision to estimates developed by Littman and Keyfitz (1977). It was published as a report from the Institute for Energy Analysis, Oak Ridge Associated Universities, ORAU/IEA-83-6(m), Oak Ridge, Tennessee.

Table 2.1 Keyfitz et al. (1983), Summary Population Data

	Area (10e6 km^2)	Variants	Population (10e6)					Factor Increase					Density (p/km^2)				
			1975	2000	2025	2050	2075	1975	2000	2025	2050	2075	1975	2000	2025	2050	2075
Africa	30	High	401	791			1668	1	2.0			4.2	13	26			56
		Medium	401	720			1200	1	1.8			3.0	13	24			40
		Low	399	697	943	1101	1150	1	1.7	2.4	2.8	2.9	13	23	31	37	38
Asia-East	12	High	1006	1477			2204	1	1.5			2.2	84	123			184
		Medium	1006	1424			1913	1	1.4			1.9	84	119			159
		Low	1026	1387	1645	1648	1797	1	1.4	1.6	1.6	1.8	86	116	137	137	150
Asia-South	16	High	1250	2375			4787	1	1.9			3.8	78	148			299
		Medium	1250	2178			3514	1	1.7			2.8	78	136			220
		Low	1248	2128	2817	3354	3358	1	1.7	2.3	2.7	2.7	78	133	176	210	210
Europe	5	High	473	535			604	1	1.1			1.3	95	107			121
		Medium	473	532			589	1	1.1			1.2	95	106			118
		Low	472	528	564	578	586	1	1.1	1.2	1.2	1.2	94	106	113	116	117
Latin America	20	High	324	615			1192	1	1.9			3.7	16	31			60
		Medium	324	569			905	1	1.8			2.8	16	28			45
		Low	313	540	718	822	849	1	1.7	2.3	2.6	2.7	16	27	36	41	42
North America	18	High	237	285			329	1	1.2			1.4	13	16			18
		Medium	237	284			324	1	1.2			1.4	13	16			18
		Low	237	283	314	321	326	1	1.2	1.3	1.4	1.4	13	16	17	18	18
Oceania	8	High	21	30			45	1	1.4			2.1	3	4			6
		Medium	21	29			39	1	1.4			1.9	3	4			5
		Low	17	21	25	26	26	1	1.2	1.5	1.5	1.5	2	3	3	3	3
USSR	22	High	255	315			375	1	1.2			1.5	12	14			17
		Medium	255	312			360	1	1.2			1.4	12	14			16
		Low	255	308	338	348	354	1	1.2	1.3	1.4	1.4	12	14	15	16	16
World	131	High	3965	6466	8956	10677	11398	1	1.6	2.3	2.7	2.9	30	49	68	82	87
		Medium	3965	6079	7723	8676	8927	1	1.5	1.9	2.2	2.3	30	46	59	66	68
		Low	3976	5892	7364	8198	8446	1	1.5	1.9	2.1	2.1	30	45	56	63	64

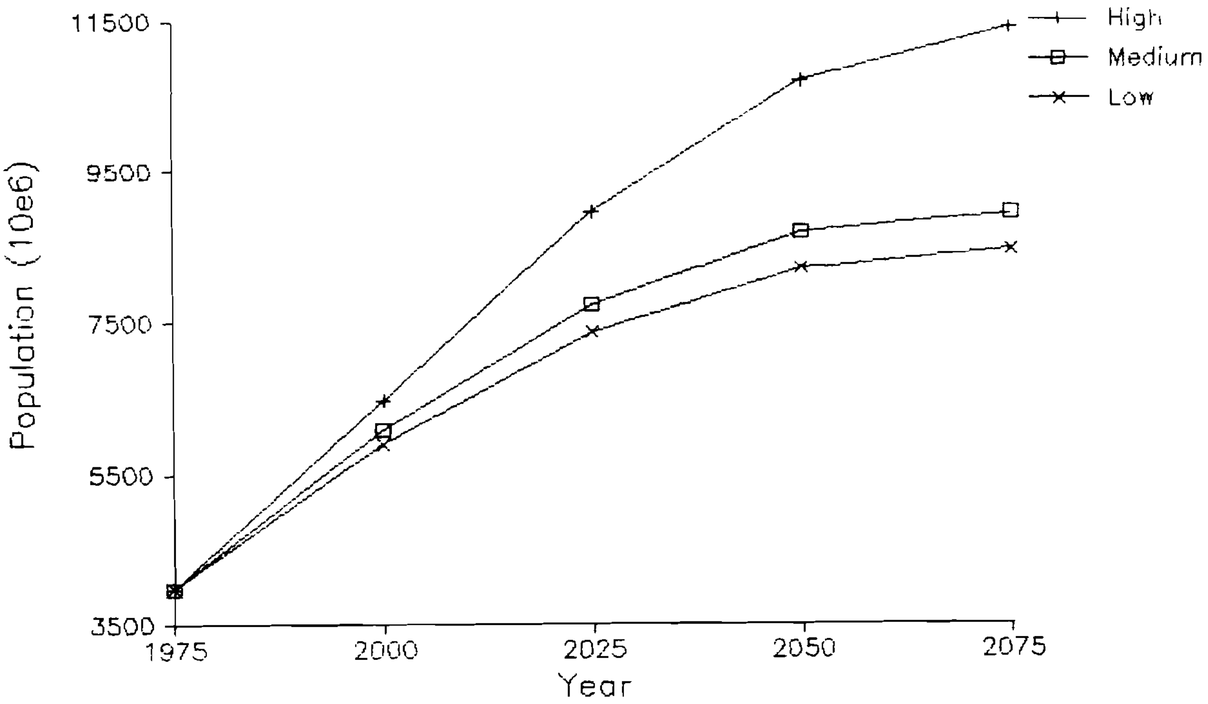

Figure 2.1 World population - Keyfitz et al.

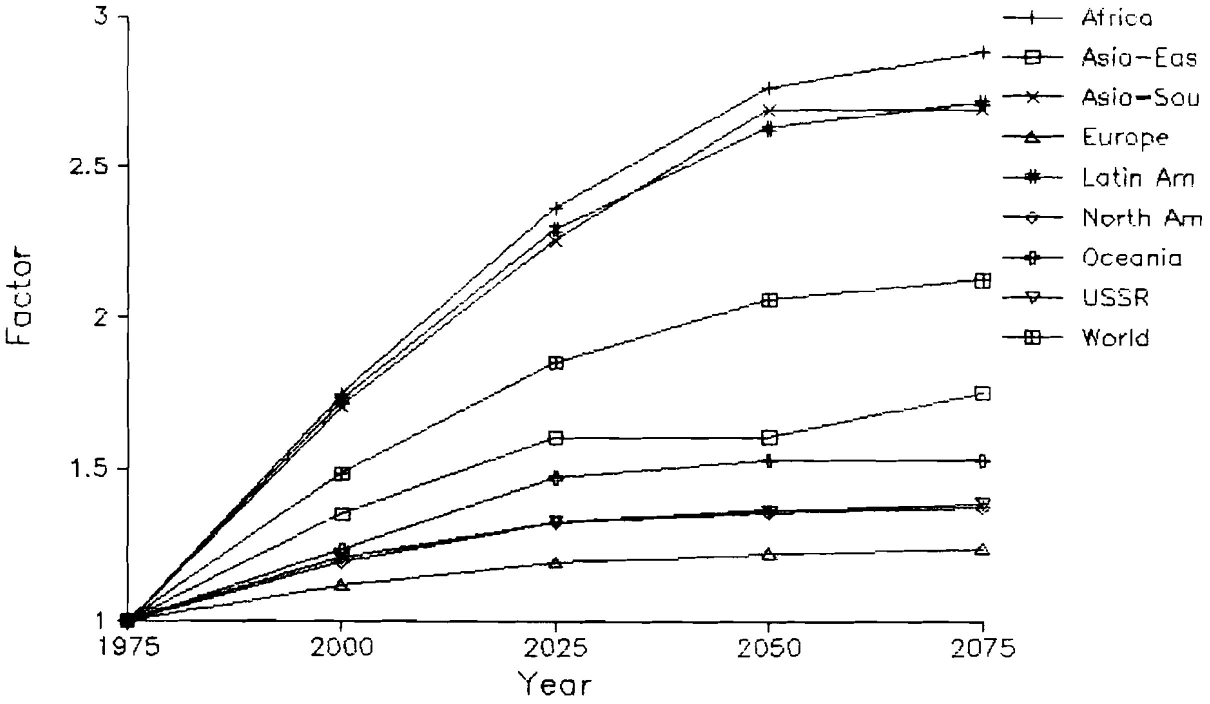

Figure 2.2 Factor increase (low) - Keyfitz et al.

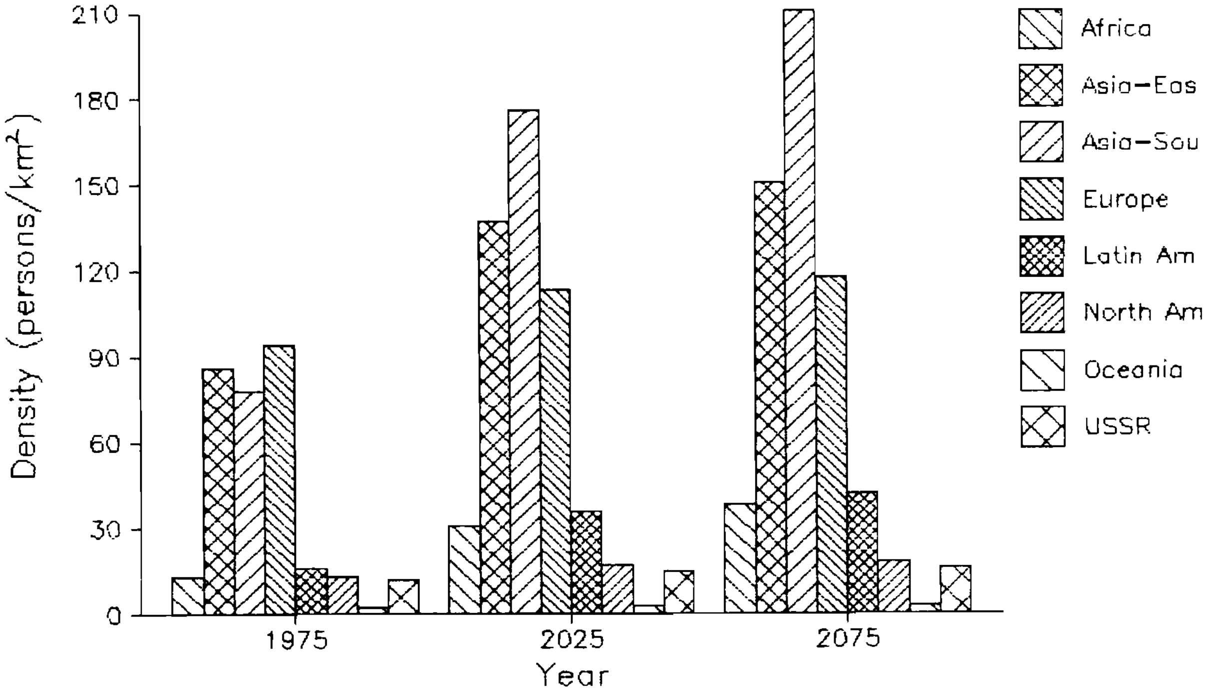

Figure 2.3 Density (low) - Keyfitz et al.

2.2.2. Scale and resolution

Projections are made for 150 main national territories and the world. The 150 national territories have been aggregated into nine regions: the United States; Western Europe and Canada; Japan, Australia, and New Zealand; centrally planned Europe; centrally planned Asia; the Middle East; Africa; Latin America; and non-communist South, East, and Southeast Asia.

The baseline year, 1975, was derived from actual counts and published surveys where available. The numbers produced by Littman and Keyfitz (1977) "were regarded as low" (Keyfitz et al., 1983:1); this more recent work attempts to improve the usefulness of the projections.

2.2.3. Method

The population projections were developed using the component method. Growth rates were estimated by assuming that population growth would slow to replacement (net reproductive rate = 1) by either 2000-05 or 2015-20. A straight line interpolation of the net reproductive rate (NRR) was then made between 1975 and the time at which replacement was assumed to be reached. These expectations of NRR were translated into country-sex-age specific rates using regional model life tables developed by Coale and Demeny (1966). We have treated the Littman and Keyfitz (1977) estimate as a low variant projection and the 2000-05 and 2015-20 projections as medium and high variants respectively.

2.2.4. Conclusions

Table 2.1 and Figures 2.1 through 2.3 present projections for the world and eight regions. These will be used for comparison with the other major population forecasts and for integration with the reports on the energy (Chapter 3) and agriculture (Chapter 4) projections.

In the more developed world, population to the year 2000 and beyond is seen to be leveling off and approaching stationarity. In 1975 the more developed countries accounted for approximately 28 percent of the world total; by 2025 this is expected to fall to 17-19 percent of the world total. In this part of the world the interesting demographic issue is the changing age structure of populations associated with stationarity. Assumptions concerning mortality and migration may hold surprises for the future.

In 1975 the less developed countries accounted for 72 percent of the world population; by 2025 this is expected to increase to 81-83 percent. For the developing world, there is greater uncertainty in both current estimates of populations and the time to achieving replacement level net reproductive rates. The difficulty in making accurate estimates for a few key developing countries has a large effect on the accuracy of world projections. Additionally, many African countries have not been judged to have entered the "demographic transition" (defined by falling death rates, followed by falling fertility) and so their actual totals may come out higher than projected. One cannot predict when or if they will enter the demographic transition, but it seems impossible, on economic and ecological grounds, for Africa's population to continue growing at its present rate.

Keyfitz et al. (1983) conclude that their projected population for 2075, ranging between 8.4 - 11.3 billion with a most likely projection of 8.9 billion persons may well approximate the ultimate stationary level of world population.

2.3. United Nations: World Population Prospects, Estimates and Projections as Assessed in 1985

2.3.1. Introduction

The projections presented in this report represent the ninth round of global demographic assessments by the United Nations. The report was published in 1985 by the Department of International Economic and Social Affairs, ST/ESA/SER.A /86, and is available from the United Nations publications office, Sales No. E. 82 XIII.5. A magnetic tape containing the major results of the present estimates and projections can be obtained from the Director of the Population Division, Department of International Economic and Social Affairs, United Nations, New York, N.Y. 10017.

2.3.2. Scale and resolution

Projections are made for 210 countries and areas, and are combined for the world; more developed and less developed regions; eight major geographical regions (Africa, Latin America, Northern America, East Asia, South Asia, Europe, Oceania, and USSR); and 24 subregions. The projections are presented for the 75 year period from 1950 - 2025. The various figures used as baseline are derived from data available generally by the beginning of 1983. National data, whenever available, have been used, adjusted for deficiencies and inconsistencies if necessary. For those countries where the data were unavailable or insufficient, the demographic indicators were determined according to reasonable assumptions for the population in question and in agreement with any existing reliable information. The base year is taken to be 1980.

Table 2.2 United Nations (1985), Summary Population Data

	Area 10e6 km^2	Variants	Population (10e6) 1975	2000	2025	Factor Increase 1975	2000	2025	Density (persons/km^2) 1975	2000	2025
Africa	37	High	509	1093	2230	1	2.1	4.4	14	30	60
		Medium	509	1070	1949	1	2.1	3.8	14	29	53
		Low	509	1034	1632	1	2.0	3.2	14	28	44
Asia	16	High	1432	2097	2672	1	1.5	1.9	90	131	167
		Medium	1432	2005	2402	1	1.4	1.7	90	125	150
		Low	1432	1932	2199	1	1.3	1.5	90	121	137
Europe	5	High	474	529	585	1	1.1	1.2	95	106	117
		Medium	474	513	527	1	1.1	1.1	95	103	105
		Low	474	501	486	1	1.1	1.0	95	100	97
Indian sub-cont	5	High	829	1416	1980	1	1.7	2.4	166	283	396
		Medium	829	1351	1766	1	1.6	2.1	166	270	353
		Low	829	1297	1604	1	1.6	1.9	166	259	321
Latin America	20	High	322	572	898	1	1.8	2.8	16	29	45
		Medium	322	550	787	1	1.7	2.4	16	28	39
		Low	322	521	686	1	1.6	2.1	16	26	34
North America	18	High	239	311	390	1	1.3	1.6	13	17	22
		Medium	239	298	347	1	1.2	1.5	13	17	19
		Low	239	283	300	1	1.2	1.3	13	16	17
Oceania	8	High	18	27	36	1	1.5	2.0	2	3	5
		Medium	18	25	32	1	1.4	1.8	2	3	4
		Low	18	24	27	1	1.3	1.5	2	3	3
USSR	22	High	253	322	394	1	1.3	1.6	12	15	18
		Medium	253	315	367	1	1.2	1.5	12	14	17
		Low	253	307	344	1	1.2	1.4	12	14	16
World	131	High	4076	6367	9185	1	1.6	2.3	31	49	70
		Medium	4076	6127	8177	1	1.5	2.0	31	47	62
		Low	4076	5899	7278	1	1.4	1.8	31	45	56

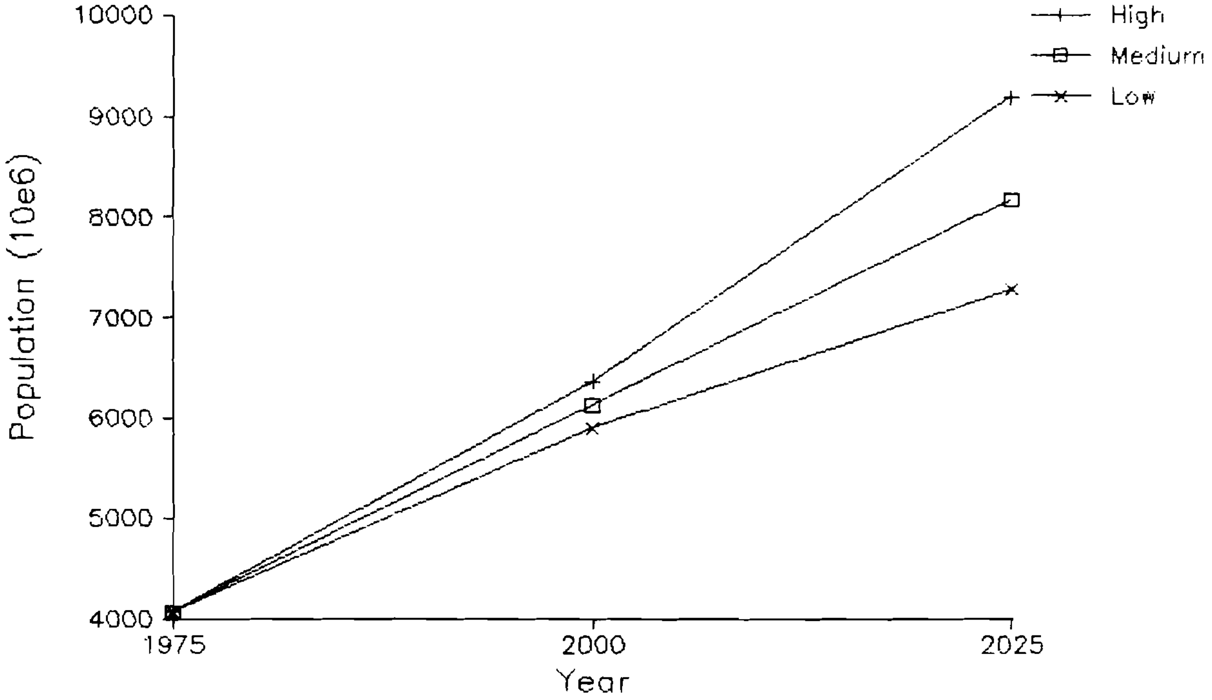

Figure 2.4 World population - United Nations

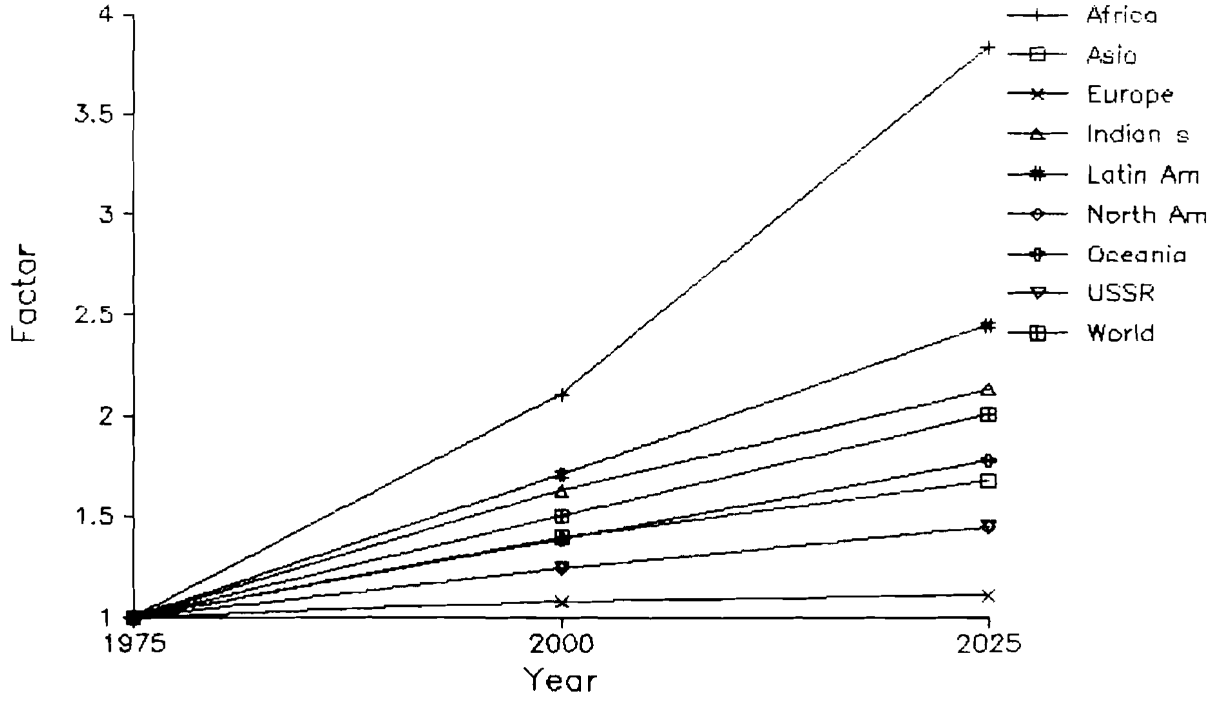

Figure 2.5 Factor increase (medium) - United Nations

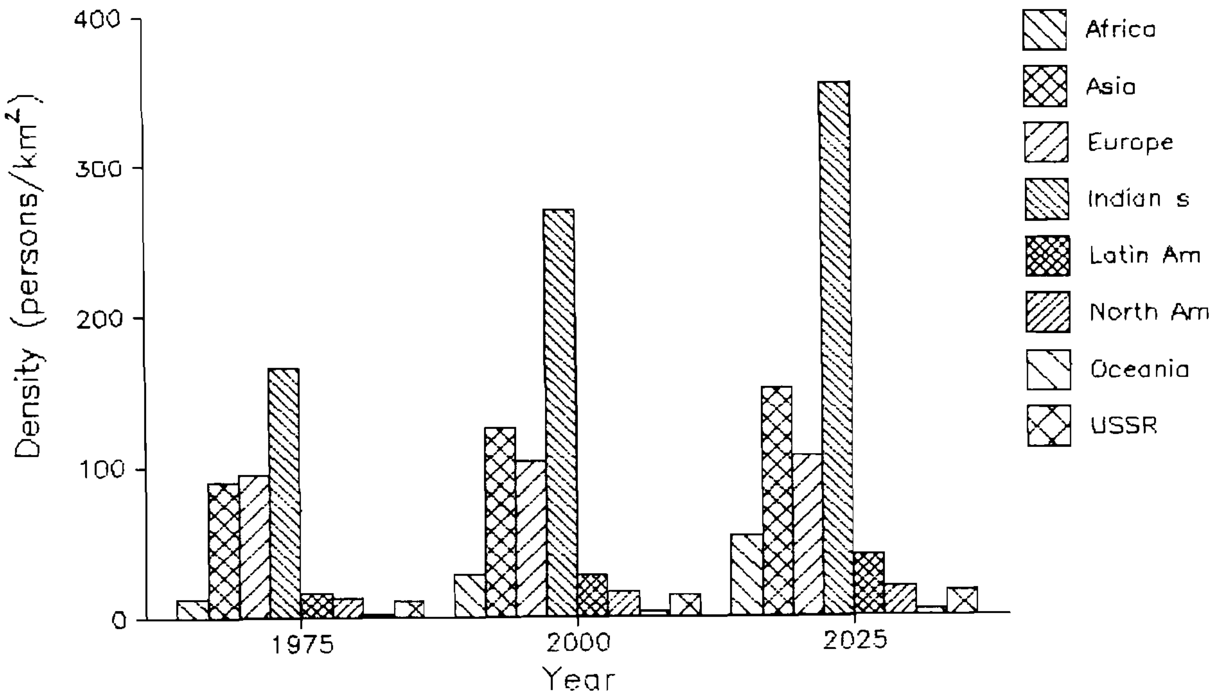

Figure 2.6 Density (medium) - United Nations

2.3.3. Method

The 1982 estimates were developed using the component projection method for all countries with a population generally of about 300,000 or more as of 1980. For smaller countries, the projections were prepared for the total population only, by applying assumed growth rates.

The age-sex structure of each country, for the base year 1980, was estimated as the first step in making population projections, where accurate demographic data were insufficient.

2.3.4. Assumptions

Assumptions concerning fertility, mortality, and migration are made for each country, determined by the specific circumstance and conditions of each country and the region in general. All projections assume no surprises or discontinuities in the projected trends.

For mortality, the trends assume a gain in each five-year period of a 2.5 year increase in life expectancy at birth, with a slowdown in the gain after reaching an expectancy of 62.5 years. Adjustments up or down are made as needed for developing countries. For developed countries where life expectancy is already high, maximum life expectancy at birth is assumed to be 70 years for males and 82.5 years for females. Life expectancy at the global level is expected to increase from 57.3 years in 1975-80 to 63.5 years in 1995-2000 to 70.0 years in 2020-25 for the medium variant projection.

Fertility assumptions are developed based on anticipated changes in the socioeconomic structure and cultural values of the society as well as the expected impacts of family planning programs.

The current projections (medium variant) assume a continued decline in fertility for the world (measured as the gross reproductive rate) from 1.91 in 1975-80 to 1.44 in 1995-2000 to 1.13 in 2020-25. In 1975-80, Africa, South Asia, and Latin America had gross reproductive rates of 3.18, 2.55, and 2.20, respectively. Rates for Africa and Latin America are assumed to decline to 1.57 and 1.18 respectively by 2025 with South Asia being approximately at replacement level.

The projections assume that net migration will slowly move towards zero, except for countries where present evidence suggests continuation of a current trend (e.g., Mexico and the United States).

Four variant projections -- high, medium, low and constant -- were developed. These were made by combining the key variables as follows:

Variant	*Fertility*	*Mortality*	*Migration*
High	High	Medium	High
Medium	Medium	Medium	Medium
Low	Low	Medium	Low
Constant	Constant	Medium	Medium

In 1975-80, the annual rate of growth of total world population was estimated to be 1.80 percent, down from the middle of the 1960s when the annual rate of growth was estimated to be 2.0 percent annually. The medium variant assumes that the growth rate will be 1.5 percent by 1995-2000 and less than 1.0 percent by 2020-25. The rates for the high and low variants are assumed to be 1.74 percent and 1.29 percent in 1995-2000 and 1.33 percent and 0.59 percent in 2020-25, respectively. For the less developed regions the 1975-80 growth rate of 2.14 percent (it was 2.14 percent in 1950-55) is expected to decline to 1.8 percent by 1995-2000 and to 1.1 percent by 2020-25.

2.3.5. Conclusions

Table 2.2 presents projections for the world and eight regions. These data are graphed in Figures 2.4 through 2.6. Low, medium, and high variant projections are presented.

In 1980 the more developed regions of the world accounted for 1.16 billion people, approximately 25 percent of the world total; by 2025 this is expected to reach 1.4 billion people, about 17 percent of the world total. The average annual growth rate was 0.7 percent in 1980 and is projected to decline to 0.5 percent by 2000 and 0.3 percent by 2025 (for the medium variant).

In 1980 the less developed regions of the world accounted for 3.33 billion people, approximately 75 percent of the world total; by 2025 this is expected to reach 7.6 billion people, about 83 percent of the world total. The average annual growth rate was 2.1 percent in 1980 and is projected to decline to 1.7 percent by 2000 and 1.1 percent by 2025 (for the medium variant).

The less developed regions will contribute the overwhelming majority of people to the future population increase (95 percent of the increase in world population by 2025). Africa exhibits the highest average annual rate of population increase, and in absolute terms South Asia will show the largest population growth up to 2025.

Demographic trends in China dictate the trends for the East Asian region as a whole. This reinforces the notion that there are eight to ten countries in the less developed regions which dominate any population forecast due to current population size and growth rates.

While the global growth rate is projected to decline, the annual increment added to the world population will continue to increase, peaking at approximately 89 million around 2000 and declining to approximately 74 million by 2025 (it was approximately 77 million in 1975).

2.4. Frejka: Long-Term Prospects for World Population Growth

2.4.1. Introduction

This projection represents an update of the projections prepared by Frejka (1973) where he first introduced the method of using the assumed date of attainment of replacement level fertility as the major determinant of the projection. It was published in Population and Development Review 7. No. 3, (September 1981) pp. 489-511.

2.4.2. Scale and resolution

Projections are made for eight areas of the world: four developing (East Asia, South Asia, Africa, and Latin America) and four developed (Europe, North America, U.S.S.R, and Oceania). These generally correspond with the "major areas" used by the United Nations and defined for global environmental studies in this project.

The primary source of data was the 1978 United Nations figures (published in 1980), supplemented with data from the U.S. Bureau of the Census, the U.S. National Academy of Science Country Reports, World Fertility Survey Reports, and national statistical documents. The baseline data are for the period 1975-80. Projections are made for 1980, 1990, 2000, 2050, 2100, and 2150.

2.4.3. Method

The component method of projection is used. The innovation introduced by Frejka (1973) is to calculate growth rates based on assumptions about the date of attainment of replacement level fertility. Four time periods for achieving replacement level fertility are used. These are: 1980-85, 2000-05, 2020-25, and 2040-45. Only a single trend of mortality is assumed. A straight line interpolation between the assumed attainment of replacement level fertility and the base year of 1980 is utilized. Model life tables developed by Coale and Demeny (1966) are used in the calculations.

2.4.4. Assumptions

The key assumption is that of the date of attainment of replacement level fertility -- which is the major determinant of the projections. The procedure of assuming that replacement level fertility will be reached at some future time decouples the projection from strict adherence to trends of the recent past concerning fertility and mortality. It provides an explicit input of "expert opinion" concerning future periods during which replacement level fertility may be achieved. This allows one to know the judgement of the

Table 2.3 Frejka (1981), Summary Population Data

	Area		Population (10e6)				Factor Increase				Density (p/km^2)			
	(10e6 km^2)	Variants	1980	2000	2050	2100	1980	2000	2050	2100	1980	2000	2050	2100
Africa	30	High	469	830	2150	2690	1	1.8	4.6	5.7	16	28	72	90
		Medium	469	815	1868	2229	1	1.7	4.0	4.8	16	27	62	74
		Low	469	800	1586	1768	1	1.7	3.4	3.8	16	27	53	59
Asia-East	12	High	1135	1497	1990	2035	1	1.3	1.8	1.8	95	125	166	170
		Medium	1135	1464	1894	1926	1	1.3	1.7	1.7	95	122	158	161
		Low	1135	1431	1797	1816	1	1.3	1.6	1.6	95	119	150	151
Asia South	16	High	1421	2304	4646	5337	1	1.6	3.3	3.8	89	144	290	334
		Medium	1421	2253	4107	4583	1	1.6	2.9	3.2	89	141	257	286
		Low	1421	2202	3568	3829	1	1.5	2.5	2.7	89	138	223	239
Europe	5	High	482	520	552	553	1	1.1	1.1	1.1	96	104	110	111
		Medium	482	502	484	473	1	1.0	1.0	1.0	96	100	97	95
		Low	482	483	415	393	1	1.0	.9	.8	96	97	83	79
Latin America	20	High	369	587	969	1015	1	1.6	2.6	2.8	18	29	48	51
		Medium	369	573	909	943	1	1.6	2.5	2.6	18	29	45	47
		Low	369	559	848	870	1	1.5	2.3	2.4	18	28	42	44
North America	18	High	243	272	287	288	1	1.1	1.2	1.2	14	15	16	16
		Medium	243	262	252	247	1	1.1	1.0	1.0	14	15	14	14
		Low	243	251	216	206	1	1.0	.9	.8	14	14	12	11
Oceania	8	High	22	27	34	34	1	1.2	1.5	1.5	3	3	4	4
		Medium	22	26	32	32	1	1.2	1.5	1.5	3	3	4	4
		Low	22	26	30	29	1	1.2	1.4	1.3	3	3	4	4
USSR	22	High	266	316	387	396	1	1.2	1.5	1.5	12	14	18	18
		Medium	266	305	345	347	1	1.1	1.3	1.3	12	14	16	16
		Low	266	294	302	297	1	1.1	1.1	1.1	12	13	14	14
World	131	High	4407	6353	11015	12348	1	1.4	2.5	2.8	34	48	84	94
		Medium	4407	6200	9889	10778	1	1.4	2.2	2.4	34	47	75	82
		Low	4407	6046	8762	9208	1	1.4	2.0	2.1	34	46	67	70

Footnotes: (1) High and Low variant from Table 7. (Frejka, 1981:508-509)
(2) Medium variant calculated as mid pt. between High and Low
(3) Not possible to conform to the 8 regions formulated for this study

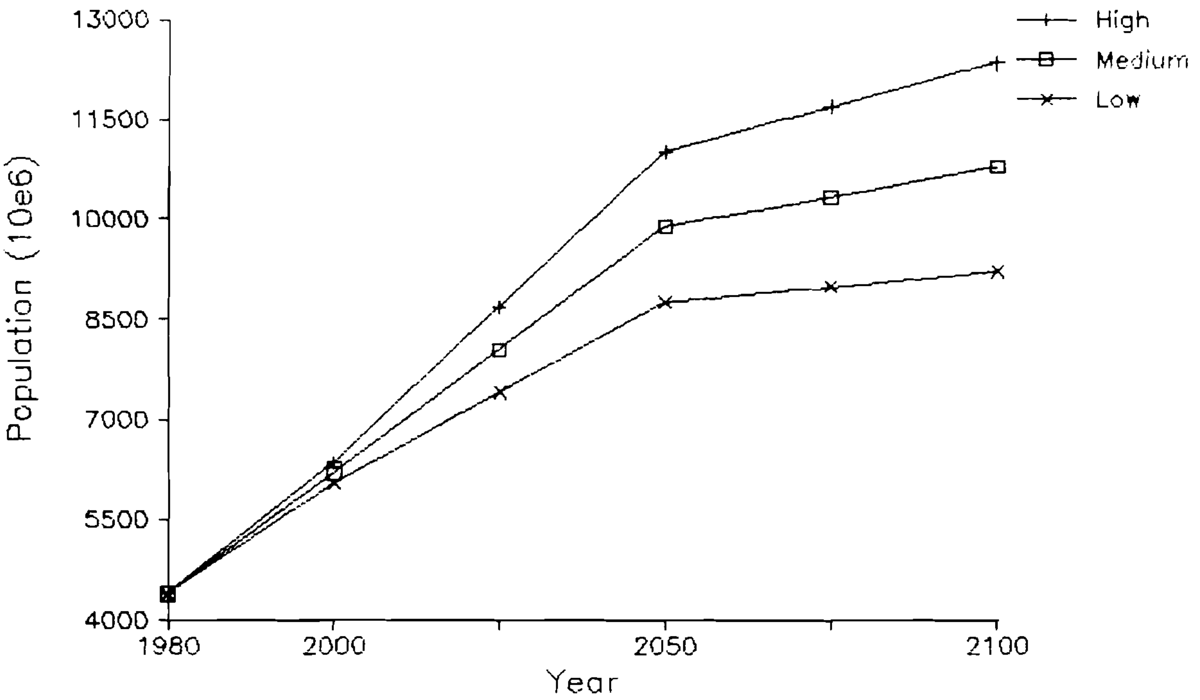

Figure 2.7 World population - Frejka

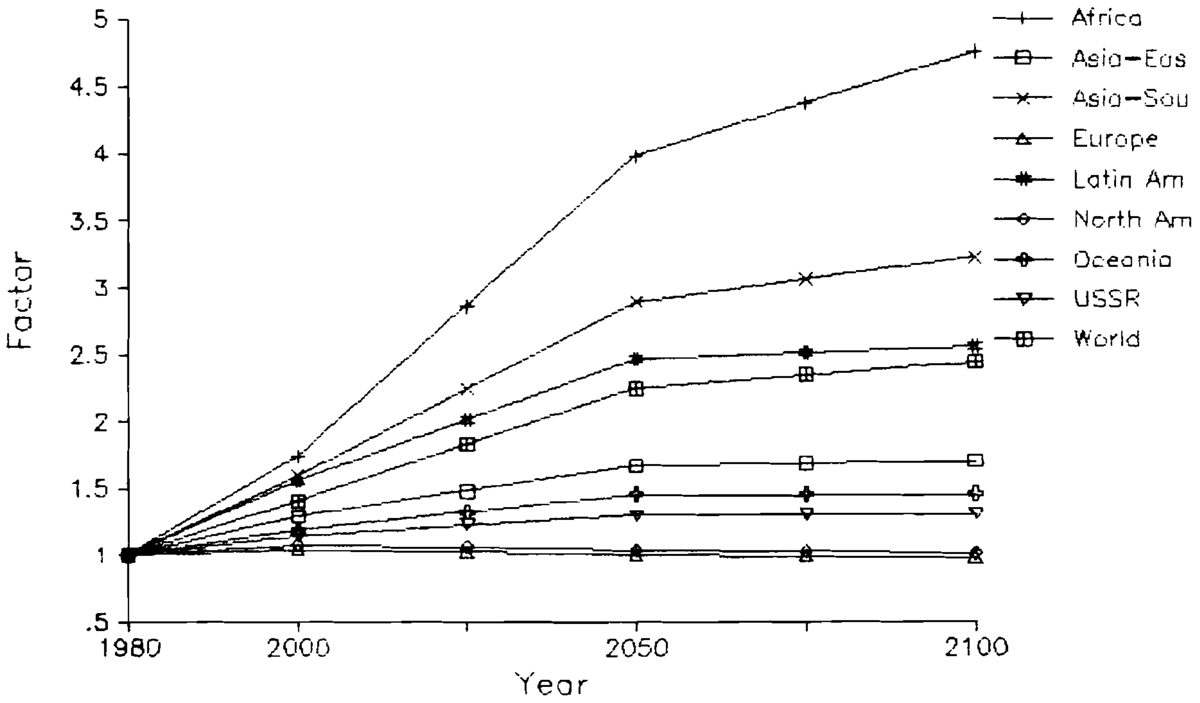

Figure 2.8 Factor increase (medium) - Frejka

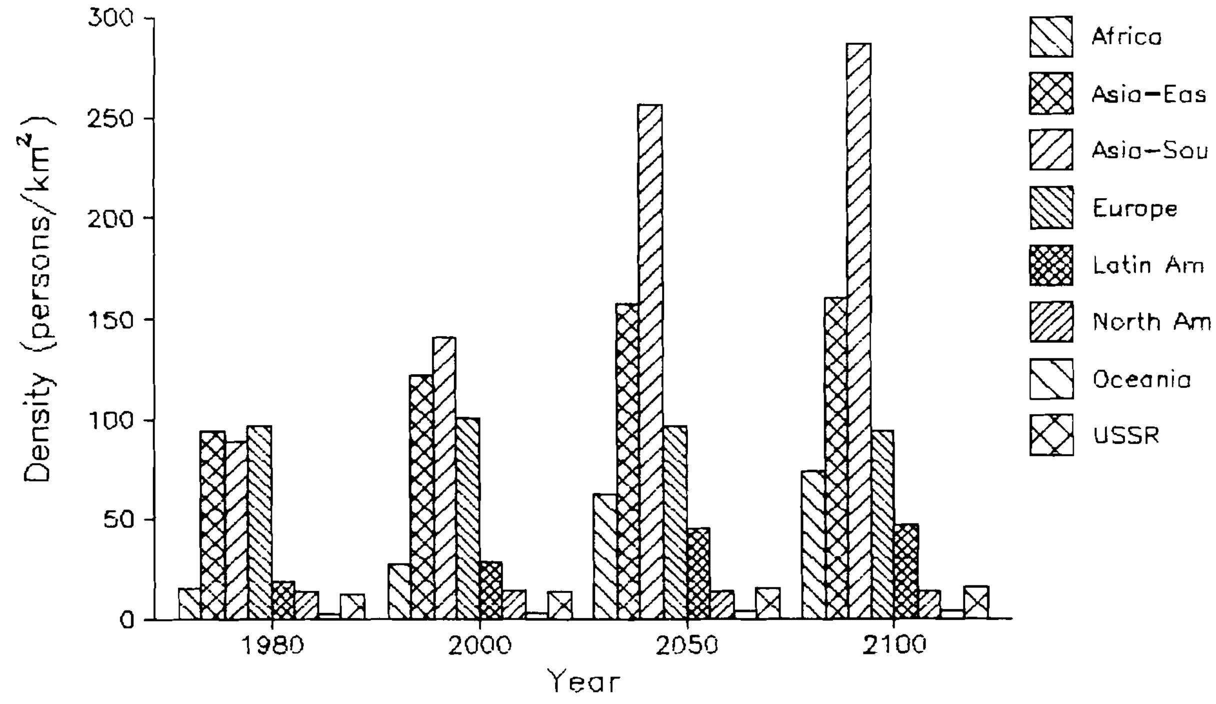

Figure 2.9 Density (medium) - Frejka

demographer and to learn about probable high, medium, and low variant future world projections.

For example, assuming that replacement level fertility is achieved between 1980-85, something we know in 1985 is not true, allows one to establish a lower limit for actual future world population. To quote Frejka, "[I]t appears almost certain that in the year 2000 the world will be larger than 5.3 billion... it is likely that in 2100 the world population will exceed 7.0 billion..."(Frejka, 1981:493).

Similarly, the projection assuming replacement level fertility is attained by 2040-45 represents a high trajectory compared with recent trends. Therefore, it is probable according to Frejka, that in the year 2000 the world population will not exceed 6.4 billion people and in 2100 it will not exceed 13.4 billion people. As with the other projections we have considered, the projections decrease in precision the further one extends them into the future, general having good predictive power in the near futures (15-20 years).

2.4.5. Conclusions

Table 2.3 presents projections for the world and for eight regions. These data are graphed in Figures 2.7 through 2.9. The figures presented by Frejka in his Tables 5, 6, and 7, have been aggregated into high, medium, and low variant projections.

The main conclusions of the projections are that "By the year 2000 the world population is likely to grow by about 40 percent from its present level of 4.4 billion people to somewhat over 6.0 billion" By 2100 the world population is not likely to exceed 13 billion people.

2.5. World Bank: World Development Report 1984 and World Population Projections 1984

2.5.1. Introduction

The World Bank's annual World Development Reports are a reference guide to the world economy: an overview of the state of development, and a detailed analysis of a related topic. The 1984 issue highlights five principal aspects of population change and economic development: demographic change and public policy; the consequences of population change; policies that reduce population growth; family planning programs; and policy agendas for specific countries. The World Population Projections 1984 presents details of the Report's projections and of the methods and assumptions on which they are based. These two books should be used together because the projections in the Projections are geographically more comprehensive and extend farther into the future, while the Report provides extensive background information and analysis. They are published as: World Development Report 1984. International Bank for Reconstruction and Development/The World Bank, 1984. (New York: Oxford University Press) and World Population Projections 1984: Short- and Long-Term Estimates by Age and Sex with Related Demographic Statistics. My T. Vu, 1984. (Washington, D.C.: The World Bank). The Report and Projections are referred to below collectively as "the World Bank's projections."

2.5.2. Scale and resolution

The Report presents two tables of projections: one shows a single estimate for each of 126 countries, for 1990 and 2000. The other shows three estimates for each of 99 countries, for 2000 and 2050. The Projections give detailed projections (one trajectory only) by age and sex for 185 countries or other geo-political entities (e.g., Greenland) at 5- year intervals from 1980 to 2025 and at 25-year intervals for a 175-year period (to 2155) during which stationarity is assumed to occur everywhere (the time when stationarity occurs is not stated).

2.5.3. Method

The cohort-component method was used to generate the tables in the Report and the Projections. The base year for these projections is 1980; sources for numbers included the UN, national censuses, the US Bureau of the Census, and the Bank. Age and sex distributions come from the UN. Base year mortality levels are from the UN except where Bank analysis indicated a difference. Because of recent evidence [not cited] linking female education and childhood mortality, the Projections' authors divided all countries into a "low" group (<70% female primary enrollment) and a "high" group (>70%) and then used these levels to estimate mortality trends. Principal sources for base fertility rates were the U.N.'s revised projections, the Bank's economic reports, the World Fertility Survey, and the U.S. Bureau of the Census. The year at which the net reproduction rate is likely to reach unity was calculated for each country (assumed to be between 2000 and 2050). The country's status regarding family planning was estimated on the basis of the percentage of married women 15-44 years of age who were currently using some method of contraception. The total fertility rate in the year in which NRR = 1 was estimated on the basis of the country's mortality level in that year. In those countries in which fertility is presently below replacement level, it was assumed that fertility would rise back up to unity. Presumably this assumption was made to make the projections consistent; no reasons for fertility to go back up to unity were given.

Table 2.4 World Bank (1984), Summary Population Data

	Area	Population (10e6)						Factor Increase					
	10e6 km^2	1980	2000	2025	2055	2080	2155	1980	2000	2025	2055	2080	2155
Africa	37	632	1160	2040	2923	3317	3554	1	1.8	3.2	4.6	5.2	5.6
Asia	16	1503	1919	2343	2518	2574	2614	1	1.3	1.6	1.7	1.7	1.7
Europe	5	484	515	540	543	550	552	1	1.1	1.1	1.1	1.1	1.1
Indian sub-cont	5	921	1392	1952	2415	2573	2756	1	1.5	2.1	2.6	2.8	3.0
Latin America	20	356	535	731	854	903	934	1	1.5	2.1	2.4	2.5	2.6
North America	18	254	292	323	324	325	326	1	1.1	1.3	1.3	1.3	1.3
Oceania	8	20	24	28	30	31	31	1	1.2	1.4	1.5	1.6	1.6
USSR	22	265	306	339	361	372	378	1	1.2	1.3	1.4	1.4	1.4
World	131	4435	6145	8297	9778	10644	11145	1	1.4	1.9	2.2	2.4	2.5

	Area	Density (persons/km^2)					
	10e6 km^2	1980	2000	2025	2055	2080	2155
Africa	37	17	31	55	79	90	96
Asia	16	94	120	146	157	161	163
Europe	5	97	103	108	109	110	110
Indian sub-cont	5	184	278	390	483	515	551
Latin America	20	18	27	37	43	45	47
North America	18	14	16	18	18	18	18
Oceania	8	3	3	4	4	4	4
USSR	22	12	14	15	16	17	17
World	131	34	47	63	75	81	85

Notes: Figures for the World, North America, Latin America, USSR, and Europe are from tables in the Projections. Figures for the Indian sub-continent, Oceania, Asia, and Africa were calculated to match the regional list of this study.

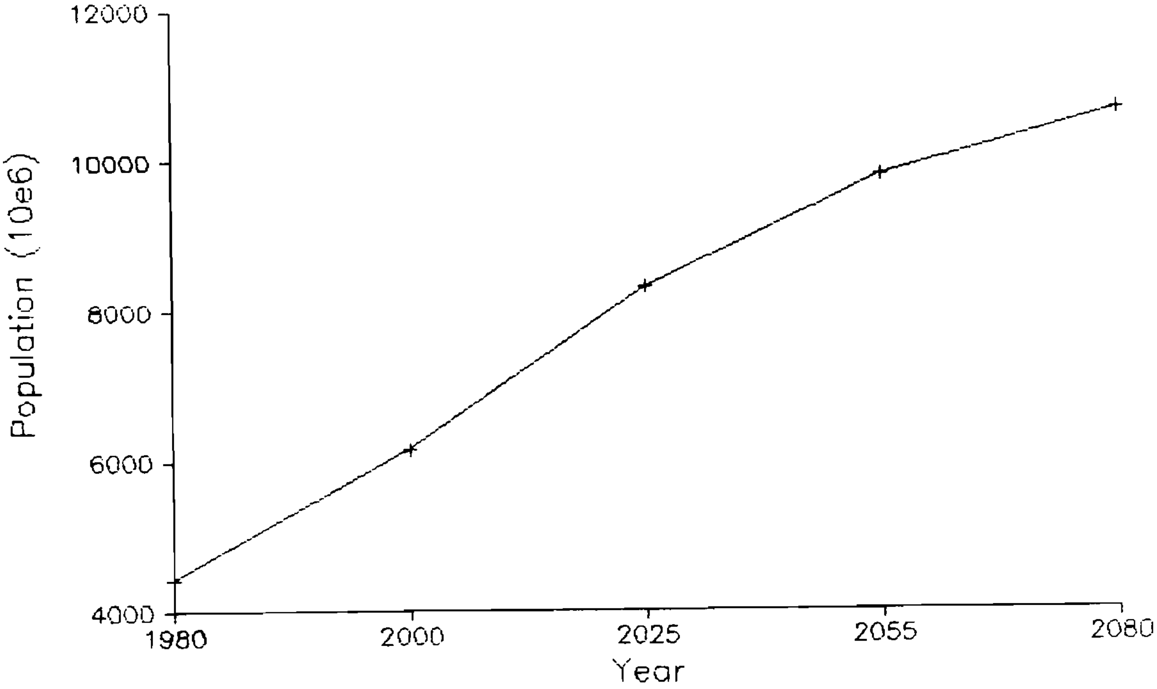

Figure 2.10 World population - World Bank

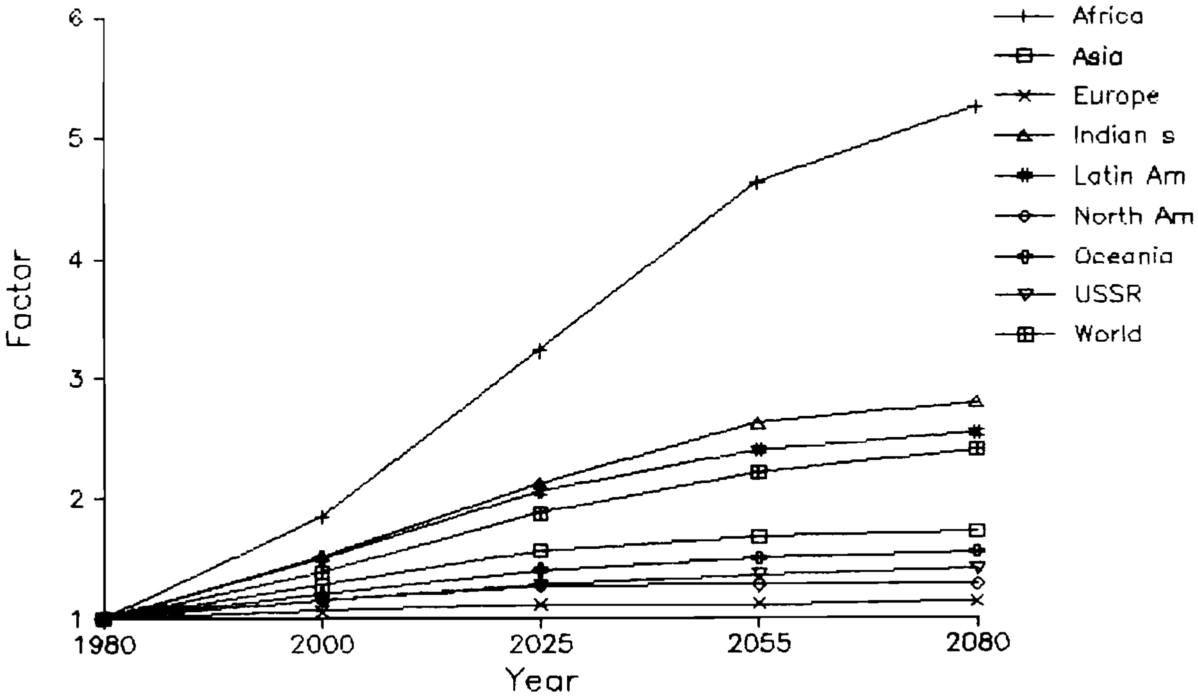

Figure 2.11 Factor increase - World Bank

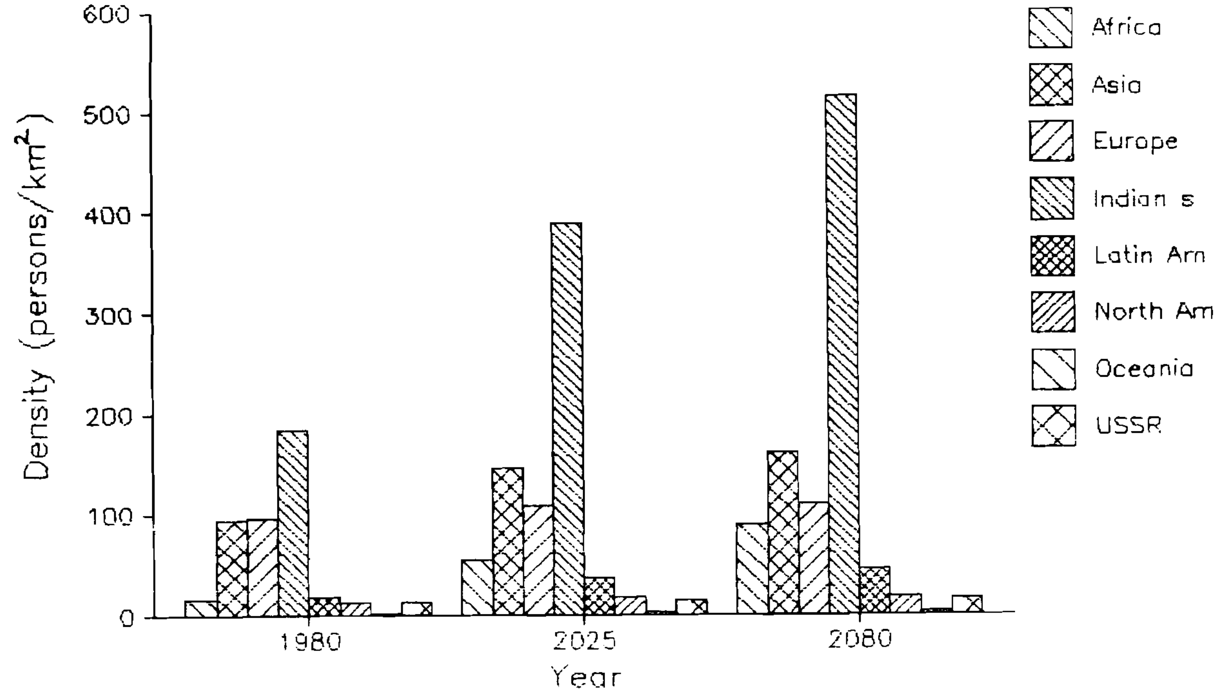

Figure 2.12 Density - World Bank

Revised U.N. population projections and data also from the U.S. Bureau of the Census and the Bank itself were used to estimate international migration; for most economies this was assumed to be zero by 2000. (The leading 10 receiving countries and the leading 10 sending countries in 1980-85 are listed in the introduction to the Projections.)

2.5.4. Conclusions

Table 2.4 and Figures 2.10 through 2.12 summarize the data from the Projections. According to them, the total world population could increase to 6.145 billion in 2000 and to approximately 10 billion by 2075 (2080 is the closest year calculated, with population of 10.644 billion). Less developed regions may account for 80% of the population in 2000 and 86% in 2050. Persons with low and lower-middle income (the Report defines these) -- at least two-thirds the 1985 population -- would constitute 82% of world population in 2000 and 90% by 2050. The estimated hypothetical stationary global population is 11.2 billion. When this number would be achieved is not stated, but the estimate for 2155 is 11.145 billion (Vu, 1984: passim). By 2000 there may be 25 urban agglomerations with population more than 10 million each (World Bank, 1984:68).

Paul Demeny (1984) has made a critique of the projections presented in the 1983 version of the Report. He claims that the Bank's projections are "poorly known" because of "limited access" [limited by what or whom, and to whom not stated] although he later characterizes the distribution of the Reports as "wide." He praises the preparation of individual country projections because it "enhances the scope for critical examination [and] ... according to criteria other than geographic contiguity" but he also comments that the table of population trends revised each year by the Bank for these Reports "lacks detail" and "is awkward in form" (Demeny, 1984:105) -- a complaint that may have been remedied by the 1984 Report's focus on population and by the Projections.

Although his point is well taken that projections a century and a half or more into the future are so remote that it may be difficult to be concerned about them, such projections -- especially the nearer long-term points, such as 50-75-100 years, calculated "along the way" -- are surely more useful to planners and policy-makers than those for only 30 years or so, in spite of the unavoidably increasing inaccuracy of projections with time.

While the 1984 Report gives three variants (for the years 2000 and 2050, for 99 countries) the Projections give only one projection (no low-middle-high). While this allows "uncluttered focus on a single hypothetical reference projection" (Demeny, 1984:105), it does not lend itself to gauging how changes in population parameters or in economic and social policies might alter the picture (the Projections [p. xvii] do caution readers, at least regarding stationarity, that "no account is taken of the effects that... future female education level and family planning might have"). A useful caveat that Demeny makes regarding stationarity is "...much of the projected growth is bound to occur in the decades immediately ahead, long before a stationary state is supposed to be universally attained" (Demeny, 1984:124), a fact to which the figures by themselves do not call attention (or at least not without close scrutiny).

2.6. C.E.Q.: Global 2000 Report to the President: Entering the 21st Century

2.6.1. Introduction

"Global 2000" is a study of the probable changes in the world's population, natural resources, and environment through the end of this century made by agencies of the US Government at the behest of President Carter, starting in 1977. It is the most comprehensive examination of the future by the US Government and may be at least as well known for the reaction it provoked as for its content. Two projections of population were prepared, one by the US Census Bureau and the other by the Community and Family Study Center (CFSC) of the University of Chicago; the CFSC's projections were included because it was felt that they provide a useful illustration of how population estimates are affected by differences in basic assumptions about such factors as fertility rates.

The Census Bureau projections (rather than those of CFSC) are used in other sections of Global 2000 where population numbers are needed, because they are US Government data and this is a US Government report. This study is published as Global 2000 Report to the President: Entering the 21st Century vol. 2, Technical Report (Washington, D.C.: Government Printing Office, 1980), and vol. 3, Documentation on the Government's Global Sectoral Models: the Government's "Global Model" (Washington, D.C.: Government Printing Office, 1981).

2.6.2. Scale and resolution

Projections were made for the world; for five major regions (Africa; Asia and Oceania; Latin America; USSR and Eastern Europe; Northern America, Western Europe, Japan, Australia, and New Zealand); for 12 less developed countries (which represent about 75% of that category's 1975 population); and for five developed countries or regions (Eastern Europe, Western Europe, USSR, USA, and Japan). Three trajectories (high, medium, and low) were produced for every five years 1975-2000. (The Census Bureau later made a single-trajectory projection to 2100; this was not integrated with its earlier ones or those of CFSC.)

Table 2.5 Global 2000, U.S. Bureau of the Census (USCB) (1980)
Summary Population Data

	Area (10e6 km^2)	Variants	Population (10e6) 1975	1980	1985	1990	1995	2000	Factor Increase (1975=1) 1980	1985	1990	1995	2000	Density (p/km^2) 1975	1980	1985	1990	1995	2000
Africa	30	High	399	460	534	622	727	847	1.2	1.3	1.6	1.8	2.1	13	15	18	21	24	28
		Medium	399	459	531	614	709	814	1.2	1.3	1.5	1.8	2.0	13	15	18	20	24	27
		Low	399	458	525	599	678	759	1.1	1.3	1.5	1.7	1.9	13	15	18	20	23	25
Asia and Oceania	36	High	2318	2580	2861	3185	3551	3951	1.1	1.2	1.4	1.5	1.7	64	72	79	88	99	110
		Medium	2274	2508	2755	3025	3320	3630	1.1	1.2	1.3	1.5	1.6	63	70	77	84	92	101
		Low	2228	2432	2651	2882	3121	3359	1.1	1.2	1.3	1.4	1.5	62	68	74	80	87	93
Latin America	20	High	325	377	439	510	590	678	1.2	1.4	1.6	1.8	2.1	16	19	22	26	30	34
		Medium	325	375	432	497	565	637	1.2	1.3	1.5	1.7	2.0	16	19	22	25	28	32
		Low	324	371	421	474	527	581	1.1	1.3	1.5	1.6	1.8	16	19	21	24	26	29
USSR and Eastern Europe	23	High	384	402	422	442	460	480	1.0	1.1	1.2	1.2	1.3	17	17	18	19	20	21
		Medium	384	401	418	434	448	460	1.0	1.1	1.1	1.2	1.2	17	17	18	19	19	20
		Low	384	399	414	426	435	442	1.0	1.1	1.1	1.1	1.2	17	17	18	19	19	19
North America, Western Europe, Japan, Australia and New Zealand	22	High	708	730	757	786	815	842	1.0	1.1	1.1	1.2	1.2	32	33	34	36	37	38
		Medium	708	728	749	771	792	809	1.0	1.1	1.1	1.1	1.1	32	33	34	35	36	37
		Low	708	725	743	759	772	781	1.0	1.0	1.1	1.1	1.1	32	33	34	35	35	36
World	131	High	4134	4549	5013	5545	6143	6798	1.1	1.2	1.3	1.5	1.6	32	35	38	42	47	52
		Medium	4090	4470	4885	5340	5834	6351	1.1	1.2	1.3	1.4	1.6	31	34	37	41	45	48
		Low	4043	4384	4754	5140	5533	5922	1.1	1.2	1.3	1.4	1.5	31	33	36	39	42	45

Table 2.6 Global 2000, Community and Family Study Center (CFSC) (1980)
Summary Population Data

	Area		Population (10e6)						Factor Increase (1975=1)					Density (p/km^2)					
	(10e6 km^2)	Variants	1975	1980	1985	1990	1995	2000	1980	1985	1990	1995	2000	1975	1980	1985	1990	1995	2000
Africa	30	High	402	465	536	616	707	811	1.2	1.3	1.5	1.8	2.0	13	16	18	21	24	27
		Medium	402	465	535	612	694	781	1.2	1.3	1.5	1.7	1.9	13	16	18	20	23	26
		Low	402	465	535	611	690	770	1.2	1.3	1.5	1.7	1.9	13	16	18	20	23	26
Asia and Oceania	36	High	2201	2418	2641	2866	3093	3325	1.1	1.2	1.3	1.4	1.5	61	67	73	80	86	92
		Medium	2201	2418	2640	2859	3073	3281	1.1	1.2	1.3	1.4	1.5	61	67	73	79	85	91
		Low	2201	2417	2634	2834	3020	3192	1.1	1.2	1.3	1.4	1.5	61	67	73	79	84	89
Latin America	20	High	312	357	405	456	510	564	1.1	1.3	1.5	1.6	1.8	16	18	20	23	26	28
		Medium	312	357	404	454	503	552	1.1	1.3	1.5	1.6	1.8	16	18	20	23	25	28
		Low	312	356	403	449	493	533	1.1	1.3	1.4	1.6	1.7	16	18	20	22	25	27
USSR and Eastern Europe	23	High	384	402	419	434	447	458	1.0	1.1	1.1	1.2	1.2	17	17	18	19	19	20
		Medium	384	402	419	434	447	457	1.0	1.1	1.1	1.2	1.2	17	17	18	19	19	20
		Low	384	402	418	432	442	451	1.0	1.1	1.1	1.2	1.2	17	17	18	19	19	20
North America, Western Europe, Japan, Australia and New Zealand	22	High	714	738	761	780	797	815	1.0	1.1	1.1	1.1	1.1	32	34	35	35	36	37
		Medium	714	738	761	779	796	812	1.0	1.1	1.1	1.1	1.1	32	34	35	35	36	37
		Low	714	738	760	777	792	805	1.0	1.1	1.1	1.1	1.1	32	34	35	35	36	37
World	131	High	4015	4380	4762	5152	5553	5974	1.1	1.2	1.3	1.4	1.5	31	33	36	39	42	46
		Medium	4015	4380	4759	5138	5513	5883	1.1	1.2	1.3	1.4	1.5	31	33	36	39	42	45
		Low	4015	4379	4749	5102	5437	5752	1.1	1.2	1.3	1.4	1.4	31	33	36	39	42	44

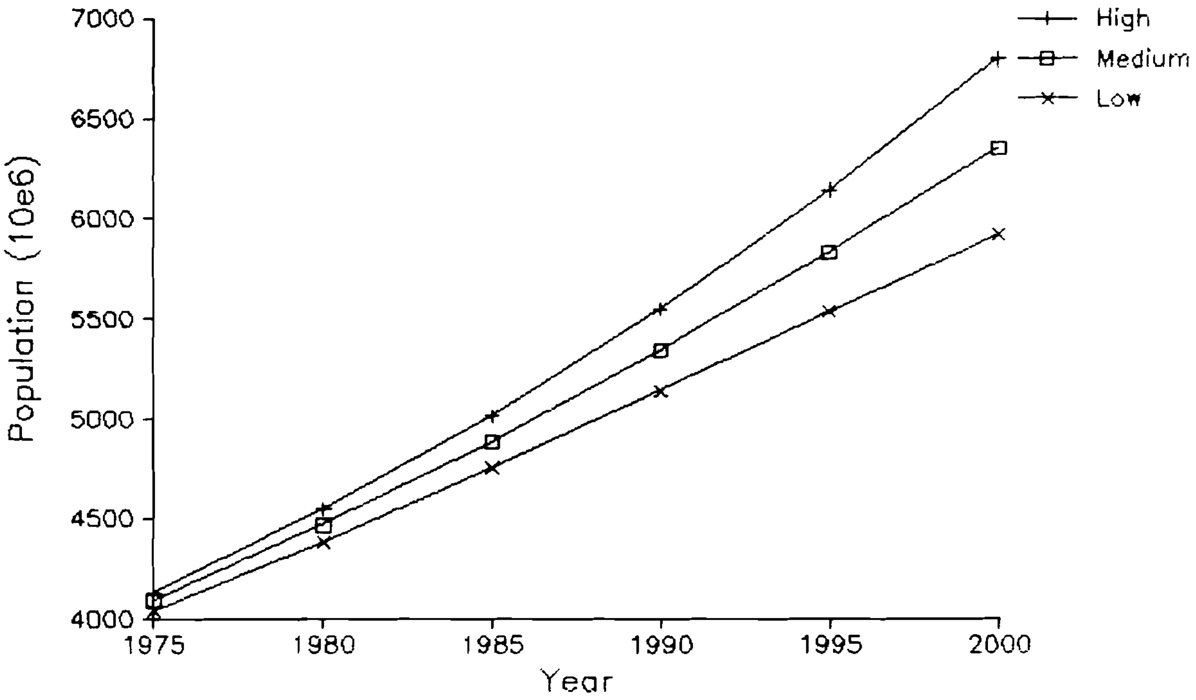

Figure 2.13 World population - Global 2000, USCB

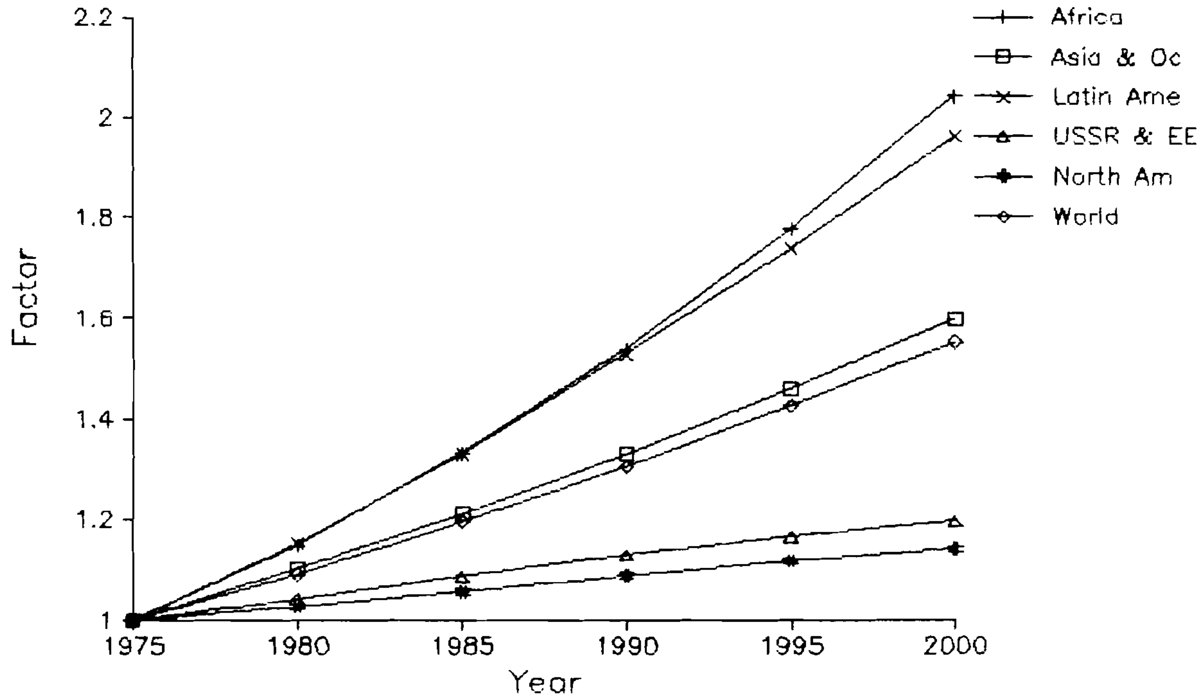

Figure 2.14 Factor increase (medium) - Global 2000, USCB

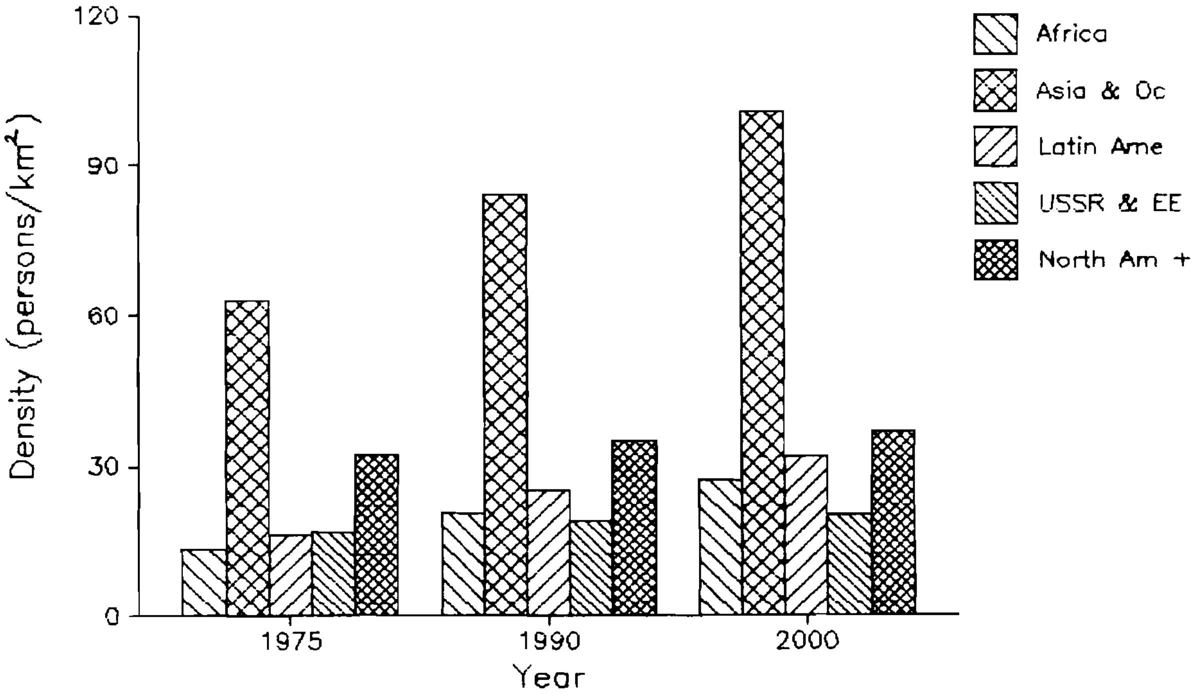

Figure 2.15 Density (medium) - Global 2000, USCB

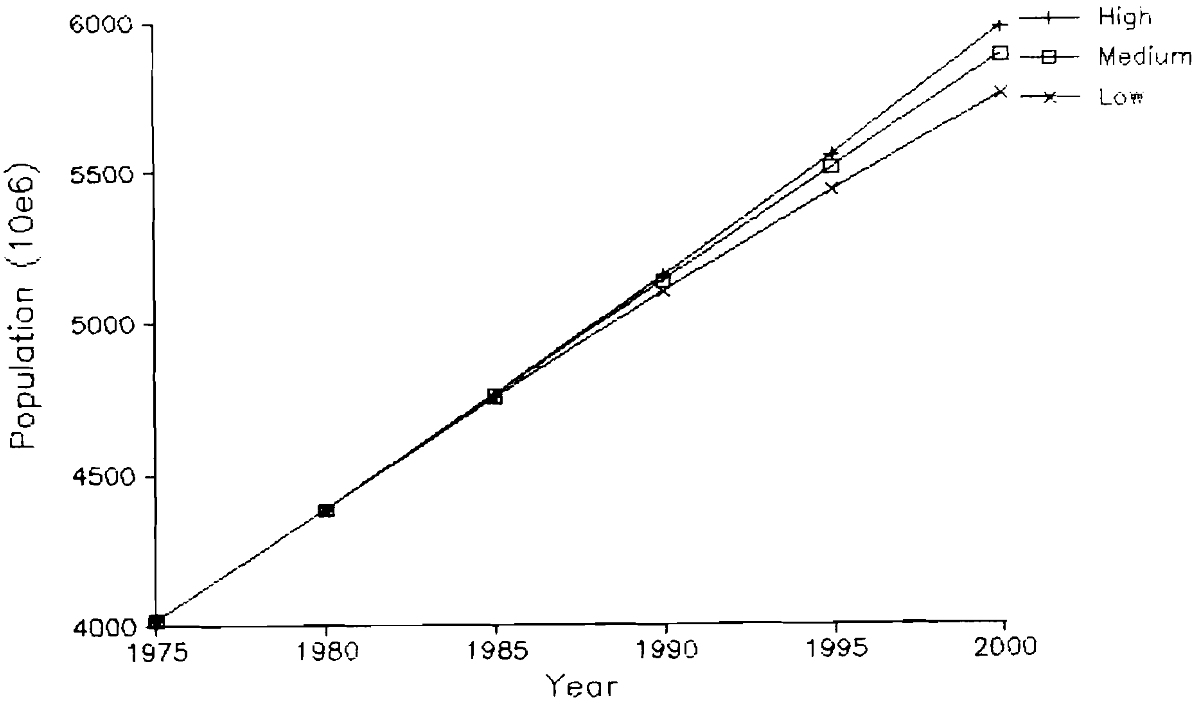

Figure 2.16 World population - Global 2000, CFSC

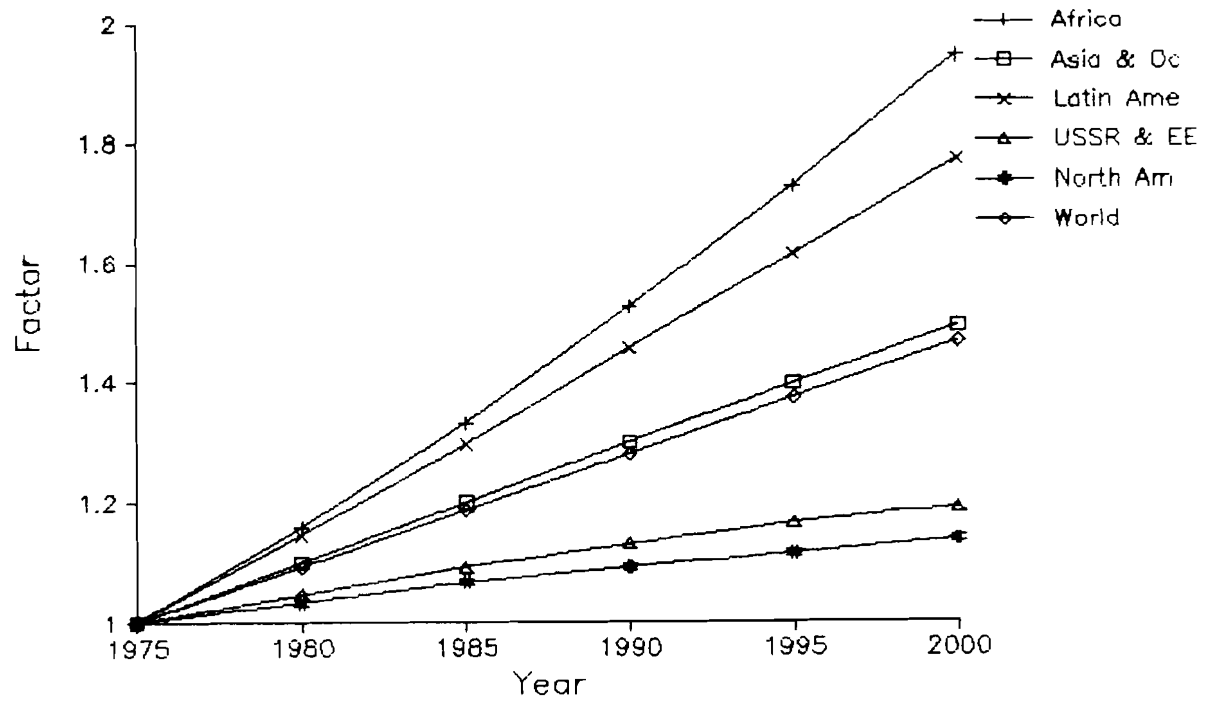

Figure 2.17 Factor increase (medium) - Global 2000, CFSC

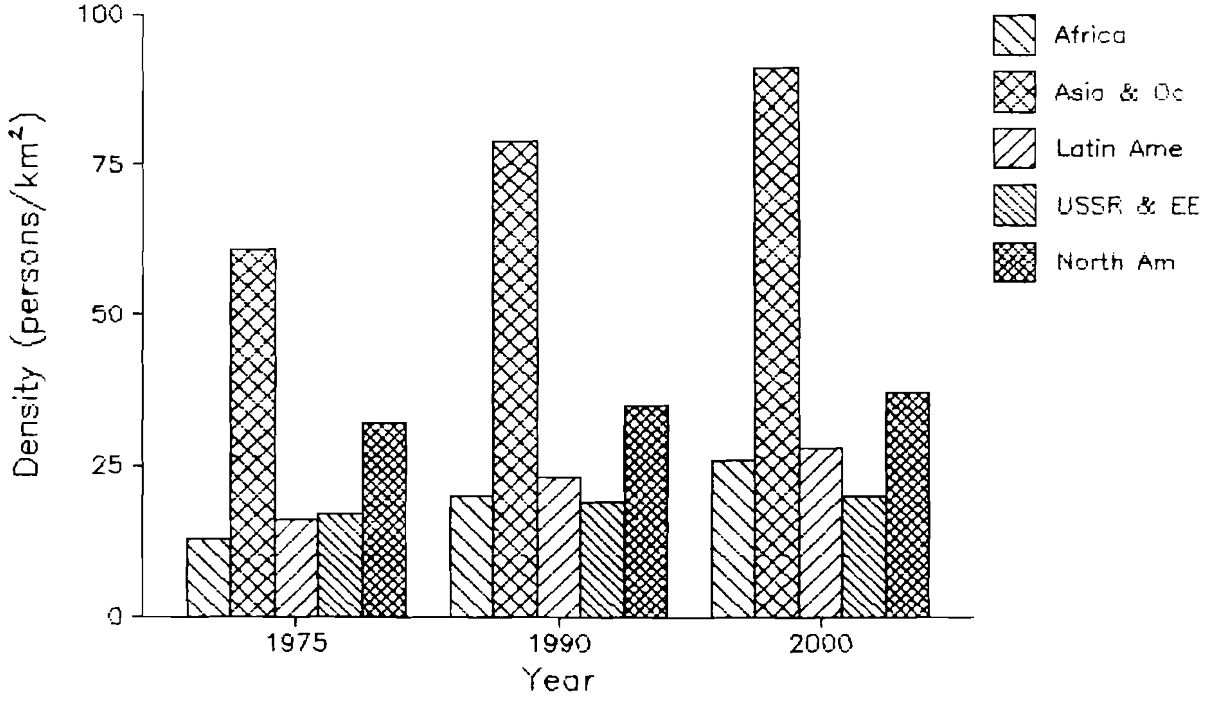

Figure 2.18 Density (medium) - Global 2000, CFSC

2.6.3. Method

Both the Census Bureau and the CFSC used the standard component method. In making its projections, the Census Bureau assumed that:

(a) the less developed countries will continue to progress;

(b) this socio-economic development will be accompanied by a decline in fertility;

(c) knowledge that families can be limited, and methods to do so, will become better known and better used;

(d) almost all countries will be making family planning programs available to an appreciable portion of their population by 2000.

The CFSC made these assumptions:

(a) Throughout the world the need to reduce the pace of population growth is being increasingly felt, even in nations where this has not been officially recognized;

(b) The present pace of economic development and modernization will bring down fertility gradually to replacement level;

(c) The pace of fertility decline being directly influenced by family planning programs, the larger the investment in such programs, the more whole-hearted the official support, and the greater the public accessibility to such services, the faster will be the fertility decline.

(d) By the end of the century, every nation on earth may be expected to have at least some kind of a substantial family planning effort, and these programs may be expected to have a substantial impact in reducing fertility faster than would otherwise be the case.

The CFSC identified each country for which projections were made as having strong, moderate, weak, or no family planning efforts. Its high projections assume no intensification in current family planning status; the medium projections assume "some" increase, and the low projections assume "a considerable" increase. The Census Bureau used life table estimates to develop mortality estimates. No specific life expectancy for any certain time is stated.

CFSC's mortality assumptions are those made by the World Bank, which rescheduled UN figures to reflect slower-than-anticipated declines in mortality [no citations given].

2.6.4. Conclusions

The average annual growth rate of the Census Bureau's medium series projections stays at 1.8% until it reaches 1.7% in 1995-2000. CFSC's medium series's average annual growth rate declines gradually from 1.82% in 1975-79 to 1.34% in 1995-99.

The Census Bureau's projections are higher than those of CFSC: high is 14% higher, medium is 8% higher, and low is 3% higher (see Tables 2.5 and 2.6 and Figures 2.13 through 2.18). CFSC uses the same 1975 figures for each trajectory, but the Census Bureau's 1975 figures for the less developed areas do vary, presumably taking into account that even retrospective historical information from those regions may be estimates subject to assumptions. Interestingly, the CFSC and Census Bureau do not agree on the 1975 population for the USA.

For the kinds of long-term, large-scale environmental studies we are interested in here, we feel that Global 2000's numbers are not particularly useful. They go only to 2000 and they cannot be re-aggregated into the eight-region grouping developed for global studies. This is not a dismissal of the whole report, however. One source of potential surprises is in scientific or technological breakthroughs. Such might be a substantially better contraceptive that became widely available; significant improvements in infant and child survival; or another "Green Revolution" which would increase the Earth's carrying capacity for humans. Another source of surprises lies in non-anthropogenic or at least not deliberate events, some of which could be a new plague in humans, or in a major food source; no more demographic transitions; some massive, relatively swift environmental change (some disruption in an element cycle, for example).

3. MODEL EVALUATION AND DISCUSSION

3.1. Introduction

Five major studies containing six projections of global population (to the years from 2000 to 2150) were reviewed. Their low, medium, and high variant projections are presented in Table 3.1 and graphed in Figures 3.1 and 3.2.

These studies were initially selected because either (1) they serve as inputs to major energy and agricultural models or (2) they were cited in the demographic literature as being major forecasts of future world population. Below we evaluate and review these projections in comparison with each other to determine their potential for contributing to the goals and objectives of the long-term, large-scale environmental studies as described in Section 1.

These studies usually seek to examine global problems of ecologically sustainable development over 100 years. Practically, this translates into our being interested in the time period from 1975-2075.

3.2. Key Variables

Population projections can be represented by the following equation (after Alho and Spencer, 1985):

$$P_{(t+1)} = P_t \ (B_t - D_t + N_t)$$

where P_t = initial population size and structure,
B_t = birth rate at time t (i.e. fertility)
D_t = death rate at time t (i.e. mortality)
N_t = net migration at time t (i.e. migration)

These are the key variables for the six population projections reviewed here. Table 3.2 presents a comparison of the values for these key variables used in the different projections. One can easily see the differences in assumptions concerning the initial values of these variables and their rates of change over time. In addition, one can compare the values for the initial population size (base year = 1975), which although representing a point in history, differ as well. The only additional factor should be considered and does not appear in this table is the age-sex structure. This is a part of the initial specifications of the projection method and is not easily obtained from the published projections. It should be noted however that this can differ between projections.

The key variables listed above comprise the major sources of uncertainty for population projections. The contribution of each factor to the uncertainty of population projections has been assessed in terms of their contribution to the possible error in a projection

Table 3.1 Comparison of global population projections (10e9)

	Variant		1975	2000	2025	2050	2075	2100
Frejka, 1981	Medium	Index	1	1.41		2.24		2.41
		Pop'n	4.41	6.2		9.9		10.6
	High	Index	1	1.44		2.5		2.8
		Pop'n	4.41	6.35		11.02		12.35
	Low	Index	1	1.37		1.99		2.09
		Pop'n	4.41	6.05		8.76		9.21
Keyfitz et al., 1983	Medium	Index	1	1.53	1.95	2.2	2.25	
		Pop'n	3.97	6.08	7.72	8.68	8.93	
	High	Index	1	1.63	2.26	2.69	2.87	
		Pop'n	3.97	6.47	8.96	10.68	11.4	
	Low	Index	1	1.48	1.85	2.06	2.12	
		Pop'n	3.97	5.89	7.36	8.2	8.45	
World Bank, 1984	Medium	Index	1	1.4	1.91	2.25		2.53
		Pop'n	4.42	6.21	8.45	9.97		11.2
United Nations, 1985	Medium	Index	1	1.5	2			
		Pop'n	4.08	6.1	8.18			
	High	Index	1	1.56	2.25			
		Pop'n	4.08	6.4	9.19			
	Low	Index	1	1.44	1.76			
		Pop'n	4.08	5.9	7.28			
Global 2000, USCB, 1980	Medium	Index	1	1.55	2.1	3.2	4.3	6.7
		Pop'n	4.09	6.4	9.3	13.3	19.1	27.6
	High	Index	1	1.64				
		Pop'n	4.13	6.8				
	Low	Index	1	1.47				
		Pop'n	4.04	5.92				
Global 2000, CFSC, 1980	Medium	Index	1	1.47				
		Pop'n	4.02	5.88				
	High	Index	1	1.49				
		Pop'n	4.02	5.97				
	Low	Index	1	1.43				
		Pop'n	4.02	5.75				

Table 3.2 Comparison of indicators of six major projections

		1975			2000			2025			2050			2075		
		HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
UNITED	popn(bil)	--	4.08	--	6.37	6.13	5.90	9.19	8.18	7.28	--	--	--	--	--	--
NATIONS	births	--	30.8	--	25.2	23.3	21.4	20.9	17.6	15	--	--	--	--	--	--
1982	deaths	--	12.1	--	8.6	8.9	9.3	7.7	8.4	9.1	--	--	--	--	--	--
(1)	growth	--	1.90	--	1.69	1.46	1.21	1.33	0.93	0.59	--	--	--	--	--	--
US	popn(bil)	4.13	4.09	4.04	6.80	6.35	5.92	--	--	--	--	--	--	--	--	--
CENSUS	births	32	30.4	28.8	29.4	25.6	21.9	--	--	--	--	--	--	--	--	--
1980	deaths	11.9	12.3	12.9	8.9	9.1	9.4	--	--	--	--	--	--	--	--	--
(2)	growth		1.8			1.7		--	--	--	--	--	--	--	--	--
	popn(bil)	--	4.01	--	--	5.97	--	--	--	--	--	--	--	--	--	--
CFSC	births	--	26.6	--	--	17.9	--	--	--	--	--	--	--	--	--	--
1980	deaths	--	11.2	--	--	8.25	--	--	--	--	--	--	--	--	--	--
(3)	growth	--	1.82	--	--	1.34	--	--	--	--	--	--	--	--	--	--
	popn(bil)	--	4.41	--	--			--	--	--	--	--	--	--	--	--
FREJKA	births	--	29.4	--	--	23.5	18.9	--	--	--	--	14.6	15	--	--	--
1981	deaths	--	11.5	--	--	8.6	8.9	--	--	--	--	10	12.1	--	--	--
(4)	growth	--	1.8	--	1.6	1.5	1.0	--	--	--	0.6	0.5	0.3	--	--	--
WORLD	popn(bil)	--	4.42(7)	--	--	6.15	--	--	8.30	--	--	9.78	--	--	--	--
BANK	births	--	--	--	--	23.8	--	--	17.4	--	--	--	--	--	--	--
1984	deaths	--	--	--	--	8.7	--	--	8.1	--	--	--	--	--	--	--
(5)	growth	--	1.73(7)	--	--	1.51	--	--	0.93	--	--	0.45	--	--	--	--
	popn(bil)	--	3.97	--	6.47	--	6.08	8.96	--	7.72	10.7	--	8.68	11.4	--	8.93
KEYFITZ	births	--		--	--	--	--	--	--	--	--	--	--	--	--	--
1983	deaths	--		--	--	--	--	--	--	--	--	--	--	--	--	--
(6)	growth	--	1.8	--	--	--	--	--	--	--	--	--	--	--	--	--

KEY:
popn(bil) - population in billions (10e9)
births - birth rate per thousand
deaths - death rate per thousand
growth - per cent annual growth
(1) - does not specify date when net replacement rate (NRR) = 1
(2) - does not specify date when NRR = 1
(3) does not specify date when NRR = 1
(4) - assumes NRR = 1 for low in 2000-05; medium in 2020-25; high in 2040-45
(5) - assumes NRR = 1.076 in 2025
(6) - assumes NRR = 1 for low in 2000-05; for high in 2015-20
(7) - figure for 1980

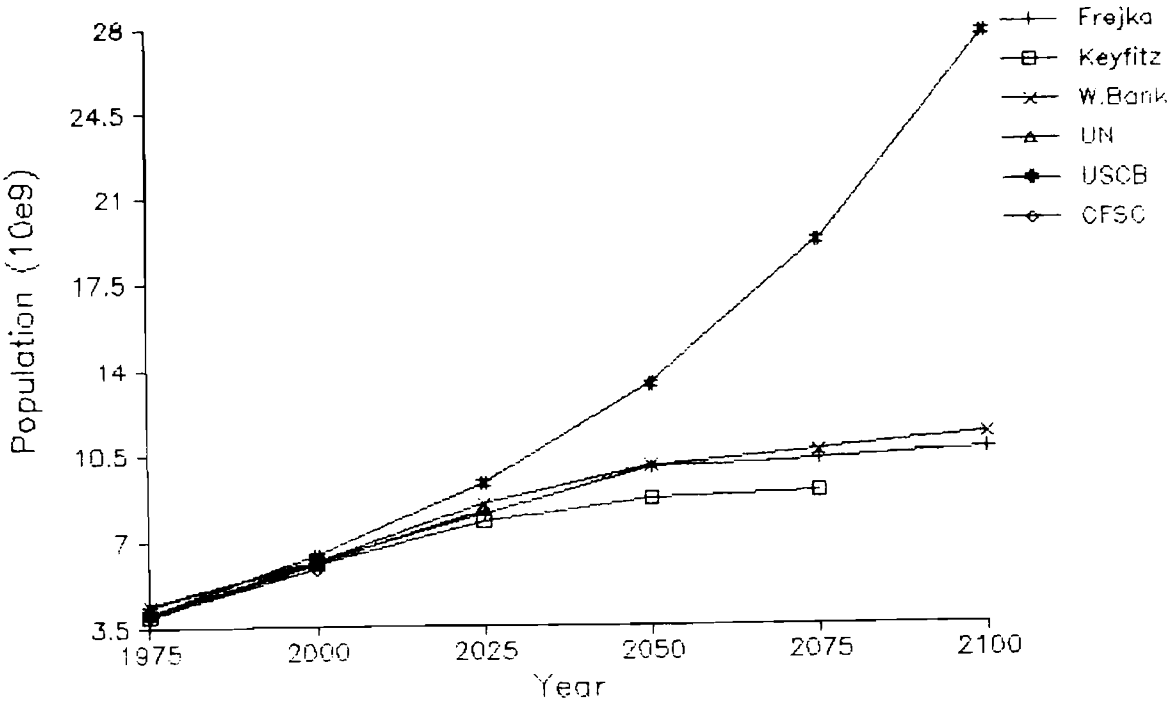

Figure 3.1 Population projections - medium

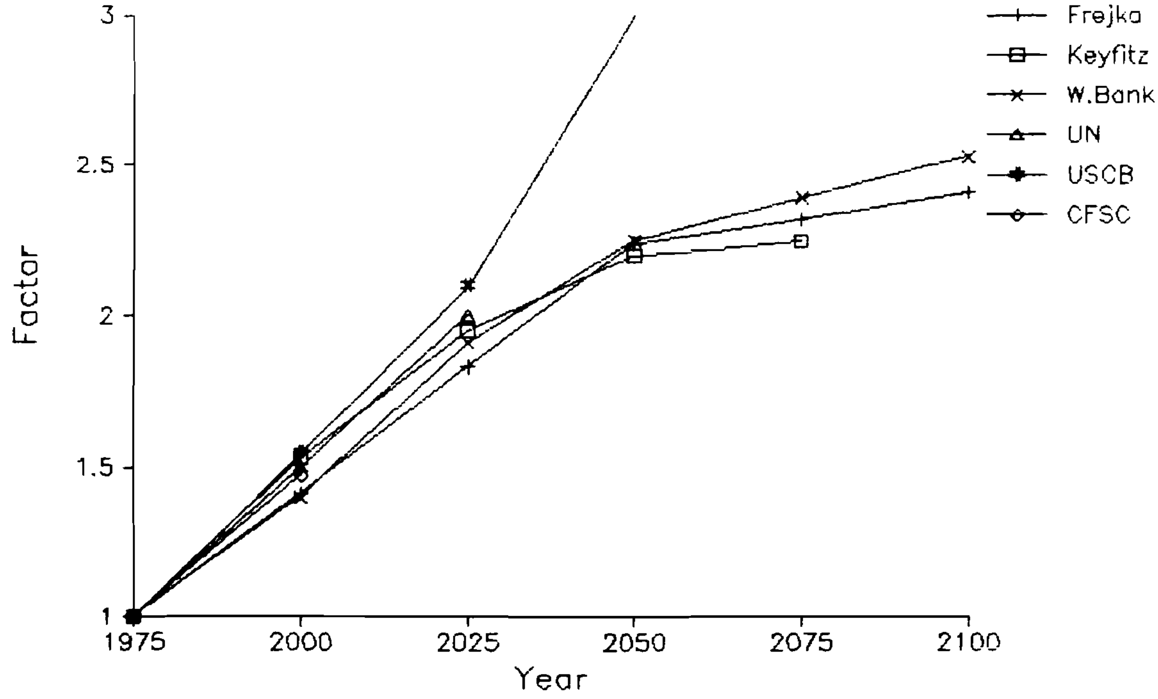

Figure 3.2 Factor increase - medium

by Keyfitz (1981a, 1981b), Stoto (1984), Alho and Spencer (1985) and Keyfitz and Hodges (1985).

A general ranking of the contribution of each of these variables to the overall error in a population projection, from largest to smallest contributor, would be fertility, migration (at the national level), base line population size and age-sex structure, and mortality.

3.3. Sensitivity Analysis

Classical sensitivity analysis (that is, the perturbation of a key variable away from its initialized value and an assessment of the effect of that change on the outcome of the projection) was not available for any of the projections we reviewed, nor did we attempt to conduct such analyses ourselves. However, the literature concerning the accuracy of population projections and information obtained from examining the changes in values of the key variables used to formulate high and low variant projections can provide information similar to that obtained from a sensitivity analysis.

Stoto (1984) has evaluated the error of population projections in terms of "jump off" error and random error. He concludes that the date when the forecast was made is the major factor determining error in population projections. This suggests a high sensitivity in short-term population projections (15 - 20 years) to errors concerning initial population size and age-sex structure. However, demographers generally assume that the uncertainty concerning initial conditions is small and therefor not a significant source of error.

With respect to fertility, mortality, and migration, Keyfitz (1981a, 1981b), Alho and Spencer (1985), and Keyfittz and Hodges (1985) have found fertility and migration to be major components affecting the accuracy of population projections. These also tend to be the key variables with the greatest uncertainty as well as the ones which are varied in developing different projections. For example, the United Nations (1985) in developing its high, medium, low, and constant variant projections vary fertility first and secondarily vary migration holding mortality and base year assumptions constant.

Mortality is generally considered to have a small effect on the error of population projections. Decreases in mortality, where life expectancy already equals or exceeds reproductive life span (15-45 years), generally have a minor impact on the total numbers of a population projection but rather affect the age-sex structure of the population. While many demographers feel there is little uncertainty surrounding mortality, others argue that there are numerous conflicting theories about the rate an d direction of future mortality change, and therefore demographers must admit uncertainty. Keyfitz and Hodges (1985) in reviewing past United Nations forecasts point out that their demographers have a better record in predicting changes in mortality than fertility. In any event, as average life expectancy exceeds the reproductive age limit in most countries, changes in mortality have a negligible effect on future population size, but important effects on the age-sex structure.

From the above discussion, one can conclude that short-term population projections are most sensitive to errors in estimating the initial population size and age-sex structure, and secondarily to errors in assumptions about rates of fertility and migration. Since the later two are the factors with the greatest uncertainty, these are the key factors which should be watched most carefully as sources of surprise and may in some sense be considered the most sensitive key variables.

3.4. Why the Projections Differ?

In general, demographers agree that in the short run (15-20 years), extrapolation of recent trends and informed judgement about their future rate of change yield reasonably accurate population projections. This can be seen in Table 3.1 and Figure 3.1 where the medium variant of the six projections for the year 2000 range between 5.9 and 6.4 billion people with a mean of 6.1 billion and a standard deviation of ± 0.2 billion. These correspond to implied average annual rates of increase of 1.5 to 1.8 with a mean of 1.6 and a standard deviation of ± 0.15. Keyfitz (1983), Stoto (1984), and Alho and Spencer (1985) have independently concluded that in the short run an error term of ± 0.34-0.4 percent for the rate of increase is acceptable. Using the work of Keyfitz (1983), a 66% confidence interval around the median of these projections to the year 2000 would be 5.6 to 6.6 billion people.

Keyfitz (1983) has also pointed out that there is a strong possibility that the projections we considered (and others) are not independent and therefore one should not attach too much significance to their close agreement. In part this is because some of the same data bases are used by all forecasters. Also, demographers do not work in a vacuum – they talk with one another, they read the same articles concerning changes in fertility and mortality and related causal factors, and so they inadvertently may influence each other.

An examination of projections beyond 2000 in Table 3.2 and Figures 3.1 and 3.2 shows that the studies differ significantly in their long-run projections. Below we discuss some of the reasons for these differences.

Judgement is a necessary ingredient of all demographic forecasting. In the six major projections reviewed here, different numbers are presented for the base year. The reasons for this difference include different sources of information, as well as judgements concerning the accuracy of various sources and subsequent adjustments made to the baseline data. These differences will be compounded for future years.

The average annual growth rates used by the various projections are shown in Table 3.2. These differ both among variants within a given projection and between different projections. Furthermore, they differ in initial magnitude and assumed rate of change over time. It is in the selection of appropriate fertility, migration, and mortality rates that judgement has its greatest effect on the outcome of projections. This is where the theoretical arguments concerning the determinants of these factors get implicitly included in the model as knowledge via expert judgement of the forecaster (as well as researcher bias).

4. CONCLUSION AND RECOMMENDATIONS

4.1. Selection of Studies

Hammel (1984), in a letter to the editor of Science has pointed out the need for "authors to provide explicit information on a range of plausible [population] estimates and the sensitivity of their analysis to the alternatives". Where this is not possible he states that "they should stress that the projection used is strictly illustrative and dependent on the validity of the particular assumptions underlying that projection". We aim to understand future, long-term environmental crises arising from the interaction of development and the biosphere. Population is important both in its role as modifier of the biosphere via development, and as a stakeholder in that development being ecologically sustainable. Population projections are one of the key inputs to agriculture and energy models to provide information on valued environmental components. Therefore a particular population projection must be selected carefully.

Our review of the leading population projections has resulted in the following conclusions.

(1) In the near and short run (15 to 20 years) one credible population projection is as good as the next. In the long run (up to 100 years) only some of the existing population projections yield useful information. Keyfitz and Hodges (1985) have developed a method of population projection which allows for the assignment of probabilities to a projection of future population size for a given year. It is possible that this method of population projection could be useful for long-term environmental studies.

(2) Wherever possible the level of aggregation utilized should be the nation-state level. This level will link well with the assessments of energy and agriculture projections. Additionally, at this level of detail we are able to aggregate the world into regions based on scale effects which may be interesting to the large-scale environmental studies.

(3) Attention must be paid to the differences between the more developed and less developed regions of the world. In the more developed regions the interesting focus will be on the requirements (ecological, fiscal, political) to support an increasingly aging population by fewer working people. In the less developed regions the area of concern will be the resource demands of populations that are still "coasting" to stationarity, with both a large proportion of young people, and rising economic expectations.

(4) Migration can have an effect on the future population growth (especially at the national and regional level) and the projection method selected should be able to treat assumptions of migration.

(5) Documentation of the projection methods and assumptions differ among the studies. Potential users should select a well documented projection.

Three of the six population projections may be appropriate for use in long-term, large-scale development-environment studies.

(1) The most recent United Nations projections appear to be the best documented (including specification of assumptions for key demographic variables) and are very credible; one limitation of these projections is that they only extend to 2025. Given the increasing uncertainty in population projections as they extend into the future, the users could make reasonable assumptions and extend these projections to the year 2075. One additional advantage of using the U.N. figures is that they are widely consulted, scrutinized and updated regularly.

(2) The Keyfitz et al. (1983) projections are particularly attractive to environmental studies as they are reasonably well documented, are at a high level of disaggregation, and are used in numerous energy and agriculture models. Additionally they extend to 2075. The drawback is that they were prepared as a one-time effort, have been criticized as being on the low side and don't provide for the easy construction of error bands on variant projections. Additionally the specification of assumptions concerning key demographic variables is not clear.

(3) The World Bank (1984) projections appear also to be a candidate for use in studies of development-environment interactions. Our preliminary assessment is that this also could serve as an adequate source of population projections.

We conclude that any of the above projections are suitable candidates for use in environmental studies. A hybrid of the above would probably be the best choice.

4.2. Time/Space Scales

We have already addressed the notion of spatial scale by pointing out the long-term nature of environmental changes and the need to consider periods of time in the range of 100 years. A 100 year look into the future should also include at least a 200 year look into the past. Such a perspective with respect to population is especially important in determining whether an event has a long-term effect on the final population trajectory or merely depresses the curve for a relatively short period of time (i.e., the plague of the Middle Ages, or the effects of a limited nuclear war -- if such an event is plausible).

With respect to spatial scale we conclude that development-environment studies must begin at the level of the nation-state with the possibility of aggregating up to regional levels as long as such an aggregation does not obscure important differences in population growth between nations. As population is not distributed proportionally to available resources (e.g. land, water, food, energy) it is important that we choose a level of aggregation that does not overlook localized problems which add up to global crises.

Another conclusion is that we should not just be concerned with the magnitude of the increase but we must also examine the rate of increase. It is possible that in a case where the magnitude of the increase presents no problem to the biosphere, the rate of increase may exceed the ability of the existing systems to meet that demand and therefore present problems to the biosphere.

Finally, Figures 4.1 and 4.2 present Lorenz curves developed for the world population in 1975 and 2075. These graphs show that 70 percent of the world's population uses 20 percent of the world's land and that this relation appears not to change as the population increases over time.

4.3. Surprise

Lacking a causal theory to forecast demographic change, and relying on forecasts based on trend extrapolation, it is likely that even using a stochastic method to project future population growth, interesting future histories will be omitted. Sources of surprise are likely in the key determinants of population growth (fertility, mortality, migration) as well as in the consequences of such growth (e.g., increasing urbanization).

4.4. Some Things Learned

Long-term, large-scale environmental studies should develop a consistent set of well documented population scenarios for the future to serve as a basis for assessing impacts mediated via population growth. These should be developed as a single projection with error bands or a series of projections where the high and low variants act to bound the uncertainty.

Since family planning may be the key determinant of population growth in the future, these environmental studies should pay attention to any attempt at assessing the causal relationship between family planning efforts and changes in growth rate. This may improve the uncertainty in human behavior (1984 and the New Utopians).

The lack of feedback between all the models reviewed here and the environment should be addressed.

Finally, and at odds with much of the preceding analysis one can argue that while population is important to the broad-scale environmental studies, it does not need to be known with any precision. Minimum possible population numbers and growth rates, which are then increased incrementally until environmental effects are discerned may prove to be the most useful learning tool in this exercise.

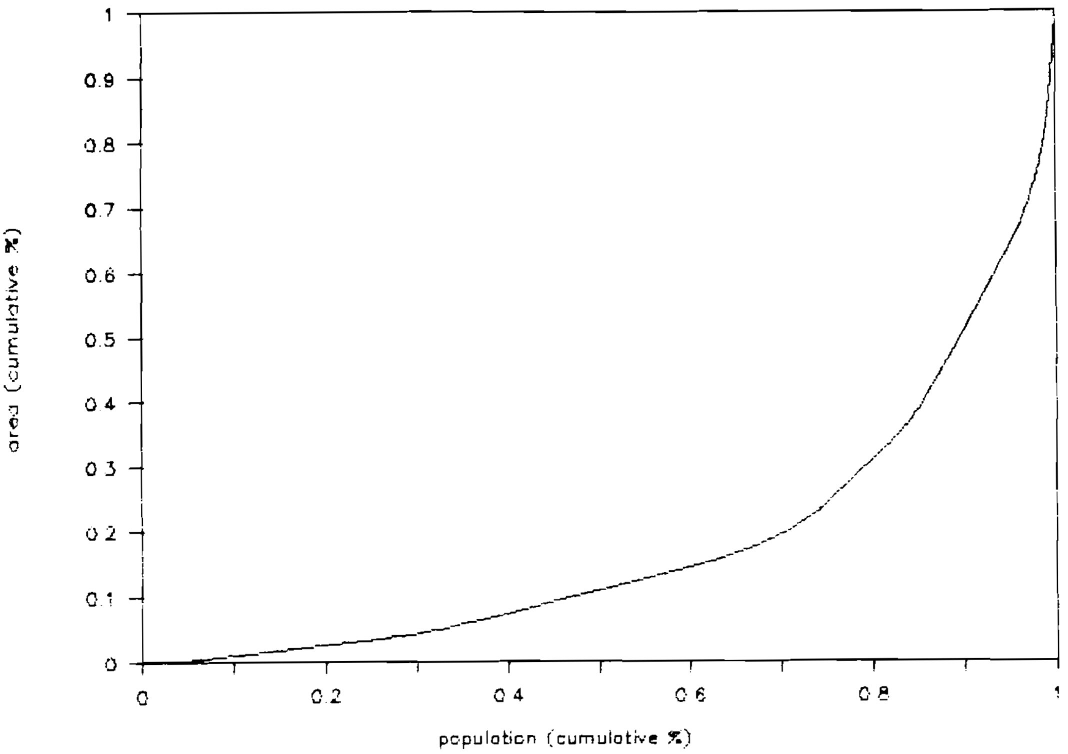

Figure 4.1 Lorenz curve for the world population in 1975

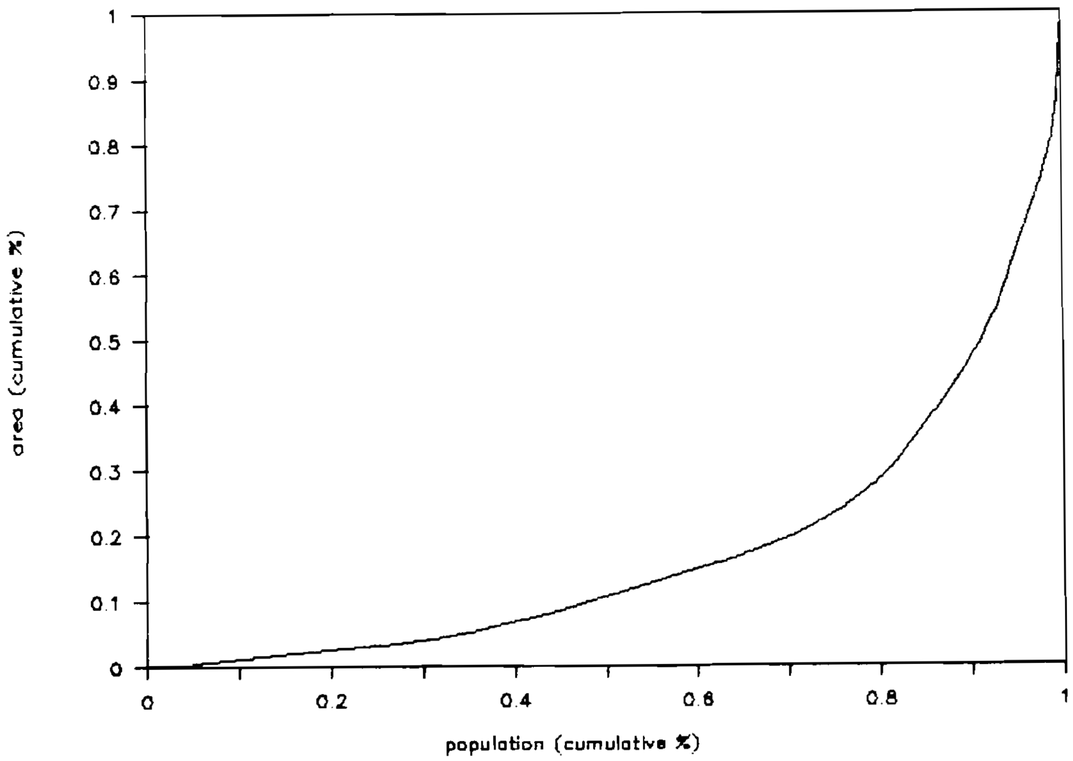

Figure 4.2 Lorenz curve for the world population in 2075

APPENDICES

APPENDIX 1: A catalogue of population effects on the environment

ACTION	EFFECT (Reference)
Filling/draining/polluting wetlands	Destruction of estuaries as fish habitat (1:96)
Fossil fuel combustion	Incr. carbon dioxide, leads to incr. absorption of infra-red radiation, which leads to increased warming; also leads to decr. heat loss from below
Biomass combustion	Incr. particulates in atmosphere => < solar radiation => > absorption/retention of heat => warming of climate
Migration	Importation of diseases by immigrants, exposure of immigrants to "new" diseases => incr. morbidity & mortality
Solid waste disposal	Physical pollution of land air and water (1:67)
Urbanization	Perception of noise, odor, congestion, "hassle," ugliness => decr. psychological satisfaction, decr. level of mental, maybe of physical well-being (2)
	Loss of cultivable land to urban use (2:375)
	Decr. wind velocity, incr. temperature (2:375)
"Mismanagement" of agriculture or tropical forestry	Deterioration of soil's long-term productivity, e.g., lateralization
Run-off from construction sites	Siltation destroys coral reef (1:96)
Toxin (e.g. pesticides) accumulating in food chain/pyramid	Diminution of predator populations => loss of natural control of prey species
Mining e.g. of coal	Acid drainage (1:49)
Mining; reservoir construction	Loss of agricultural, recreational, & residential lands, of wild-life habitat (2:375)
Power generation	Release of radioactivity (1:53)

Liquefied natural gas carrier accident	Release of methane (1:53)
Oil spill in polar waters	Reduced albedo of pack ice => climate warming (1:53)
2nd law of thermodynamics ("All energy ends as low- temperature heat no matter for what purpose or by what means it has been converted")	Release to atmosphere of anthropogenic heat=> possible climate change (1:86)
Petroleum combustion	Hydrocarbon pollution of air (1:66)
Discharge of untreated domestic/industrial wastewater	Water polluted with pathogens or with industrial chemicals => unpotable (1:67)
Agricultural runoff	Pesticide pollution of water => unpotable (1:67)
Agricultural runoff	Nutrient overloading => eutrophication (1:67)
Increased demand for groundwater (irrigation, domestic, etc.)	Land subsidence, salt-water intrusion into aquifer, depletion of aquifer (1:11)
Exceeding maximum sustainable yield of fishery	Stocks depleted beyond re-generative capability (1:20)
Exceeding carrying capacity of grazing land or forest	Desertification, flooding (1:20)

References

1 = United Nations, 1975. The population debate: dimensions and perspectives. Papers of the World Population Conference, Bucharest, 1974, vol. 2. (New York: United Nations.)

2 = United Nations, 1973. The determinants and consequences of population trends: New summary of findings on interaction of demographic, economic and social factors, vol. 1. (New York: United Nations.)

APPENDIX 2: List of countries belonging to the eight major regions developed for global environmental studies

Africa

Algeria
Egypt
Libya
Morocco
Sudan
Tunisia
Chad
Mali
Mauritania
Niger
Benin
Cape Verde
Gambia, The
Ghana
Guinea
Guinea-Bissau
Ivory Coast
Liberia
Nigeria
Senegal
Sierra Leone
Togo
Burkinafasa
Angola
Cameroon
Centr.Afric.R.
Congo, Peop.R.
Equat. Guinea
Gabon
Sao Tome&Princ.
Zaire
Burundi
Comoros
Ethiopia
Kenya
Madagascar
Malawi
Mauritius
Mozambique
Rwanda
Seychelles
Somalia
Tanzania
Uganda
Zambia
Zimbabwe
Botswana
Lesotho
Namibia
South Africa
Swaziland
Afghanistan
Bahrain
Cyprus
Iran,Isl.Rep.
Iraq
Israel
Jordan
Kuwait
Lebanon
Oman
Qatar
Saudi Arabia
Syrian Arab R.
Turkey
Un.Arab. Emir.
Yemen Arab. R.
Yemen, PDR

Latin America

Antigua&Barbuda
Bahamas
Barbados
Belize
Costa Rica
Cuba
Dominican Rep.
Dominicana
El Salvador
Grenada
Guatemala
Haiti
Honduras
Jamaica
Mexico
Nicaragua
Panama
Puerto Rico
St. Lucia
St. Vincent&Gren
Trinidad&Tobago
Bolivia
Colombia
Ecuador
Guyana

Paraguay
Peru
Suriname
Venezuela
Brazil
Argentina
Chile
Uruguay

South Asia

Bangladesh
Bhutan
India
Maldives
Nepal
Pakistan
Sri Lanka
Burma

East Asia

Chi.Turk.&Tibet
Chi.Proper
Chi.Man.&In.Mon
Mongolia
Hong Kong
Japan
Korea, Dem.Rep.
Korea, Rep. of
Macau
Taiwan
Indonesia
Kampuchea,Dem.
Lao PDR
Malaysia
Philippines
Singapore
Thailand
Viet Nam
Papua New Guinea

Oceania

Australia
Fiji
New Zealand
Solomon Islands
Vauatu
Western Samoa

Europe

Albania
Austria
Belgium
Bulgaria
Czechoslovakia
Denmark
Finland
France
German Dem.Rep.
German Fed.Rep.
Greece
Hungary
Iceland
Ireland
Italy
Luxembourg
Malta
Netherlands
Norway
Poland
Portugal
Romania
Spain
Sweden
Switzerland
United Kingdom
Yugoslavia

U.S.S.R.

USSR in Europe
USSR Kaz&C.Asia
USSR Siber&F.East

North America

Canada East.Pr.
Canada West.Pr.
Alaska&Yukon T.
Canada NW. Terr.
USA East&Center
USA West&Prair.

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Chapter 3

A Critical Review of Energy Projections for the Study of Long-term, Large-scale Interactions between Development and Environment

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Michel Gelobter
Piotr Holnicki
Stefan Anderberg
Christoph Schlenzig

1. INTRODUCTION

1.1. Tools for Syndrome Analysis

The Biosphere Project's purpose is to attempt to examine strategies for understanding and managing syndromes that emerge from the interaction of human activity and the environment. Syndromes, in this context, should be understood to be large-scale complexes of social, economic, and environmental forces that interact in an extremely interdependent and non-linear fashion. The understanding and the management of environmental syndromes require tools for the analysis of their interactions and of the impacts of various control and development strategies on these interactions.

One of the main goals of this report is to provide a guide to energy models that may be useful in conducting meaningful research on energy development-biosphere interactions. Another one is to identify variables and actions that could seriously affect these development-environment interactions.

As a result, we have been examining studies of the long-term (50-100 years) global energy future. Within this time and space framework, we have concentrated primarily on the environmental and economic implications of energy use.

1.2. Energy, Environment and Society

Energy use is essential for each society. It is central to most human activities and is one of the major determinants of the structures of socioeconomic life. Its interconnections with all different levels of society are close:

- The biophysical environment gives energy resources and absorbs energy use's often serious impacts.
- The socioeconomic system demands, produces and consumes energy, and, importantly, it determines the distribution of energy use and products made with energy.
- Infrastructure is a major determinant of which energy form we can use because each fuel needs systems for distribution, technology etc..
- Political institutions try to rule these systems, deciding rules for energy use and energy taxes, and by investing in R&D and in infrastructure.

- On the level of ideological attitudes, perspectives on energy use, on different fuels and new ideas, or on inventions and discoveries can influence the energy system particularly in the long-term perspective.

Most energy models try to simulate the possible development of energy use by approximating the workings of the economic system in particular, with some linkages to infrastructure (realized technology) and the biophysical environment, perceived primarily as a resource base. Changes in the structures of socioeconomic, institutional and environmental systems and how such would influence energy use are not considered. Such simplifications are of course necessary. The models are often complicated enough as it is. But especially in a long-term perspective we should not expect these external (to the model) structures to be stable. They could be an important place to look for possible sources of surprise. Let us keep this in mind.

The models are the central theme of this report. We try here to approach them from a broad perspective with the final aim of assessing their ability to illuminate important relations for the real energy future and to make useful predictions for shedding some light upon future collisions between biosphere and development.

1.3. Problems of Scale and Resolution

Determining appropriate tools for analysis is difficult because of the fact that syndromes' effects may be felt on time and space scales far different than those associated with their generation. An example of this would be the syndrome of sulfur-related lake acidification. While the emission and deposition of SO_x has a time scale on the order of days, and a space scale on the order of hundreds of kilometers, the use and construction of SO_x-generating energy systems is dependent on social and economic forces with national to global space scales, and time scales at least on the order of years, if not decades. The effects of acid deposition have yet a third time-space scale. Lake acidification scales, for example, center in space around a watershed, and in time on a period of up to thirty years.

1.4. Grounds for "Tool" Classification

Our assessment of models was guided by at least three sorts of time/space resolutions of effect (as distinguished from resolutions of creation, which, from the nature of our study, are taken to be global/long), which we characterize by the following examples of the types of impacts energy use may have on human well-being.

World resolutions

As a symbol of problems with the largest resolution (which we shall call "world"), we may picture a world in which some substantial climatic change has occurred due to the emission of greenhouse gases. The impacts of such change would presumably be spread, albeit unevenly, all over the world, and over a relatively long time frame.

Regional resolutions

As a symbol of the second type of resolution (which we shall call "regional"), we should picture a collection of regions, each of which may well overlap the boundaries of several nations, and each of which is facing soil, forest, or lake acidification (with related impacts on productivity or environmental quality) as a result of installed fossil fuel burning capacity.

Local resolutions

The third type of resolution (which we shall call "local") may perhaps best be seen as an even larger collection of cities, each of which is faced with extremely serious air pollution/public health problems as a result of dense population and concentrated toxics emissions due to intensive energy use.

1.5. Overview

The rest of this report describes the results from our assessments of energy models and projections. We start in the second section with a description of how we arrived at environmental criteria, or "valued environmental components" (VECs) with which we assessed our studies. In the third section of this report, we describe and evaluate the models that we have examined and that we felt were relevant to the particular problems/concerns of the long-term large-scale environmental studies. In the fourth and concluding section we attempt to evaluate the issues of energy and biosphere across models to reach some summarizing conclusions.

2. VECs AND OTHER INDICATORS

2.1. Bases for a VEC Framework

One of our tasks was to develop some key actions and indicators from which interesting scenarios could be constructed. For the Biosphere Project, the identification of such actions must be based on the degree of their influence on the environment (or VECs). During work on Action-VEC-matrices of the global energy system we encountered serious inconsistencies in the action list. Our actions (energy use, resource availability, fuel mix, conservation, pollution control) spanned several very different levels within the energy sector. They covered a wide range of social activities, beginning from lifestyle patterns and government policies up to the very direct impacts of burning fossil fuels.

Apart from the fact that these actions can't be put into one category, our main problem was that such a general matrix wouldn't be very useful for explaining the environmental impacts of the energy system because of its too great aggregation.

We decided then to split the framework into two parts, the modeling of the energy sector and the assessment of impacts of the energy sector. In order to be able to directly measure the impacts of various energy futures, we identified fuel mix and energy demand as immediate actions on the environment and called them "activity levels" of the energy system. The matrix in the second part should be an analysis of the pathways by which these direct actions lead to stresses on the VECs and should give a characterization and quantification of these stresses. All other activities - we call them system descriptors - belong to the first part and only act on the activity levels. The distinction of two steps helps to avoid confusion and allows the description of environmental impacts more precisely.

Figure 2.1 shows the general structure of the framework. At the beginning is a description and formulation of the sociopolitical and economic framework of the world. The future evolution of the world is formulated in a so-called scenario, a kind of short story of possible futures. This gives the background for the development of the energy sector which itself can be characterized by main driving forces, the key variables. These system descriptors are numeric variables that quantify the general sociopolitical and economic formulations and the particular scenario assumptions. To assess the activity levels of the energy system one uses either formal models or expert judgement.

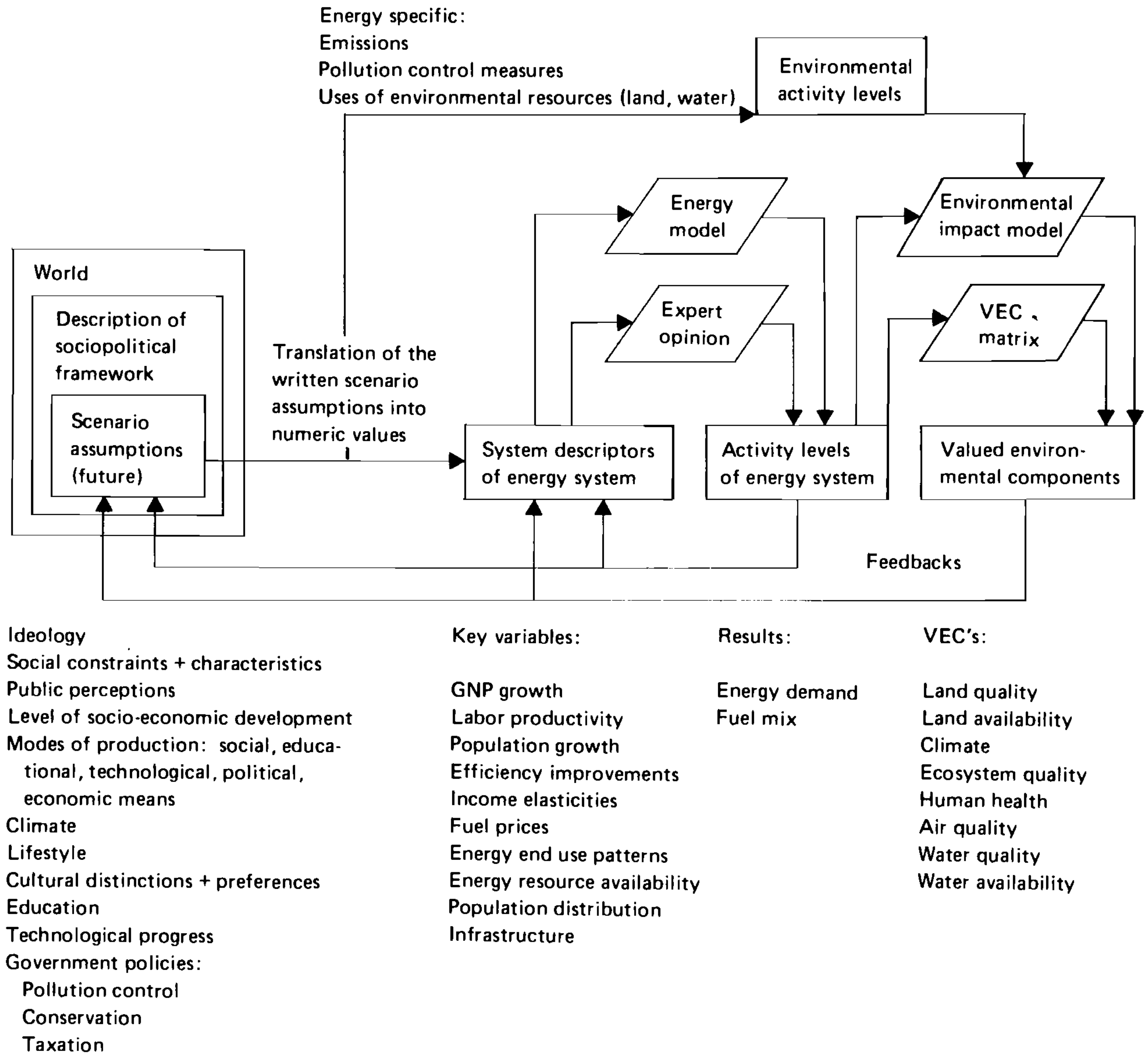


Figure 2.1 Bases for a VEC framework

	LOCAL VECs																			
	LAND					BIOTA					WATER					AIR				
	Quality			Availability							Availability		Quality							
FUEL TYPES	Erosion and Sedimentation	Soil quality, pH and soil fertility	Topographic change and subsidence	Permanent consumption	Temporary consumption	Radiation	Noise	Bio-toxics	Disease and injury	Eco-system disruption (vegetal destruction, etc.)	Altered resource flows	Evaporation or ground-water consumption	Toxics and chemicals	Heat	Suspended solids	Toxics and pollutant particles	Temperature	Visibility	Humidity
COAL	+++	+++	+++		+++	+	+	+	+++	+++		+++	+++	+++	+++	+++	+	+	++
OIL (coal and oil shale)		++	+		++		+++	++	+				+++	+++		+++			+
GAS		+			+				+ +				+	+		+ +			
NUCLEAR				++	+	+++		+	?			++	+	+++		+			
HYDRO	+++	++	+++	+++						+++	+++	+++					+	+	
BIOMASS	+++	+++	+++							++		+++	+			+++		+	++
RENEWABLES	+			+++	+++					+?			?			+			

Figure 2.2 Local VECs

FUEL TYPES	REGIONAL VECs									GLOBAL VECs		
	LAND	BIOTA	WATER				AIR					
	Soil quality	Radiation	Altering resources flows	Water consumption	Water chemical & toxic pollution	Water material effluents	Air acidity	Air toxic pollution	Cloudiness	Greenhouse gases		
COAL	+++			++	+++	++	+++	+++	+(?)	+++		
OIL	+				+++		++	++	+(?)	++		
GAS					+		+	+	+(?)	++		
NUCLEAR		++		+	+			+				
HYDRO	+++		+++	++								
BIOMASS	+++			++	+	+	++	+++	+(?)	+(?)		
RENEWABLES					+(?)							

Figure 2.3 Regional and global VECs

Once the energy demand is calculated, the matrix in our second step gives a qualitative assessment of the impacts on the VECs. If a more detailed and quantitative result is desired, the matrix has to be replaced by a more formal model. After establishing this framework one can start to consider possible feedbacks of VECs on the other system components. These feedbacks can impose very important constraints on the input side of the model and should therefore be carefully evaluated - a consideration that is left out in most of the studies.

2.2. VEC Matrices

In order to determine the environmental components that were important to the energy sector, we conducted a literature review that was initially split according to the media where the impacts or "stresses" to the environment took place (Holdren and Budnitz, 1976; Ehrlich et al., 1977; Smil, 1984; Holdren, 1977; Bach et al., 1980).

Energy systems' impact on the environment are most clearly traced through the mix of fuel sources that they use to generate energy services. We felt that the most direct way of identifying the relative importance of future energy options was to trace the influence of various fuel types on the environment. Thus we initially specified five VEC/fuel type tables, one each for air, water, land, biota, and sociopolitical systems/interactions (see Appendix 2 for some of these). Initially, these tables were semi-quantitative indicators of the relative importance of various actions on those VECs that we discovered.

Once we had compiled some media-specific VEC tables, we felt that recombining the VECs according to the time and space scales discussed above (local, regional, global) would enhance their usability (see Figure 2.2 and 2.3). The congruence between small spatial scales and short time scales, or large spatial scales and long time scales of interaction was relatively good, so that the classification represented a fair guideline. We tried to classify VECs in accordance with these guidelines by seeking to answer the question, for each VEC, "At what resolution would you need to measure an indicator or to design a policy in order to understand or to influence a particular development/environment interaction?"

A simple example of this process is the case of land erosion. While land erosion due to coal mining may take place over thousands of square kilometers, any action taken to mitigate it must be designed to affect the resolution at which individual mines sit, e.g. local. This categorization does not exclude broad-scale policies like taxation, but simply specifies that such policies as may be implemented must have an effect on the scale of concern. For example, a taxation policy designed to change the end-use patterns of coal burning must be very differently designed than a policy directed at changing mine locations.

In the matrices, our already crude quantifications were simply translated into relative symbols of the importance of our fuels on environment. The types of VECs that emerge grouped from our re-aggregation according to time and space scales constitute an interesting result of our efforts. We find, for example, that air is present at every scale of resolution. At the global level, the only energy VEC was the rather aggregate one of greenhouse gases. At the regional level, water concerns enter the picture, along with one land component: soil quality, mostly influenced by the more regional factors (acidified water, heavy metal transport in air, etc.). We found the greatest multiplicity of factors at the local level. Most of these observations can be explained by examining the relative mobility of the factors involved (air more mobile than water, water more mobile than land).

In retrospect, we seemed to run into two difficulties with this approach in the energy field. First and most importantly, we found very few VECs that had direct feedbacks on energy production. According to the models we examined, and our own sense of the energy world, most of the feedbacks (such as CO_2-induced warming) were mediated by at least one, if not several, social processes (increased energy use for cooling, environmental opposition to coal burning, etc.).

This conclusion was considerably different than those reached by the agriculture assessment study (Chapter 4), whose VECs had some definite impacts on and within their own realms. This limitation of our tables may due to a more general limitation of imposing direct environmental and development feedbacks on energy systems.

The second limitation we encountered was in clearly specifying the valued sociopolitical components. We found that energy was so intertwined with all stages of action that no single framework that we came upon could capture its impacts on sociopolitical systems (see the previous discussion of the role of energy in the world). The Valued Sociopolitical Components may be too complex for simple matrix representation (see an attempt at one in Appendix 2).

3. MODEL DESCRIPTION AND EVALUATION

3.1. Projection Methodologies

3.1.1. Introduction

In order to relate the energy sector to the biosphere we conducted a review and evaluation of different energy studies, their approaches, assumptions, and the different futures they predict. A guiding criterion was the usability of the models for assessing environmental impacts.

To stay consistent with the time and space scale of the long-term, large-scale environmental studies, we selected only global, long-term studies. We decided to look only at prominent, ambitious studies which were heavily used or cited. These studies differ greatly in their design, the extent to which formal models are employed, in their aggregation and resolution with respect to fuels, geography and other factors (Ausubel and Nordhaus, 1983). This is the reviewed set of studies:

- International Institute for Applied System Analysis (IIASA), Energy in a Finite World by the Energy Systems Program Group (Haefele et al., 1981).
- Edmonds & Reilly, Institute for Energy Analysis (IEA), Oak Ridge Associated Universities (Edmonds & Reilly, 1983a, 1983b, 1985).
- Nordhaus W.D. & Yohe G.W., Future Paths of Energy and Carbon Dioxide Emissions, (Nordhaus & Yohe, 1983).
- World Energy Conference, J.R. Frisch, ed., World Energy Conference, New Delhi, Conservation Commission Report, (Frisch, 1983).
- Global 2000, Report to the President by the Council on Environmental Quality and the Department of State, US. (CEQ, 1980).
- World Energy Outlook, International Energy Agency (OECD) (IEA, 1982).

Other comparative studies of energy system projections have been conducted by Ausubel and Nordhaus (1983) and by A.M. Perry at the Energy division of Oak Ridge National Laboratory (Perry, 1982) in order to assess future carbon dioxide emissions.

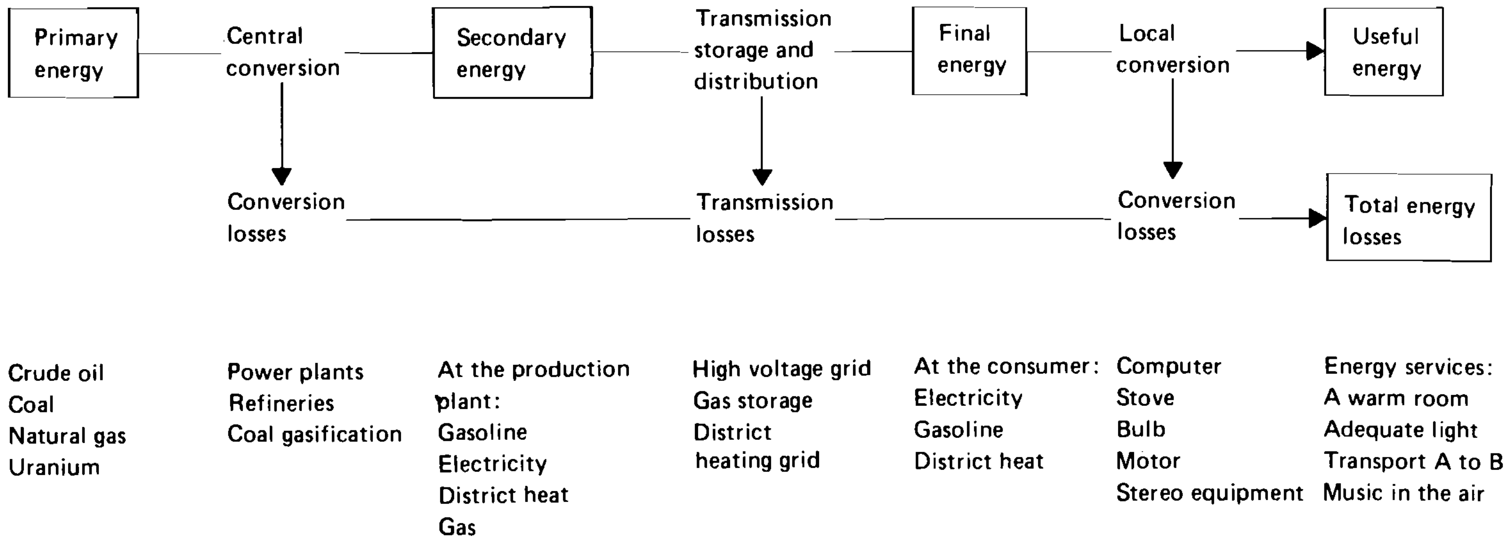


Figure 3.1 Energy conversion and use

3.1.2. Methodologies

Figure 3.1 gives some definitions about energy forms and levels at various stages of conversion and use in order to clarify the nature of the energy problem.

This section is a short introduction to the main approaches used in projection studies of global energy demand and indicates some of the differences that exist, the methods' relative advantages and problems. One can distinguish five main approaches:

- end use approach: formal model;
- economic approach: formal model;
- expert opinion approach: expert estimations, simple economic calculations;
- IEW approach: International Energy Workshop, comparing different study-results;
- phenomenological approach: discerning patterns from phenomena of the past, and applying them to the future.

The formal model approach uses a mathematical description of the complex structures and links of the energy sector. These mathematical structures can be implemented on computers and provide a very useful tool for developing and reproducing alternative scenarios in order to get a better understanding of the system behavior. The other approaches mainly profit from the experience and the knowledge of a group of experts. One has to keep in mind that studies, although using the same approach, can differ in size, complexity, scale and resolution.

3.1.2.1. End use approach

The energy sector is disaggregated into a multitude of end use categories. The "useful energy demand" is then converted into final energy, taking into account the technical efficiencies. For each end use category the energy demand is related to a set of determining factors which can be macroeconomic aggregates, physical quantities or technological coefficients. These general scenario parameters are then disaggregated in terms of economic structure (set of industrial products), demographic structure (lifestyles), and technological structures (energy intensiveness/efficiencies). The energy demand projections result from the evolutions assigned to these factors. This approach has a good ability to handle structural and technological changes because scenarios are built in a very "close-to-reality" way. It is also good at evaluating the effect of policy strategies on the end use sector (fuel taxation, conservation measures favored by government, etc.). The IIASA study Energy in a Finite World is an example of a study using this approach (Haefele et al., 1981).

Problems: High need for disaggregated data, many input parameters, high need for expert knowledge to use the model, difficulty in defining a consistent set of input parameters for the construction of a consistent scenario, because of the quantity of parameters.

3.1.2.2. Economic approach

This approach uses the interrelationships of highly aggregated economic indicators to model the energy system. The most important parameters are often: GNP, as an indicator of economic activities, and income and price elasticities of energy demand. The expression of different demand patterns and structural and technological changes is accomplished by varying elasticities. Based on these elasticities, the model calculates the energy demand, the economic activities, the cost of energy production and the changes of energy prices. Because the description of real world is done with a few variables, the model is very usable and compact, and allows easy scenario building. Examples of studies using this kind of approach are the Edmonds & Reilly model (Edmonds & Reilly, 1983a, 1983b) and - less complex - the Nordhaus & Yohe study (Nordhaus & Yohe, 1983).

Problems: Such models require a lot of experience to translate complex structures into elasticities. It is difficult to check the assumptions built into the elasticity figures. Elasticity coefficients are more widely used for short term projections. They become more questionable, as the long-term are considered.

3.1.2.3. Expert opinion approach

This type of projection is based on experts' judgements. The World Energy Conference, as an example of this approach, consisted of one central team (coordination) and 10 regional working groups (50 experts and 20 national committees). Because these experts use different approaches and techniques, the cooperation profits from various knowledge and is likely to produce reasonable results. This methodology represents a more normative approach, and is often used by governments to develop medium-term energy policy programs.

Problems: Difficulty of reproducing results and the impossibility of creating new and different scenarios out of this approach.

3.1.2.4. International Energy Workshop approach

This approach is a variation of the expert opinion approach. It does not create an original projection, but takes the most up-to-date, long-term energy studies available and compiles them. The range thus produced may permit the establishment of a kind of uncertainty bound around expert opinion. This approach is very useful for obtaining a better understanding for the reasons for differences between energy projections and it acts therefore as a corrective measure in the energy modeling field. The IEW approach makes a kind of inventory in the energy modeling field, gives an overview of the state of the art and is very well suited as an consistency check for modeling techniques.

Problems: This comparative approach does not really create new insights in the real world of energy systems. It cannot be used to create different future energy scenarios.

3.1.2.5. Phenomenological approach

The phenomenological approach looks at the empirical history of an aspect of the energy system and seeks to fit a functional form to this evolution. It describes and predicts those processes without explanation. Marchetti and Nakicenovic (1979) have developed a model that treats energy sources as technologies competing for a market and applies a form of market penetration analysis. A logistic function is used to describe the evolution of energy sources and is fitted to historical statistical data. A driving force appears to be the geographical density of energy consumption. The mechanisms leading to switch from one source to another are the different technical characteristics associated with each energy source (Ausubel and Nordhaus, 1983). This model explains very well the substitution processes between competing fuels and is very useful to show time constraints for new energy technologies. Another example of this methodology is the resource depletion studies of M.K. Hubbert (1962).

Problems: The phenomenological approach can only make very rough estimates of the total energy demand. It is therefore not very well suited for evaluating the amount of future energy demand. Because of its ability to describe substitution processes it should be integrated into other studies (It was in fact used in the IIASA study, see Haefele et al., 1981).

3.1.3. Concluding remarks

It is not easy to classify energy models, because many of them use a combination of the different approaches. Furthermore, the expert opinion method will always play a role because it determines the structure of the mathematical models, as well as the values of the input parameters. Each approach has its pros and cons. In fact, it is nearly impossible to decide which technique is the best adapted for long-term energy projections for use in environmental studies. Not only the approach, but also the complexity, the scale and the resolution of a model are very important for evaluating its contributions to an understanding of the global links between the energy sector and the biosphere.

3.2. IIASA: Energy in a Finite World

3.2.1. Description

3.2.1.1. Source and objective

Source: Haefele et al., 1981. Energy in a finite world. Vol1: Paths to a sustainable future, a summary and analysis. Vol2: A global systems analysis, the technical report. Report by the Energy Systems Program Group of the International Institute of Applied System Analysis (IIASA). Program leader: Wolf Haefele. Ballinger Publishing Company, Cambridge, Massachusetts.

Objective: Study of the global and long-term development of the energy system, exploration of possible energy futures, especially the transition to post-fossil systems.

3.2.1.2. Scale and resolution

Time scale: Standard time frame of 50 years, 1980 - 2030. Base year: 1975

Space scale: Global

Time resolution: Iteration intervals of 5 years

Spatial resolution: Division of the world in seven groupings, selected for their economic and energy similarities, and not so much for geographic proximity

Region 1: NA	North America
Region 2: SU/EE	Soviet Union and Eastern Europe
Region 3: WE/JANZ	Western Europe, Japan, Australia, New Zeeland, South Africa, Israel
Region 4: LA	Latin America
Region 5: Af/SEA	Africa, South and Southeast Asia
Region 6: ME/NAf	Middle East and Northern Africa
Region 7: C/CPA	China and Centrally Planned Asian Economies

Fuel disaggregation: Seven fuels are considered in this study. Oil, Gas, Coal (conventional/synfuels), Nuclear (Light Water Reactor/Fast Breeder Reactor), Hydroelectricity, Solar, Renewables (biogas, geothermal, commercial wood)

3.2.1.3. Exogenous variables and key assumptions

Input variables:

- Population growth
- Economic growth
- Lifestyles/private consumption
- Investments
- Resource availabilities and costs
- Future energy prices
- Market penetration of fuels and new technologies
- Efficiencies of energy use
- Imports and exports
- Potential labor force
- Cost/buildup rates of energy producing facilities
- Institutional variables (productivity, capital-output)

Output (derived variables, results):

- Aggregate final energy demands in macrosectors
- Regional and global primary energy production, fuel mix
- Energy - GDP elasticities
- Total required capital investments
- Potential market for final energy forms
- Contribution of new technologies
- Shadow prices of fuels and electricity
- Socioeconomic and environmental impacts (indirect investments, water-, energy-, land-, material-, manpower- requirements, climate, risks)

Main scenario assumptions:

- Continuity, no jumps and surprises in evolution (wars, technological breakthroughs)
- Modest population and economic growth
- Match demand and supply, no gaps
- Only economic and resource- and energy-related constraints are considered. Political, social and environmental constraints are recognized, but were not applied explicitly
- The US dollar and other monetary units have constant (1975) value, inflation aspects of the energy problem are neglected
- Temporal frame assumptions: Three time phases (IIASA, 1981, Vol 2, p.9)

Present phase:	1980-2000, oil supply problem
First transition phase:	2000-2030, moving from clean and cheap oil to different energy carriers
Ultimate trans. phase:	2030-xxxx, moving to a sustainable energy supply system

3.2.1.4. Approach

The modeling techniques:

MEDEE: end use approach

MESSAGE: linear programming optimization model

IMPACT: energy oriented dynamic input-output model

MACRO: aggregated economy model

Description of the model structure:

The three of IIASA energy models are connected by an information flow between the models, in what has been described as a loop of models (Figure 3.2). The demand for final energy in each of the seven world regions is evaluated in the demand model MEDEE, which is driven by population and economic growth (exogenous). The supply model MESSAGE then determines the optimal cost conversion system and calculates the required primary energy, taking into account resource availability, technological, environmental and other relevant constraints. The economic and other impacts of these energy supply strategies are evaluated in the model IMPACT (only interpretative results, no direct feedback links), and the macroeconomic issues are assessed in the aggregated economy model MACRO (which, in the end, was never applied). This whole procedure is iterated region by region, taking into account interregional energy trade, until a globally consistent energy demand and supply pattern evolves.

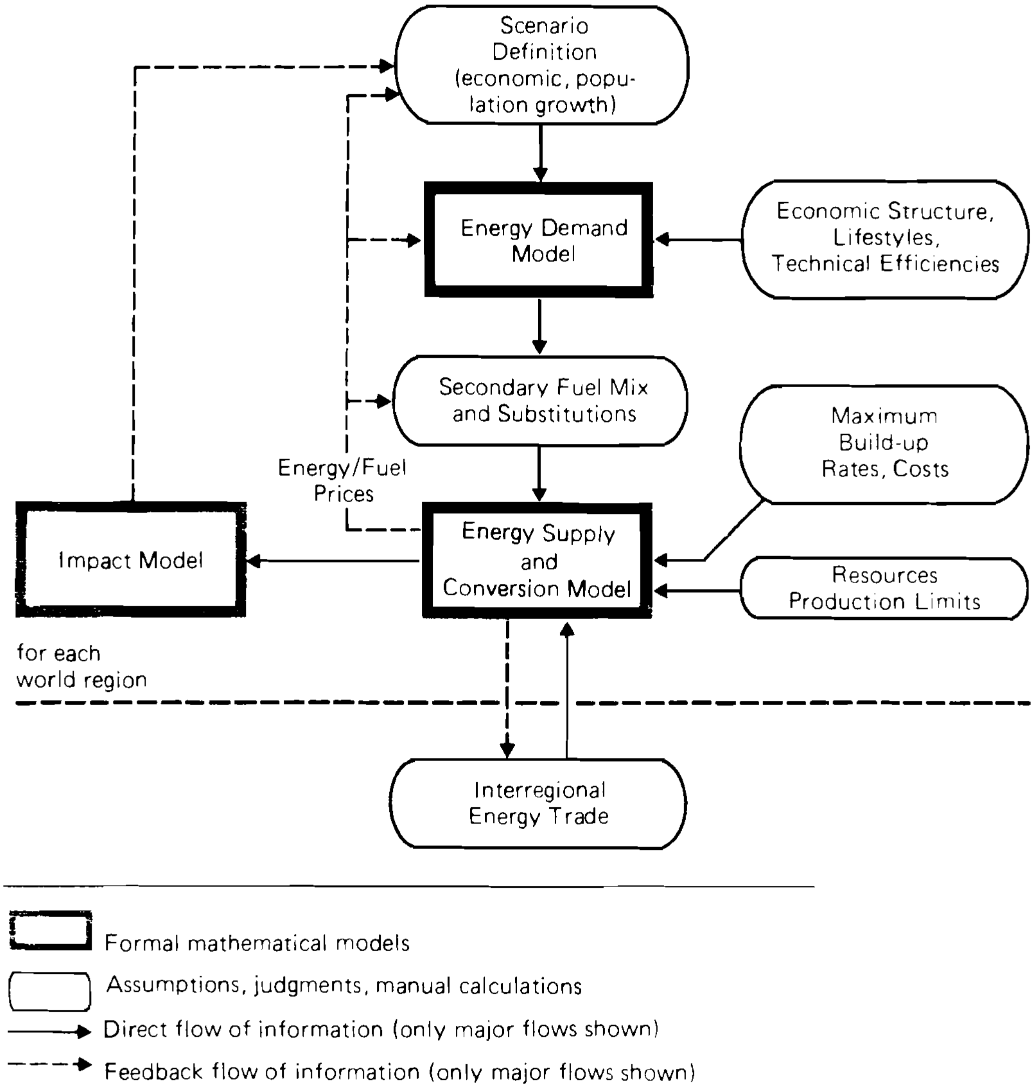


Figure 3.2 IIASA's set of energy models: a simplified representation

Consistency checks are also carried out on the information flow between the models in each step of iteration. This is because the models are not "hard-wired" together, but rather allow for human judgement. All the inputs and outputs are examined to be sure that credible results appear at all steps.

Final energy demand model MEDEE

MEDEE is an end-use-approach energy demand model that evaluates the influence on energy demand of social, economic, technological and policy changes. This model is only a calculation tool interrelating the major determinants of both useful and final energy demand. Although it contains many variables and relations, its structure is quite transparent and simple.

The energy sector is disaggregated into a multitude of end use categories. For each category the useful energy demand is related to a set of determining factors which can be macroeconomic aggregates, physical quantities or technological coefficients. These general scenario parameters must be disaggregated in terms of economic structure (set of industrial products), demographic structure (economic growth, lifestyles) and technological structure (energy intensiveness, efficiency, market penetration). A macroeconomic module translates the socioeconomic scenario assumptions into specific activity levels of the end use categories. Final energy demand is then calculated for each category in three other modules (household/services, industry, transportation) using activity levels and technological determinants. Because of the high level of disaggregation, few structural assumptions are built in the model.

MEDEE does not deal directly with the problem of interfuel substitution because this problem is treated within the supply model MESSAGE. For competing final energy sources no market penetration is modeled; it has to be introduced exogenously. Energy demand is also not related directly to energy prices by means of elasticity coefficients - this approach is considered inapplicable for making energy predictions because it uses primarily trend analysis and trend extrapolations from the past. Price-energy relations are used in the scenario writing process as expert-opinion-based background information for modifying past trends.

Primary energy demand model MESSAGE

A number of primary energy sources and their associated conversion technologies are considered to calculate the primary energy demand from the secondary energy demand assessed in MEDEE. The MESSAGE model has an objective function which is the sum of discounted costs of capital, operating, maintenance and fuels (primary energies). This function is minimized by the optimization model. The conversion model takes account of costs, availability and quality of resources, buildup rates, and energy production capacities. Emission constraints and pollutant concentration constraints (Krypton, CO_2) were available but neither used nor binding in the model.

Economic and environmental impacts model IMPACT

IMPACT is an energy oriented dynamic input-output model that calculates the following:

- Direct and indirect capital investments in energy system development
- Investment in energy system development
- Required energy-related indirect capital investments, materials, equipment and services
- Direct and indirect "WELMM" requirements (non energy resources), i.e. Water (mining, energy production), Energy (for construction), Land (for power plants and mining capacities), Materials (for construction), Manpower

- Impacts on climate (CO_2, Waste heat, changes in surface characteristics due to large scale solar power plants)
- Risks of energy technologies for human health. Risk estimation, risk evaluation, risk management, valued as costs
- Time constraints for market penetration (Marchetti)

Macroeconomic model MACRO

This aggregated economy model would have supplied the economic input values for MEDEE after integrating the capital requirements for the energy sector in the overall economy. This model finally was not used, because the group had difficulties in integrating it with the rest of the model set (compatibility of aggregation levels).

3.2.1.5. Model results

Figures 3.3 and 3.4 show the input assumptions for Population and GNP per capita and the results for primary energy per GNP, which is an important measure for efficiency, total primary energy supply and primary energy per capita. These values are plotted in the form of factor increase where the 1975 value equals 1 (see Table 4.3 "The Model DATA" and Table 4.4 for the exact values). Figure 3.5 shows the evolution of the fuel mix.

3.2.2. Evaluation

3.2.2.1. Structural evaluation - appropriateness for environmental studies

The model describes the potential of a reasonable evolution of global and regional energy systems. It captures long-term slowly changing macro-economic characteristics, structural changes on regional and global level. Thus the model is able to capture the effects on the energy sector of investment policies, technological changes, lifestyle patterns, structural changes in the economy like the transition to a postindustrial phase and development policies/strategies for LDC's. The model provides global and regional final energy demand, primary energy production and fuel mixes. It models the evaluation of energy supply, conversion and distribution systems and incorporates impacts of alternative strategies on resources, economy (capital, cost) and some on environment (land use, water use, CO_2 emissions).

A major constraint is that no feedbacks of environmental impacts are taken into account to impose limits on the energy sector. Only technical and economic constraints are considered. The fact that non-commercial energies are not included makes it very difficult to create realistic development scenarios for LDC's (todays share of non-commercial fuels: 40 - 90%). Major environmental problems of developing countries like competing land uses between non-commercial energies and agriculture or the impacts of extensive use of biomass fuels cannot be considered. This flaw holds true for most of the global energy studies.

The resolution in time and space of the IIASA study is valuable to consider even regional (parts of the model work on national level and are later aggregated to the 7 regions) and medium term effects (decade), but the time scale could be too short for long-term impacts on the biosphere (1975 - 2030). It is questionable to extend the time frame up to 2075 with a five year time resolution. Time periods for long-term models might have to be longer in order to describe only the general trends and to limit uncertainties caused by short-term bias.

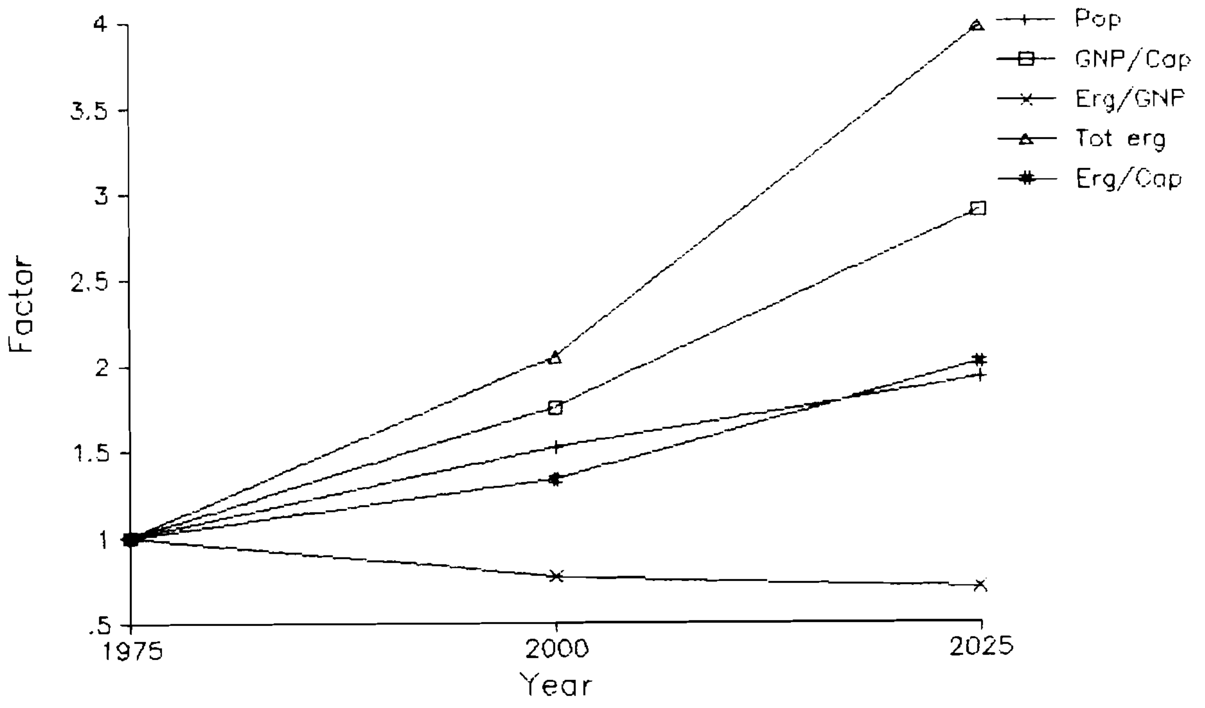


Figure 3.3 Factor increase in the IIASA model - high

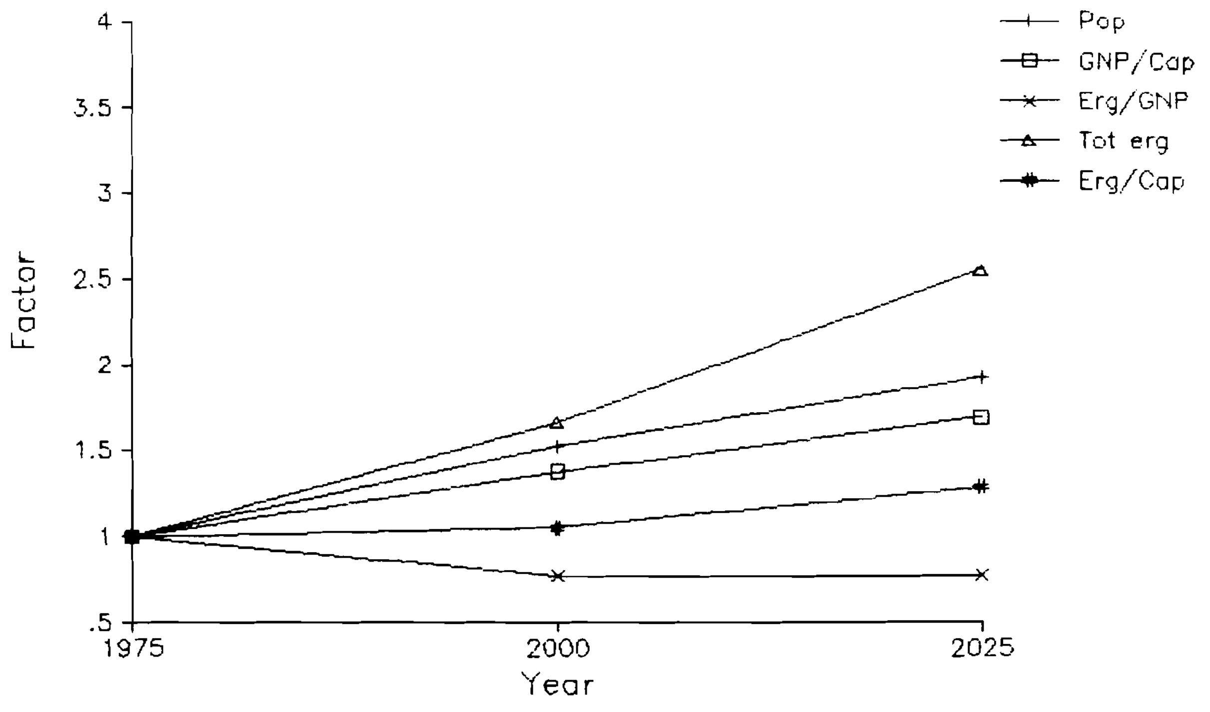


Figure 3.4 Factor increase in the IIASA model - low

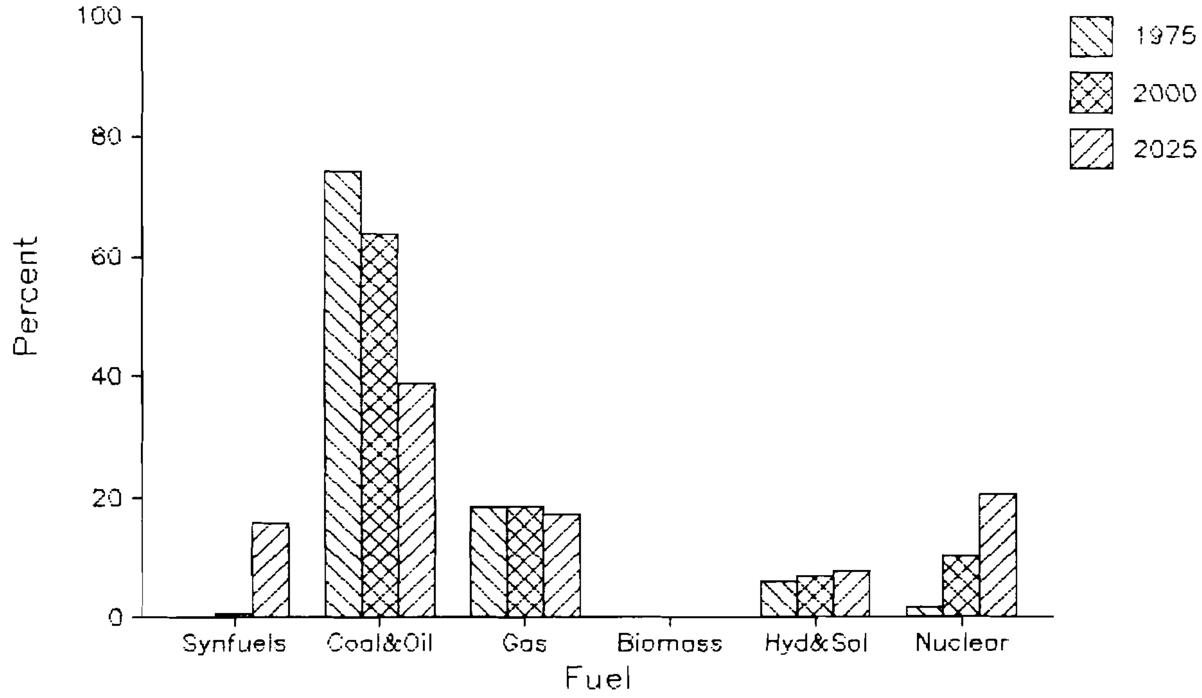


Figure 3.5 Fuel mix in the IIASA model - high

For most of the atmospheric pollution problems (like acid rain, NO_x), except for CO_2, the regional grid seems to be too large. But it seems to be possible to get a higher spatial resolution with few modifications.

Some other socioeconomic considerations left out by the model are institutional, societal and policy issues. The model does not predict energy pricing policies, market fluctuations, interest rates or multisectoral dynamics. It does not evaluate the effects of specific tax, quota, regulatory and financial incentive policies in detail or explain inter-country migration effects on the energy sector. It does not treat technological details of small scale energy systems, simulate carefully the full nuclear fuel cycle or address questions of safety or arms control. Nor can the model identify local gaps in energy supply.

3.2.2.2. Scenario design and use

The model is very complex and not easy to handle. This is caused by the high disaggregation of the energy sector, which creates a great number of variables. It takes a long time and much experience to create consistent scenarios. This was the reason why only a few scenarios were built: high case, low case, nuclear moratorium case, enhanced nuclear case, alternative 16 TW demand case, IIASA '83 scenario. Only the first two scenarios have been completely accomplished, the others did not pass through the iterative modeling process to make them totally consistent (Haefele et al., 1981, Vol 2). The complexity of the model makes it difficult to summarize and understand the differences between scenarios.

The model is therefore not very suitable to be used to create as many different pictures of the future energy world as possible in order to get a better understanding of global environmental problems.

3.2.2.3. Criticisms

The model results are criticized for being "highly unstable and based on informal guesswork" (Keepin and Wynne, 1984:691). The main reproach is that "the models essentially reproduce informally the prescribed input projections that pass through the model set unchanged". The study shows a considerable lack of sensitivity analysis on the models key variables. Mainly the energy conversion module MESSAGE, which uses a linear programming approach, is shown to be very sensitive to the energy price assumptions for different fuels. Only small changes in assumptions (less than 20%) led to totally different fuel mixes. These findings bring several conclusions drawn from the scenarios into question (Keepin, 1984).

Nevertheless the IIASA study is valuable for providing detailed informations on many other fields - the modeling was only one part of the entire program. Important results were produced concerning global energy resources and production limits. Other contributions include the logistic substitution model (market penetration analysis of different fuels) and the work on CO_2, technological risk perception, and solar energy.

3.3. Edmonds & Reilly: Global Energy - Assessing the Future

3.3.1. Description.

The Edmonds & Reilly model, developed by Jae Edmonds and J.A. Reilly of the Institute for Energy Analysis of the Oak Ridge Associated Universities (IEA/ORAU), has been extensively used in the United States since at least 1982 (Edmonds and Reilly, 1984). A second version of the model that is somewhat differently specified has been developed in the last year, but has yet to be widely diffused (Edmonds et al., 1985). As a result, this description will focus primarily on the former version, while mentioning some of the more salient differences that exist in the latter.

3.3.1.1. Scale and resolution.

Time Scale: Analysis in the authors' published expositions of the model is conducted to the year 2050 in four steps: 1975, 2000, 2025, 2050. The model has been used in several other contexts to examine intervals as far out as 2100 (Rose et al., 1983; Reister, 1984; Edmonds and Reilly, 1983a). A fundamental assumption of the model is that capital in the energy system is completely replaced every twenty-five years, thus the 25 year interval between model iterations.

Space Scale: The Edmonds and Reilly (E&R) model divides the world into 9 spatially contiguous regions: four "developing" (Africa, Middle East, Latin America and South & East Asia), two "centrally planned"(Eastern Europe/USSR and China and some surrounding countries), and three OECD (USA, Canada and Western Europe, and OECD Pacific, meaning Japan, Australia, etc..).

Fuel Disaggregation: The model provides, for each time and space interval, the mix of six primary sources (oil, coal, gas, hydro, solar, and nuclear), four secondary sources (liquids, solids, gas, and electricity), and biomass, shale oil, and synfuels.

3.3.1.2. Approach and structure.

Initially conceived as a tool for exploring the CO_2 problem and policy/development options influencing it, a run of the Edmonds and Reilly model provides, in a relatively simple framework, five detailed and balanced commercial energy demand/supply and CO_2 snapshots out to 2100. For each of the nine regions, model outputs include detailed primary and secondary fuel mixes, a variety of trade, price and development indicators, and CO_2 emissions information.

Two parts of the model are economically driven: the demand module and the energy balance module. The supply module is primarily resource-constrained, with only a partially economic specification. (The major change in the most recent version is a further economic specification in the energy supply sector). Fundamental to the approach are assumptions about the importance of market mechanisms, prices, incomes, labor productivity, and population as driving variables in the energy sector. This basic structural underpinning of the E&R model is well expressed in Figure 3.6. The energy forecasting part of the model is broken up into three sub-sections.

Energy demand

The model uses population and GNP projections, based on assumptions about the fraction of the population in the active labor force as well as the productivity of labor, as indicators of economic activity and income. Regional primary energy prices are derived from world prices with region-specific add-on costs (mimicing transport costs, taxes and tariffs). The model may be manipulated, via these costs, to restrict trade or simulate various government policies.

The cost of secondary and tertiary (including electric) energy services is calculated next in a framework of interfuel, cost-based competition for shares of the electricity market. The regional demand for energy services is then calculated from a region-specific energy service price, and income and price elasticities of energy demand. Demand can be further affected by a parameter for technological change/energy productivity, which permits the incorporation of various assumptions about structural economic change and improved energy efficiency.

The demand module then calculates a final energy demand for four secondary fuels, based on this aggregate demand for energy services and the relative cost of energy production with each of these fuels. The relative fuel shares within this demand are again determined in a market share competition framework. These demands for secondary fuels are converted into a demand for six primary fuels (oil, biomass and coal, gas, nuclear, hydro, and centralized solar) using appropriate conversion efficiency and production loss factors.

Energy supply

Three types of energy resource are defined: resource-constrained conventional (including conventional oil and gas), resource-constrained renewable (including biomass, centralized solar, and hydroelectric), and unconstrained (including coal, shale oil, and nuclear).

Resource-constrained energy supply is determined using a logistic depletion function (Hubbert, 1962) for non-renewable sources. Renewables are modeled under an assumption of a growth path leading to their being exploited at their maximal rate. Unconstrained technologies are assumed to be of a "backstop" type, meaning that they break into the market at certain price levels, and thereafter provide relatively unlimited amounts of energy, according to a price-supply schedule. Most of the modifications to the model have occurred in this supply section, and have been geared towards increasing the economic aspects of this section, rather than making it more complicated.

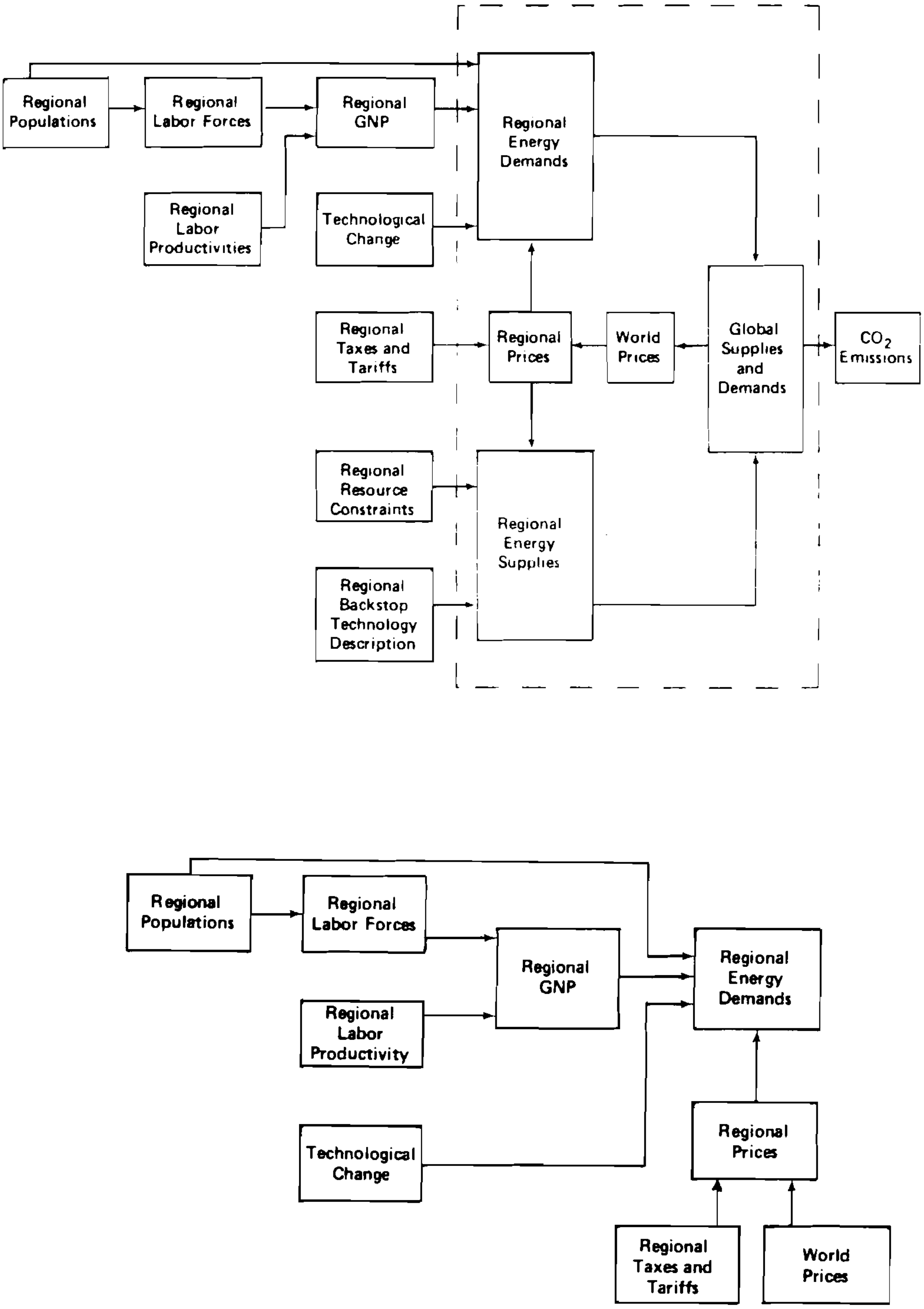


Figure 3.6 Structure of the IEA/ORAU model (Edmonds and Reilly, 1985)

Finally, synthetic fuels production from coal has an economic dependency on the cost of coal, oil and gas, the cost of conversion, and the market shares of primary energy demand that synfuels are able to capture through price competition.

Energy balance

With trade occurring only in fossil fuels, world prices are modified to ensure that all markets clear. These market-clearing-prices are iteratively used until an equilibrium is reached for each and every fuel market.

CO_2 *emissions*

There is a fourth part of the model dedicated to evaluating CO_2 emissions that result from energy use projections. In this module, CO_2 emission coefficients are applied to the projected fuel uses for four fuel types (gases, liquids, solids, and shale oil).

3.3.1.3. Model results

Figure 3.7 shows the input assumptions for Population and GNP per capita and as results primary energy per GNP, which is an important measure for efficiency, total primary energy supply and primary energy per capita. These values are plotted in form of factor increase where the 1975 value equals 1 (see Table 4.3 "The Model DATA" and Table 4.4 for the exact values). Figure 3.8 shows the evolution of the fuel mix.

3.3.2. Model Evaluation.

3.3.2.1. Table of key variables

(see Table 3.1)

3.3.2.2. Sensitivity analysis

The recent version of the Edmonds and Reilly model has been tested for sensitivity and uncertainty through extensive Monte Carlo analysis (Edmonds et al., 1985). From such testing three input variables clearly emerged as being the most important in determining energy demand for most time and regional distributions calculated within the model. These were the rates of labor productivity growth, and of energy efficiency change, and the income elasticity of less developed countries. A less rigorous analysis conducted on the earlier version of the model found base GNP, coal supply and unconventional oil parameters more important than labor productivity. These shifts in sensitivity are most likely attributable to the aforementioned model modifications. This shift points to the value of sensitivity analysis in determining how closely a model conforms to our expectations of how the world works. Such shifts illustrate the variance that can exist within even one model as to what are sensitive inputs to the energy system.

Within the more recent analysis, the explanatory power (or correlation to variability) of about 80 input variables on such outputs as region-specific fuel mixes, prices, and production was also tested (Edmonds et al., 1985:41). Edmonds et al. note in that study that no unexpected results emerge from their uncertainty analysis. For example, coal production as projected by the model turns out to be sensitive to labor productivity increase and environmental costs of coal more than anything else.

Knowing that model outputs make sense is valuable in assessing its suitability for use in environmental studies. It would be unreasonable, however, to assign explanatory powers or to base actions in reality on the ranking of those variables explaining detailed results of the model. These input variables had generally low correlations associated with

Table 3.1 Key variables in the Edmonds & Reilly model

	BASE	LOW	HIGH
DEMAND VARIABLES			
GENERAL			
Population growth rate (%/year)	.94		
GNP growth rate (%/year)	2.9	2.1	3.5
Developed	2.3	1.8	3.1
Developing	4	3.1	4.4
Population base (millions)	3976		
GNP base (billion 1975$)	6056		
Labor productivity growth (%/year)			
Exogenous energy efficiency growth (%/year) (soft case=2.0)	.35	1.0	0
SUBSTITUTION RATES			
Fuel substitution (cross-elasticities)			
oil-own	-.7		
oil-gas	.1		
oil-coal	.1		
gas-own	-.52		
gas-oil	.13		
gas-coal	.12		
coal-own	-.56		
coal-oil	.22		
coal-gas	.16		
Electricity generation substitution			
ELASTICITIES			
Income			
3 OECD REGIONS			
res./comm.(/cap.income)	1		
industrial (/GNP)	1		
EUSSR	1.25		
ELSE	1.4		
GNP feedback	.05		
Aggregate price			
OECD REGIONS			
(industr.)	-.8		
(transport)	-.7		
(commercial)	-.9		
ELSE	-.8		
DEMAND RELATED FUEL ASSUMPTIONS (prices include taxes and transport costs)			
Coal			
price (1975$/GJ)	.26		
electricity generation costs (1975$/GJ)			
w/scrubbers	6.87		
w/o	5.86		
conversion efficiency	.3		
Conventional Oil			
price (1975$/GJ)	2		
electricity generation costs (1975$/GJ)	4.53		
conversion eff.	.27		
Oil shale			
price (1975$/GJ)	3.85	19.25	3.85
Natural gas			
price (1975$/GJ)	1		
electricity generation costs (1975$/GJ)	4.51		
conversion eff.	.27		
Unconventional gas			
breakthrough price (1975$/GJ)	3.7		
Synfuels			
cost oil	4.55		
gas	3.3		
Nuclear			
electricity generation costs (1975$/GJ)	9.19	9.19	infinite
Solar/Renewables			
electricity generation costs (1975$/GJ)	20	9	infinite
Biomass			
cost waste	0		
farmed	2.1		
Hydroelectric			
electricity generation costs (1975$/GJ)	6.12		
Electricity from coal (non-fuel costs)			
SUPPLY RELATED VARIABLES			
Coal			
increase in production (rate/year)	2.9	1.4	3.3
min. breakthrough price			
normal breakthrough price			
short-term price elasticity control			
Oil			
resource (EJ)	12715		
logistic path constraints			
Gas			
resource (EJ)	9953		
logistic path constraints of supply and flaring			
Hydroelectric			
resource (EJ)	35.41		
Non-coal backstop technologies			
min. breakthrough price			
normal breakthrough price			
short-term price elasticity control			
Synfuels			
production costs			
cost of other fuels			

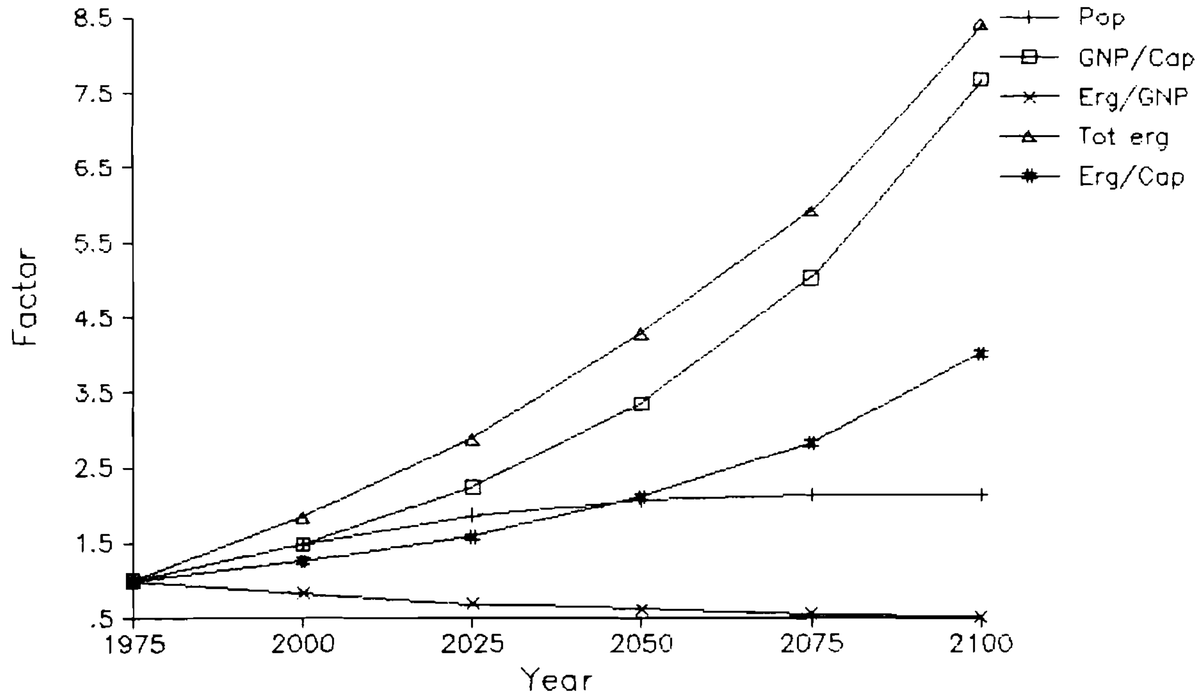


Figure 3.7 Factor increase - Edmonds and Reilly

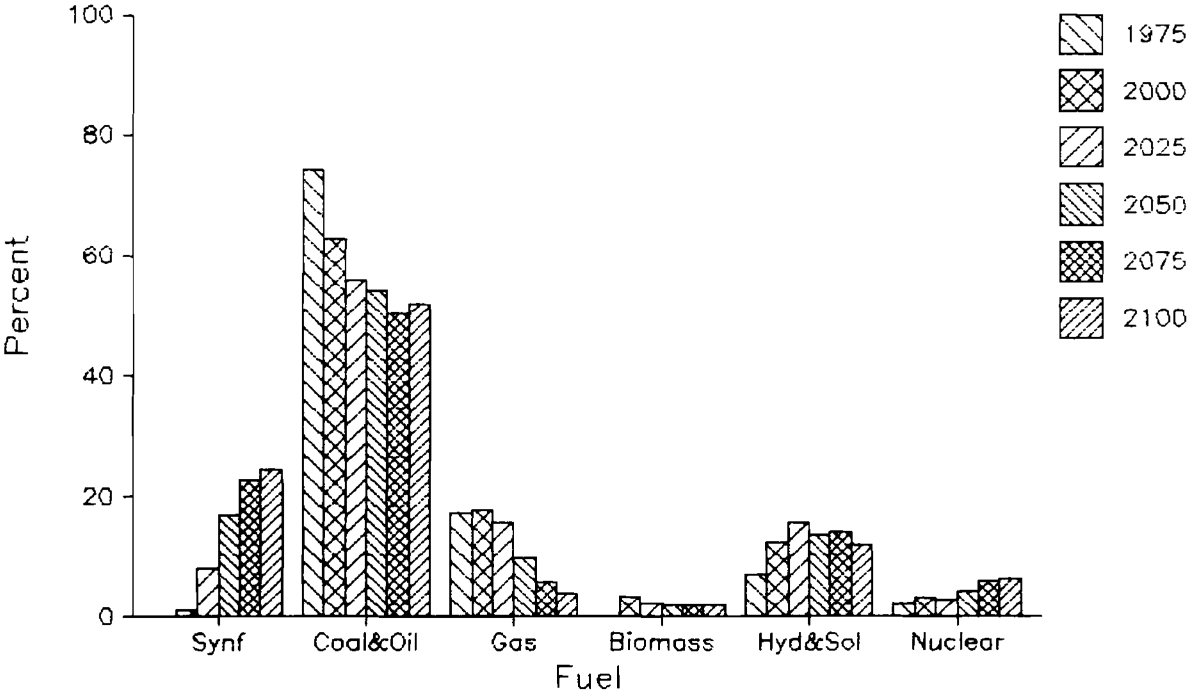


Figure 3.8 Fuel mix - Edmonds and Reilly

their rankings as explanatory variables.

In the Monte Carlo analysis that was conducted, another interesting feature of the Edmonds and Reilly model emerged. The model, when its inputs are varied over the kinds of ranges used for Monte Carlo analysis, can provide an extremely wide range of total primary energy use and carbon emissions scenarios. For example, the 95% confidence bounds for primary energy use in 2075 range from a little less than 7 terawatts (TW) to a little more than 314. This result indicates that the model can really be used as a "scenario generating" machine, delivering a set of internally consistent projections for a wide range of input assumptions.

Despite the breadth of the Monte Carlo results, some interesting conclusions do emerge. One is that, of all the model runs, only 10% projected growth akin to that that has occurred in the last 55 years (Edmonds et al., 1985:65). Whether this represents a genuine insight into the energy world or the model's biases is difficult to judge. Edmonds and Reilly strongly link energy growth with GNP growth, based on their long-term analyses of the energy market. But this growth-inducing tendency is offset by their modeling of resource availability as having peaked for the cheapest fuels. The time-frame from which model calibration data is drawn strongly influences such parameters in models.

3.3.2.3. Structural evaluation

Overall, the Edmonds and Reilly model is a simple and worthwhile tool for exploring global energy and CO_2 futures. It is admirably documented, fairly simple to use in light of its level of disaggregation, and has been extensively tested and run in several independent settings.

Through its use by several different studies (Rose et al., 1983; Reister, 1984; Edmonds and Reilly, 1983a), a number of criticisms have emerged, not all of which have been answered by the recent modifications. The criticisms here listed will be applicable to the older version of the model. We have split other studies' criticisms and our own into three categories: inadequately or incompletely specified key relationships, non-modeled economic variables or relationships, and non-modeled energy relationships. Model flaws in the first category may have been remedied in the new version.

The first category of problems with the model includes the fact that the supplies of oil and gas are not price-determined (Lave, 1981:2; Keepin et al., 1985:55; Rose et al., 1983:42), that the modeled supply function for coal has proven to be quite inelastic (Reister, 1984), and that these incomplete economic specifications cast some doubt on the model's suitability for analyzing energy use in economies with active government intervention (Keepin et al., 1985:55).

The second category of flaws are reported in Rose et al. (1983). In their use of the Edmonds and Reilly model, they question the model's procedure of assuming no carry over in capital stock for periods greater than the model's 25 year interval, because of the potentially longer life that many energy systems in fact have. They further report that the model's elasticity oriented approach to the energy sector leaves a lot to be desired when trying to understand or design scenarios aimed at exploring the role of specific sectors of the economy. This flaw clearly emerges from the sensitivity analysis' identification of income elasticity as a key variable. To know that the income elasticity of energy demand is a driving variable is almost a trivial result because income elasticity is such an aggregate measure of the behavior of commercial energy systems. Finally, the model lacks an adequate structure for introducing really new energy technologies.

The third set of flaws are shared with most of the energy field, and are discussed in further detail later. They include the fact that non-commercial fuels and environmental feedbacks on the energy system, such as societal response to CO_2-induced warming are not included in the E&R model. For example, the model predicts a rise in primary energy/GNP ratios at least through 2050 for less-developed countries. Were non-commercial fuels to be included, it would be hard to imagine how the ratio could not drop, considering the inefficiency of traditional fuel use.

The model also predicts an absolute increase in the already large energy gaps between less-developed and developed countries. Policy makers using detailed scenarios generated from this model may find their credibility somewhat limited because of this factor. This too may be due to the lack of model structure describing the transition from non-commercial to commercial energy use.

3.3.2.4. Scenario design and use

Because of the speed with which the model runs, and the relative simplicity of its design, scenario construction with the Edmonds and Reilly model has been relatively prolific. The differences between scenarios are easily summarized and understood. The criticism of too much end-use aggregation mentioned above here becomes a strong benefit in using the model. While all the input variables we might want to tune are not explicitly incorporated in the model, the model permits a design through broad variables of many of the energy sector evolutions that might be interesting.

As mentioned earlier, a model that is flexible enough to provide a large range of scenarios can be extremely useful for exploring energy futures in a consistent way.

3.3.2.5. Appropriateness for long-term, large-scale environmental studies

Besides its widespread use in the analysis of the CO_2 problem, the Edmonds and Reilly model holds some promise for the analysis of other interactions between energy and development and the environment. Most clearly, it represents a good tool for exploring long-term energy futures at global and large-region scales.

The model may prove, with some further modification and/or verification, also to be useful in analyzing some of the environmental concerns on the regional/national scale. For example, the model might be able to provide some continental scale indicators of land use by biomass farms, heavy metal mobilization from mining and combustion of fossil fuels, or emission levels of other radiatively active gasses. This would require some re-calibration and verification with respect to those Action/VEC relationships that might be explored with the model, but the effort may be worthwhile.

Finally, the time scale of the model may be able to be changed in order to explore other intervals. This would have to be undertaken with great care for the model's underlying assumptions about capital turnover and transitions in the energy sector.

3.4. The Nordhaus and Yohe Model

3.4.1. Description

3.4.1.1. Source and objective

Source: Nordhaus, W.D., Yohe, G.W. (1983). Future Paths of Energy and Carbon Dioxide Emissions. In Changing Climate, Washington D.C.

References: Rose et al. (1983), Edmonds et al. (1983a, 1983b), Keepin et al. (1985)

Objective: Global CO_2 emissions and concentration predictions.

3.4.1.2. Scale and resolution

Time scale: Basically 1975 - 2100 (can be adapted to a particular case).

Space scale: Global, for the world.

Time resolution: A continuous-time simulation model with possibility of different time resolution according to the time scale and the purpose of simulation. In the basic source the resolution applied is: 1975 - 2000 - 2025 - 2050 - 2075 - 2100.

Space resolution: 1 Region - the World.

Fuel disaggregation: 2 aggregated fuel types - fossil fuels (oil, gas, coal, shale oil, synfuels) and nonfossil fuels (nuclear, solar, hydro, renewable).

3.4.1.3. Variables

Inputs: Population growth rate, labour productivity, rates of technological change in energy industry, the fuel mix among fossil fuels.

Outputs: Consumption of fossil fuels, consumption of nonfossil fuels, fossil fuel prices, nonfossil fuel prices, GNP, carbon emissions, CO_2 concentration.

3.4.1.4. Approach

An aggregated, dynamic, econometric model for energy consumption based on generalized Cobb-Douglas production function. The main output of energy part is fuel mix between fossil and nonfossil fuels. Then, using an exogenously assumed fuel mix among fossil fuels, the model calculates CO_2 emissions and atmospheric CO_2 concentration.

3.4.1.5. Model results

Figure 3.9 shows the input assumptions for Population and GNP per capita and as results primary energy per GNP, which is an important measure for efficiency, total primary energy supply and primary energy per capita. These values are plotted in form of factor increase where the 1975 value equal 1 (See Table 4.3 "The Model DATA" and Table 4.4 for the exact values). Figure 3.10 shows the evolution of the fuel mix.

3.4.2. Evaluation

The report presents a dynamic, global-scale econometric model of energy consumption, focused on such environmental impacts as CO_2 emissions and cumulative CO_2 concentration in the atmosphere.

The model represents a compact, mathematical structure utilizing a generalized Cobb-Douglas production function - a fundamental relationship used for calculation of global GNP. There is no spatial resolution within the model; the World is considered as one region. Energy sources are divided into two categories: fossil and nonfossil fuels. Substitution between them is driven mainly by fuel prices, depending on technological changes in energy industry, resource availability, extraction/transportation cost of fuels, taxation policy.

The unique feature of the study is the systematic treatment of uncertainties within the model predictions by probabilistic scenario analysis. As a result, the set of key variables and parameters explaining most output uncertainty has been recognized.

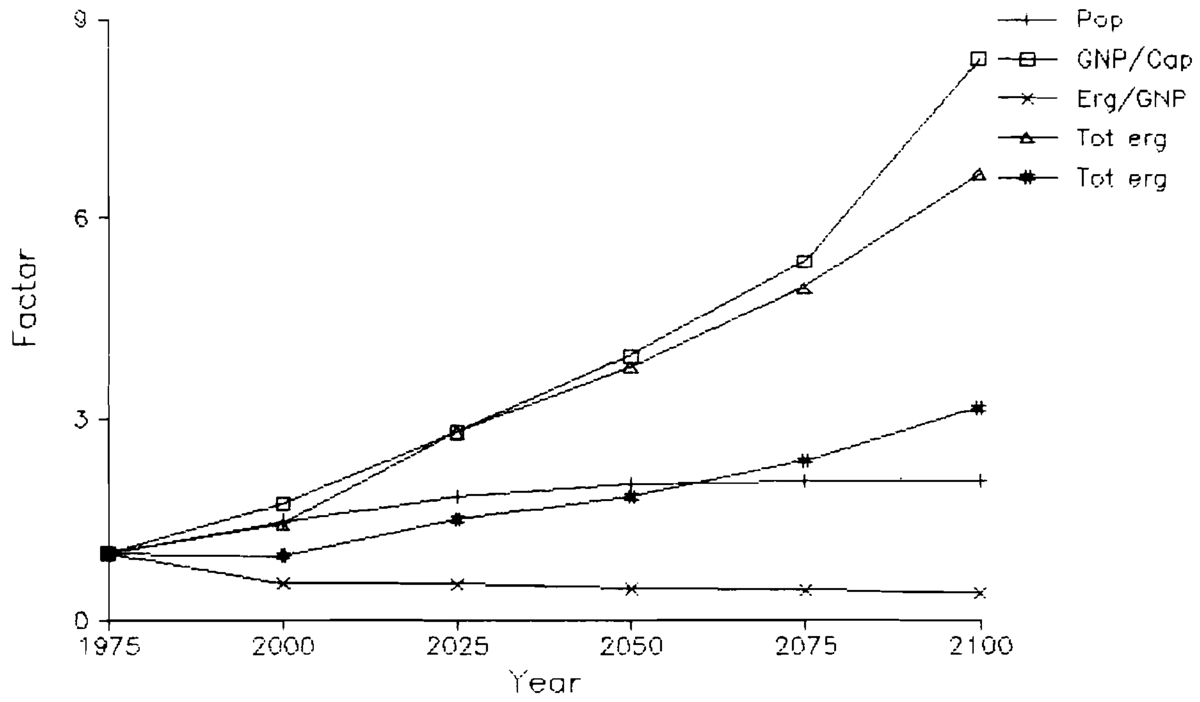


Figure 3.9 Factor increase - Nordhaus and Yohe

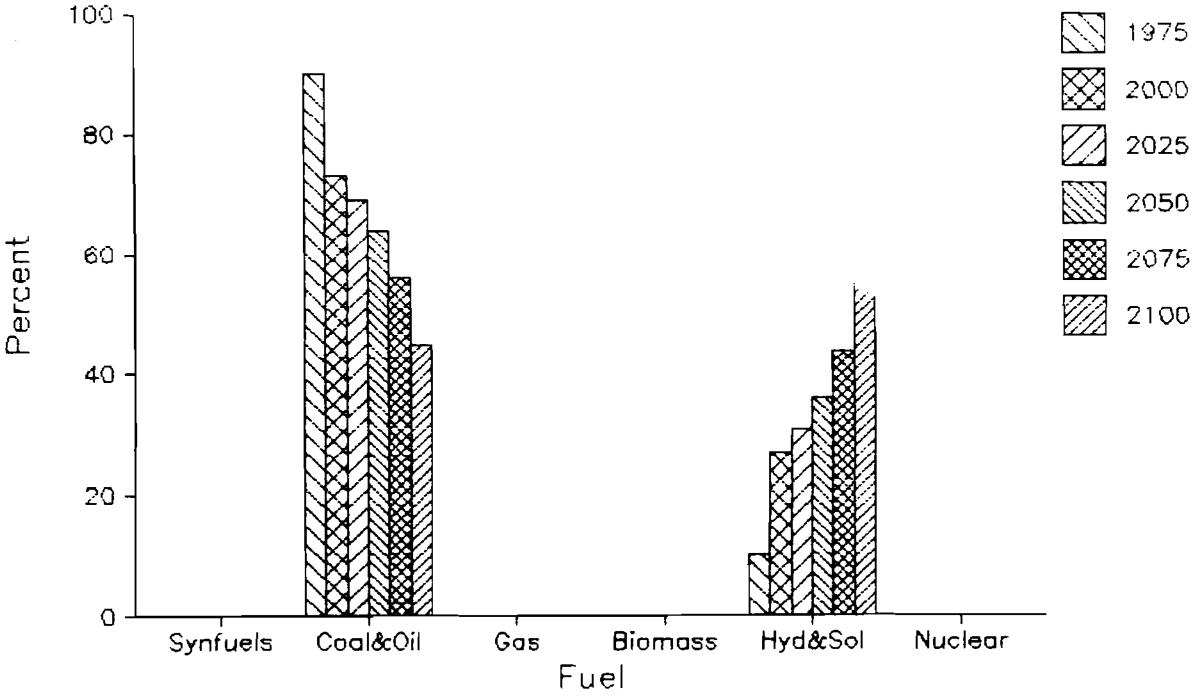


Figure 3.10 Fuel mix - Nordhaus and Yohe

The highly aggregated structure causes the model to lose some information concerning substantial differences between regions (especially between industrialized countries and less developed countries). The existence of only two fuel types leads to high sensitivity among parameters controlling the substitution between them. Furthermore, the specific model structure overestimates the importance of some parameters (such as elasticity of substitution fossil-nonfossil fuels, elasticity of substitution labour-energy). These are probably less important in real systems, and are not considered explicitly at all in other models (compare Appendix 5 for more detailed analysis).

On the other hand, the simple structure of the model facilitates the calculations and makes investigation of different strategies and scenarios possible. For this reason, the approach can be useful in constructing environment oriented strategies. In the main report, some examples of alternative taxation polices focused on environment protection are presented. A modified version of the model, based on combination of the Nordhaus-Yohe approach with some elements of the Edmonds and Reilly model, is applied in Appendix 5 to investigate a simple "surprise" rich scenario.

3.5. The World Energy Conference Model

3.5.1. Description

3.5.1.1. Source and objective

Source: Frisch, J.D. ed. Energy 2000-2020: World Prospects and Regional Stresses. Report of Conservation Commission of the World Energy Conference, New Dehli 1983. Graham and Trotman, London.

References: Keepin et al. (1985).

Objective: Primary energy forecast for the World, disaggregated by the regions and fuel types.

3.5.1.2. Scale and resolution

Time scale: Basic scale 1978 - 2020 (historical data for the year 1960).

Time resolution: 1960 - 1978 - 2000 - 2020.

Space resolution:

10 Regions of the World considered
- R1 - North America,
- R2 - Western Europe,
- R3 - Industrial Countries of the Pacific,
- R4 - Eastern Europe,
- R5 - North Africa/Middle East,
- R6 - Sub-Saharian Africa,
- R7 - South Asia,
- R8 - South-East Asia,
- R10 - Latin America.

Fuel disaggregation: 8 fuel types considered; oil, coal, natural gas, hydro, nuclear, wood, vegetable and animal waste, new energies.

3.5.1.3. Variables

Inputs: Population, GNP, income elasticities.

Outputs (state variables): Commercial energy consumption, noncommercial energy consumption, primary energy consumption, fuel mix, international trade of fuels.

3.5.1.4. Approach

The forecast is a static prediction of historical trends, based mainly on expert opinions and simple calculations of main relations. The Central Team provides 10 Regional Working Teams with consistent (1960 - 1978) historical data as well as input forecasts for population and GNP growth. The Regional Working Teams calculate primary energy demand and supply (disaggregated by 8 fuel sources), fuel imports and exports. The CO_2 emissions are not directly considered but they can be calculated from primary energy consumption.

3.5.1.5. Model results

Figures 3.11 and 3.12 show the input assumptions for Population and GNP per capita and as results primary energy per GNP, which is an important measure for efficiency, total primary energy supply and primary energy per capita. These values are plotted in form of factor increase where the 1975 value equals 1 (see Table 4.3 "The Model DATA" and Table 4.4 for the exact values). Figure 3.13 shows the evolution of the fuel mix.

3.5.2. Evaluation

The report presents forecast of global primary energy consumption for the years 2000 and 2020, based on historical data for 1960 and 1978 (the latter as the base year). A consistent and relatively detailed regional resolution (10 Regions) takes the following criteria in consideration: (i) geographical proximities, (ii) continental frontiers, (iii) types of economic systems, (iv) the stage of development of the countries.

The final forecast reflects energy experts' opinions from all the Regions, stated in the year 1982. The prediction method does not use a single mathematical framework; it is based on the cooperation of a Central Team (which provides consistent historical data and basic assumption for scenarios) with 10 Regional Working Teams (elaborate detailed regional forecasts). Two alternative scenarios are considered: (i) high - "normative cooperation scenario", and (ii) low - "increasing stresses scenario".

The final results present total and per capita economic growth, commercial and noncommercial energy consumption - disaggregated by region and by fuel type. An important feature of the project is its detailed fuel disaggregation by 8 types. The model's identification of noncommercial energy use (fuel wood, vegetable and animal waste) as being important over the next decades mainly in LDCs is valuable for environmental considerations .

The report can not be directly applied to an environment-oriented project since it does not represent any formal, reproducible approach. On the other hand, since it is a consistent representation of a complex expert opinion, it may be valuable as a comparative and auxiliary study for other projects. It is also important that the results will be up-dated by the future World Energy Conferences.

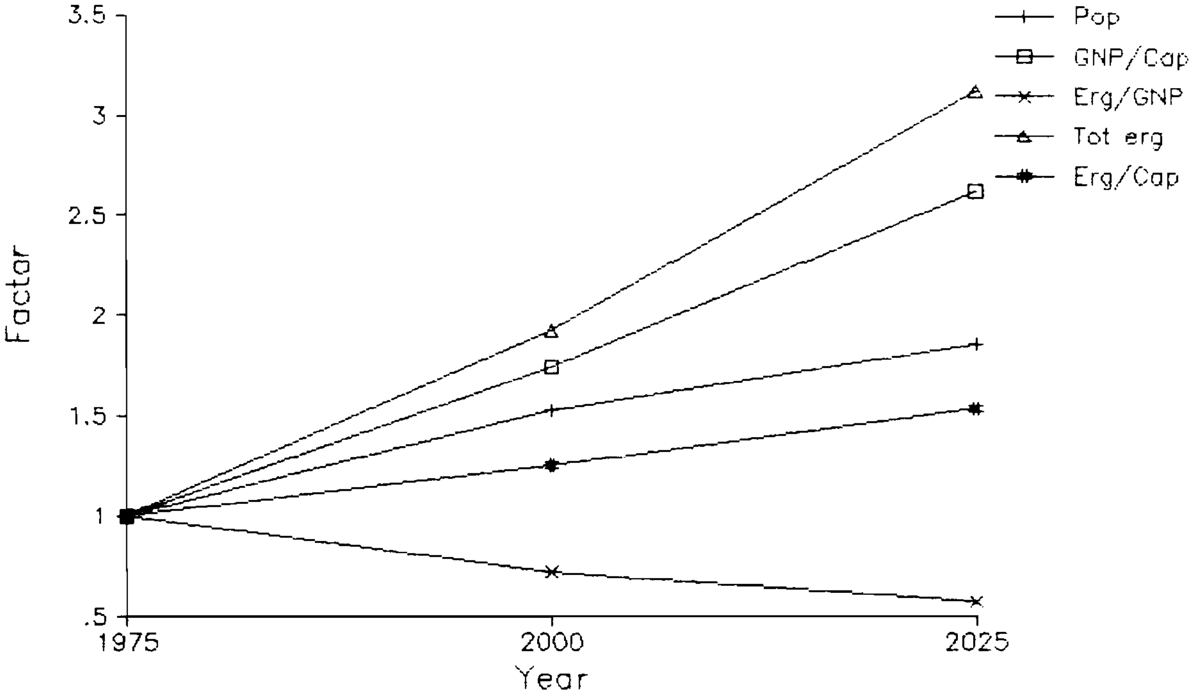


Figure 3.11 Factor increase - WEC high

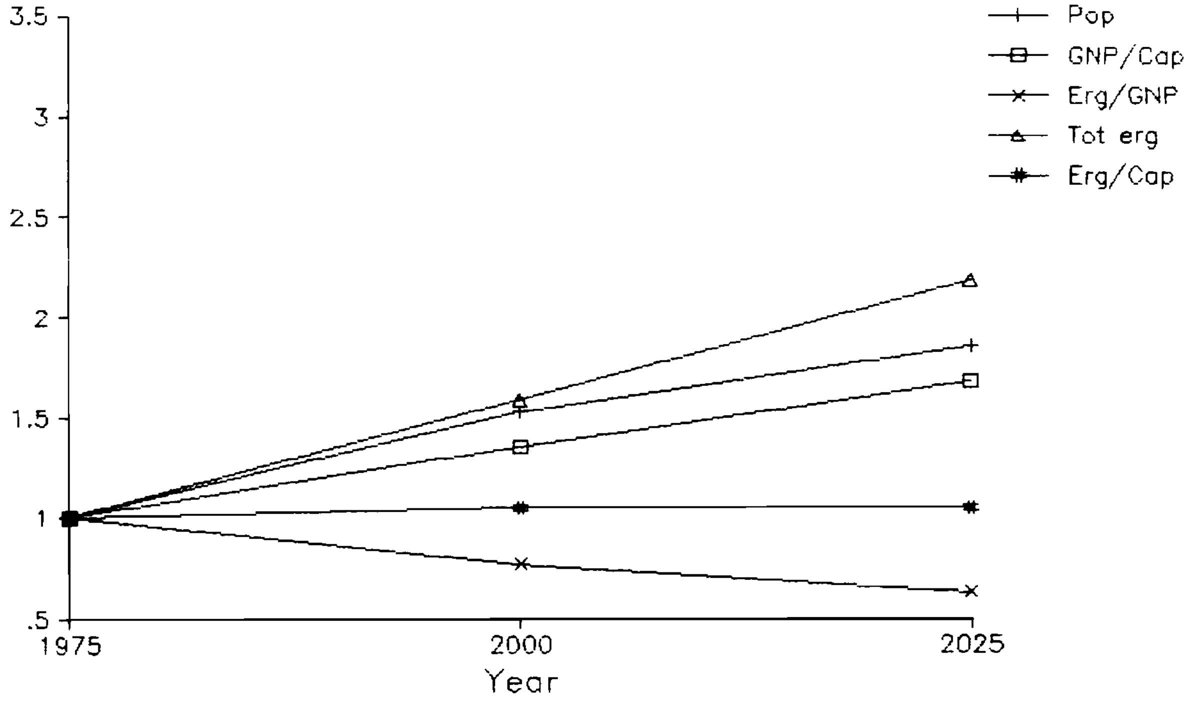


Figure 3.12 Factor increase - WEC low

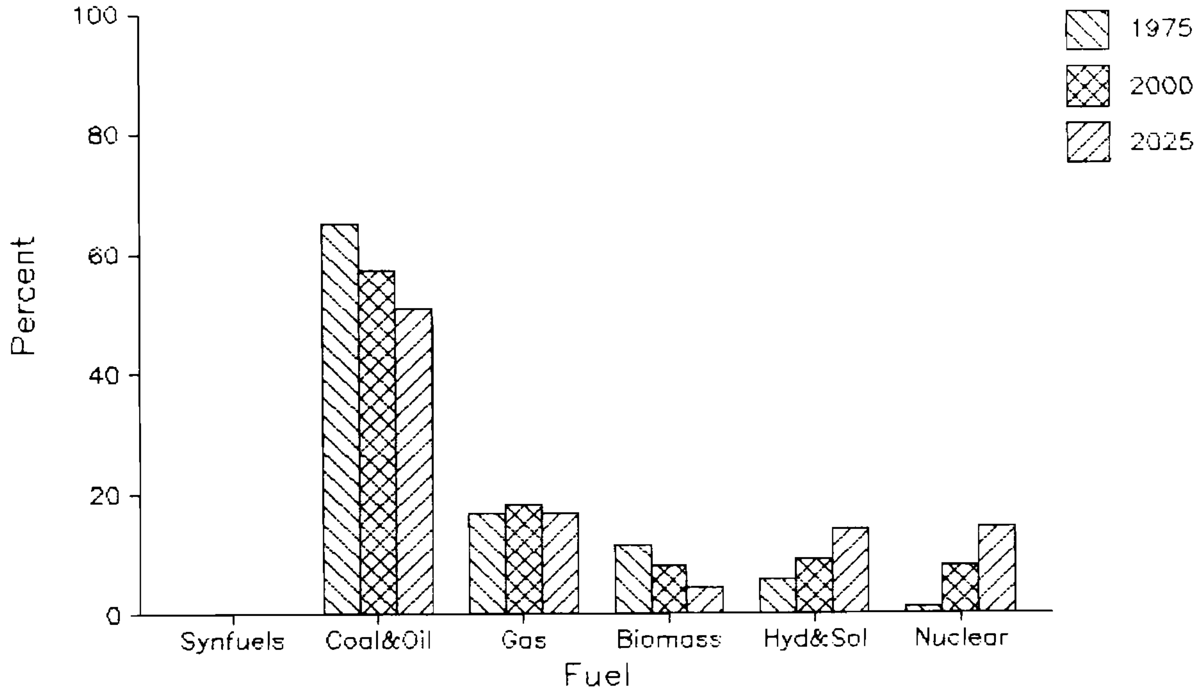


Figure 3.13 Fuel mix - WEC high

3.6. Short-Term Studies: Global 2000 and World Energy Outlook

3.6.1. Global 2000

Source: CEQ: The Global 2000 Report to the President, U.S.Government Washington 1981. Vol.2:161-185, 569-577; Vol.3:289-327.

Objective: Forecast the World's energy future (from an American perspective).

Time-span: 1975-1990 (2000)

Time resolution: 1985, 1990

Space resolution: Four main regions: OECD, CPE, OPEC and non-OPEC LDCs. OECD can be highly disaggregated for both subregions, nations and sectors. (This is because of the fact that the input-data for OECD are disaggregated and often modeled in the beginning.) The other regions' demand and supply are based on expert opinions and trend-extrapolations i.e. without very much sectoral and national disaggregation.

Fuel disaggregation: Oil, coal, gas, nuclear and others. Only the fossil fuels are modeled, the others are used as constants for each year.

Modeling: Six submodels for Demand (for OECD the OECD Demand Model is used), Supply, Transportation, Electric Utilities, Refining and Miscellaneous Conversions prepare data for the linear programming matrix IEES that approximates the workings of a competitive market. These are all econometric models using elasticities. The common goal is to minimize the total global cost. The LP-matrix is run, with new prices calculated with price elasticities for fuels and sectors from the OECD-model, until supply and demand are equilibrated.

Inputs:

Population Growth
Economic Growth
Oil Supply / Price Model Parameters: Technological Progress
Electrification
Conservation
Country Policies for import, conservation and taxation of energy.

Built-in Assumptions: Continuity, no surprises except for oil price and supply.

Data: Mainly OECD and other Global 2000-studies.

Outputs: Fuel mix (primary energy); Energy consumption (commercial) for different sectors and regions with special emphasis on U.S. and OECD.

Scenarios: High, medium and low. In the high there are high population growth, high economic growth and a relatively stable and cheap oil supply.

3.6.2. World Energy Outlook

Source: World Energy Outlook , IEA/OECD Paris 1982

Objective: To forecast the World's energy future to set the scene for a discussion of problems of energy availability for the OECD-countries. An important objective is to draw some conclusions that is meant as advice for governments in the industrialized world.

Time-span: 1980-2000

Time resolution: 1985, 1990 and 2000.

Space resolution: Four main regions: OECD, CPE, OPEC and non-OPEC LDCs.

Fuel disaggregation: Oil, gas, coal, nuclear and others.

Modeling: The OECD Energy Demand Model is an elasticity model used to forecast energy demand in the OECD-countries. For other regions demand and for regional and global supplies expert assumptions and trend-extrapolations are used. Demand and supply sides are not balanced. Final energy demand is for OECD disaggregated for five sectors in the OECD: industry, electricity, transportation, residential-commercial and non-energy uses.

Inputs:

Economic Growth
Oil Price/Supply

Model Parameters:

Technological Progress
Electrification
Conservation

Built-in Assumptions:

Electricity expands at higher rates than during the 70s.
Price of energy follows oil price.
Private consumption follows GNP.
Policy actions will encourage energy conservation.

Data: Mainly OECD.

Outputs: Energy demand (especially for the sectors and different parts of the OECD-region); Energy supply (expert opinions, in other regions than OECD mainly the excess supply is interesting).

Scenarios: High (High economic growth, stable oil price and supply), low and low oil scenarios are presented.

3.6.3. Commentary to the Short-Term Studies

We considered after some analysis both Global 2000 and World Energy Outlook as inappropriate for long-term, environmental studies and decided to concentrate on the other studies. The main reasons for this were:

(1) Their too short time-perspective. This makes them too anchored in the present situation. They further don't take great changes in the energy system into account.

(2) No deeper discussion of environmental impacts. The only environmental issues mentioned are those connected with coal and nuclear power use. Their short time-perspective makes of course that all long-term effects of energy use are not of any interest.

(3) The relative ethnocentrism or concentration on the OECD-region and the relatively crude treatment of the other regions that is a common trait for many of the studies is a bit extreme in these studies. This makes them inappropriate for providing a base for any deeper discussions of the energy future of the developing world.

This critique, however, does not at all disqualify them as future studies. They are certainly as good as most other studies. What has been the most interesting thing about them and that has made them interesting to have as comparative material is their "normative" approach. They both have the explicit objective to provide a base for policy-making. That should also be one of the areas of concern for the project.

4. MODEL EVALUATION

4.1. Introduction

The main objective of our study is to formulate a general approach to the scientific investigation of long-term, environmental implications of energy production. For this purpose, in Section 2 we have recognized the set of most "vulnerable" Valued Environmental Components that can be affected by energy production. The linkages (mainly qualitative) between activity levels in the energy sector and VECs were presented in a form of the respective matrices.

Now we want to recognize the main factors which determine the state of energy system. In this case, as opposed to the energy-environment relationship, there exist tools for quantitative evaluation of input - output relationships within energy system. These tools are mathematical energy models presented in Section 3.

Each model is built to give an answer to some specific question. For this reason, models differ as to their main assumptions as well as to their mathematical structure. On the other hand, it may be possible to distinguish a set of descriptors which can characterize some general family of models or even the energy system as a whole.

By a comparative analysis of a set of energy models we have tried to find a general set of "key variables" driving a representative model of energy system. Such an analysis, and a resulting set of key variables are presented in Section 4.2.1.

The results of this analysis, however general as it may be, reflects some limitations of the models used as a base for consideration. In Section 4.2.2 we try to find key variables representing the real energy system, based on a direct analysis of this system, not its mathematical models.

In attempting to understand the nature of actions that could be useful in exploring energy-environment interactions, we have primarily sought to identify those "key variables and relationships" that are most interesting for those phenomena. Two of the studies (Edmonds & Reilly, and Nordhaus & Yohe) that we have examined have actually conducted quite rigorous analysis of the causes of uncertainty and variation in their models. Keepin et al. (1985), among others, caution us, however, not to confuse sensitivity, as determined in a model, with sensitivity of the real system being considered.

False sensitivities abound in any model. They can arise because of the greater degree of specification that certain variables enjoy over others (see the previous evaluations of Edmonds & Reilly and Nordhaus & Yohe for more on this) and they can fade out with excessive tuning of a model.

The quantification of uncertainty is extremely important for improving our ability to model the evolution of the environmental system. Our fundamental inability to describe accurately all the relationships that can influence it must never be forgotten. In using and interpreting model results their value must be assessed with an understanding of such inherent limits to their "realism".

These considerations led us to the following illustrative framework for variable analysis (see Figure 4.1). In this diagram, a distinction is drawn between modeled evolutions of the energy system, and real evolutions. There are "inputs" to both paths, with the model inputs always being a (usually) small subset of the real ones. These inputs then evolve, respectively, into a modeled and a real energy scenario. The modeled energy system usually has an assigned uncertainty represented here by a grey area, and in actual studies by high and low scenarios. We believe that the real system, though we cannot often measure it precisely, has no such uncertainty and therefore is, from point to point, precisely determined. Depending on luck, the time/space frame of the model, and the skill of the modelers, the model's uncertainty range will overlap more or less with the real world situation.

This energy situation then evolves into various environmental impacts that are of particular interest to us. Here again we find a real and modeled evolution. We felt that one more input that might not so directly affect the energy evolution but would certainly affect the environment, was the degree of environmental control in effect at the time of energy-biosphere interactions. Thus in the diagram environmental controls are seen as modifying the biosphere impacts of energy use directly through the energy sector. In the modeling of energy-environment impacts however, they are usually seen as having an insignificant effect on the energy system. If considered at all, they have more of an effect on the environmental sector. We believed this to be a crucial variable whose role has not been adequately explored.

4.2. Evaluation

4.2.1. Overall key assumptions and sensitivities

One of the objectives of this study was to select a set of energy models appropriate for investigating alternative environment-oriented strategies and scenarios. For this purpose, we have recognized some criteria which should be satisfied by the models used. It seems that the most important are the following:

(1) A relatively simple, dynamic mathematical structure that can be repeatedly used for constructing alternative scenarios;

(2) The possibility of global, long-term analysis for investigating cumulative environmental impacts;

(3) A flexible structure with a possibility of adaptation to a specific purpose;

(4) Availability of input data;

(5) Ease of transition from model's output to the respective VECs.

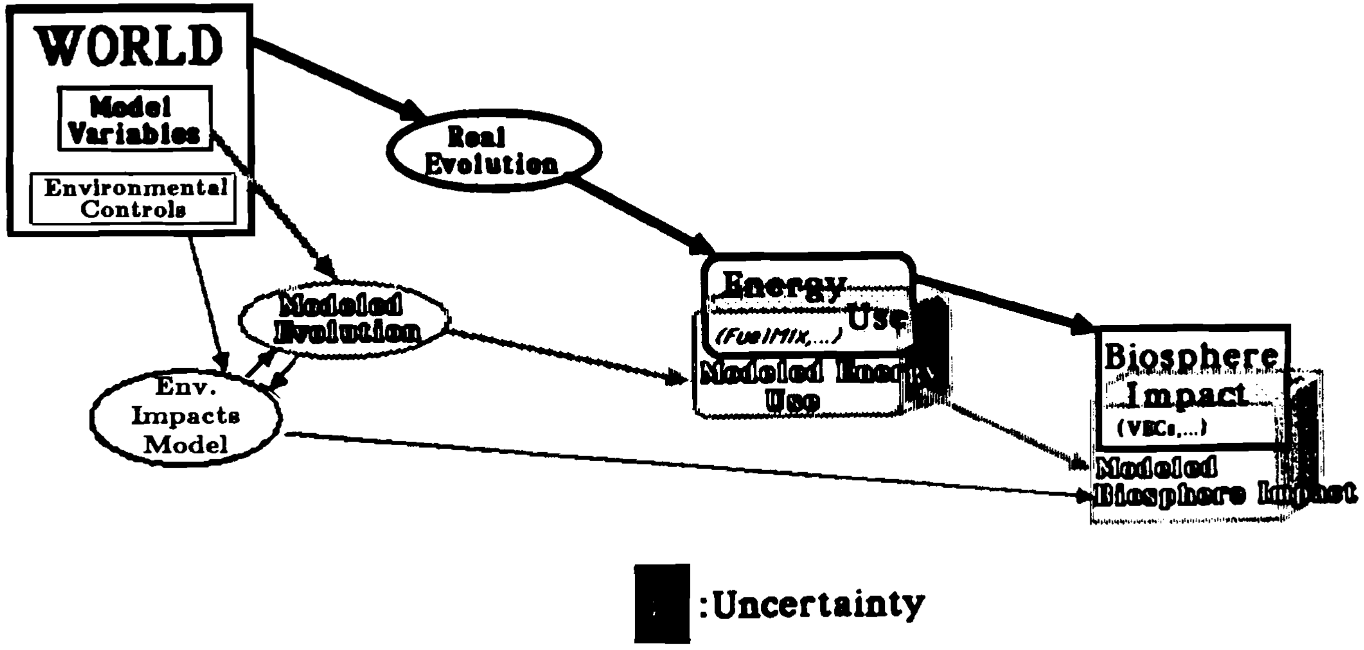


Figure 4.1 Energy system and real world

Following the above conditions we have analyzed the energy models presented in Section 3. We believe that three of the models characterized there are the most appropriate for biosphere-oriented applications. These are: the IIASA model, the Edmonds and Reilly model (E-R) and the Nordhaus and Yohe model (N-Y).

The other models, for various reasons, can not be used directly but are valuable as comparative studies. In particular, the WEC model can not be repeatedly used since it is based on an expert opinion and lacks a specific mathematical structure. Some of its results, on the other hand, may be useful, eg. precise spatial resolution and very detailed splitting of fuel types. For environmental impacts, the distinction that study draws of non-commercial fuels (fuel wood, animal and vegetable wastes) is very important due to the fact that they provide a significant share of energy in Developing Countries.

The Energy Outlook and the Global 2000 models are focused on OECD countries which constrains them to specific assumptions and model structures. For these reasons it would be difficult to adapt them directly to more general applications. It seems, however, that their specific energy demand submodels can be useful for more disaggregated approaches.

The studies selected for the further analysis represent advanced, up-to-date techniques of energy modeling and can be adapted to environmental applications. The E-R model and the N-Y model, in spite of differences in levels of aggregation and spatial resolution, use the same time-space scale and have similar structures. Both are focused on global CO_2 emissions and cumulative CO_2 concentration in the atmosphere.

Given the representative set of energy models, we have conducted a comparative sensitivity analysis in order to recognize the key variables and parameters that could be important not only to specific models but also to the real energy system being considered.

For the N-Y model and the E-R model very detailed, probabilistic uncertainty analysis has been conducted (Nordhaus and Yohe, 1983; Edmonds and Reilly, 1985). As a result, a ranked list of key variables for each model was established. The ranking position of a specific variable or parameter indicates what amount of uncertainty in model's output is explained by this variable (see Edmonds and Reilly, 1985, for details). The amount of uncertainty explained by a specific variable in the model's output depends, in the general case, on time (it is actually an indirect effect of state-dependence). For further analysis we assume, for simplicity's sake, the average values for the forecasting period.

For the IIASA model, the importance of specific variables was evaluated by analysis of the model's assumptions, its mathematical structure and how they relate to reality.

Results of this comparative analysis are summarized in Table 4.1 which groups the most important variables and parameters indicated by the individual models comparison. Since our objective was to obtain a set of key variables representing the system - not a specific model, the table contains some adjustments as to the importance of some variables indicated by the models considered. In particular, the N-Y model is most sensitive to a labor-energy substitution parameter which does not appear in other models. Importance of this parameter is a consequence of a specific form of production function (Nordhaus and Yohe, 1983) - the fundamental relationship within this model. On the other hand, population - the driving force in all the models - has very low uncertainty ranking and does not appear at all in the E-R ranked list. This fact is a result of very narrow input uncertainty attributed to population predictions (Edmonds and Reilly, 1985) which implies the low output uncertainty explained by this variable.

Table 4.1 shows a sort of correlation across the models, with respect to the importance of some variables. The variables that we concluded were the most important determinants of the energy system as explained by the models' own sensitivity analysis are grouped in Table 4.2.

Table 4.1. Key variables in energy models

INPUT VARIABLES	E-R	N-Y	IIASA
Capital Availability			x
Energy Efficiency Rate	x	x	x
Fuel Prices	x	n	x
Fuel Resources	x	x	x
Fuel Substitution	x	x	
GNP Growth	n	n	x
GNP-Feedback Elasticities	x	n	
Income Elasticities	x		
Price Elasticities	x		
Labor Productivity	x	x	x
Labor-E Substitution		x	
Life Style			x
Market Penetration			x
Population Distribution			x
Population Growth	x	x	x
Production Constraints	x		x
Taxes	x	x	
Structural Change			x

Note:

x - Exogenous variable n - Endogenous variable

Table 4.2 lists, in no particular order, the variables that our models indicated explained the most about the evolution of the energy system. The first five variables are essential for all the models considered. The growth of GNP, labor productivity and population are the factors which, in one way or another, combine in our three models to determine the level of energy services provided. In the Edmonds and Reilly model, population and labor productivity give GNP. In the Nordhaus and Yohe model they are also the main factors in production function which determine the final GNP level. In the IIASA model, GNP is directly input to give the relative level of energy service demand, and population is used to determine the distributional and basic needs energy requirements (automobile-miles traveled, etc.).

The growth of energy efficiency and technological change, depending on a specific model structure, are important to the calculation of secondary and final energy use. In some models, energy conservation, resulting from these two factors, is considered as an additional fuel. The fuel share is strongly controlled by fuel prices and energy resources availability.

Income elasticities and life style/energy use patterns are very important in some specific model approaches. The first parameter is commonly used in econometric models (the Edmonds and Reilly model) whereas the second one is characteristic for the end-use approaches (the IIASA model).

Table 4.2 Key variables in energy field
(models' sensitivity analysis)

GNP / Labor Productivity
Population Growth
Energy Efficiency / Technological change
Fuel Prices
Energy Resources Availability
Income Elasticities
Life Style / Energy End-Use Patterns

4.2.2. Unmodeled or insensitive but important variables and relationships in energy-environment interactions

This section of the report attempts to define two sets of variables: those that we felt were either left out of, or didn't emerge as particularly important variables for the energy sector in the energy models we examined, and those that may not be crucial to the energy sector, but are important in determining its impact on the environment.

In the first category, we felt that population distribution and infrastructure, though they are implicitly modeled in Edmonds and Reilly, and explicitly in the IIASA study, deserve an importance as influencers of energy-environment interactions far greater than that indicated in the results of those studies and sensitivity analyses. Considerations such as the patterns in which energy is used, the structures available for implementing new energy options, and the location of energy users are all recognized as crucial in the determination of final energy demand. While these models do capture some of these effects, we felt that their sensitivity to these issues was too low.

We further felt that the entire field of long-term non-commercial energy use is grossly neglected. The nature of our ignorance about the noncommercial sector can be broken into three groups variables and their relationships. First, we found a clear lack of an understanding of the nature of the transition from non-commercial to commercial fuels, which in turn introduced some unrealism in these models' descriptions of LDC energy futures. Today, 70% of the world's people use 15-25% of its primary energy. Their transition to marketed fuels in the coming century will no doubt be critical.

Second, in order to illuminate and perhaps model the transition, we felt that an understanding was needed of what the present and future availability of non-commercial fuels would be (in the form of fuelwood, dung, wind, solar, etc.) to various energy-using sectors. Third, we felt that some attempt would also have to be made to understand the long-term quantities and patterns of non-commercial fuel uses.

In the framework described in the introduction to this section, we drew a distinction of key variables that might be critical to energy's impact on the environment without being critical to the actual future of energy demand and supply. The only such variable we felt the need to identify was the degree of pollution control, both structural (due to economic and use-pattern shifts) and technological, that may exist in the future.

4.2.3. Comparison of the results

In this section we present the basic input data and the results generated by the models considered. Predictions of population growth shown in Figure 4.2 confirm a very narrow range of uncertainty attributed to this input variable (compare Edmonds et al., 1985); predictions are almost the same in spite of different sources used by the authors. Some differences in GNP/cap values (Figure 4.3) between the models follow from different mathematical approaches to GNP calculation.

In spite of differences in model structures, there are no significant differences in the total primary energy predictions (Figure 4.5). This may indicate that the aggregated model results reflect the actual state of the knowledge rather than a specific model structure. The values of primary energy/cap (Figure 4.6) are also very similar because of very small differences in the population predictions mentioned above. Differences across the models in energy efficiency (Figure 4.4) flow from different assumptions about energy efficiency increase.

In Figures 4.7 through 4.9 the fuel mix evolution over the forecasting period 1975 - 2100 is presented. Here we can also observe a general correlation between the models, especially for the period 1975 - 2025. The higher values of fossil fuels calculated by the Nordhaus and Yohe model are a result of the fact that only two fuel types (fossil/nonfossil) were considered by this approach. This implies a significant difference, in comparison to the other models, in the year 2100. The existence of only two fuel types in this model implies very high substitution of fossil fuels by nonfossil fuels as a result of price increases in conventional fuels.

All the results for the models considered are grouped in Table 4.3 which shows population and economic growth, total and per capita values of energy use, energy efficiency and fuel mix. Two different scenarios for the WEC and the IIASA model are taken into account. Table 4.4 presents the above results in a form of factors of increase from 1975, which make a direct comparison between the models possible.

4.3. The Models' Constraints and Abilities to Serve as Tools for Assessing Future Environmental Impacts of Energy Use

Through the summer, we have sought to identify key variables and actions to the energy field that would be crucial to develop interesting and consistent energy futures (see Scenario Appendix 1). As a final conclusion of this report we will present some thoughts on the use of these models in long-term, large-scale environmental studies.

The environment is not in general an area of primary concern for the energy studies. The only part of it that is of concern is most often its function as resource base. Only two of the studies we have looked at, Edmonds & Reilly and Nordhaus & Yohe, went any further towards studying the impacts of future energy use and only the IIASA study had some form of environmental feedbacks, except for resource constraints. This is a serious lack because it is not unlikely that environmental concerns will be one determinant of the energy future.

But if we keep this limitation in mind it is not unreasonable to use these studies as a base for analysis of the environmental impacts connected with possible energy futures. The task of long-term environmental studies is just that: to try and use the knowledge we have, however uncertain it may be, to manage environmental interactions.

The ability of the studies to serve as such tools are very dependent on their resolutions in time and space. To be able to say something about for example the acid rain in Scandinavia you need to know something on the development of energy use in a about a dozen European countries, on at least a five year resolution. For other impacts there are other resolutions needed. (For a further discussion see Piotr Holnicki's paper in the Appendix 5) What follows here is an assessment of the usability of the different studies to

Table 4.3 Summary data of the energy projections

Year	Pop [mio]	GNP/Cap [$]	Erg/GNP [W/$]	Tot erg [TW]	Erg/Cap [KW]	Synfuels	Coal&Oil	F U E L Gas	- M I X Biomass	[%] Hyd&Sol	Nuclear
Edmonds & Reilly (DOE)											
1975	3975	1523	1.38	8.34	2.1	.0	74.0	17.0	.0	7.0	2.0
2000	5892	2256	1.15	15.31	2.6	1.0	62.6	17.6	3.4	12.3	3.1
2025	7363	3405	.95	23.93	3.3	7.9	55.9	15.6	2.2	15.5	2.9
2050	8197	5088	.86	35.67	4.4	16.7	54.1	9.7	1.7	13.6	4.2
2075	8446	7645	.76	49.32	5.8	22.5	50.2	5.5	1.9	14.0	5.9
2100	8446	11681	.71	70.10	8.3	24.5	51.8	3.8	1.7	12.0	6.2
WEC high											
1975	3949	1836	1.19	8.73	2.2	.0	65.0	16.9	11.4	5.6	1.2
2000	6040	3200	.86	16.80	2.8	.0	57.0	18.0	8.0	9.0	8.0
2025	7328	4825	.69	27.30	3.4	.0	50.8	16.8	4.3	14.0	14.3
WEC low											
1975	3949	1918	1.18	9.06	2.3	.0	65.1	17.0	11.1	5.6	1.2
2000	6040	2600	.91	14.40	2.4	.0	56.0	17.0	10.0	9.0	8.0
2025	7328	3225	.75	19.78	2.4	.0	48.5	17.0	7.5	14.0	13.0
Nordhaus & Yohe											
1975	4000	1750	1.24	8.71	2.2	.0	90.0	.0	.0	10.0	.0
2000	5900	3050	.69	12.49	2.1	.0	73.0	.0	.0	27.0	.0
2025	7400	4900	.67	24.47	3.3	.0	69.0	.0	.0	31.0	.0
2050	8150	6900	.59	32.89	4.0	.0	64.0	.0	.0	36.0	.0
2075	8300	9400	.56	43.34	5.2	.0	56.0	.0	.0	44.0	.0
2100	8350	14700	.51	57.90	6.9	.0	45.0	.0	.0	55.0	.0
IIASA high											
1975	4000	1600	1.30	8.21	2.1	.0	74.2	18.4	.0	5.9	1.5
2000	6100	2800	1.00	16.80	2.8	.6	63.7	18.6	.0	6.8	10.3
2025	7683	4633	.92	32.55	4.2	15.8	38.9	17.1	.0	7.6	20.6
IIASA low											
1975	4000	1600	1.30	8.21	2.1	.0	74.2	18.4	.0	5.9	1.5
2000	6100	2200	1.00	13.60	2.2	.3	63.5	18.6	.0	8.1	9.5
2025	7683	2700	1.00	20.93	2.7	12.8	40.5	16.0	.0	9.9	20.8

Table 4.4 Factor increase in the energy projections

Year	Pop [mio]	GNP/Cap [$]	Erg/GNP [W/$]	Tot erg [TW]	Erg/Cap [KW]
Edmonds & Reilly (DOE)					
1975	1.0	1.0	1.0	1.0	1.0
2000	1.5	1.5	.8	1.8	1.3
2025	1.9	2.2	.7	2.9	1.6
2050	2.1	3.3	.6	4.3	2.1
2075	2.1	5.0	.6	5.9	2.8
2100	2.1	7.7	.5	8.4	4.0
WEC high					
1975	1.0	1.0	1.0	1.0	1.0
2000	1.5	1.7	.7	1.9	1.3
2025	1.9	2.6	.6	3.1	1.5
WEC low					
1975	1.0	1.0	1.0	1.0	1.0
2000	1.5	1.4	.8	1.6	1.0
2025	1.9	1.7	.6	2.2	1.0
Nordhaus & Yohe					
1975	1.0	1.0	1.0	1.0	1.0
2000	1.5	1.7	.6	1.4	1.0
2025	1.9	2.8	.5	2.8	1.5
2050	2.0	3.9	.5	3.8	1.8
2075	2.1	5.4	.5	5.0	2.4
2100	2.1	8.4	.4	6.6	3.2
IIASA high					
1975	1.0	1.0	1.0	1.0	1.0
2000	1.5	1.8	.8	2.0	1.3
2025	1.9	2.9	.7	4.0	2.0
IIASA low					
1975	1.0	1.0	1.0	1.0	1.0
2000	1.5	1.4	.8	1.7	1.0
2025	1.9	1.7	.8	2.5	1.3

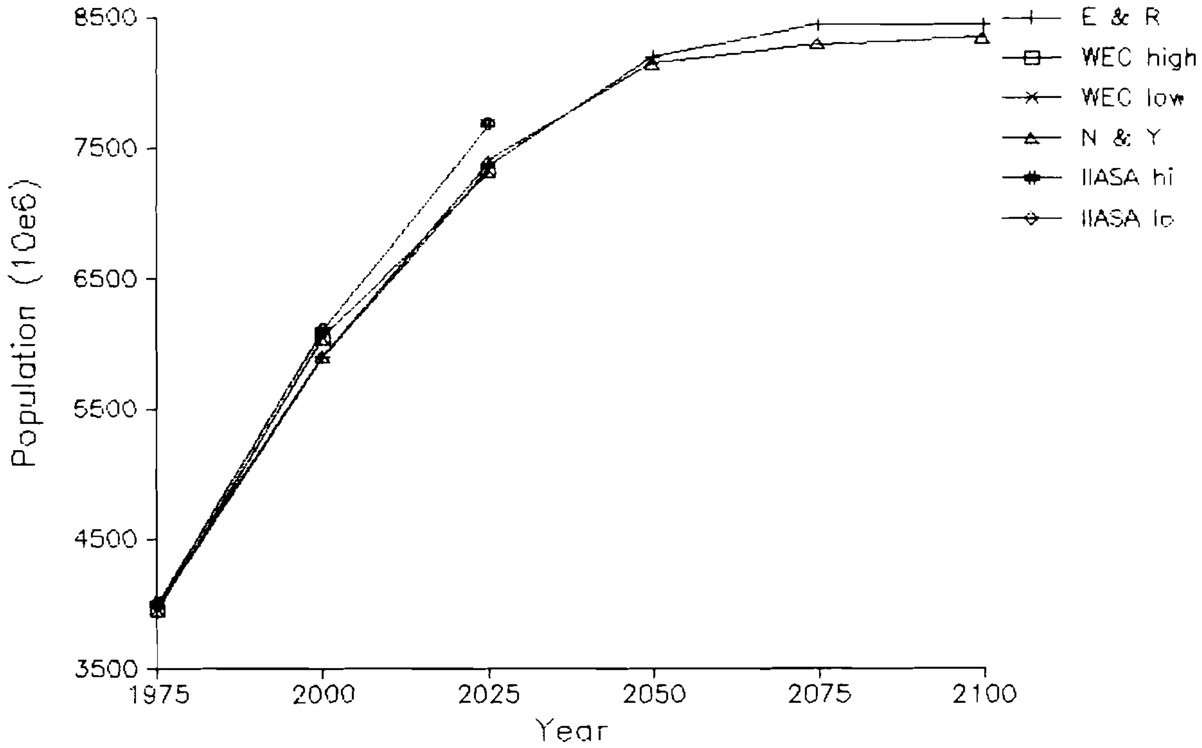


Figure 4.2 Population assumptions

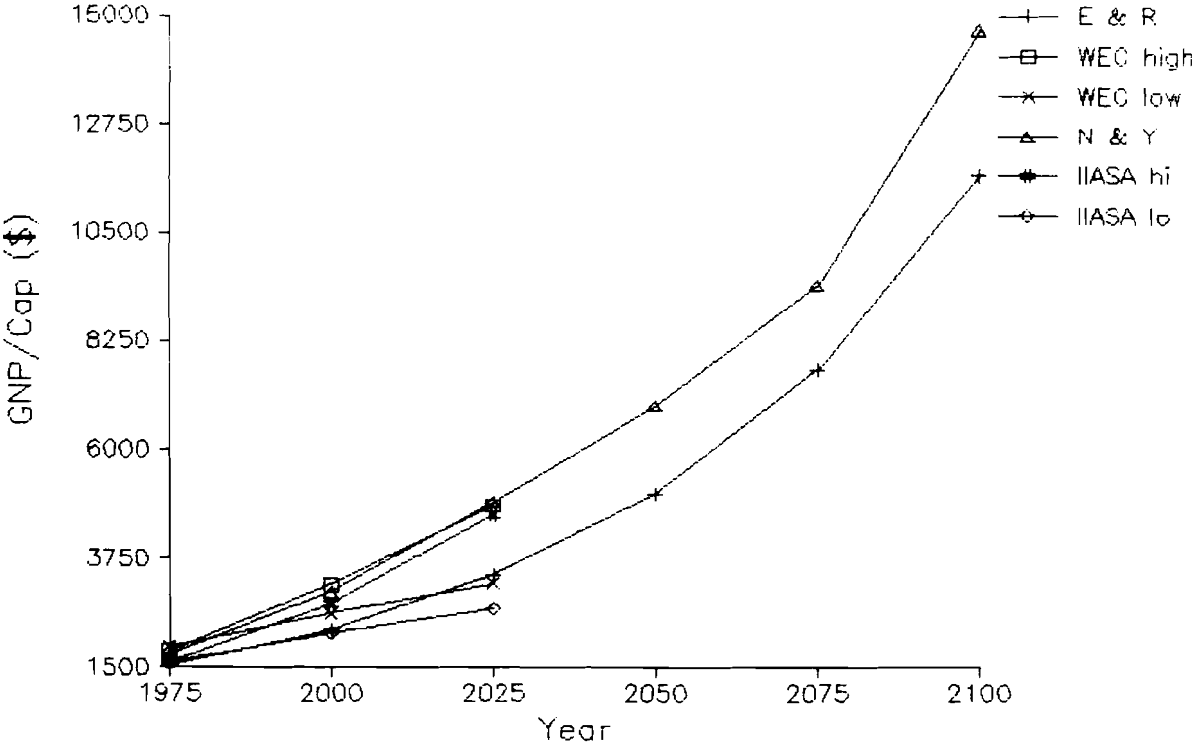


Figure 4.3 GNP per capita assumptions

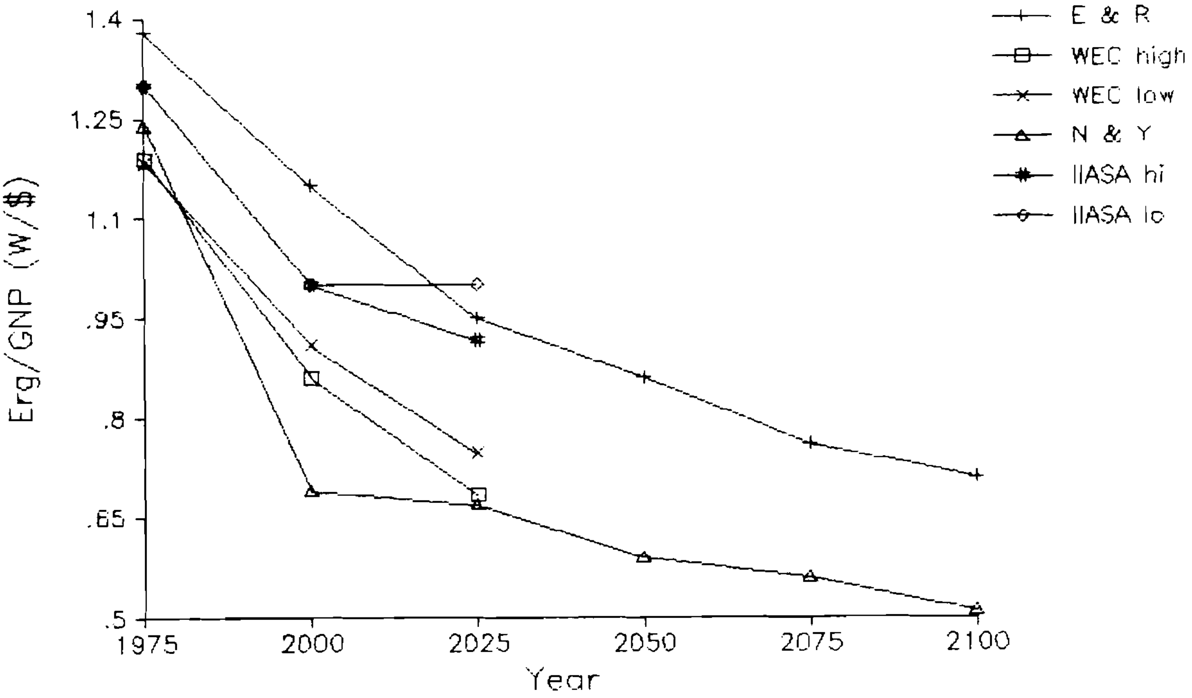


Figure 4.4 Primary energy per GNP

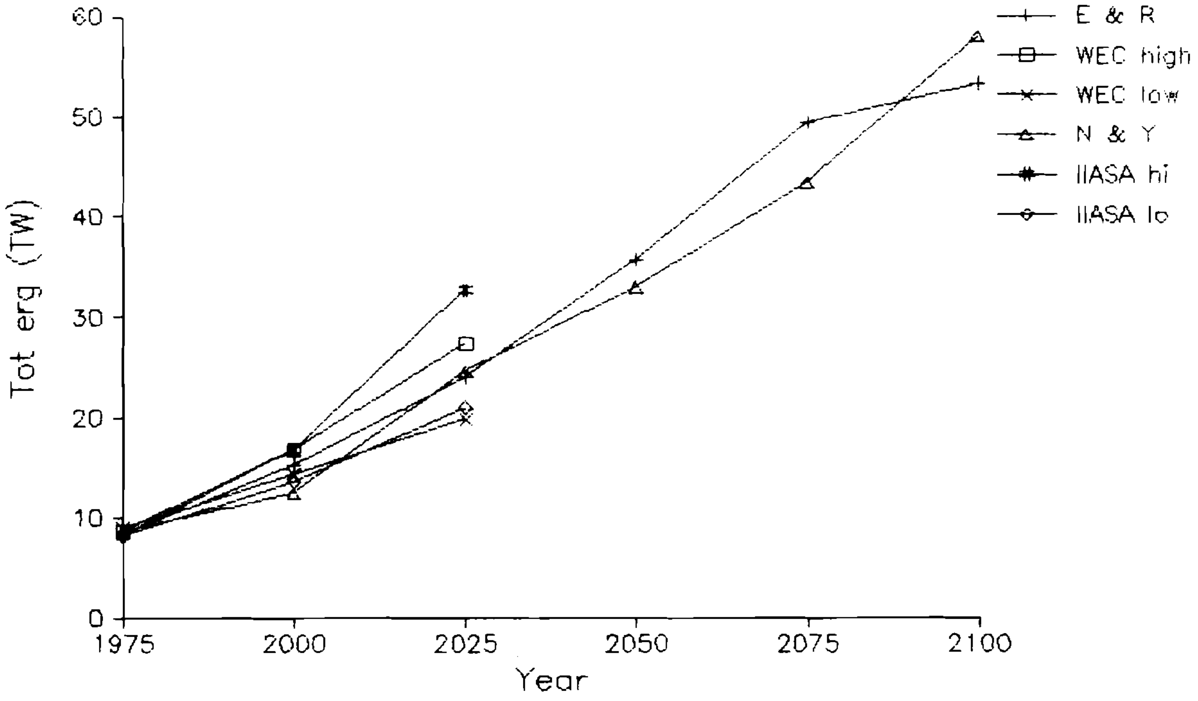


Figure 4.5 Total primary energy

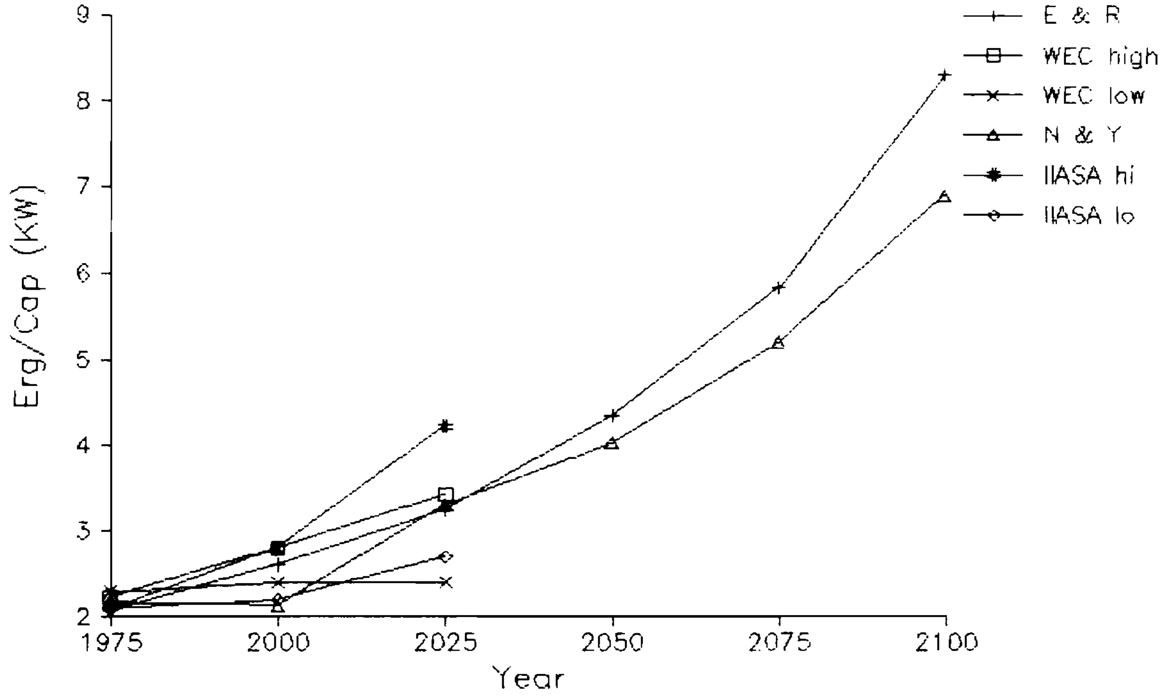


Figure 4.6 Primary energy per capita

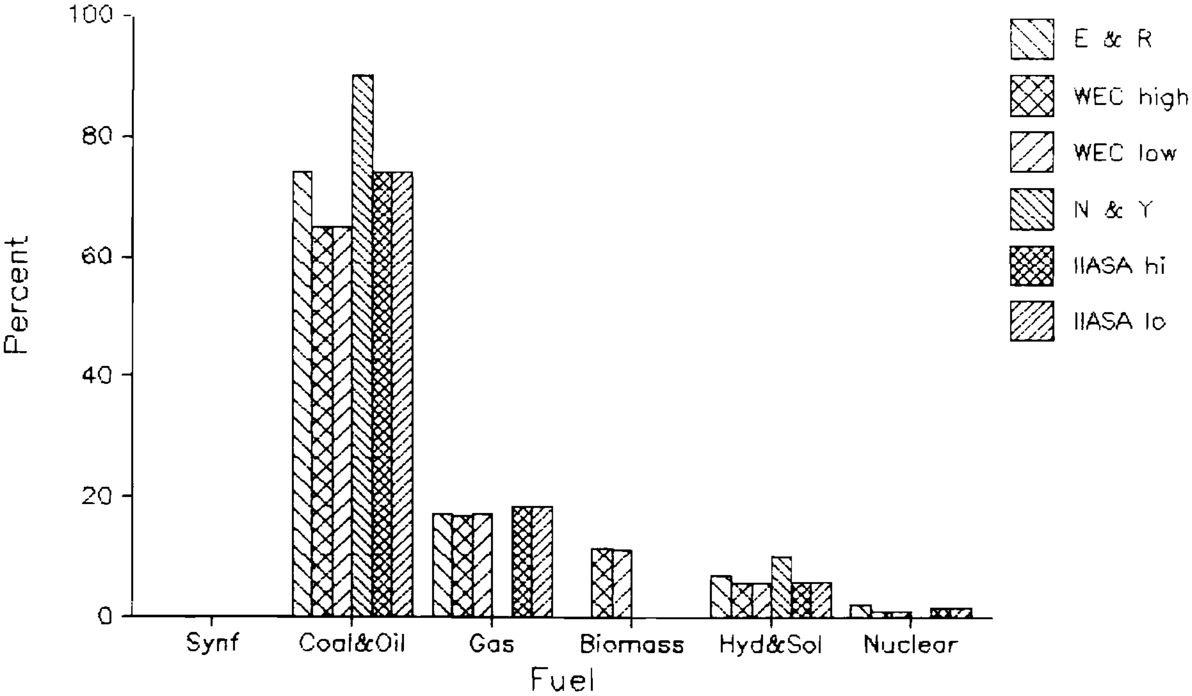


Figure 4.7 Fuel mix - 1975

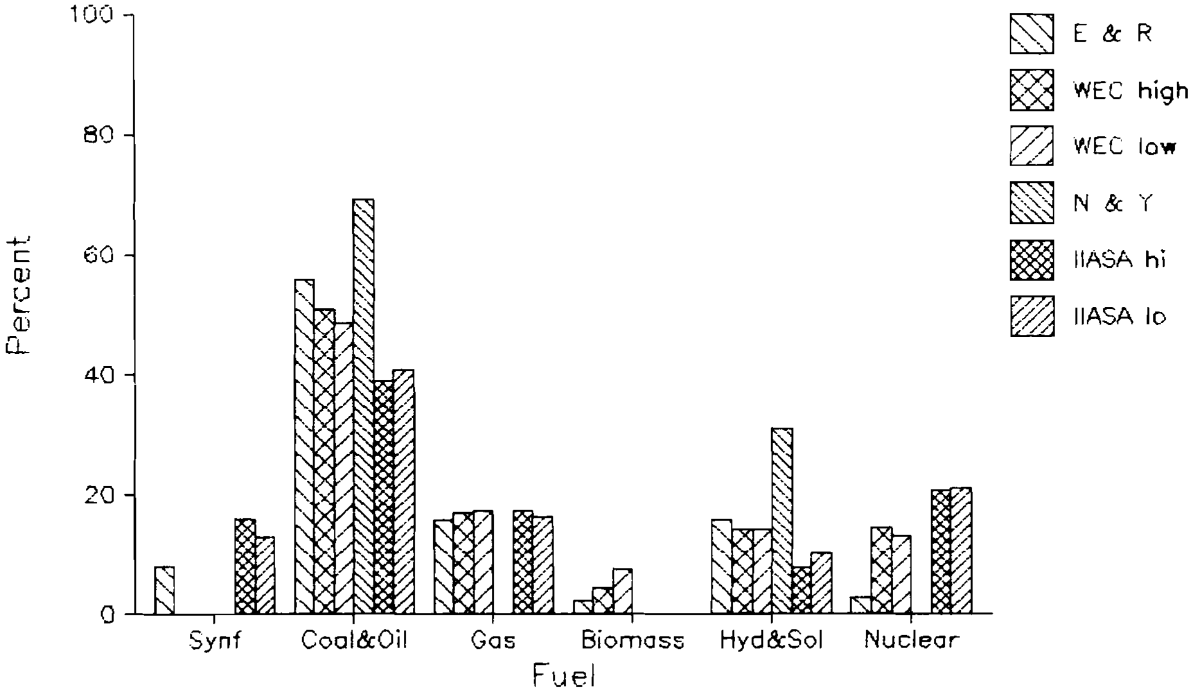


Figure 4.8 Fuel mix - 2025

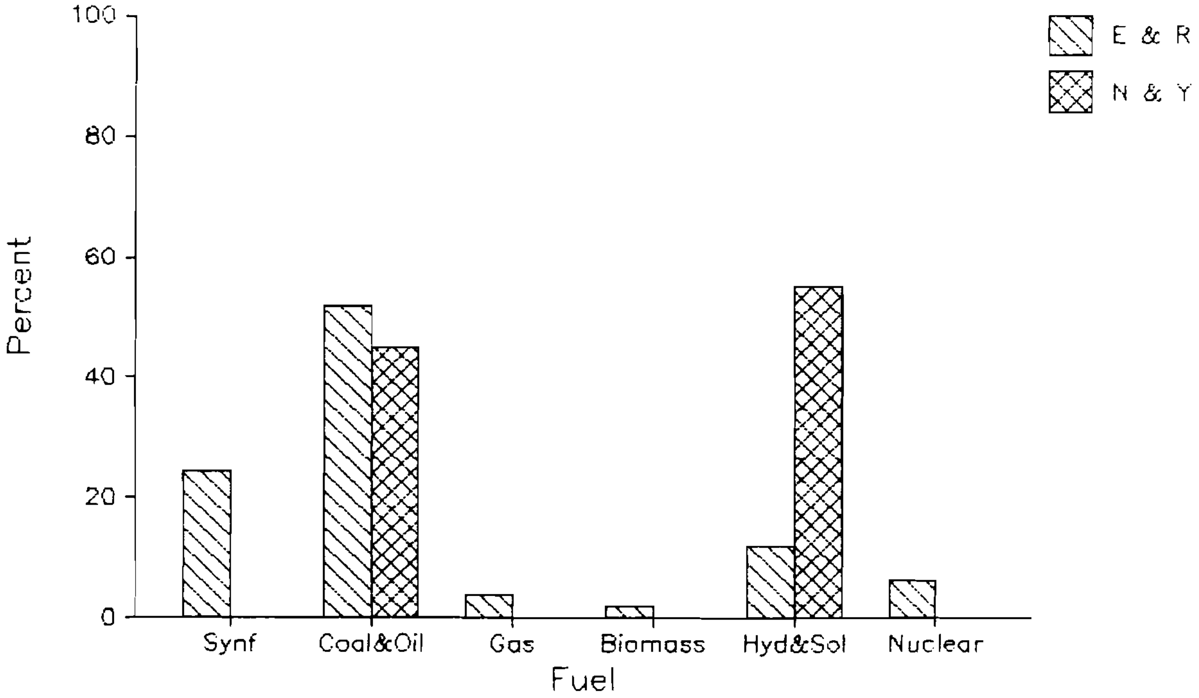


Figure 4.9 Fuel mix - 2100

illuminate energy use impacts on the VECs.

4.3.1. Space scale considerations

On the global scale there are usually not any problems. With the exception for WEO, the studies all give the global fuel mix, which can be a tool to calculate the development of the concentration of CO_2 and other climate-changing gases in the atmosphere.

But when we come down to smaller scales the real problems begin. The regions chosen are definitely not very often well-adapted to assess any environmental effects. More disaggregated regions than are most often offered are for example needed to analyze acid rain (part of a continent), land-use competition (national at least) and water questions (most often subnational). Some models allow further disaggregations (e.g. IIASA and the OECD Demand Model), but these are usually not easily accessible or usable, and are not included in the presentation of the scenario results.

In several of the studies the data and forecasts concerning the industrialized world are much more elaborate and disaggregated than those of the developing world, which often are very crude estimates. This makes it impossible to come to terms with problem-complexes like biomass-deforestation in the developing countries. Only one study, WEC, touched for example on the use of non-commercial fuels, which in many parts of the world is the most important energy source. One can certainly discern a need for more ambitious studies of the energy future of the Third World. In such a study it would probably be impossible not to put more emphasis on the connections between energy use and environment.

4.3.2. Time scale considerations

When it comes to time-scales the main concern for global environmental studies is the very long-term perspective. For this most of our studies are insufficient. Only Edmonds & Reilly and Nordhaus & Yohe (for CO_2) really try to tell us something about the future towards 2100. The IIASA study gives some indications.

In the short-term we are better-off. But here time-resolution is really important. A time resolution of, for example, 25 years as in Edmonds & Reilly is too long for most regional, medium to short term problems like acid rain and land-water-biota issues.

We feel that additional work on the needs identified above would be extremely beneficial to the understanding of development-biosphere interactions in the energy field.

APPENDICES

APPENDIX 1

Surprise

The important thing is to try to find surprises that have large-scale consequences both in time and space. To be able to have this the surprise event got to influence some basic structures in the environmental, technological, social, economical, political or ideological fields. But since we don't have any general frameworks for the scenarios yet we have tried to connect the surprises as closely as possible to the key variables and to save the more scenario related ones to later occasions.

1. LIFE-STYLE CHANGES

Important countries try the Lovins way. The high increase in energy use in connection with urbanization could make it very hazardous to try to foresee energy use expansion in LDC. The increase in primary energy use as a consequence of electrification.

2. RESOURCE AVAILABILITY

A Decisions not to use nuclear power (or coal)

B Decisions of producers not to produce enough to balance demand, e.g. coal-cartel to keep coal-use within an environmentally acceptable range.

3. AN UNSTABLE ENERGY SYSTEM WITH SHOCKS REGULARLY

A Nuclear: New Three Mile Island-accident

B Price shocks

APPENDIX 2

The Different Energy Fuels Problems and Consequences for Societies

Stefan Anderberg

This paper focuses on and tries to summarize problems, consequences and impacts of the use of the different energy fuels. It is a short development of a matrix on societal impacts of energy use. The matrix contained the following VECs: Health, Social Acceptability, Investment, Distribution of Energy (centralized or decentralized use), Energy Availability (distribution of energy use between generations and nations), Dependencies (Level of autonomy) and Political Stability (Security). On the other axis were the different fuel alternatives. The background is for each fuel to assess the consequences if it was to be, if not the leading so a very important fuel globally. Point of departure must be:

- What are the possibilities (supply, substitution etc.) for this fuel in the future ?
- What is needed for expansion of its use?

In this part primarily investment and social acceptability are discussed. Then what would the consequences be:

- Centralized or decentralized control and decision-making?
- How independent can the various nations be?
- Which are the critical dependencies ?
- Could this create tensions in the social and political systems ?
- What would be the consequences of long-term energy-use ?

Some problems are general for all the different fuels: primarily the problem with the uneven distribution. For everything, energy resources, technological know-how, capital, etc. there are haves and have-nots. For industrialized countries it is often a main problem that they do not control the production of the energy fuels they use e.g. oil. For the LDCs it might be that one has a lack of almost everything. Most important is perhaps the inability to develop appropriate technologies for the use of energy-sources one has got.

Oil

The future

The use of oil has severe restrictions in a long-term perspective. After the year 2000 conventional oil will be more and more replaced by unconventional (e.g. oil shales). No higher market share than today will ever be possible. But oil is hard to substitute totally and as a liquid fuel it is very comfortable. Its dominant position as base for the industrialized society with built-up distribution, refining and consumption systems etc. will probably make an active large-scale revolutionary transition from oil a less attractive alternative than going on using it as long as possible, even with much more expensive and complicated production processes (see the different energy studies).

Health

Oil has direct health risks. The closest example is pollution, noise etc. from traffic-pollution.

Social Acceptability

Despite the obvious health-risks its necessity is not seriously questioned by the public. Investment would be needed both for production and to continue to minimize the risks that are connected with its use.

Independence

The base for oil use is a highly integrated technological and economical system, which is unique in history (Pimentel & Pimentel, 1979). Inside this system there are definitely limits for national and local decision making. For example, it is not possible for a small country to make environmental legislation on its own, set new standards, etc. (the car sector could serve as an example). Because of the economic linkages and the dependencies on technology and supply, all actors must adapt to the system. Other actions would result in high costs both for consumers and producers. As a base for the "dominating technology" oil has a wide range of advantages in comparison with other fuels just by its widespreadness, developed distribution, higher competition etc. The possibility of decentralized use is one of oil's great advantages.

Availability

Oil has many important and valuable features and this will make it hard to find a really satisfactory substitution for it. (Loennroth et al., 1977, Goodman et al., 1981). Would it be fair towards the coming generations in both the industrialized and developing world that the industrialized countries in the years between 1950 and 2000 consumed the main-part of the world's petroleum resources?

Political stability

A large part of the reserves is in OPEC-countries. This is a fact that made "the oil price shock" in 1973 possible. The distribution-net and much of the capital and know-how in oil- production, refining etc. are in the hands of relatively few multinational corporations, a controversial fact. These corporations are hard to control and a country could at least in theory be left without oil. But based on what happened in 1973 and 1979, one must say that the corporations made a relatively equal distribution of the available oil possible. Even if this often gave them high profits it somehow shows that it is in their interest that the markets have faith in them (IEA, 1982).

OECDs dependence upon OPEC-exports is one of the reasons behind the fact that conflicts in the Middle East are of main concern for the whole world and that the region is a main arena for confrontation between the superpowers. Events that threaten to disturb oil-trade could make e.g. USA or some of its allies intervene. Inside OECD there are no open conflicts because of oil. One shares a common interest to have a stable and cheap oil supply and their own reserves are not that big that they can be anything else but a complement.

Gas

The future

The reserves seem to be large enough to support a greater use than today, although not enough to really replace oil.

Investment

It is very dependent upon infrastructure in distribution-systems etc. This will delay large-scale use in LDCs (Haefele, 1981).

Health and Social acceptability

Gas has with careful treatment less environmental impact than oil and has therefore high acceptability. This might not be true for the domestical sector, but it depends often on how used people are to gas use.

Dependency and stability

Often very direct dependence between producer and consumer through the distribution-system. The important producers are some more than for oil. Important trade-linkages will go from the USSR to Western Europe and from North Africa to Western Europe (IEA, 1982). These might be used as weapons in a conflict but would of course have limited effects on the long-term. I believe that the long-term effects are greater from the gains in negotiation-position.

Since implementation of a gas network can serve as an important tool for regional policy there could be a competition between different areas at the national level.

Coal

The future

There are relatively large resources of coal. It is often expected to be used more both in relative and absolute numbers (See most of the studies in this report). Liquefied coal might replace oil (Haefele et al., 1981).

Investment

R&D in for example new coal combustion techniques is needed to make it socially acceptable (Global 2000). Decentralized use is possible, but for a considerable increase in coal use new international systems for control and distribution would need to be formed.

Dependency and stability

As we can see it now, increased coal-use would not create any new crucial dependencies east-west or north-south. The largest reserves are in North America, the Soviet Union and China. But an increased coal demand must be met with a considerable increase of coal at the world market. An often forgotten constraint on coal use expansion could be that the main exporters, which also have most of the reserves are a couple of industrialized countries, that would not be so interested in exporting unlimited amounts of coal:

- A too large share of resource-exports might make their industry less able to compete (in the short run) (Foley & Loennroth, 1981).
- There could be environmental constraints to a massive expansion like for example water availability. It is a serious constraint already today to the coal industry in the USA (Hollander, 1981).
- Environmental concerns and public opinion could be an incentive not to expand production too much. With a handful of the world's most powerful countries together in a such dominating position, it would not be to strange to imagine some sort of agreement to limit coal use expansion because of the problem with the ever-growing CO_2-concentrations in the atmosphere, especially if they do not have very large marginal profits in the coal trade.

Nuclear Power

The Future

For LWR-fission a more dominating role than what is planned for 1990-95 is highly unlikely because of fuel availability constraints. Breeders might create a new situation. It could be the base for a long-term energy system (Haefele et al., 1981; Fortescue, 1982).

Investment

Everything that concerns nuclear power demands large investment, high-technological control and centralized decisions. In most countries this means the national level (Loennroth, 1977). In the short-term it is probably not an alternative for the LDCs (El-Hinnawi et al., 1983).

Acceptability

To make its large-scale implementation possible it will be necessary to make a reliable impression on the public. Primarily this demands an acceptable solution of the waste problem (See e.g. Global 2000 and IEA, 1982).

Energy Availability

NP could relieve the pressure on other fuels and thereby maybe make more fossil fuels available for the LDCs.

Dependency and stability

More than fossil fuels, nuclear power requires national action to be implemented. There are international dependencies through the whole cycle. It is not unlikely that pressures are put upon countries that do not participate. Especially if they could give valuable contribution with e.g. fuel resources, waste storage, technology etc. As a protection against nuclear arms diffusion, attentats etc. more totalitarian centralized technocratic "police-state" system could be formed. This could create dangerous tensions inside the industrialized world that could be used in conflicts between north-south or east-west.

Renewable Energy Sources

There are many promising kinds of renewable energy fuels. Some do need much more research and development before being ready for commercial use while others are quite mature. All of them need to pass some kind of threshold to gain full economies of scale to be able to really penetrate the world market. This would need deliberate international action and cooperation. On the national level a closer matching between the objectives of energy planning and overall social and economic development might be needed for a development in this direction (See e.g. El-Hinnawi et al., 1983 and Kursunoglu et al., 1982).

SOLAR

There is a big difference between centralized and decentralized solar power. Centralized would mean enormously huge technological installations. It would probably have similar consequences as nuclear power. A problem with it, is that it demands large investments and that the countries most suited for it e.g. in North Africa will not be interested for a while. Decentralized solar for primarily heating can rather fast penetrate the market with some support from oil price development and eventually subsidies (El-Hinnawi et al., 1983).

BIOMASS

Biomass can in different forms become an important fuel. But it is important that it will not compete with other essential activities like for example agriculture in the LDCs. The most suited areas here would probably be in the industrialized world, but today it still seems unlikely that for example Europe would try to substitute biomass for imported oil (Lyttkens and Johansson, 1981).

HYDRO

Hydro-power is already a mature energy source and very much developed. It will still be an important energy source regionally but with rather low expansion-possibilities.

The other renewables like wind could come to play marginal roles globally but could become very important locally or regionally, especially in the developing world. In the field of renewable energy sources there are still many questions to consider before a large-scale implementation. But since such an implementation according to our studies seems remote it might be too early to see the real problems and to try to solve them.

Final Remarks

This paper does not have higher ambitions than trying to summarize some of the problems with the different energy fuels from a societal point of view as they were shown in the studies we have reviewed. The energy situation and development are concerns for the whole society (the global as well as the local) and are intertwined with all different levels of human activity (see e.g. section 1.2 in this report). By political actions it is possible to influence the energy system. If these actions are going to be wise, especially in a long-term perspective, they need to be based not only on economic or environmental considerations, but some sort of view of the whole societal web. This is one of the reasons why the sociopolitical framework never can be excluded more than temporarily.

APPENDIX 3

Detailed Description of the Edmonds and Reilly Model

Michel Gelobter

Energy demand

The model uses population and GNP projections, based on assumptions about the fraction of the population in the active labor force as well as the productivity of labor, as indicators of economic activity and income. Regional primary energy prices are derived from world prices with region-specific add-on costs (mimicing transport costs, taxes and tariffs). The model may be manipulated, via these costs, to restrict trade or simulate various government policies. In the original model there are no such costs for non-traded fuels like solar, nuclear, or hydro-electric, but the newer implementation includes an environmental add-on cost that is applicable to all fuels.

The cost of secondary and tertiary (including electric) energy services is calculated next in a framework of interfuel, cost-based competition for shares of the electricity market.

The regional demand for energy services is then calculated from a region-specific energy service price, and income and price elasticities of energy demand. Demand can be further affected by a parameter representing technological change/energy productivity, that permits the incorporation of various assumptions about structural economic change and improved energy efficiency. Demand in the OECD regions is disaggregated into the three standard economic sectors: residential/commercial, transport, and industrial. In all other regions energy demand stems from one aggregate economic sector.

The demand module then calculates a final energy demand for four secondary fuels based on this aggregate demand for energy services and the relative cost of energy production with each of these fuels. The relative fuel shares within this demand are again determined in a market share competition framework. These demands for secondary fuels are converted into a demand for six primary fuels (oil, biomass and coal, gas, nuclear, hydro, and centralized solar) using appropriate conversion efficiency and production loss factors.

Energy supply

Three types of energy resource are defined: resource-constrained conventional (including conventional oil and gas), resource-constrained renewable (including biomass, centralized solar, and hydroelectric), and unconstrained (including coal, shale oil, and nuclear). Resource-constrained energy supply is determined using a (Hubbert, 1962) logistic depletion function for non-renewable sources. Renewables are modeled under an assumption of their eventually being exploited at their maximal rate. Unconstrained technologies are assumed to be of a "backstop" type, meaning that they break into the market at certain price levels, and thereafter provide relatively unlimited amounts of energy, according to a price-supply schedule. (There is a further function that determines the extent of natural gas flaring, again due to its importance as a source of CO_2.) Most of the modifications to the model have occurred in this supply section, and have been geared towards increasing the economic aspects of this section, rather than making it more complicated.

Finally, synthetic fuels production from coal has an economic dependency on the cost of coal, oil and gas, the cost of conversion, and the market shares of primary energy demand that synfuels are able to capture through price competition.

APPENDIX 4

The IIASA final energy demand model MEDEE
Structure and scenario assumptions

by
Christoph Schlenzig

1. Objectives

The scope of the final energy demand model MEDEE was to reflect structural changes in the socioeconomic and technological system affecting long-term energy demand and to analyze different consumption patterns of the energy sectors: household, industry and transportation. The idea was also to identify the potential market of each final energy form. A more technical consideration was that the model should be easily applicable to many countries. Figure A4.1 shows the general structure of MEDEE.

2. Description

MEDEE is an end-use-approach energy demand model that evaluates the influence of social, economic, technological and policy changes on energy demand. This model is only a calculation tool interrelating the major determinants of both useful and final energy demand. Although it contains many variables and relations, its structure is quite transparent and simple.

The energy sector is disaggregated into a multitude of end use categories. For each category the useful energy demand is related to a set of determining factors which can be macroeconomic aggregates, physical quantities or technological coefficients. These general scenario parameters must be disaggregated in terms of economic structure (set of industrial products), demographic structure (economic growth, lifestyles) and technological structure (energy intensiveness, efficiency, market penetration). A macroeconomic module translates the socioeconomic scenario assumptions into specific activity levels of the end use categories. Final energy demand is then calculated for each category in three other modules (household/services, industry, transportation) using activity levels and technological determinants. Because of the high level of disaggregation, few structural assumptions are built in the model.

MEDEE does not deal directly with the problem of interfuel substitution, because this problem is treated within the supply model MESSAGE. For competing final energy sources no market penetration is modeled, it has to be introduced exogenously. Energy demand is not directly related to energy prices by means of elasticity coefficients - they are considered not applicable to the present energy situation because of trend extrapolation from the past. Price-energy relations are used in the scenario writing process as expert background information for modifying past trends.

2.1. Resolution

MEDEE works at the national-level, it calculates the final energy demand for each country. Later on the results are aggregated to global regions.

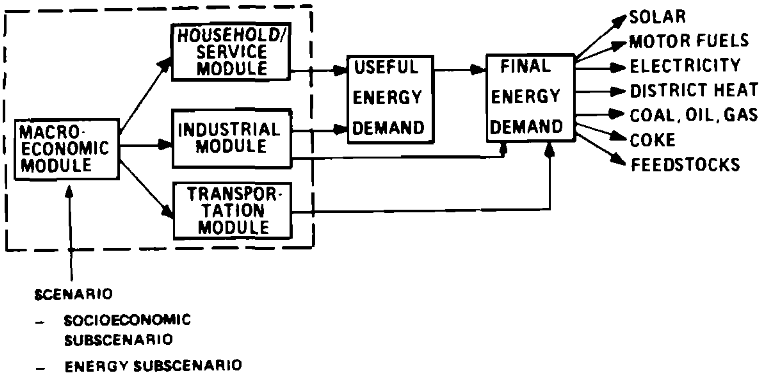


Figure A4.1 General structure of MEDEE 2 (*Source*: Lapillone, 1978)

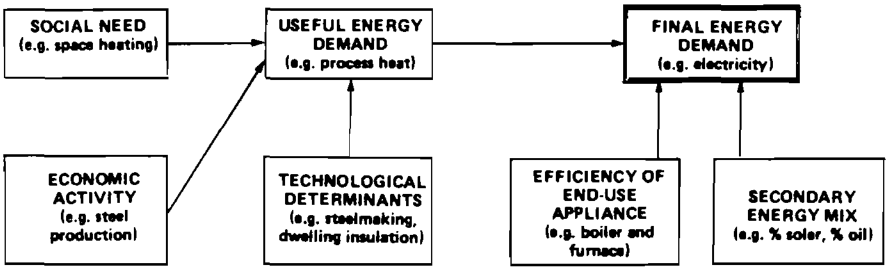


Figure A4.2 Determinants of useful and final energy demand (*Source*: Lapillone, 1978)

2.2. State variables

Socioeconomic:

- Total population
- Urban-rural split
- Economically active population
- Household size
- Specific heat requirements
- Type and size of dwellings
- Travel distances
- Automobile ownership
- Preferences for modes of travel (modal split)
- Load factors of transport means

Macro-economic:

- GDP expenditure (private consumption, investments)
- GDP formation
- Activity level of industrial sectors (value added, GDP contribution)

Technological:

- Efficiencies of energy using equipment
- Specific energy intensity of industrial sectors
- Fuel economy of vehicles
- Dwelling insulation
- Market penetration rates of competing energy sources

2.3. Categories of final energy forms used in the model

Substitutable final energy demand:

- Electricity (coal, nuclear)
- Solar
- District heat (coal, nuclear, geothermal)
- Coal
- Gas
- Liquid fuel

Non-substitutable (specific) final energy demand:

- Electricity (for lighting, small engines)
- Motor fuel
- Coal (for steam engines)
- Coke (steel industry)
- Feedstocks (petrochemical industry)

2.4. Disaggregation

Transport	Urban car, mass transport Intercity car, plane, bus, train Freight truck, train, pipeline
Industry	Agriculture Construction Mining Manufacturing

Household &Services	Space heating Water heating Cooking + Cooling Electrical appliances Thermal uses

2.5. Derived variables and results

Potential market shares of final energy forms Sectoral and regional final energy demand Secondary fuel mix Sectoral demand for energy services

2.6. Scope of the model

- How will income growth affect energy demand through the increase of social needs?

- How and when will the saturation of specific social needs influence energy demand in industrial countries?

- How can a modification in the consumption patterns of the population affect energy demand?

- How can the evolution of the international division of labour between industrialized and developing countries modify the industrial energy demand pattern?

- How could a shift from automobile use to public transportation (intercity and urban) affect energy demand?

- What is the potential for energy conservation (increasing efficiency of energy using facilities)?

- What is the potential market for new energy technologies (solar heating, heat pumps, district heating)?

- How can price increases affect the energy demand or fuel mix?

3. The Scenario Writing Approach

This chapter describes the scenario writing philosophy and technique used by the Energy Systems Group at IIASA.

3.1. Some general definitions of a scenario:

- Scenarios are an aid to the learning process about smooth evolution of the energy system.

- A scenario is a consistent description of a possible long-term development pattern of a country (economy), characterized mainly in terms of the long-term direction of governmental, socioeconomic policy.

- A scenario specifies a logical sequence of events that could transform the reference or base year state into the postulated future state. The postulated future state can represent the consensus of many experts or be outrageously absurd, provided that it follows from the assumptions made.

3.2. The procedure

- Identify the determinants of useful and final energy demand within the society (Figure A4.2 shows the determinants of useful and final energy demand).

- Organization of these qualitative scenario descriptors into a hierarchical structure: how do "macro-determinants" affect end use categories? (See Table A4.1)

Table A4.1 Structure of qualitative descriptors in the MEDEE approach

1.	International Environment	Primary energy prices Technological innovations New international economic order like: Strategy of multinational companies Policy of the developing countries block	
2.	Slow moving trends	Economic growth Human settlements Lifestyle features Industrialization type	
3.	General policy of the government	Transportation policy:	Objectives Infrastructure
		General energy policy:	Objectives Energy conservation
		Environment policy:	Objectives Recycling, etc.
4.	Energy supply characteristics	Final energy price characteristics Role of new energy sources (solar, district heat, etc.)	
5.	Technologies	Technological changes Energy efficiencies Fuel mix (market penetration)	

- Quantification of the qualitative scenario description. This is done by simplifying the system structure and grouping the determinants into the following variable categories:

(a) Constants. They include initial values (from the base year) as well as some parameters which are assumed to be time constant throughout all model runs.

(b) Exogenous determinants are factors for which the long-term evolution can be extrapolated from past and present trends in an acceptable way. This means that an intermediate evolution is postulated exogenously and assumed to be the same for all scenarios (e.g. population, load factors, etc.).

(c) Scenario elements are variables whose evolution cannot be extrapolated from the past because structural changes might affect them in the long-term.

In order to easily describe the scenario, the number of scenario elements is reduced as much as possible. Those factors, that only slightly influence energy demand are discarded and considered exogenous determinants. Figure A4.3 shows the conceptual scheme of the MEDEE approach, how these determinants are related to the study elements.

- The scenario writing (Figure A4.4) consists of formulating assumptions about the evolution of the scenario elements. To reduce the risk of inconsistencies one starts at the top of the hierarchy of qualitative descriptors going to the bottom (see Table A4.1).

- The quantification of qualitative scenarios must be carried out after a careful analysis has been made of the likely future evolution of the scenario elements.

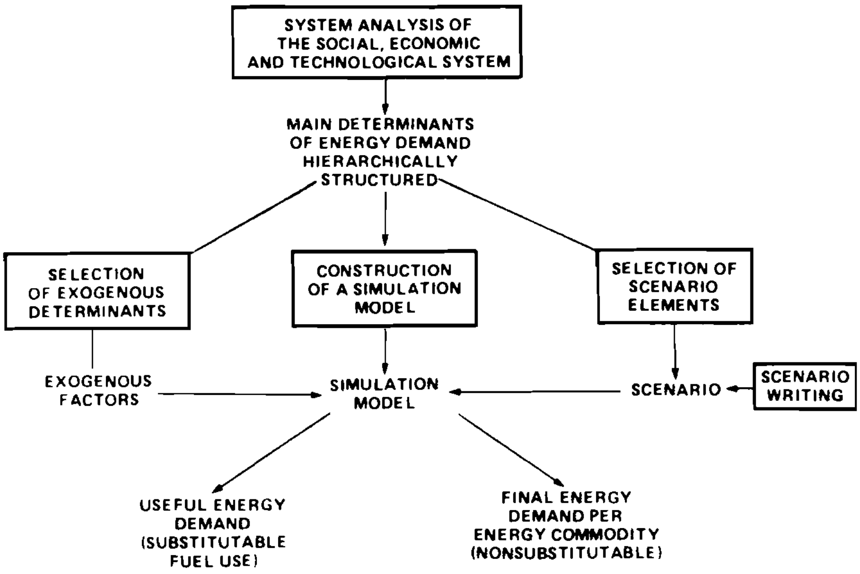


Figure A4.3 Conceptual scheme of the MEDEE (*Source*: Lapillone, 1978)

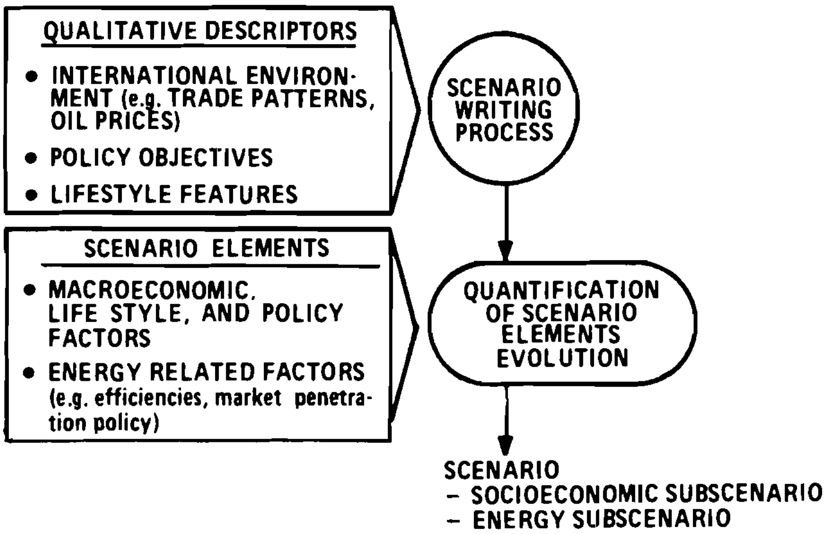


Figure A4.4 Scenario writing in MEDEE 2 (*Source*: Lapillone, 1978)

- The model translates the quantified assumptions (the "projection" of the socioeconomic evolution) in terms of final energy demand patterns.

4. Development of a Scenario Using an Iterative Process

- Make assumptions about basic input variables
- Estimate final energy demand and supply in detail
- Analyze results
- Identify inconsistencies, unreasonable implications
- Make appropriate changes to basic input variables (feedback)

4.1. Guiding criteria in the IIASA study:

- Consistency. Supply matches demand for each region, prices correspond to availability, energy trade corresponds to energy use in various economic sectors.
- Reasonableness. Scenario projections in their totality must not be unreasonable judgement from experts.
- Continuity. Assumed changes to historic trends develop in an orderly fashion (smoothness).
- Variation. Scenarios must span a sufficiently wide range in order to incorporate unavoidable uncertainties.

4.2. Qualitative description of the MEDEE scenario

Population growth and GDP growth (macroeconomic development) are considered the main driving variables of the final energy demand.

General Assumptions

- Decreasing GDP growth rates
- No major changes in the sociopolitical environment or in lifestyles, except those that accompany economic development
- Improvements in energy efficiency of facilities
- Focus on the transition away from oil towards renewable energy sources
- Strong energy conservation trends
- Increasing energy costs and prices
- Structural changes of economy towards a postindustrial phase
- No breakthroughs of new energy related technologies
- No major cost changes for energy producing or resource extracting technologies
- No explicit constraints with respect to environmental problems

4.3. Detailed description of the assumptions

4.3.1. Population

- Bare replacement level of fertility in developing regions reached by 2015
- Change in the age structure
- Increasing urbanization

4.3.2. GNP

- Decreasing growth rates
- Growth rates of developing regions are higher then of developed regions
- Developed regions: decrease of industrial and agricultural share, increase of the service share

- Developing regions: increase of the industrial sectors share, constant service sector share

4.3.3. *Transportation sector*

- Slow growth of personal travel in developed regions, reaching saturation level
- High growth of personal travel in developing regions, far from saturation mark
- Higher share of air travel in developed regions
- Moderately increased use of public transportation
- Greater economies of gasoline consumption of cars
- Reduction of average load factors (especially in developed regions - less crowded transport means)
- Considerable increase in freight transportation (2-4 fold) because of increasing industrial output

4.3.4. *Household & services*

- Number of persons per household dropping in all regions
- By 2030 in NA, WE/JANZ, 90% of the dwellings are centrally heated, 30-40% with air-conditioning
- By 2030 in LA, Af/SEA, ME/NAf, 25% of dwellings require space heat, 17-19% are assumed to use it
- Service sector floor area increases quickly in all regions, especially fast in developing regions
- Insulation improvements in new buildings (50% less heat losses) and of the existing housing stock (20-30% less heat losses)
- Saturation for electrical appliances in households (NA, WE/JANZ, SU/EE), high increases in developing regions
- Use of air-conditioning not limited to NA by 2030 but spread over all regions, applied especially in the service sector
- Efficiency improvements for all fuels (10-25%)
- Penetration of electricity, soft solar, district heat and heatpumps (extensive use of the latter, 40-50% in NA, SU/EE, WE/JANZ, 12% in DC)

4.3.5. *Industrial activities*

- The overall final energy demand is obtained from the following: Distribution of value added among economic sectors. Energy intensiveness coefficients (energy/value added) of each sector. Penetration of competing energy sources (electricity, district heat, heatpumps, solar energy, fossil fuels). Average process efficiencies.

- The share of manufacturing activities out of total energy consumption decreases from 90-97% (1975) to 76-90% (2030) in all regions

- Decreasing energy requirements by improving efficiency and production processes and using less fossil fuels

- Reduction of energy intensiveness due to modernization and structural changes by 35-55%

- Increasing efficiency in steal industry, reaching Japanese standard

4.3.6. *Agriculture*

- Agricultural GDP increases by a factor of 3.7-4.5 in LA, Af/SEA, ME/NAf, 2.2-2.5 in NA, SU/EE, WE/JANZ

- Low potential for expanding arable land in DC (LA, Af/SEA, ME/NAf)

- Essential agricultural productivity improvements come from increases in the use of fertilizers, irrigation (underground water) and from mechanization

- These improvements lead to a tenfold increase in agricultural energy intensiveness in developing regions, whereby the energy used to produce fertilizers (2030: 2.8 KWh/dollar = present value of developed regions) is counted in the manufacturing sector

- Final energy demand increases by 37-45 times in developing regions, 2-2.4 times in developed regions

- The share of agriculture in industrial energy consumption lies in the range of 3-5% (except for Af/SEA: 10-15%), 1975: 1-4%

4.3.7. Fuel use and fuel mix

Careful, intelligent, and selective use of fuels can be a highly effective means of energy conservation:

- Liquid fuels to be used primarily for premium uses as motor fuel and as feedstock for petrochemical products (share of premium uses from 64% in 1975 to 88-92% in 2030) mainly as a response to the relative price rises of liquid fuels

- Shift towards coal and gas in developed regions for heat purposes in the industrial and household/service sector

- Extensive use of renewable resources in developing regions. Organized commercial supply of charcoal and wood, agricultural wastes and biogas, 273-424 GW by 2030 in Af/SEA, 166-247 GW by 2030 in LA. Nevertheless oil remains a major supplier of heat, although its share drops and is substituted by coal and gas

4.3.8. Electricity use

- The electricity use is demand driven in the near-term, but supply limitations impose constraints in the medium and long-term

- Electricity enters modestly the domestic heat market (2030: 17% for NA, WE/JANZ)

- Electricity slightly penetrates the industrial heat market (5-10%)

- Electricity use for transportation (railways, urban mass transit, electric cars) is assumed to increase (1-2% globally, 4-9% in Europe and SU)

4.3.9. Soft solar

- In region NA, WE/JANZ 50% of all new (post-1975) single family centrally heated homes and low rise service sector buildings are installing solar heating systems, which are 50-70% solar and require 50-30% backup from oil, coal, gas

- By 2030 nearly 40% of all households are using solar water heating systems

- The ultimate contribution is limited by the market size - the demand for space and water heat in detached or low rise buildings is limited

- Because of the lower heat demand in developing countries, soft solar heating systems penetrate later and relatively slowly

- Solar share of	NA	WE/JANZ	LA,Af/SEA,ME/NAf
Space heat demand (res.)	14%	7%	14%
Water heat demand	28%	28%	
Service sector heat	6-7%	6%	
Industrial heat demand	10%	10%	4%

4.3.10. Conservation

The ratio final energy demand/GDP continues to decrease for NA, SU/EE, WE/JANZ. It increases, at least initially, for the developing regions, but later on it levels off and even starts decreasing in LA, ME/NAf.

- The demand reduction through conservation measures represent an important "supply" source (7.3 to 18.3 TW globally by 2030).

- These savings are only achieved by improving efficiencies, not by cutting back energy demand.

- Time constraints for conservation measures: it takes a decade to retool a major industry, a century to replace a nation's housing stock.

APPENDIX 5

A Procedure for Investigating Global Environmental Impacts of Energy Sector

Piotr Holnicki

1. Introduction

Scientific investigation posits that long-term, cumulative environmental impacts of human activities are the basic determinants of sustainable development of the biosphere. However, we can observe that in most actual cases, long-term implications are analyzed at the global scale while short-term effects at the local. This time-space correlation of models' scale of investigation is illustrated in Figure A5.1 (see Clark, 1985), where different scale phenomena, affecting air quality (a) or meteorological conditions (b), are grouped.

For reasons mentioned above, global long-term environmental models play an important role in investigations of possible development scenarios and strategies. They give us a significant insight into the main sources of cumulative degradation of environment and therefore can provide us with knowledge for formulating optimal development policy.

Large levels of uncertainty result in such large-scale modeling, since the global structure of a model is usually only a very simplified picture of the real system. In addition, long forecasting periods form another source of uncertainty.

One way of dealing with the problem is formal sensitivity analysis (Edmonds et al., 1984) or uncertainty analysis (Edmonds et al., 1985; Nordhaus and Yohe, 1983], which is usually applied to a specific model, examining its structure and key variables. Some general remarks and definitions concerning a formal approach are presented in Section 2.

Given sensitivity analysis results for a specific model (or a family of models with similar descriptors), we can consider which portion of the resulting sensitivity can be explained by real world variations and which is explained by a specific model structure. Consequently, we can try to modify the structure of the model in order to eliminate the most "vulnerable" elements. An example of such an "optimization", based on the combination of two existing models (Edmonds and Reilly, 1985; Nordhaus and Yohe, 1983), is suggested in Section 3.

Next, a calculation procedure is formulated in Section 4. In Section 5 the procedure is applied in the investigation of a very simple surprise-rich scenario.

2. Uncertainty and sensitivity in global energy modeling

Numerous studies have addressed the issue of future global impacts of energy production (McDonald, 1981; Edmonds and Reilly, 1985; Nordhaus and Yohe, 1983). All of them are based on mathematical models which are more or less sophisticated. A schematic outline of such a model is shown in Figure A5.2. The basic determinants are: (i) input variables driving a system, (ii) state (or output) variables which uniquely determine the state of the system at each time point - t, (iii) structural linkages between input and state variables, determined by mathematical relations and parameters.

For reasons mentioned above, a large level of uncertainty exists as to the nature of the state variables. Even if an energy model structure accurately represents the system being modeled - uncertainty flows from the input variables and the model's parameters (Edmonds et al., 1984). Therefore, it is critical to know not only the prediction itself, but

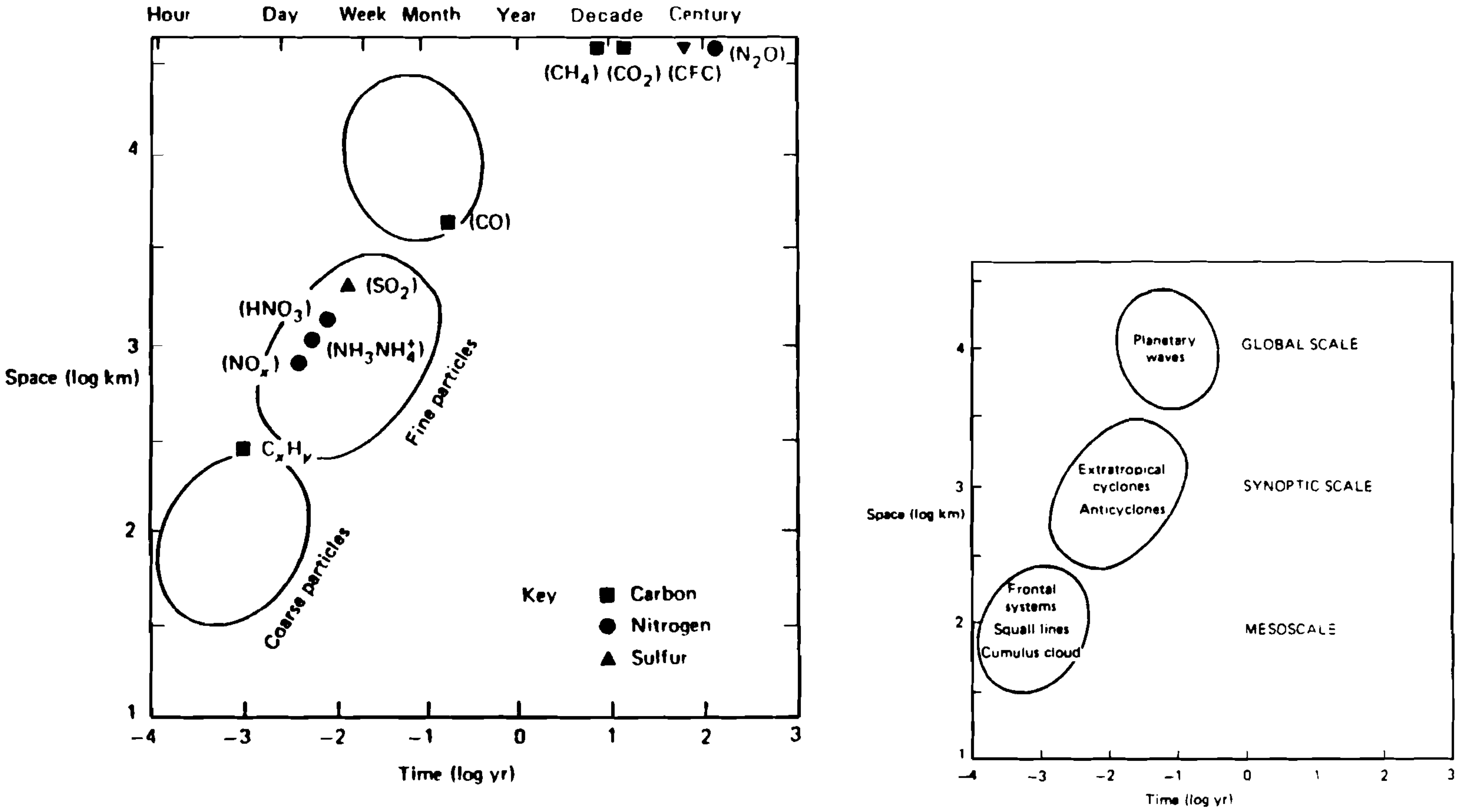
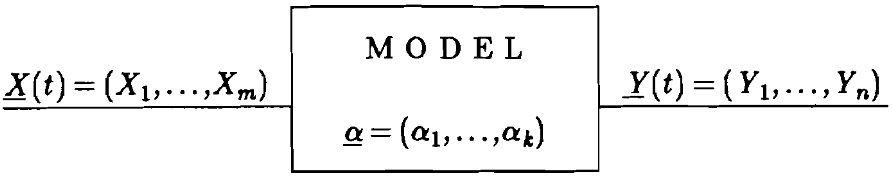


Figure A5.1 Time-space correlation in model scale



$\underline{X}(t)$ - input vector
$\underline{Y}(t)$ - state vector
$\alpha_1,\ldots,\alpha_k$ - parameters
$t \in [T_0, T]$ - forecast. period

Figure A5.2 The main descriptors of the model

to also have some notion of the uncertainty surrounding the forecast. Referring to the diagram shown in Figure A5.2, uncertainty may be attributed to input variables, parameters or a specific structure of the model.

Sensitivity analysis is a classical technique which can be used for examining the first two types of uncertainty. The technique indicates the contribution of each variable or parameter to the state (Y) variability. It is usually expressed as the percentage of variability of the model's prediction explained by a normalized variance of a particular variable or parameter. For a general dynamic model, sensitivity to the respective input variable X can be characterized by the index:

$$S_{X_j}(t) = \frac{\partial Y_i}{\partial X_j}(t) \qquad (2.1)$$

$$X_j = X_j^* \qquad \begin{matrix} i=1,\ldots,n) \\ t \in (T_0,\ T). \end{matrix}$$

Sensitivity with respect to time independent parameters is characterized in a similar way.

The presented formal approach can be utilized in simple mathematical structures which make a formal differentiation possible. In practice, sensitivity is investigated in an experimental way, as the ratio of the percentage change of the output to the percentage change of the input variable (Edmonds et al., 1984).

We must bear in mind that sensitivity depends on time and on the specific scenario being investigated. This is implicitly expressed by formula (2.1), where the sensitivity index S_{x_j} is uniquely equation or a fixed time moment - t and a specified scenario - X_j^*. For this reason, a "cross sensitivity" index against alternative scenarios is an important indicator (compare Edmonds et al., 1984).

In recent years, more complex, probabilistic uncertainty analysis has been developed (Edmonds et al., 1985; Gardner and Trabalka, 1985; Nordhaus and Yohe, 1983). The approach is to recognize the set of key variables or parameters in terms of a percentage of uncertainty in the model's state explained by each them. This is done by specifying, for each variable or parameter, the full range of possible input values. Next, these are examined in terms of a set of input scenarios. The emphasis is not to resolve uncertainties into particular variables, but to represent their current values and thus to integrate them into the model structure in a consistent way. The process generates a range of possible paths for major state variables (Nordhaus and Yohe, 1983).

By attributing portions of uncertainty to individual variables or parameters one can rank their importance (compare Edmonds et al., 1985). Such a ranking is more useful than a classical sensitivity ranking because it reflects the full range of possible input variabilities rather than a single scenario (sensitivity can be useful if the prediction of a specific variable is precisely known). On the other hand, as it is shown in Figure A5.3, the indicator of uncertainty also depends on time.

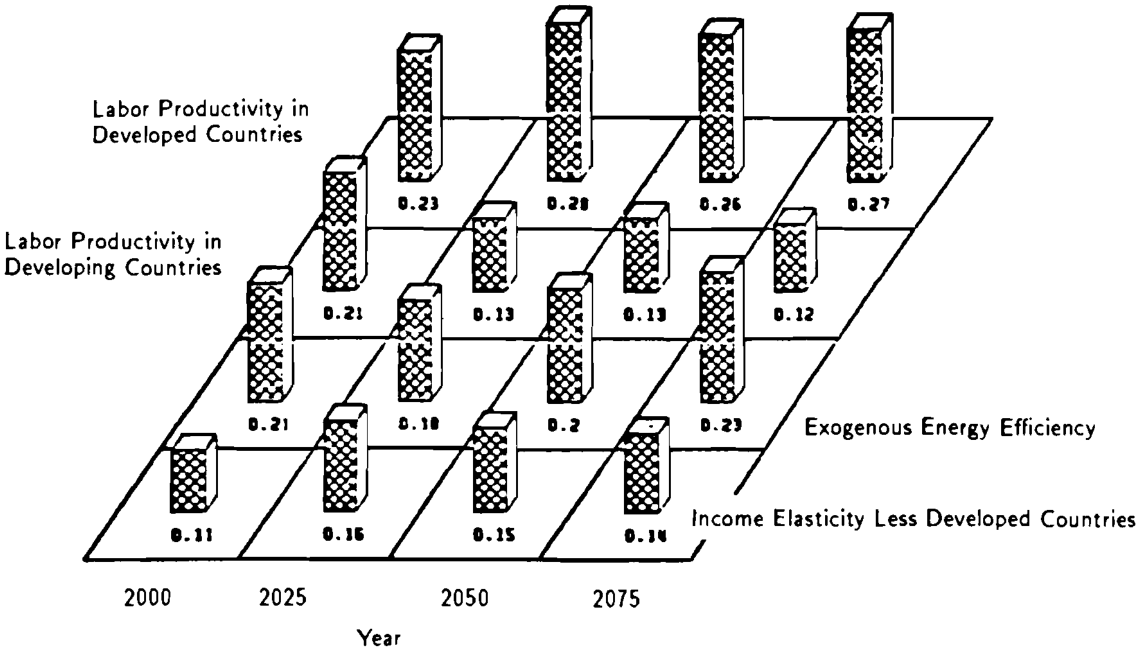


Figure A5.3 Some parameters explaining uncertainty in primary energy use in the E-R model

Analytical or experimental methods for examining the uncertainty attributed to the structure of the model are almost non-existent. Once a basic structure is fixed, it can not be easily altered to make exploration of structural uncertainty possible. In the next section we try to introduce some elements of structural analysis, discussing uncertainty in terms of two specific models.

3. Application of sensitivity analysis to optimization of model structure

Each model usually has a precisely determined domain of possible applications; it is built to give an answer to a set of specific questions. Given the preliminary structure of the model, sensitivity analysis can provide useful information for the design of a reasonable formulation of spatial resolution, as well as for recognizing the most appropriate aggregation of key variables and parameters. Provided that the precise range of the model's applications is known, we can try to "optimize" its structure. In other words, the objective is to find the simplest structure sufficient for investigating problems which provide the focus of the model. Sensitivity (or uncertainty) analysis enables us to select a set of key variables, as well as to determine a cross correlation between them - a very important criterion of variable aggregation.

For illustrative purposes, we have analyzed the Edmonds and Reilly (E-R) model (Edmonds and Reilly, 1985; Edmonds et al., 1985) and the Nordhaus and Yohe (N-Y) model (Nordhaus and Yohe, 1983). Both models were built to investigate how global CO_2 emissions can be controlled by alternative long-term energy polices. The general structure of the models is similar, but they differ in their spatial resolution, their levels of variable aggregation as well as in differences in specific parameters. Both apply population growth rate and labour productivity as base input variables used to calculate GNP and energy demand. The principal state variables are GNP, fuel prices and fuel mix.

As far as the spatial resolution is concerned, the E-R model uses 9 regions; while the N-Y approach considers the world as one region. To illustrate some aspects of spatial aggregation let us consider population and GNP growth for the E-R regionalization, shown in Table A5.1. We observe a significant correlation among industrialized countries (Regions 1-4) and developing countries (Regions 6-9). China could be included in either of the groups. On the other hand, the highly aggregated N-Y model loses essential information about differences between industrialized and developing countries. This suggests that the optimal spatial resolution might be a two-regional disaggregation of the World (or three-regional with China handled by itself). This conclusion is confirmed by Table A5.2 which presents differences in labour productivity between these two big regions. Labour productivity is one of the most important key variables in both models (compare Table A5.3 and Table A5.4).

In Table A5.3 we present a ranked list of the most important key variables for the disaggregated E-R model, obtained through a very complex probabilistic uncertainty analysis. The numbers in the central column also indicate spatial regionalization of a particular variable. We see, that in a disaggregated E-R model, the most important source of uncertainty is labour productivity, but this is considered only for two large regions.

The N-Y model does not utilize an energy efficiency variable, while the E-R model considers only one aggregated value for the world. In general, we can also consider two distinct patterns of energy efficiency - one in industrialized countries and another in developing countries (McDonald, 1981) (see Figure A5.4). Regional income elasticity is disaggregated into 3 big regions, but significant correlation between the respective variables: .7-.9 (see Edmonds et al., 1985:28), makes two-regional aggregation possible.

The next three parameters in Table A5.3 explain relatively little uncertainty in the model's output. In addition, price elasticity is aggregated to give one global value. Magnitudes of environmental costs of coal and biomass can be distinguished for industrialized countries and developing countries, respectively. As a result, both variables would be disaggregated into two global regions.

It is important to note that population, which is the principal driving variable in the model, does not affect uncertainty. This fact is explained by only a narrow range of input uncertainty of this variable (compare Edmonds et al., 1985:16).

The above analysis shows that, with respect to basic functions, the spatial resolution into 2 big regions - Industrialized Countries (IC) and Developing Countries (DC) is possible and is likely to be sufficient. Such an approach implies aggregation of variables and parameters in the E-R model into two regions. On the other hand, the overly aggregated N-Y version neglects many important differences in energy patterns.

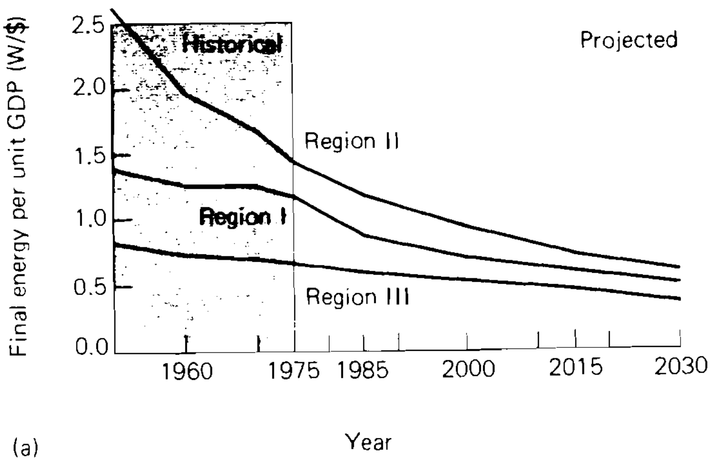
The list of ranked key variables in the N-Y model is given in Table A5.4. We can observe similarities with respect to some variables presented in Table A5.3. On the other hand, high sensitivity of the price-induced elasticity of substitution of fossil by nonfossil fuel, as well as the elasticity of substitution of labour by energy is implied by a specific

Table A5.1. Population and GNP growth for the E-R model (1975 multiples) (*Source:* Edmonds et al., 1985)

OECD REGIONS						
UNITED STATES		WEUR+CAN		OECD PACIFIC		
Population	GNP	Population	GNP	Population	GNP	Year
1.000	1.000	1.000	1.000	1.000	1.000	1975
1.189	1.877	1.176	1.978	1.201	2.701	2000
1.317	3.021	1.303	3.534	1.279	5.432	2025
1.347	4.505	1.365	5.709	1.305	9.121	2050
1.3664	6.699	1.3872	8.490	1.3176	13.234	2075
1.3664	9.720	1.3872	12.318	1.3176	19.202	2100
CENTRALLY PLANNED AND MIDDLE EAST REGIONS						
EUSSR		ACENPL		MIDEAST		
Population	GNP	Population	GNP	Population	GNP	Year
1.000	1.000	1.000	1.000	1.000	1.000	1975
1.196	1.815	1.370	2.665	1.803	3.649	2000
1.308	2.943	1.645	5.468	2.448	8.959	2025
1.351	4.442	1.770	10.335	2.847	18.044	2050
1.372	6.606	1.8081	17.376	2.9595	30.337	2075
1.372	9.585	1.8081	28.507	2.9595	49.771	2100
DEVELOPING COUNTRY REGIONS						
AFRICA		LATIN AMERICA		SOUTH & EAST ASIA		
Population	GNP	Population	GNP	Population	GNP	Year
1.000	1.000	1.000	1.000	1.000	1.000	1975
1.745	3.069	1.728	3.475	1.685	3.079	2000
2.361	7.327	2.298	9.005	2.226	7.169	2025
2.758	13.806	2.631	16.395	2.556	13.502	2050
2.8807	23.787	2.7144	28.248	2.6504	23.263	2075
2.8807	39.025	2.7144	46.343	2.6504	38.166	2100

Table A5.2 Initial (1975) labor productivity (*Source:* Edmonds et al., 1985)

LABOR PRODUCTIVITY	BASE GNP	
0.017	1519890	USA
0.017	1817860	WEURECAN
0.017	586400	JANZ
0.017	966400	EUSSR
0.029	323600	ASENP
0.029	138410	MIDEAST
0.029	154690	AFR
0.029	315490	LA
0.029	233620	SEASIA



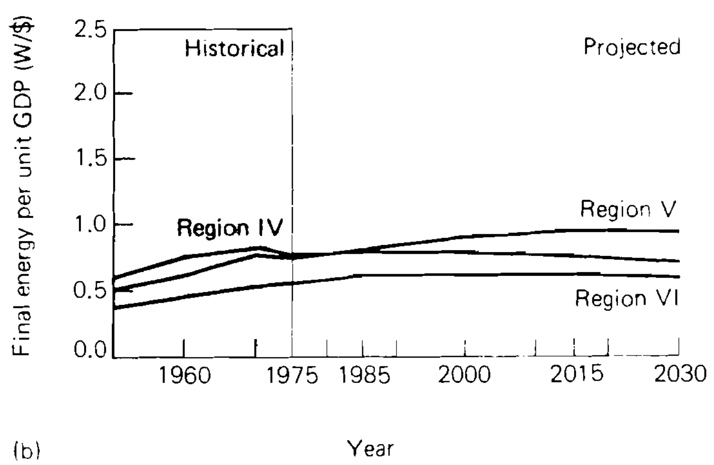


Figure A5.4 Final energy per unit of gross domestic product for the high scenario in (a) developed, and (b) developing regions

Table A5.3. Variables ranking in the E-R model.

Variable or parameter	Number of regions	Uncert. rank.
Labour productivity	2	.14 - .27
Energy efficiency	1	.16 - .19
Income elasticity	3	.2 - .17
Price elasticity	1	.1 - .2
Environm. cost of coal	3	.1 - .2
Biomass cost scale	1	.4 - .0
Population	3	.0

Table A5.4. Variables ranking in the N-Y model

Variable or parameter	Variance
1. Price elasticity of substitution fossil-nonfossil fuels	100
2. Labour productivity	76
3. Elasticity of substitution energy-labour	56
4. Extraction cost of fossil fuels	50
5. Production cost of energy	48
6. Fuel mix among fossil fuels	31
7. Population growth	22

form of the production function - a fundamental relationship in the N-Y model (compare Nordhaus and Yohe, 1983:102). The overestimation of the importance of these two variables arises because they are treated as power factors in two further equations (see Nordhaus and Yohe, 1983:104-105). Furthermore, the N-Y formulation of the production function implicitly aggregates labour and energy productivity growth in the labour productivity parameter, while the two component variables are not correlated in either case (Edmonds et al., 1985). These inconsistencies suggest some modifications in calculation of energy demand.

The next two parameters in Table A5.4 refer, in general, to fuel prices (they drive substitution between fossil and nonfossil fuels) and emission characteristics. Existence of only two fuel types in the model leads to high sensitivity among parameters controlling - by fuel prices - the substitution between them.

Uncertainty attributed to the fuel share among fossil fuels also suggests necessity for a more detailed disaggregation. Table A5.5 illustrates that in models focusing on CO_2 emissions, dividing fossil fuels into two groups: (i) conventional fossil fuels (oil, natural gas, coal) and (ii) unconventional fossil fuels (synfuels, shale oil) is likely to be sufficient. This conclusion is confirmed, to some extent, by carbon emission predictions generated by the family of models listed in Table A5.6. We can observe that variability of fuel mix among conventional fuels does not significantly change the carbon emissions, whereas shale oil has strong effect.

Table A5.5. Carbon emissions from fossil fuel (*Source:* Nordhaus and Yohe, 1983)

Fuel	kg of C/10^9 J	kg of C/mtce
Petroleum	19.7	577
Gas	13.8	404
Coal	23.9	700
Shale oil	41.8	1224

Table A5.6. Aggregate carbon emissions (*Source:* Nordhaus and Yohe, 1983)

Fuel proportions		Proportions				
Year	Source	Oil	Gas	Coal	Shale	Carbon Emissions
1975	Table 2.3	0.50	0.20	0.30	0.00	580
2025	IIASA high	0.33	0.29	0.38	0.00	580
	IIASA low	0.34	0.23	0.43	0.00	590
	IEA	0.28	0.18	0.54	0.00	612
	RFF	0.28	0.23	0.37	0.06	607
2050	IIASA high	0.25	0.10	0.65	0.00	604
	IIASA low	0.28	0.19	0.53	0.00	598
	IEA	0.26	0.08	0.66	0.00	644
	RFF	0.02	0.02	0.65	0.31	854

Based on the remarks in this section, it would be useful to formulate a simplified global-scale energy model focusing on specific environmental impacts. One possible version of such a model is suggested in the next section.

4. The simple calculation procedure

Following the conclusions of Section 3 we shall try to formulate a mathematical algorithm for investigating global, long-term environmental impacts of energy production. We focus on CO_2 concentration but with a little modification the procedure could be applied to trace through other impacts.

As we pointed out above, the world can be represented by:

(1) Industrialized Countries (Regions 1-5 in the E-R model) - IC,

(2) Developing Countries (Regions 6-9 in the E-R model) - DC.

An additional advantage of such a resolution is that regions are homogeneous with respect to such global effects as: CO_2 concentration increase and greenhouse effect, global acidity and, use of biomass as a fuel. The regions cover both Hemispheres, that allows investigation of global differences in temperature distribution.

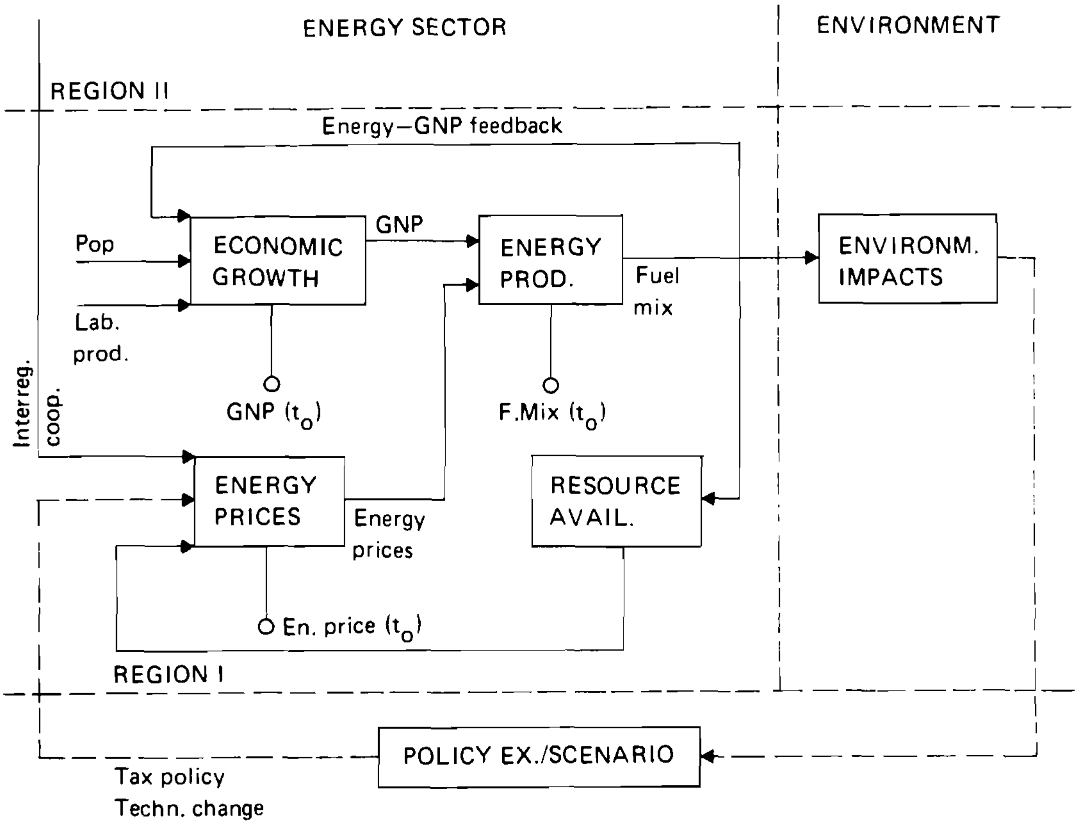


Figure A5.5 General structure of the algorithm

Fuels can be aggregated into three groups:

(1) Conventional fossil fuels (coal, oil, gas, biomass) - CF,

(2) Unconventional fossil fuels (synfuels, shale oil) - SF,

(3) Nonfossil fuels (nuclear, hydro, solar, renewable) - NF.

A general structure of the algorithm, shown in Figure A5.5, is based on the N-Y approach combined with the elements of the E-R model which calculate GNP and fuel mix.

Below we present the basic mathematical relations for a region (we use values of elasticities recommended by Nordhaus and Yohe, 1983).

1) Prices of three types of fuels

$$P^c(t) = P^c_d + [P^c_0 + g\,\frac{R(t-\Delta t)}{\bar{R}-R(t-\Delta t)}]\, exp[h_1(t) + h_2(t)]\, t + T_c(t - \bar{t}), \qquad (4.1a)$$

$$P^s(t) = P^s_d + P^s_0\; exp[h_1(t) + h_3(t)]t + T_s(t - \bar{t}), \qquad (4.1b)$$

$$P_n(t) = P^n_d + P^n_0\; exp[h_1(t) + h_4(t)]t + T_n(t - \bar{t}). \qquad (4.1c)$$

2) Relative fuel shares

$$S_1(t) = \frac{E^c(t)}{E^n(t)} = b_1[P^c(t)/P^n(t)]^{-1.2} \tag{4.2a}$$

$$S_2(t) = \frac{E^s(t)}{E^n(t)} = b_2[P^s(t)/P^n(t)]^{-1.2} \tag{4.2b}$$

$$S^n(t) = 1/(S_1(t)+S_2(t)+1), \tag{4.2c}$$

$$S^c(t) = S_1(t)^*S^n(t), \tag{4.2d}$$

$$S^s(t) = S_2(t)^*S^n(t). \tag{4.2e}$$

3) Total price of energy

$$P(t) = S^c(t)^*P^c(t)+S^s(t)^*P^s(t)+S^n(t)^*P^n(t). \tag{4.3}$$

4) Part of GNP devoted for paying for energy (1 - d(t))

$$d(t) = [k^*P(t)^{-0.4} + 1]^{-1}. \tag{4.4}$$

5) GNP prediction

$$X(t) = X(t - \Delta t)^*(1 + \alpha)^{\Delta t}\ {}^*L(t)/L(t - \Delta t). \tag{4.5}$$

6) The final fuel mix

$$P^c(t)^*E^c(t) + P^s(t)^*E^s(t) + P^n(t)^*E^n(t) = (1 - d(t))^*X(t), \tag{4.6}$$

7) Total conventional fossil fuel consumption since t_0

$$R(t) = E^c(0) + \cdots + E^c(t - \Delta t). \tag{4.7}$$

8) The feedbacks: energy-GNP and interregional cooperation-GNP

$$X(t) = X(t)^*[\delta E(t)/\delta E(t - \Delta t)]^{0.05}\ {}^*[IR(t)/IR(t - \Delta t)]^{0.05}. \tag{4.8}$$

The expressions used to calculate CO_2 emissions and concentrations are given in Nordhaus and Yohe (1983).

The variables used in (4.1) - (4.8) are as follows;

***Ad.*1**
$P^c(t)$, $P^s(t)$, $P^n(t)$ - real prices of CF, SF, NF in [75 dollar/mtce],
P_d^c, P_d^s, P_d^n - initial distribution costs in [75 dollar/mtce],
P_0^c, P_0^s, P_0^n - initial production costs in [75 dollar/mtce],
$h_1(t)$ - rate of technological change in energy industry,
$h_i(t)$, (i=2,3,4) - rate of technological change toward the respective type of energy,
$\bar{R}$ - resources of CF in [mtce],

$R(t)$ - total CF consumed in the period (t ,t) in [mtce],
T_c, T_s, T_n - taxes in [75 U.S. dollar],
g - depletion parameter,
Δt - time interval in [nmb. of years].

*Ad.*2
$E^c(t)$, $E^s(t)$, $E^n(t)$ - consumption of CF, SF, NF in [mtce],
$S^c(t)$, $S^s(t)$, $S^n(t)$ - relative fuel shares,
$S_i(t)$, $(i=1,2)$ - auxiliary factors,
b_i, $(i = 1, 2)$ - scale parameters.

*Ad.*3
$P(t)$ - total price of energy in [75 U.S. dollar].

*Ad.*4
$(1-d(t))$ - portion of GNP devoted for paying for energy,
k - parameter identified for initial conditions.

*Ad.*5
$X(t)$ - GNP in [75 U.S. dollar],
$L(t)$ - population,
$\alpha(t)$ - productivity growth rate.

*Ad.*8
$E(t)$ - total energy consumption in [mtce],
$\delta E(t)$- relative change of energy consumption,
$IR(t)$ - interregional cooperation indicator.

The algorithm can be utilized to investigate various energy development scenarios, including alternative energy price polices, taxation polices (e.g. reflecting environmental costs), technological change. It can also simulate discontinuities within the system. An example of how the algorithm can be used to generate a "surprise"-rich scenario is presented in the next section.

5. Application of the algorithm to price-discontinuity case

In this section the algorithm of Section 4 is used to investigate temporal changes of fuel mix in a simple price-shock scenario. Between 1975-2075 we have assumed the population growth as presented in Table A5.7 (Edmonds et al., 1985). For simplicity we have not included energy-GNP feedback and assumed a "normative" interregional cooperation (Frisch, 1983) ($IR(t)=IR(t-\Delta t)$).

The values of GNP reported in Table A5.7 are calculated according to (4.5) for labour productivity values given in Table A5.8 (Edmonds et al., 1985; Nordhaus and Yohe, 1983).

To simplify further, we consider only industrialized countries (the procedure for developing countries would be the same). We assume one global price for each fuel type and use data presented in Table A5.9 to set initial 1975 values of fuels consumption (Nordhaus and Yohe, 1983).

The scale parameters in (4.2a,b) are then approximated as: $b_1=0.96$, $b_2=0.42$ (the last one relates to the initial values for the year 2000 - the "surprise" case described below). Next, applying the "normative" price evolution reported in Table A5.10 (compare Nordhaus and Yohe, 1983) we calculate by (4.2a-e) the percentage fuel mix for the

Table A5.7 Population and GNP forecasts

	1975	2000	2025	2050	2075	
Population	IC	1.14	1.36	1.49	1.54	1.56
(10^9)	DC	2.90	4.54	5.87	6.66	6.88
GNP	IC	4.89	9.10	14.8	22.0	32.8
(10^{12} dollar)	DC	1.05	3.56	9.41	17.06	29.33

Table A5.8 Labour productivity growth rate

	1975-2000	2000-2025	2025-2050	2050-2075
α_{IC}	0.017	0.014	0.012	0.011
α_{DC}	0.029	0.023	0.019	0.016

Table A5.9 Energy consumption in the year 1975

CF [mtce]	6.0
SF [mtce]	0.0
NF [mtce]	0.7

Table A5.10 Relative fuel mix for the base case

	1975	2000	2025	2050	2075
P [U.S. dollar/mtce]	67	133	144	163	207
P [U.S. dollar/mtce]	257	295	298	303	309
S [-]	0.89	0.72	0.70	0.66	0.61
S [-]	0.11	0.28	0.30	0.34	0.39
S [-]	0.0	0.0	0.0	0.0	0.0

surprise-free case. The calculated values are presented in Table A5.10.

In the "surprise" scenario we consider a drastic limitation of nuclear production in the year 2000 as a consequence of two serious nuclear power plant accidents. The accidents lead to a higher price of nuclear energy due to high environmental and social restrictions (T_n). The price stabilizes over the next decades, largely through technological progress in solar and renewable energy production (h_n - negative). As a result of a rapid growth in demand for fossil fuels, coal exporting countries and OPEC countries fix very high prices for conventional fossil fuels, which continue to rise over the next decades. The

Table A5.11 The fuel mix for the year 2000

	1975	2000
CF [mtce]	6.0	6.6
SF [mtce]	0.0	0.7
NF [mtce]	0.7	2.0

Table A5.12 Relative fuel mix for the "surprise" scenario

	1975	2000	2003	2025	2050	2075
P [dollar/mtce]	67	133	350	360	370	380
P [dollar/mtce]	500	360	340	340	340	340
P [dollar/mtce]	257	295	600	570	550	550
S [-]	0.89	0.66	0.38	0.37	0.36	0.35
S [-]	0.0	0.08	0.41	0.41	0.41	0.42
S [-]	0.11	0.26	0.21	0.22	0.23	0.23

price of shale oil falls due to substantial technological progress (h_s - negative). All the shock changes take place during the three-years period 2001-2003. The initial 2000 fuel mix is assumed as defined in Table A5.11.

Thus, the formulas (4.2a-e) can be applied to calculate the relative fuel mix for the "surprise" scenario. The values calculated for the whole forecasting period are presented in Table A5.12.

Using the data from Table A5.10 and Table A5.12, the amount of carbon released per unit energy can be calculated. Assuming an aggregated carbon emission for conventional fossil fuels of 600 kg of C/mtce (compare Table A5.5), we obtain the following CO_2 emissions in the year 2075:

a) for the base scenario
$0.61 * 600 = 366$ kg of C/mtce,

b) for the "surprise" scenario
$0.35 * 600 + 0.42 * 1224 = 724$ kg of C/mtce.

The fuel mix (total amount of energy by fuel type) can be calculated from Table A5.7, Table A5.10 and Table A5.12 by the set of equations (4.4) -(4.6) (the $k = 2$ value of the parameter in equation (4.4) can be estimated from the initial data). Using formula (7) in Nordhaus and Yohe (1983) - the cumulative CO_2 concentration over the forecasting period can be calculated.

Note that the fuel-type disaggregation presented above focuses on global CO_2 impacts. Using another criterion for disaggregation, the algorithm procedure can be applied to an analysis of global acidity or other impacts. Extending the "surprise" scenario described above to DCs it is possible to trace through a substantial increase of noncommercial biomass use, together with its environmental effects.

The analytical procedure described above is not a precise mathematical model but rather an algorithm that can be applied to simulate environmental impacts of various energy strategies and scenarios. It can potentially be used as a part of an interactive biosphere game (compare Figure A5.5), which could investigate environmental impacts of energy production.

The purpose of this paper is to suggest a simple approach for analyzing alternative impacts of the energy sector on the biosphere. Further refinements should be focused on eliminating some of the formal weaknesses and inconsistencies within the algorithm presented. In particular, is important to consider international trade of fuels, and to formulate more precise methods for model calibration.

APPENDIX 6

A Simplified Explanatory Approach to the Global Energy System

Christoph Schlenzig

Objective:	Calculating global primary energy demand (= consumption) and the fuel mix	
Time scale:	1975 - 2075	
Spatial scale:	Global	
Time resolution:	Periods of 25 years	
Spatial resolution:	8 regions	North America Latin America Europe Africa USSR Indian subcontinent Asia Oceania
Fuel disaggregation:	6 fuels	Synfuel + Shale Coal + Oil Gas Biomass Hydro + Solar Nuclear
Input:	For every region and period: GNP/Cap Population figures Energy - GNP elasticities Yearly growth rates of energy demand Efficiency coefficients Fuel shares in % Production Ceilings	
Output:	Regional and global primary energy demand fuel mix GNP Energy/Cap Depletion times of resources	

The approach

The simple modeling approach can be used to get a quick overview of the energy sector and a feel for the orders of magnitude of the main statistical indicators GNP, population, energy per capita and fuel mix. It cannot provide detailed analysis of energy futures. It should be a useful tool to learn about the critical components and evolutions of the energy system.

The approach consists mainly in projecting the future Energy per Capita Consumption (ErgCap). In order to get these values we use two different methods (see Figure A6.1):

In the so-called economical approach we use GNP per capita projections and Energy-GNP elasticity coefficients. To cross-check the GNP/Cap assumptions, total GNP is calculated in order to judge reasonableness.

In the technical approach we calculate the Energy per Capita from a yearly demand growth rate, reflecting lifestyle, income situation and fuel prices, combined with one efficiency coefficient for the 25 year period reflecting improvements in efficiency and technological change achieved during this period.

The assumptions of these two methods have to be made consistent, which means that both calculated Energy per Capita figures should match each other.

Together with population figures the regional and global primary energy demand is calculated.

In order to assess some implications for the environment, the shares of different fuels have to be calculated. This is done by introducing the percentage split of primary energy demand into the different fuel types for every region.

In order to check whether the scenario is realistic or not, annual global production ceilings (maximum production capacities) for every fuel type together with the global amount of resources are provided.

Note: Unfortunately the task of creating the actual spreadsheet with graphic representation of the results has not been accomplished.

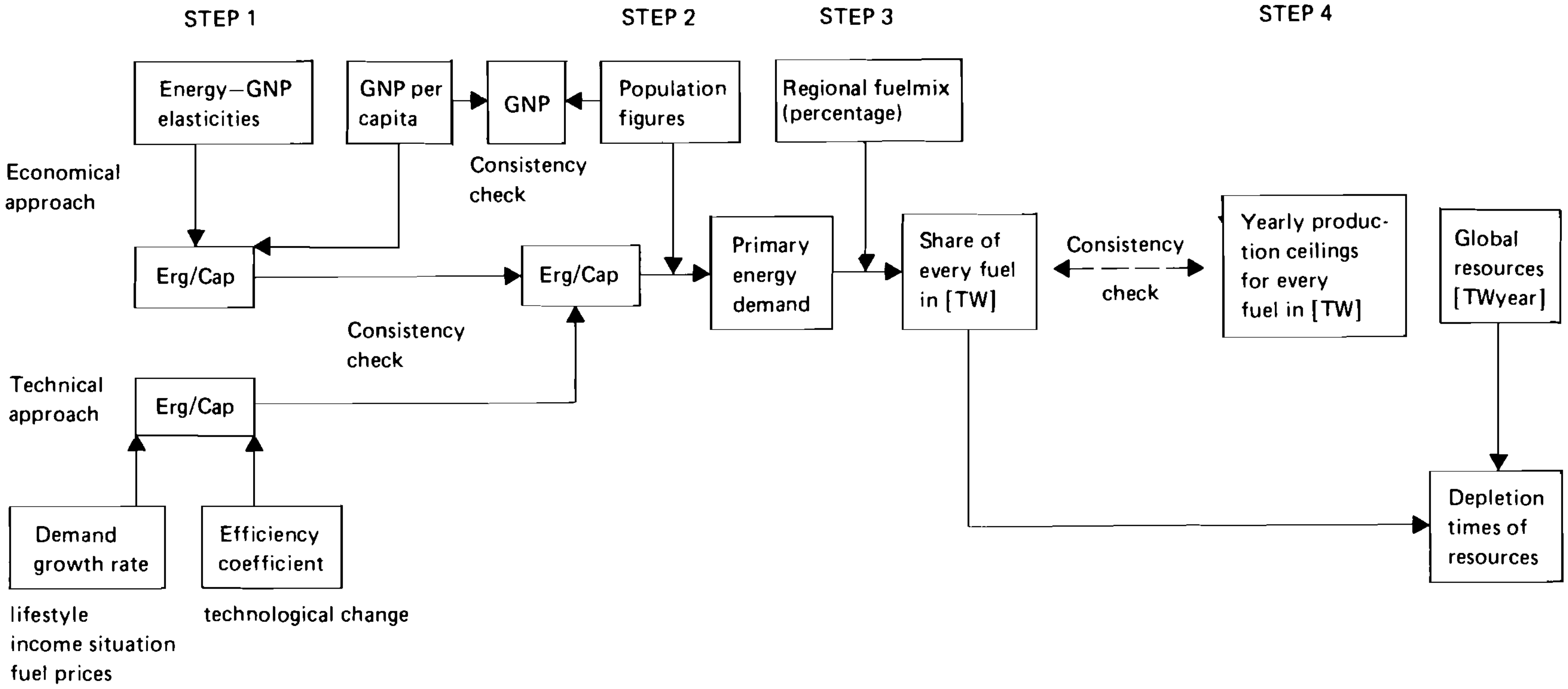


Figure A6.1 A combined approach to energy modeling

Set of equations

Step 1

Economical approach:

$$\mathrm{ErgCap}_{Ti+1} = \mathrm{ErgCap}_{Ti}\,(\mathrm{GNPCap}_{Ti+1}/\mathrm{GNPCap}_{Ti})^{\mathrm{El}_{Ti}}$$

ErgCap	Energy per capita (KW)
Ti	time period i (i=0 is the base year)
GNPCap	Gross national product per capita (S)
El	Energy - GNP elasticity

Technical approach:

$$\mathrm{ErgCap}_{Ti+1} = \mathrm{ErgCap}_{Ti}\,\mathrm{EFF}_{Ti}\,(1+\mathrm{Demgrw}_{Ti}/100)^{N}$$

Demgrw	yearly growth rate of energy demand in %
N number	of years in one period (N=25)
EFF	Efficiency coefficient for one period (1975 EFF = 1)

Step 2

$$\mathrm{ErgCap}_{Ti}\,\mathrm{Pop}_{Ti} = \mathrm{PrimErg}_{Ti}$$

Pop	Population figures
PrimErg	primary energy demand (TW)

Step 3

$$\mathrm{PrimErg}_{Ti}\,\mathrm{Fuelj\%}_{Ti}/100 = \mathrm{Sharej}_{Ti}$$

Fuelj%	percentage share of fuel j
Sharej	Share in TW of fuel j

Step 4

$$\mathrm{Dpltimej} = \mathrm{Resj}/\mathrm{Sharej}_{Ti=2075}$$

Dpltimej	depletion time of resource j
Resj	amount of resources for fuel j

These equations have to be evaluated for each period and each region. Afterwards the global results are aggregated.

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Chapter 4

A Critical Review of Agricultural Projections for the Study of Long-term, Large-scale Interactions between Development and Environment

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1. INTRODUCTION

The objective of the Biosphere project at the International Institute for Applied Systems Analysis is to examine the long run sustainable development of the biosphere. Specifically can the world's biosphere support the possible course of socioeconomic development and how might future conflicts between development and the environment be managed? Focusing on the agricultural component of economic development, we were concerned with two key questions:

(1) What are the implications of projected agricultural development for the environment and for the resource base; and

(2) What consequences might degradation of the environment and the resource base have on the future of agriculture?

No study of long-term global agricultural development has explicitly addressed these questions. However a number of studies have attempted to define future scenarios and describe how agriculture may evolve. This paper is a critical review of six of these studies (listed in Table 1.1) in light of the above stated objectives. The studies are described and evaluated here to define how each may contribute to studies of long-term, large-scale environmental problems. Reviews of the individual studies comprise Section 2 of this paper. The descriptive section of each review reports the scale and resolution of the study, the basic approach undertaken, the key assumptions and major exogenous variables of the study and finally the principal results or output.

In the evaluation part, we first discuss the sensitivity of results of each study. The sensitivity of results is analyzed with respect to both changes in initial values of exogenous variables and altered structural assumptions and constraints.

The second part of the evaluation responds to the question, "What are possible sources of surprise to the study?" An analogous question would be, "To what shocks are the results most vulnerable?" We take it as given that surprises or shocks will alter the setting established for each study. The question is intended to identify explicit or implicit assumptions or model linkages that may change in a dynamic and uncertain world.

Table 1.1 Agricultural Studies

Agro-ecological Zones Project (AEZ)	Food and Agriculture Organization of the United Nations. 1978-1981. Reports of the Agro-ecological Zones Project. World Soil Resources Report 48. Vol.1-Vol.4. Rome:FAO. Shah, M.M., G.M. Higgins, A.H. Kassam and G. Fischer. 1985. Land resources and productivity potential - agro-ecological methodology for agricultural development planning. Publication number CP-85-14. IIASA, Laxenburg, Austria.
Agriculture-Toward 2000 (AT 2000)	Food and Agriculture Organization of the United Nations. 1981. Agriculture toward 2000. Economic and Social Development Series, 23. Rome:FAO.
Model of International Relations in Agriculture (MOIRA)	Linnemann, H., J. De Hoogh, M. A. Keyzer, H. D.J. Van Heemst. 1979. MOIRA Model of International Relations in Agriculture. Amsterdam: North-Holland Publishing Company.
Global 2000	Council on Environmental Quality and Department of State. 1980. Global 2000 Report to the President: Entering the Twenty-first Century. Washington, D. C.: U. S. Government Printing Office. (Three Volumes.)
Food and Agricultural Program (FAP)	Parikh, K. S. 1981. Exploring national food policies in an international setting. Publication number WP-81-12. IIASA, Laxenburg, Austria. Food and Agricultural Program. 1985. A background note for the task force meeting on economic strategies: hunger, equity and growth. Manuscript. IIASA, Laxenburg, Austria.
Resources for the Future (RFF)	Crosson, P. R. and B. Sterling. 1982. Resource and environmental effects of U.S. agriculture. Research paper from Resources for the Future. Washington, D.C.

The relevance of each study to the objectives of long-term, large-scale environmental studies is evaluated next. A list of six environmental characteristics and four development characteristics was compiled as an aid for assessing the contributions of the studies. This list is presented in Table 1.2. The reviews of Section 2 report whether or not these are addressed in the studies. The first six are broadly stated characteristics of the environment deemed critical for sustaining a high level of agricultural production. Both quality and quantity characteristics are included because, over the long run, the biosphere must both absorb the effects of production and supply future inputs to agriculture.

Table 1.2 Environmental and development characteristics

Environmental characteristics

- land quality and availability
- water quality and availability
- ecosystem quality, including genetic diversity, assimilative capacity, and biota
- air quality
- climate
- mineral resources.

Development characteristics

- wealth (GDP)
- equity (income distribution)
- nutrition
- self-sufficiency.

The development characteristics are important because different paths of agricultural growth have significantly different effects on human welfare. Producing enough food to feed the world's population is not sufficient to solve the problem of hunger. Distribution is also critical. The production objective also fails to address other development goals. Thus a study of the future of agriculture must account for progress (or lack of progress) in attaining broader social goals. Another reason to direct attention to welfare indicators is that often agricultural policies are designed with such indicators as goals. As a result welfare, agriculture and the environment become completely intertwined.

Section 3 is a comparative evaluation of the six studies. The first part describes how the diversity among the studies contributes to a better understanding of agricultural development. Differences between the studies establish a broad base from which we can explore how could they be used in environmental studies. The second part compares the approaches and scope of the six studies to identify differences and similarities. A list of common variables is also developed. The final part discusses a number of limitations and omissions common to the six studies.

2. DESCRIPTIONS AND EVALUATIONS OF AGRICULTURAL STUDIES

2.1. Agro-Ecological Zones (AEZ) and Land Resources for Future Populations (LRFP)

FAO. 1978-1981. Reports of the Agro-ecological Zones Project. World Soil Resources Report 48.Vol.1-Vol.4. Rome: FAO.

Shah, M.M., G.M. Higgins, A.H. Kassam and G. Fischer. 1985. Land resources and productivity potential - agro-ecological methodology for agricultural development planning. Publication number CP-85-14. International Institute for Applied Systems Analysis, Laxenburg, Austria.

2.1.1. Description

"AEZ, the Agro-ecological Zones Project, was initiated in 1977 in the Soil Resources Management and Conservation Service of the Land and Water Development Division (FAO). The aim of the Project was to assess the rainfed production potential of the world's land resources..."(Higgins and Kassam, 1980:99). Later it was decided that the population supporting capacity of the world's land resources should also be addressed in a different study (LRFP). Another important aim of these studies is to show that in the long run, land productivity may diminish due to some specific ways of using the land. Land productivity can be maintained only by preserving the land base.

2.1.1.1. Scale and resolution

Since AEZ is a methodology whose goal is to assess the potential land based productive capacity of the world, it is "timeless" with no fixed time scale. Spatially AEZ has a global scope built up from national or regional components. Only the developing world (117 countries) has been studied so far. However the methodology can theoretically be expanded to the rest of the world.

The data base of AEZ consists basically of a climate inventory (a generalized map from the monthly record of 3500 weather stations) and a soil inventory (FAO/UNESCO Soil Map of the World containing 106 soil units in over 5000 mapping units).

The climate inventory contains 14 major climates. On the basis of moisture availability, temperature, and length of growing period, zones are defined into which climatic regions are classified. The Global study, based on the FAO/UNESCO 1:5 million Soil Map of the World, used a 10,000 km^2 grid. The Kenya Case study used the 1:1 million exploratory soil map of Kenya that was digitized based on a 100 ha grid size. By comparison, MOIRA uses 222 land units for the whole world while AEZ uses about 50,000 for the developing world alone.

2.1.1.2. Approach

AEZ determines potential biomass production of the most significant crops based upon their genetic characteristics, climate and natural resources. This maximal biomass production is reduced by agro-climatic, soil and input constraints and by the level of technology. The principal steps of the AEZ methodology are:

- climate
    - inventory of climate
    - evaluation of climatic requirements of crops

    - classification of climatic characteristics into climate suitability categories
    - calculation of the productivity of crops by agro-climatical zones - Length of Growing Period (LGP)
- soils
    - inventory of soils
    - evaluation of soil requirements of crops
    - classification of soils into soil suitability groups (very suitable, suitable, marginally suitable, non-suitable)
- combination of climatic suitability with soil suitability into land suitability by crops for three levels of technology
- establishment of potential crop yield by crops at three levels of technology.

2.1.1.3. Key assumptions and exogenous variables

A set of assumptions underlie the AEZ methodology. A number of these, including criteria for class definitions are listed below.

(1) Soil suitability is fixed in the first classification, but conceptually could change in the soil characteristics, mainly degradation, through insufficient fallowing of land, soil erosion, salinity, alkalinity, and other changes which influence soil phases. Of these, only soil erosion has been formally accounted for.

(2) The non-agricultural requirement for land is .05 ha. per person.

(3) Only 50% of the biomass production is assumed to be available for human consumption. Further allowances are made out of this edible portion for seed, waste and feed.

(4) Agro-climatic productivity may be increased by multiple cropping.

Several important characteristics enter the AEZ methodology exogenously. These include the level of irrigated production (taken from the AT 2000) and the demand for food per capita when estimating carrying capacity. Other criteria are used to have alternative solutions, by using different levels of technology and choosing different objectives in the optimizing process for the choice of crops and their growing areas. Three levels of technology are used:

low: traditional seeds, no fertilizer or chemicals, no soil conservation and continuation of presently grown crop mix on all potentially cultivable rainfed land

high: improved seeds, recommended fertilizers and chemicals, full soil conservation, most productive cropping pattern on all potentially cultivable land.

intermediate: mix of low and high.

2.1.1.4. Results

The results of AEZ are presented with respect to the three objectives of the study. One set of results is with respect to the land base and production potentials. The AEZ study not only assesses the land base by region (Figure 2.1) but also shows the possible losses of that base due to erosion when no conservation practices are employed (Figure 2.2). On the production side the study identifies potential crops, yields and input requirements for various categories of lands and climates.

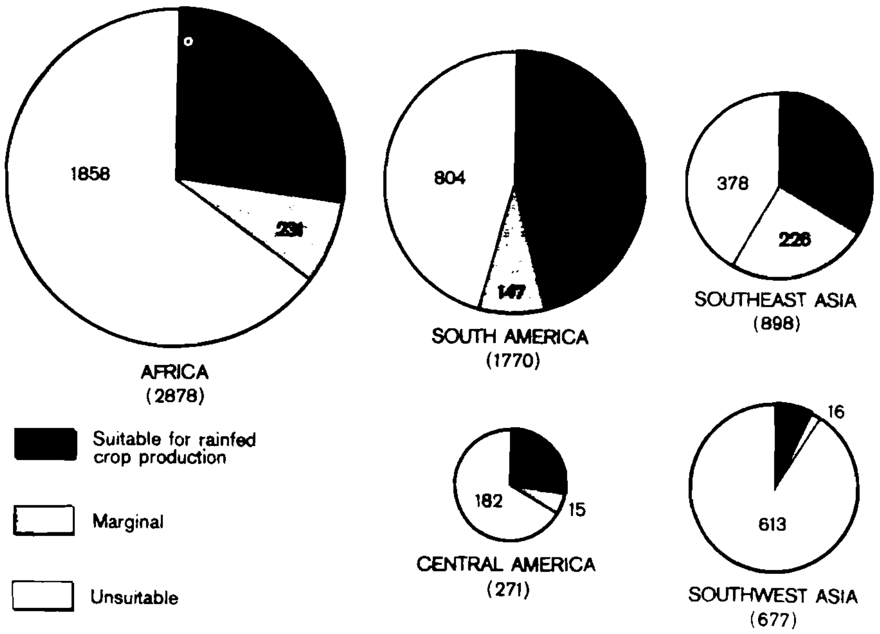


Figure 2.1 The potential land base for rainfed agriculture (million ha)
(*Source:* FAO, 1984:10)

A second set of results links production potentials with consumption needs and development strategies for agriculture. The population supporting capacity of an area is derived in the study by comparing production with the per capita calorie and protein requirements of the present and future populations. Also, one can calculate the difference between actual and potential production with data on present land use and its intensity (area, cropping pattern, input level, etc.).

Finally the results of AEZ can be used to answer questions in connection with the choices in strategy of agricultural development in a certain country such as: "which area to develop, how much to invest, which crops to promote, what level of farming technology is appropriate..."(Shah et al., 1985a:1).

2.1.2. Evaluation

2.1.2.1. Sensitivity analysis

No formal sensitivity analysis has been performed for AEZ. Checking AEZ's sensitivity to a certain variable is difficult due to the large size of the data base. Only one part of the evaluation (the crop module) has deterministic relations. This part uses the net photosynthesis equation. Other estimations, such as those coming from climatic, soil and input constraints and the level of technology are based on expert estimations and use either a certain fixed ratio or wide range of values. An external action can affect AEZ results only if it causes a shift in some property of the model, e.g. in climatic or soil properties.

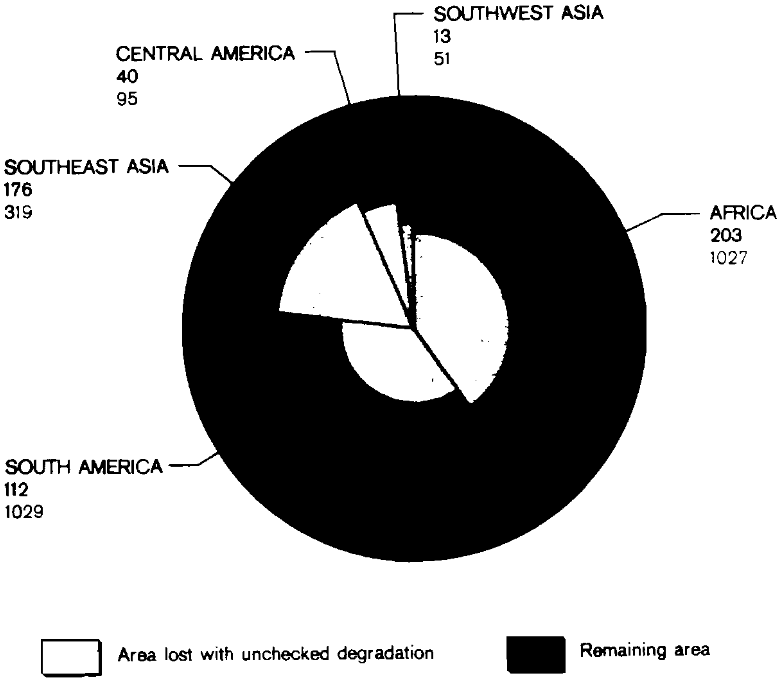


Figure 2.2 The degradation threat: losses of rainfed cropland (million ha)
(*Source:* FAO, 1984:9)

2.1.2.2. Structural analysis

The structure and approach of AEZ is static. There is no feedback in it, so it is not suitable for simulation. Consequently environmental effects and the effects of development cannot be evaluated endogenously. Instead, the climate and resource data base must be exogenously adjusted to determine the long-term outcome. This means that to introduce climate change it is necessary to redraw the climate map.

Another characteristic of AEZ is that potential production of the land resources is overestimated because areas for growing non-food crops (eg. vegetables, beverage crops, etc.) and forest (for timber, fuel wood, etc. - except steep areas and conservation forestry) have not been considered. For this reason "the result of the study would have to be reduced by at least one third" (Shah et al., 1985b:5). However, the LRFP Kenya Case study includes both non-food crops and forests.

A third feature of AEZ is that "the study assumed average mean climatic patterns. The effect of neither the short-term weather fluctuations nor the long-term changes in climate have been considered" (Shah et al., 1985b:6). Here again, the LRFP Kenya Case study includes rainfall distribution patterns and provides production estimates for "good" and "bad" years in addition to the "average" years.

2.1.2.3. Sources of surprise to AEZ

Surprises to the AEZ study can come from two sources: climate changes and new crop varieties. It is not easy to assess the adaptability of present crop varieties to new climate or soil conditions. Similarly the changes implied by a new crop or variety may be of a similar magnitude to those coming from climatic shifts.

2.1.2.4. Relevance to long-term, large-scale environmental studies

AEZ is concerned with the environment only with respect to land suitability. Land suitability in turn is a function of environmental indicators such as climatic changes and soil suitability changes. The indicators are highly dependent on the technological level applied.

The AEZ study covers the environmental and development characteristics of interest to development-environment studies only indirectly:

- Water quality and quantity
  Water quality can be affected through a changing soil phase (namely salinity phase), while water quantity can affect crop production. Water quantity more directly affects land area through irrigation. The extent of irrigation in AEZ comes from estimations provided by AT 2000.
- Land quality
  One of the main objectives of the AEZ study is to assess the extent of land area which are suitable for the production of the most important crops. Suitability is defined as meeting the climate and soil requirements of a specific crop, and is further classified into very suitable, suitable, marginally suitable and non-suitable. Soil conservation activities are needed to maintain soil suitability.
- Land quantity
  On the basis of the land suitability assessment AEZ identifies the potentially usable land area by region/country. Potential usable land area can be diminished by land degradation. Total land is adjusted using a rough estimate of non-agricultural land use, namely 0.05 ha per person. Thus potentially available agricultural land is also a function of population growth.
- Climate
  AEZ results are highly dependent on climate. Land suitability is established on a climatic basis. It can be concluded that any climatic changes may significantly affect the land suitability evaluations and through that the potential production values as well.
- Air quality, ecosystem quality and resource availability are practically not considered.
- Development Characteristics:
  AEZ compares several different land uses, crops and levels of technology in evaluating production potentials and the costs of production.

To summarize the appropriateness of AEZ for environmental studies: (1) The model does not deal realistically with environmental interactions, which must be introduced exogenously. (2) In calculating net biomass production, the growth function is estimated only from climate parameters and genetic properties of the crops. All other constraints which reduce the potential production and yield are estimated by expert judgement. (3) All the model's constraints and structural elements are static (except soil loss and productivity loss).

2.1.3. Other relevant publications

Higgins, G.M. and A.H. Kassam. 1980. The Agro-ecological Zone Inventory In: Report on the Second FAO/UNFPA Expert Consultation on Land Resources for Population of the Future. Rome:FAO.

Kassam, A.H., J.M. Kowal and S. Sarraf. 1977. Climatic adaptability of crops. Consultants' Report, Agro-ecological Zones Project. AGLS. Rome:FAO.

Kassam, A.H. 1977. Net biomass and yield of crops. Consultants' Report, Agro-ecological Zones Project. AGLS. Rome:FAO.

Kassam, A.H. 1979. Agro-climatic suitability classification of rainfed crops. Consultants' Report. AGLS. Rome:FAO.

Wood, S.R. 1980. The allocation of irrigated areas and production of agro-ecological zones. Consultants' Report. AGLS. Rome:FAO.

The following studies pertain to the estimation of population supporting capacity in AEZ:

FAO/IIASA/UNFPA. 1983. Potential supporting capacities of lands in the developing world. Technological Report of Land Resources for Population of the Future Project, Rome:FAO.

Shah, M.M. and G. Fischer. 1980. Assessment of population supporting capacities. In: Report on the Second FAO/UNFPA Expert Consultation on Land Resources for Population of the Future. Rome:FAO.

Shah, M.M., G. Fischer, G. Higgins, A.H. Kassam and L. Naiken. 1985b. People, land and food-production potentials in the developing world. Publication number CP-85-11. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Food and Agriculture Organization. 1984. Land, food and people. Rome: FAO.

2.2. Agriculture Toward 2000 (AT 2000)

Food and Agriculture Organization of the United Nations. 1981. Agriculture Toward 2000. FAO, Economic and Social Development Series, 23. Rome.

2.2.1. Description

Agriculture Toward 2000 (AT 2000) is the result of a four year study completed in 1981 by the Food and Agriculture Organization of the United Nations. An early draft of the work was published in July 1979 and contains an extended summary.

The study analyzes the implications for world agriculture of population and income growth up to the year 2000. It proposes a strategy for the development of world agriculture to abolish world hunger by the end of the century. It recognizes that increased food production alone will not solve the hunger problem: distribution of agricultural products also needs improvement.

2.2.1.1. Scale and resolution.

The unit of analysis is the individual country with 90 developing countries studied in detail (China is not included in the detailed analysis). Thirty-four developed countries are aggregated and studied in less detail. Analyses of the latter production, input and investment requirements rely mainly on existing trends. China is examined only with respect to possible future agricultural trade.

2.2.1.2. Approach

AT 2000 sketches a global framework for future world demand, production, trade and nutrition. National and international policy actions and options which enable agriculture to contribute to overall economic and social development are considered.

The model is normative and demand driven. Demand for food and agricultural export products is derived using socio-economic objectives as constraints. AT 2000 analyzes quantitatively three scenarios for agricultural development. Instead of producing a forecast or projection the study describes requirements for achieving development goals. For each of the 90 developing countries the analysis covers a variety of crops, land classes, and technologies.

Food demand is projected for 27 groups of commodities for 131 countries. For each of the 90 developing countries, production is analyzed for 28 crops, 6 livestock products, 6 classes of rainfed and irrigated land, 9 levels of current inputs and 26 investment items. Twenty four production techniques are distinguished, based on 6 land/water resource combinations (based on the AEZ study) and 4 management levels. For each management level a production technique represents a certain yield level, and is associated with a combination of input factors (24 in total, i.e. 6 land types x 4 management levels).

The model first projects food demands at the national level. Then the potential agricultural production is assessed. Projections differentiate between developed and developing countries, and between crops and livestock. The estimates of country-specific production levels and required inputs are based largely on expert judgement of yield levels for each crop and land class. Both present and possible future combinations are accounted for.

The AEZ study (see section 2.1) is used to analyze the land base and production potentials. Production targets are derived taking into account total demand, self sufficiency and export targets, and the projected national production. From projected demand and input requirements, resource requirements are calculated including area of land in each class, labor, and capital inputs. This gives rise to the net trading position of each country. World trade balance is achieved by iterative output adjustments largely by the developed countries.

Three scenarios were evaluated in AT 2000:

(1) trend: production and consumption of agricultural products is extrapolated from past trends between 1963 and 1975;

(2) scenario A: an optimistic high growth scenario in which the global economy grows in accordance with the UN International Development Strategy (UN, 1980);

(3) scenario B: a moderate growth scenario in which current trends of economic growth improve.

2.2.1.3. Key assumptions and exogenous variables

The scenarios have six assumptions in common:

(1) world population will grow according to the UN medium variant of population growth (UN, 1985) which estimates the world population in the year 2000 to be 6.2 billion people;

(2) developed countries adopt an equilibrating role in world trade; hence imbalances are corrected mostly by production adjustments in the developed countries;

(3) relative prices are held constant, therefore production is driven by changing demand not changing prices;

(4) demand is a function of population and economic growth;

(5) agricultural growth cannot exceed 3-4% per year in the long run (20 years), hence non-agricultural GDP growth must be substantial to meet projected overall GDP growth rates; and,

(6) all technologies in use by the year 2000 are already known.

In addition, scenario A assumes realization of the International Development Strategy, developing countries improve their self sufficiency ratios in basic foods and increase their exports. Developed countries also continue their growth rates and maintain self sufficiency ratios at the late 1970 levels.

Population and GDP growth rates are the key exogenous variables in AT 2000. Values for these variables are shown in Table 2.1. The table also lists a number of study results such as growth in demand, production, consumption and required inputs. Factor increases of the variables are shown in Table 2.2. The results are presented graphically in Figures 2.3 to 2.9.

2.2.1.4. Results

Continuation of past trends leads to a situation in which per capita production levels in many developing countries stagnate or decline. Demand for imported food also will be low due to slow growth in average incomes. Consequently socio-economic conditions in the developing countries worsen: the number of undernourished people increases from 435 million in 1974-1976 to 590 million in 2000, landlessness increases, size of landholdings decreases, and distribution of income becomes more unequal. Increased pressure on the land degrades natural resources and lowers their productivity permanently. The poorest countries have cereal deficits and must import food from the developed countries.

In scenarios A and B population and per capita income growth cause demand to increase by 29% and 17% respectively. The difference in caloric intake between developed and developing countries decreases. In scenario A all developing countries have sufficient supplies to feed their populations adequately, provided rapid economic and production growth is supported by other measures such as increased employment, and improved income distribution. To attain the consumption and production objectives of scenarios A and B a set of technological achievements and institutional and policy changes is needed.

Production is doubled in scenario A and nearly doubled in B. In both scenarios A and B 80% of the increased production is provided by crops and 20% by livestock. Expansion of arable land accounts for 25% of the increase, increased cropping intensity for 14% and higher yields for 60%. Fertilizer and commercial energy use will be 4 to 5 times higher in 2000 than in 1980.

Scenario A projects a reversal of the existing pattern of agricultural trade which is now increasingly dominated by exports from the developed countries. Scenario B only modifies this pattern. Intra group trade is not studied. Under both scenarios imports in the developing countries increase steeply. Exports must increase as well to improve the agricultural trade balance, employment, and farm income. Improved market access is essential to reach these goals.

Table 2.1 Growth rates in % per year (1980-2000) for exogenous variables, results and required inputs for three scenarios of AT 2000.

	Trend			Scenario A			Scenario B		
	DC	LDC*	WORLD	DC	LDC	WORLD	DC	LDC	WORLD
Exogenous variables									
Population	0.7	2.0	1.7	0.7	2.0	1.7	0.7	2.0	1.7
GDP	-	4.5	-	3.8	7.0	4.4	3.2	3.6	5.7
Results									
Aggregate demand agric. products	-	2.9	-	1.2	3.7	2.3	1.2	3.2	2.0
Gross agric. production	1.5	2.8	-	1.1	3.7	2.3	1.2	3.1	2.0
Calorie supply**	-	0.3	0.1	0.2	0.8	0.4	0.2	0.5	0.2
Number of undernourished persons**		1.2			-2.1			-0.4	
Agric. prod./capita			0.4			1.0			0.6
Required inputs									
Arable land					0.9			0.7	
Irrigated land					1.7			1.3	
Fertilizers (NPK)					8.5			3.7	
Labour (man-days)					2.0			1.6	
Biocides					4.6			3.7	
Energy					8.3			6.9	
Capital inputs					5.8			4.7	

Notes:

* LDC's = the 90 study countries, except for population growth rates and agricultural production per capita, which include China.

** For total calorie supply and number of undernourished persons, growth rates are valid for the period 1975-2000.

2.2.2. Evaluation

2.2.2.1. Sensitivity analysis

AT 2000 seems to be very sensitive to changes in its key exogenous variables as is shown by the outcomes of the three different scenarios. Sensitivity cannot be determined precisely because of the large number of subjective parameters used. It is not clear which parameters form part of the formal model and which are incorporated subjectively.

Table 2.2 Factor increase of exogenous variables, results and required inputs between 1980 and 2000 for three scenarios of AT 2000.

	Trend			Scenario A			Scenario B		
	DC	LDC*	WORLD	DC	LDC	WORLD	DC	LDC	WORLD
Exogenous variables									
Population	1.14	1.50	1.40	1.14	1.50	1.40	1.14	1.50	1.40
GDP	-	2.46	-	2.14	4.06	2.41	1.90	3.13	2.05
Results									
Aggregate demand agric. products	-	1.80	-	1.27	2.09	1.55	1.27	1.90	1.49
Gross agric. production	1.35	1.75	-	1.25	2.08	1.55	1.27	1.87	1.49
Calorie supply**	-	1.09	1.03	1.05	1.21	1.10	1.05	1.15	1.06
Number of under-nourished persons**		1.36			0.60			0.90	
Agric. prod./capita			1.11			1.29			1.17
Required inputs									
Arable land					1.26			1.21	
Irrigated land					1.56			1.42	
Fertilizers (NPK)					7.00			5.60	
Labour (man-days)					1.61			1.49	
Biocides					3.16			2.50	
Energy					3.19			2.56	
Capital inputs					5.26			4.97	

Notes:

* LDC's = the 90 study countries, except for population growth rates and agricultural production per capita, which include China.

** Factor increase between 1975 and 2000, not marked: factor increase between 1980 and 2000.

2.2.2.2. Sources of surprise to AT 2000

(1) Latin America has been assigned a major role in producing food for a growing world population. Social instability would substantially decrease food production in this part of the world.

(2) Debt defaults may disturb international relationships and decrease the international trade which is a critical element in reaching the goals of this normative study.

(3) Economic recession in the developed world may decrease the percentage of GDP allocated to aid, again a major component of the New Economic Order assumed in AT 2000.

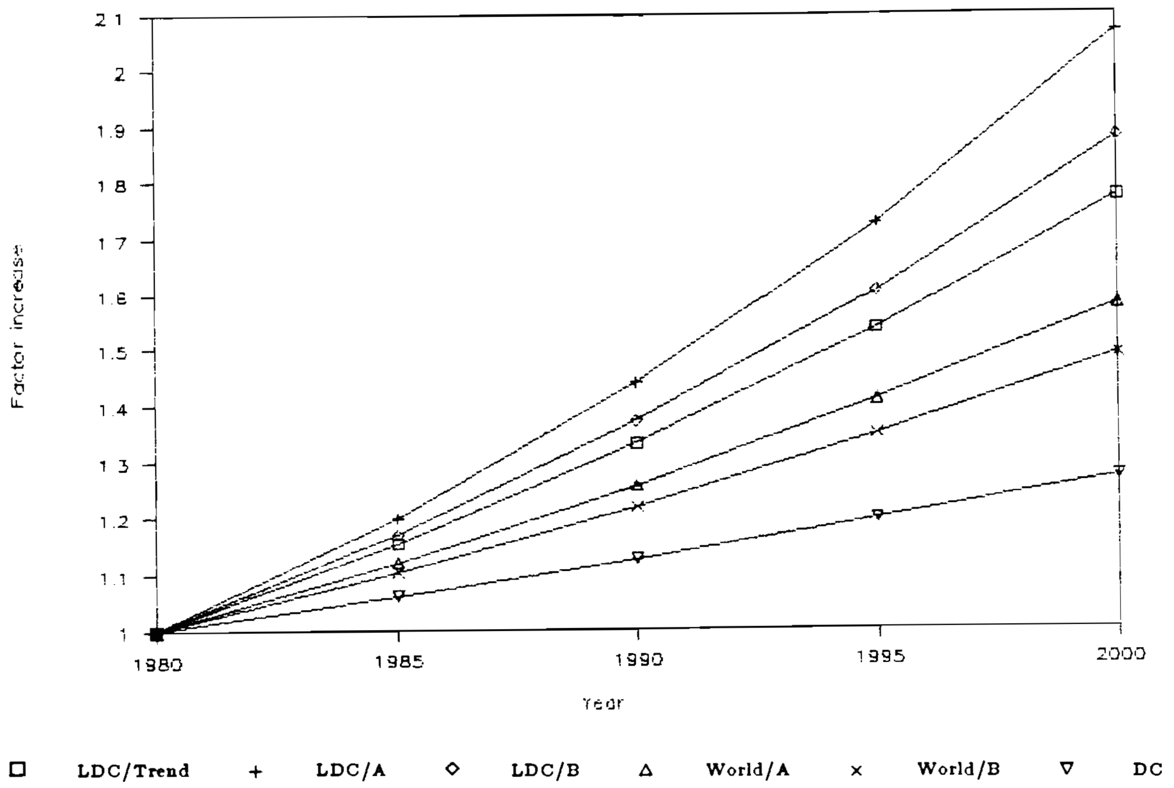


Figure 2.3 Increase in aggregate demand for agricultural products

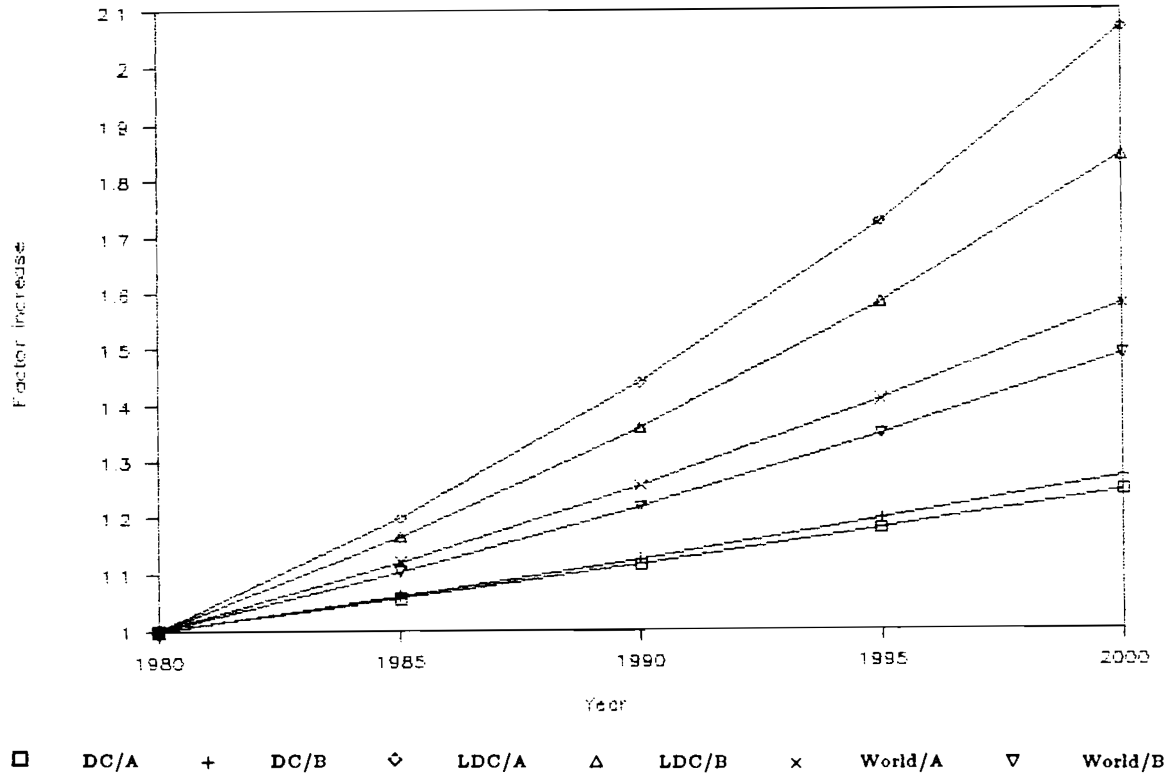


Figure 2.4 Increase in gross agricultural production

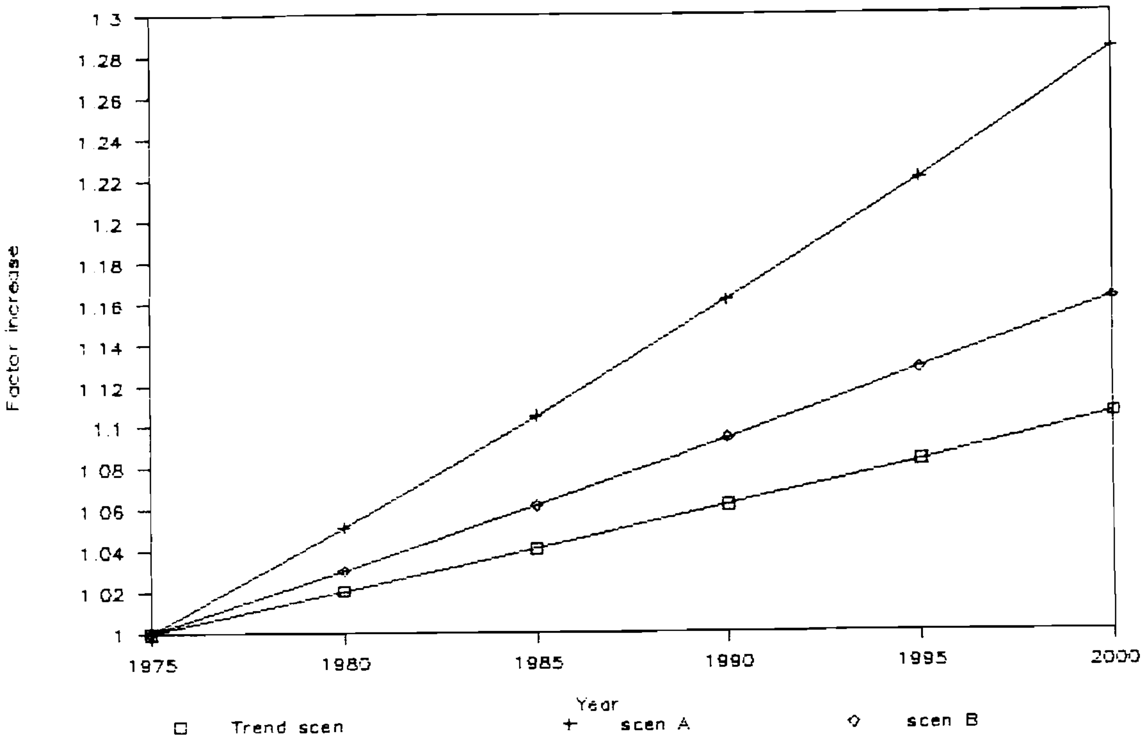


Figure 2.5 Increase in production per capita in the 90 study countries (1975=1)

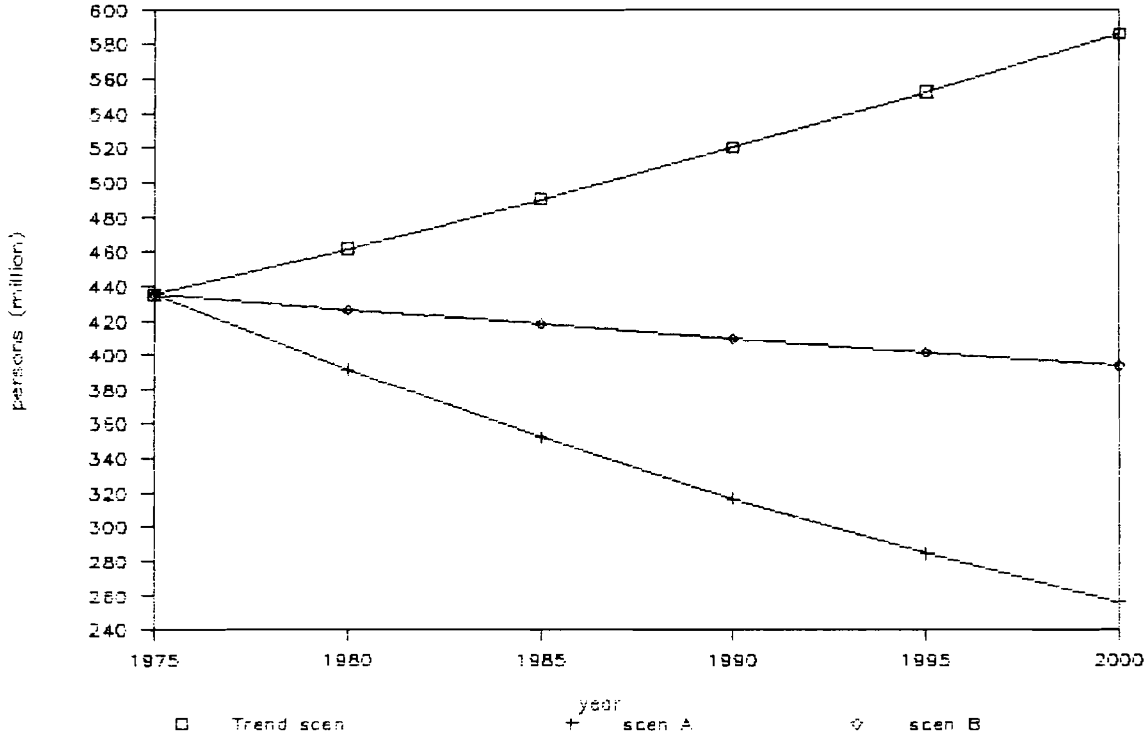


Figure 2.6 Number of undernourished persons in the 90 study countries (1975=1)

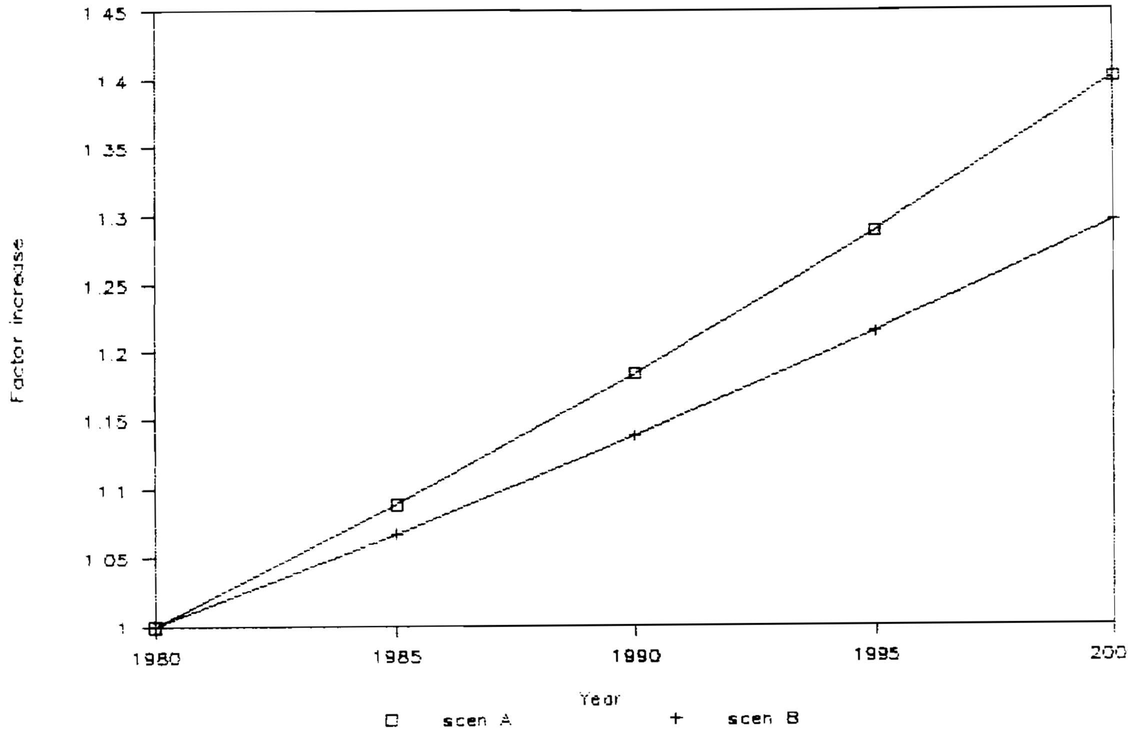


Figure 2.7 Increase in irrigated area in the 90 study countries

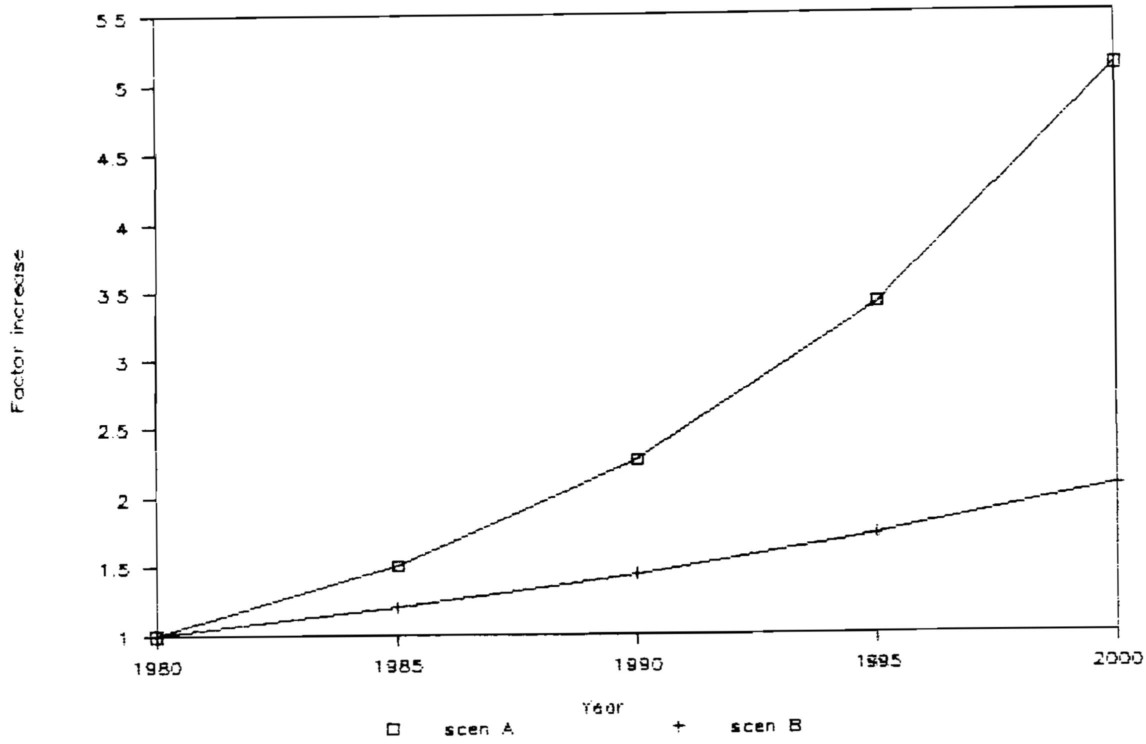


Figure 2.8 Increase in total fertilizer use in the 90 study countries

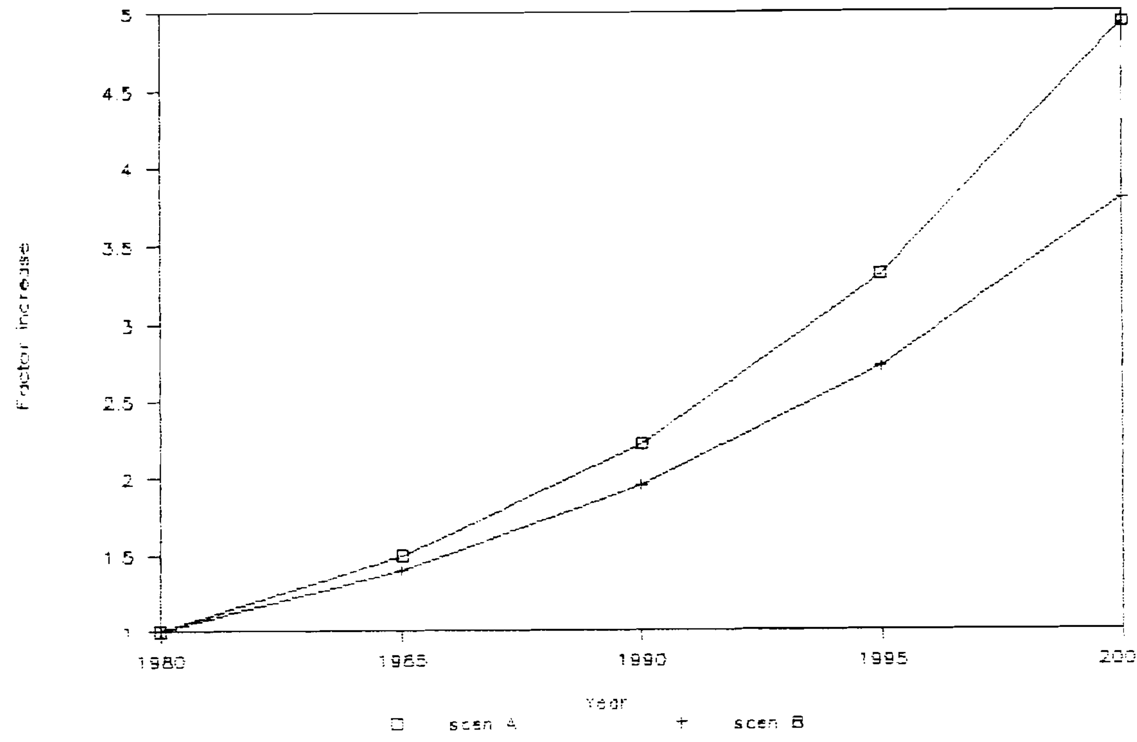


Figure 2.9 Increase in energy used in agriculture in the 90 study countries

(4) Rapid rates of penetration of new technologies could alter the study's results. Penetration is assumed to take 20 years in AT 2000. Relevance to long-term, large-scale environmental studies

Pressure on the environment as a result of the proposed development is not explicitly analyzed. However, the enormous increase in inputs projected in the study will surely affect the environment. Input requirements such as water, land, chemicals, energy and capital are given in the study and can provide a basis for analyzing environmental impacts (see Tables 2.1 and 2.2 and Figures 2.7 through 2.9).

2.3. Model of International Relations in Agriculture (MOIRA)

Linnemann, H., J. De Hoogh, M. A. Keyzer, H.D.J. Van Heemst. 1979. MOIRA Model of International Relations in Agriculture. Amsterdam: North-Holland Publishing Company.

2.3.1. Description

MOIRA, the Greek goddess of fate, is the acronym for a global agricultural model developed by a group of Dutch agronomists and economists to examine world hunger. The authors address two main questions:

(1) Can the world grow enough food to feed 8 billion people?

(2) What policy actions can be taken to ameliorate world hunger? By when?

The first question stems from the Malthusian concern with production limits. A theoretical model is developed to estimate potential world food production.

The second question stems from the observation that world hunger results primarily from insufficient purchasing power rather than insufficient production. A sectoral simulation model is developed to describe the causal processes of world hunger. It is this economic model which actually bears the name of MOIRA.

2.3.1.1. Scale and resolution

Potential world food production is estimated on the basis of 222 soil regions, varying in size from 2.5 to 400 million ha. These are aggregated for presentation purposes into 6 geographical regions:

North and Central America
South America
Asia
Africa
Australia and New Zealand
Europe

The evaluation has no time dimension since relations are presumed to be static.

MOIRA is made up of 106 geographical units. Most are individual countries, however some have been aggregated as groups. There are 103 market economies and 3 centrally planned economies. Results are frequently presented in 7 regions but their composition is not specified. The regions are:

- Developed countries:
  - North America
  - European Community
- Developing countries:
  - Tropical Africa
  - Middle East
  - Southern Asia
- Centrally Planned economies

Projections are made up to 2010, using 1965 as the base year. Calculations are made for time periods of one year.

2.3.1.2. Approach

Food Production Potential: Potential world food production is estimated by determining the availability of agricultural land and applying a theoretical maximum rate of photosynthesis. The photosynthetic rate depends on climatic conditions.

Economic model: MOIRA is a mathematical model using both recursive and simultaneous equations. Countries which each have two sectors (agriculture and non-agriculture) are linked by an equilibrium model of international trade in food.

Production in terms of consumable protein is modeled for the agricultural sector as a whole, while consumption is differentiated by income class and sector.

Both production and consumption are functionally dependent on the domestic price of food which is influenced by government intervention in domestic markets. Effective demand per income class and sector at given prices is compared to a nutrition norm to judge the extent and distribution of hunger in each country.

Cross-sectional regression is used to estimate parameters for the functions. Country-specific differences are reflected by differences in values of the input variables. Parameters for market economies and centrally-planned economies are estimated separately, partly due to structural differences and partly to data limitations.

2.3.1.3. Key assumptions and exogenous variables

The authors make three major assumptions in estimating world food potential:

(1) optimal agricultural practices and conditions for each soil region;
(2) no further non-agricultural encroachment on arable land;
(3) no climatic change.

The first is explicit, while the latter two are implicit. In addition a series of structural parameters is imposed. These include:

Assumptions for calculations:
1. Conversion from dry matter into grain equivalent
    roots and stubble: 25% of dry matter
    straw and grain: 75% of dry matter, ratio 1:1
2. Moisture content of grain is 15%
3. Dry matter amounts to 65% of gross photosynthesis
4. The standard crop is a C3 plant with the properties of a cereal
5. Harvest losses amount to 2% of grains
6. Average monthly temperature during growing season is >10 C

Other assumptions
1. Sufficient water is available for irrigation
2. Optimal
    water management
    soil cultivation
    fertilizer use
    maintenance
    pest control
    environmental protection

Two conceptual assumptions are made within MOIRA:

(1) the food sector operates largely independently of the rest of the economy; and,
(2) within the food sector, most actors adopt classical economic behavior.

These two assumptions simplify the task of modeling global agriculture. The first allows MOIRA to be developed as a sectoral model driven by a limited number of exogenous variables. The second allows adoption of classical economic theory in formulating functions, and taking mathematical derivatives.

Cross-sectional regression analysis using country level data for 1965 has been used to statistically verify assumed functional relationships in MOIRA. From these analyses several country-specific structural constants have been imposed. These empirically determined structural attributes assume the 1965 level was optimal or representative. The structural parameters include:

Country-specific structural parameters:
1. ratio of food to non-food (including wood)
    agricultural production over time, measured in consumable proteins
2. disparity ratio over time, measured as the ratio of
    non-agriculture to agriculture per capita incomes,

3. sectoral income distribution
4. fish catch and distribution
5. technological parameters in agriculture.

Other structural parameters:

1. between country income distribution
2. consumption patterns by income class

Weather induced variations in yields are exogenously imposed, assuming a constant weather pattern. The disturbance factor is region-specific, with a 7 year cycle replicating observed fluctuations in the period 1966-1972.

In specifying the structure of centrally planned economies, MOIRA presumes production targets are set to reflect consumption needs of the desired income level. As long as the implied agricultural growth rate does not exceed 4%, the only shortfalls are due to weather variation. Therefore centrally-planned economies are assumed to be self-sufficient as a group.

MOIRA is driven by 3 exogenous variables: country-specific population growth and non-agricultural GDP growth, summarized in Table 2.3 and regional fertilizer prices. Growth of non-agricultural GDP is the most important exogenous variable: it determines non-agricultural income and hence directly influences food consumption, migration, and government price policy. This variable is derived from published country-specific overall GDP growth rates which were subjectively revised. The revision takes into account the country's wealth and size of the agricultural sector.

Table 2.3 Exogenous assumptions in MOIRA

	World	Rich countries	Poor countries	
Population				
average annual growth %		0.7	2.2	
2010 total (10e9)	7.3	1.5	5.8	
		Developed market econ	Developing market econ	CPE
Non-agric GDP average growth %				
1975-85	5.0	4.5	7.6	6.5
1985-95	4.8	4.2	7.1	6.4
1995-05	4.5	3.8	6.8	5.8

Source: Table 8.2 (p.245) and Table 8.5 (p.247), Linnemann et al., (1979)
Note: CPE = Centrally Planned Economies

2.3.1.4. Results

The food potential model estimates a physical limit of production equivalent to 30 times the 1965 volume. While noting that the "ecological implications of such a massive expansion of agricultural production remain rather uncertain", the authors conclude "at least in the coming decades- world food supply need not be endangered by upper limits set by mother nature" (Linneman et al., 1979:8).

Nevertheless MOIRA shows that continuation of present trends will increase world hunger threefold between 1975 and 2010 despite a threefold increase in world production. Tropical Africa and Southern Asia remain the major food-deficit regions. Trends are toward decreased self-sufficiency among the developing nations and increased importance of North America as an exporter of basic foods.

MOIRA simulates two types of policy measures to reduce world hunger and malnutrition:

(1) redistribution of available food,

(2) stimulation of food production in the developing countries.

Results of the policy simulation runs are summarized below:

Type	*Policy*	*Outcome*
1	Reduction of food consumption by the rich	Lower food prices, decreased incentives to agricultural production, and increased total world hunger.
2	Liberalization of international trade	
1	Food aid and distribution to underfed groups	Eliminates hunger if food is purchased at market prices and given away.
2	Stabilization of inter-national food prices	Stimulates production in poor countries, reduces world hunger but increases food deficit in urban areas.

2.3.2. Evaluation

2.3.2.1. Sensitivity analysis

A series of sensitivity runs were made with MOIRA. Each of them was based on the assumption of a 50% reduction in a specific exogenous variable or parameter. Reduction of the non-agricultural economic growth rate causes much lower market prices in the agricultural sector and increases world hunger by 35%. Reduction of the population growth rate results in a decrease of world hunger by 30%. Gradual reduction of income inequality outside agriculture reduces hunger by 50%. However, the impact of reduced inequality in the agricultural sector cannot be examined in this model.

The authors conclude that "all simulation runs with alternative assumptions regarding exogenous variables have one thing in common: if policies remain unchanged, the number of people who cannot obtain sufficient food will increase" (Linneman et al., 1979:303).

No sensitivity analysis was carried out for the food production model.

2.3.2.2. Structural analysis

The distributional features in MOIRA are static: they remain fixed at the 1965 proportions. This precludes any change in relative income distribution which could be interpreted as social development. MOIRA is very sensitive to the fixed disparity ratio because it is the target of government policy and plays a significant role in determining domestic prices and consequent production incentives.

Sectoral income disparity is the outcome of market and political forces in which the political forces are considered to be predominant. Recognition of this is realistic and MOIRA's use of the disparity ratio to capture the role of government policy in the agriculture sector is elegant. Each country is constrained to achieving its 1965 disparity ratios by interfering with domestic price levels within a country-specific budget constraint. However maintaining a fixed disparity ratio implies:

(a) the 1965 level was politically optimal; and,

(b) no change occurs in the relative power of the agricultural and non-agricultural sectors of the society.

The authors include their own evaluation of MOIRA's limitations and weaknesses as a model. Points of relevance to development-environment studies include:

1. Neglect of interactions between: (a) environment and agricultural development, (b) economic development and income distribution (which may influence agricultural development strategies) and (c) demographic development and the food situation.
2. Lack of differentiation of agricultural products.
3. Weak empirical basis and artificial modeling dynamics (the centrally planned economies were presumed to be self sufficient and were excluded from the world food system).

2.3.2.3. Sources of surprise to MOIRA

(1) Major shifts in the relative power or income distribution of countries over time would change the disparity ratio and hence the target of government price policy. In principle this can be considered in MOIRA by altering structural constraints.

(2) Widespread adoption of aquaculture or other less conventional food sources would affect the demand for agricultural production.

(3) A change in the proportion of non-food agricultural production due for instance to increased production of non-food export crops or energy crops.

(4) Restriction of world trade which would force countries to adopt a self sufficiency policy both in food and energy. The world market would no longer balance supply and demand.

(5) Crop failures arising from events which did not occur in the 1965 to 1972 years, such as prolonged drought in the Northern Hemisphere.

(6) Increased participation by the centrally-planned economies in world food trade.

(7) Change relative productivity in the long run due to climatic shifts.

2.3.2.4. Relevance to long-term, large-scale environmental studies

MOIRA does not directly address the pressure that agriculture exerts on the environment. Most of the environmental characteristics in MOIRA are treated as static resources after an initial quantitative assessment. However MOIRA can shed some light on the conflicts. Taken in conjunction with other land base data the study can be used to identify potential levels of erosion and contamination. Consider a region where MOIRA indicates there is rural hunger and a land study shows marginal land available. We can assume that land will be used and probably degraded. For instance if high levels of hunger prevail in the agricultural sector of arid countries it can be concluded that desertification is advancing rapidly.

For the purposes of development-environment studies MOIRA has 6 main drawbacks:

(1) the time horizon is only 2010;

(2) it takes no account of environmental/ecological consequences, constraints, and feedbacks including degradation, hazards of monoculture and urban encroachment on arable land;

(3) it takes no account of energy as an input into agriculture;

(4) it does not distinguish between intensive and extensive uses of land as a means to increase agricultural production;

(5) non-food agricultural production is treated as a fixed fraction of total agricultural output; and

(6) fish production is treated as a constant, no allowance is made for a contribution from fish farming (aquaculture).

Despite these flaws, MOIRA also has a number of contributions and insights to make to studies of development-environment interactions. Possibly of more use than the reported model results, is the information that can be gleaned from incidental calculations or by inference when compared to other models or the real world:

(1) The relative inherent productivity of regions is derived by comparing the broad soil regions. This is a more useful result than the absolute numbers of land availability and food production.

(2) Soil specific development costs are given in Table 2.4 and column 7 of Table A2 (Linnemann et al., 1979:25-26). Less than 1/3 of the potentially arable land can be developed at less than average cost. Most of this land is in Africa and Asia. This suggests that the enormous potential production envisaged from Latin America can only be obtained at very high development costs or alternatively high degradation if the requisite conservation investments are not made.

(3) MOIRA stresses the importance of social and political factors in shaping development of the agricultural sector. Income levels are particularly important both in determining consumption and as targets for government policies.

2.3.3. Data sources

1. Soils:
   FAO/UNESCO (1974) Soil Map of the World, 1:5,000,000.
   Stace, H. (1968). A Handbook of Australian Soil. Glenside.
   Dudal, R., R. Tavernier and D. Osmond (1966). Soil Map of Europe. FAO:Rome.

2. Irrigation:
   Moen, H.J. and K.J. Beek, (1974), Literature study on the potential
   irrigated acreage in the world. I.L.R.I., Wageningen.

3. Photosynthesis:
   Wit, C.T. de, (1965), Photosynthesis of leaf canopies.
   Agr. Res. Rep. 663, Wageningen.

4. Population:
   Projections are from K.C. Zachariah and R. Cica, Population Projections

for Bank Member Countries 1970-2000 (World Bank, Development Economic Department, Population and Human Resources Division). The fast fertility decline variant was used in the standard run of MOIRA.

5. Economic Growth Rates:
   Assumed economic growth rates are based on projections of total GDP derived from UN and World Bank reports. (W.Leontief, "Impact of Prospective Environmental Issues and Policies in the International Development Strategy" and IBRD, "Additional External Capital Requirements for Developing Countries").
   These provide 10-yearly overall GDP growth rates for 15 regions of the world with 3 variants based on different assumptions with respect to capacity and speed of adjustment of developing countries to new relations.

2.4. Global 2000

Council on Environmental Quality and Department of State. 1980. Global 2000 Report to the President: Entering the Twenty-first Century. Washington, D. C.: U. S. Government Printing Office. (Three Volumes.)

2.4.1. Description

Global 2000 was commissioned by the President of the U. S. to study the long-term implications of present policies, to establish a foundation for future planning, and to assess the current analytic capability of the U.S. government.

Global 2000 projects trends to A. D. 2000 for population, GNP, climate, technology, food and agriculture, fisheries, forestry, water, energy, fuel minerals, and non-fuel minerals. Experts then assess the impacts on the environment of these projections. The environmental impacts of each of the above projections is considered in turn, forming a significant part of the study (Vol. 2, Chapter 13). Finally, the results are compared with those of other global models.

For the purposes of the Agriculture group of the Biosphere project, we have concentrated on examining the food and agriculture projections (Vol. 2, Chapter 6) and the associated environmental implications (Vol. 2, pp. 272-297). The basis of the food and agriculture results is the USDA's Grain-Oil-Livestock (GOL) model, which is discussed in depth in Vol. 2, pp. 545-561. GOL is a static equilibrium model. Results generated by the GOL model use projections from other models for conditions in non-agricultural sectors.

2.4.1.1. Scale and resolution

The Technical Report (Vol. 2: 455-6) discusses the scope of the research. The study considers the time period between 1975 and 2000. Food and agriculture projections are made for two points in time, 1985 and 2000. No estimations are available for intervening years. The study is global in scope, with a strong U. S. bias. This bias arises because the submodels used are agency models that were designed to assess impacts on the U. S.

GOL uses region-specific models to estimate arable area, fertilizer use, and total food production and consumption. Output is reported for the regions and for assorted groupings (e.g. exporters, industrialized, centrally-planned, LDC's).

2.4.1.2. Approach

Global 2000 relied on various models that are used by different U. S. government agencies for their long-range forecasting. First, population and economic growth were forecast. These projections were used to determine demands for natural resources. These demands plus the direct effects of population and economic development were then used to calculate environmental effects. The process was not iterative, so the environmental effects did not influence population, the economy, nor the use of natural resources.

The goal of the study is to determine the outcomes of present policies if these policies were to continue unchanged for twenty years (except population growth, which is assumed to slow due to of increased population control). Global 2000 assumes no innovative strategies for meeting the problems that it projects nor is there feedback from the problems to policy mechanisms.

The GOL model and methodology are discussed in Vol. 2 of the report (pp. 73-74). It is a conglomeration of 28 regional agricultural sector models. The 930 econometric equations describe grain, oilseed, and livestock demand, supply, and trade. The GOL model does not explicitly consider environmental issues, although they are discussed in the report.

2.4.1.3. Assumptions

One of the greatest strengths of the Global 2000 report is its explicitness about its assumptions and its frankness about the limitations implied by them. To some extent these assumptions are presented along with the descriptions of the models. However, because Global 2000 is a collection of agency models, one needs a clear statement of the assumptions embodied in these models. Table 14-2 (Vol.2:470-5) lists some of the assumptions that were used in each of the submodels and cross-references them.

Many overriding assumptions were imposed upon the agency models to give them consistency. Among them: (1) There will be no change in public policy, except for increased population control. (2) The rate of technological growth will be linear, with no major breakthroughs and no serious setbacks. (3) There will not be any social opposition to new technologies. (4) Trade will continue under present arrangements, with no disruptions. (5) Climate will be similar to that of the past few decades. (6) Price will reduce demand when supply constraints are encountered. The assumptions of the GOL model (listed on Vol. 2, pp. 547) are consistent with those listed above.

2.4.1.4. Results

According to the study's projections, the world in A.D. 2000 will have 6.35 billion people, with population growing at 1.77 % per year. Per capita income will be rising at 1.53 % per year. However, this global aggregation hides the fact that the gap between the rich and poor nations will increase.

Global 2000 projects a 90% increase in food production occurring between 1970 and 2000. This will mean a per capita increase of 15%. Intensification of agriculture (i.e. higher inputs of fertilizer, pesticides, irrigation, and mechanization) will account for most of the growth in production, although in the developing world, much of the increase will come from cultivating more land. For example arable land will expand only 4% globally but will increase by 21% in Latin America.

Table 2.4 lists the population and per capita income growth rates that were used to drive the GOL model, along with rates of fertilizer use, amount of arable land and yield variations. These are given for Western industrialized nations and centrally planned countries, LDC's, and for the world. For the same four groups Figures 2.10 through 2.13 show the projected growth in food production.

Table 2.4 Input and projections of the GOL model.

Regions	Industrialized		Centrally planned		LDC's		World	
Year	1975	2000	1975	2000	1975	2000	1975	2000
Population growth (%/yr) (V.2:78)								
Alt. I	0.57	0.52	1.25	1.21	2.50	2.37	1.79	1.77
II	0.48	0.34	0.99	0.94	2.36	2.04	1.63	1.48
III	0.67	0.71	1.45	1.43	2.66	2.71	1.95	2.05
Per cap income growth (%/yr) (V.2:78)								
Alt. I	3.41*	2.57#	2.35	2.20	2.54	2.01	2.26	1.53
II	4.40	3.35	3.22	3.15	3.52	3.00	3.23	2.42
III	2.41	1.77	1.50	1.25	1.55	1.03	1.29	0.66
Fertilizer (thousand metric tons N, P2O5,K2O as 2:1:1) (V.2:100)	39900	84000	28125	77500	11925	58750	79950	220250
Fertilizer kg / arable ha (V.2:101)	100	210	70	185	20	80	55	145
Arable area (million ha) (V.2:97)	400.3	399.1	414.5	420.0	662.0	723.5	1476.8	1538.6
Yield variations due to climate (%) (V.2:79)								
Aggregate of regional variations weighted by production							7.20	7.20
Calculated using world yield series							3.00	3.00

*,# Per capita income growth rates are given for the periods 1975-1985 (*) and 1985-2000 (#).

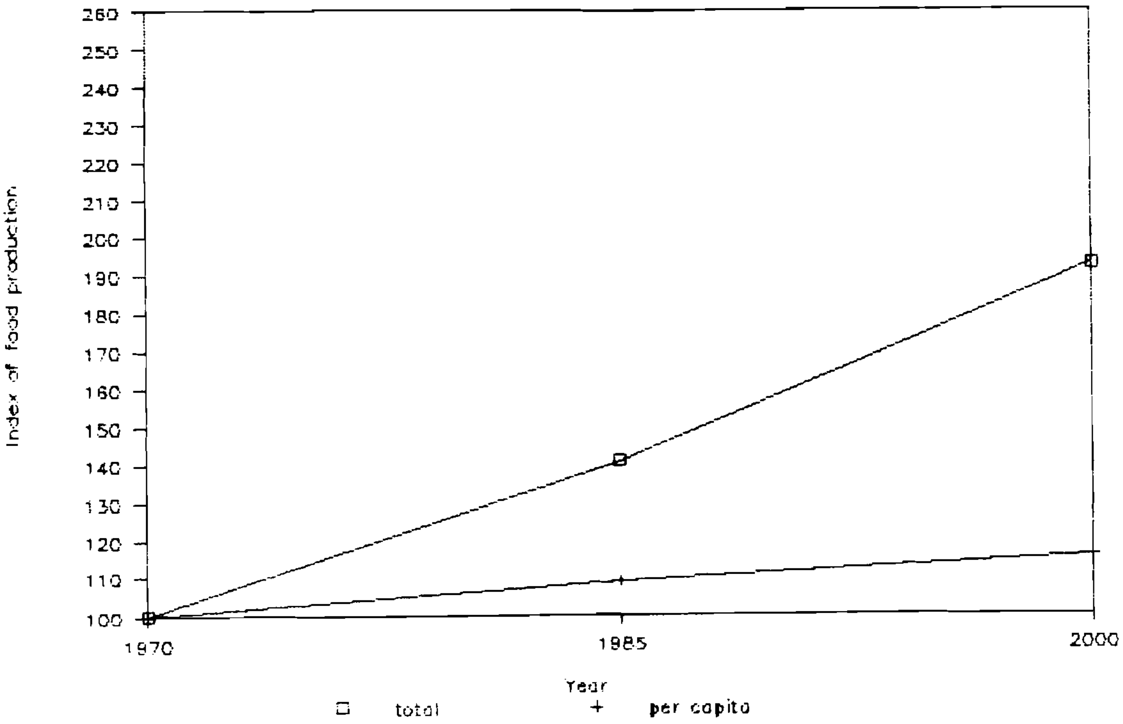


Figure 2.10 World food production
(Source: Tables 6-7, 6-8, CEQ, Vol.2:91-94)

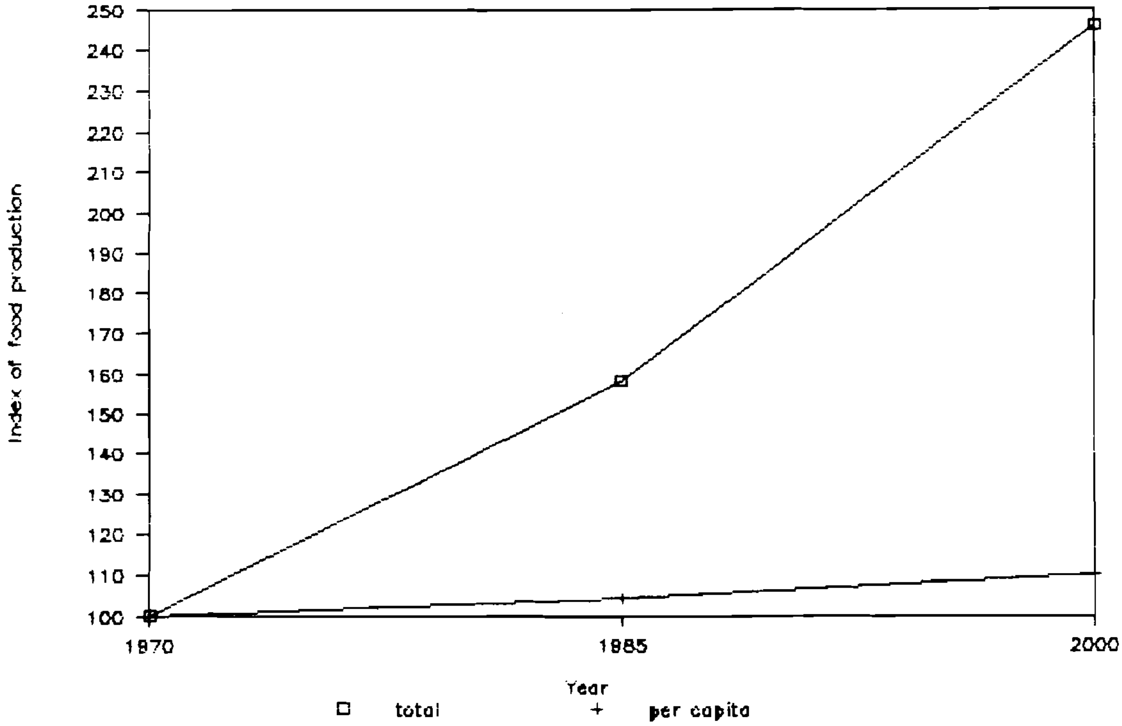


Figure 2.11 Food production in LDCs
(Source: Tables 6-7, 6-8, CEQ, Vol.2:91-94)

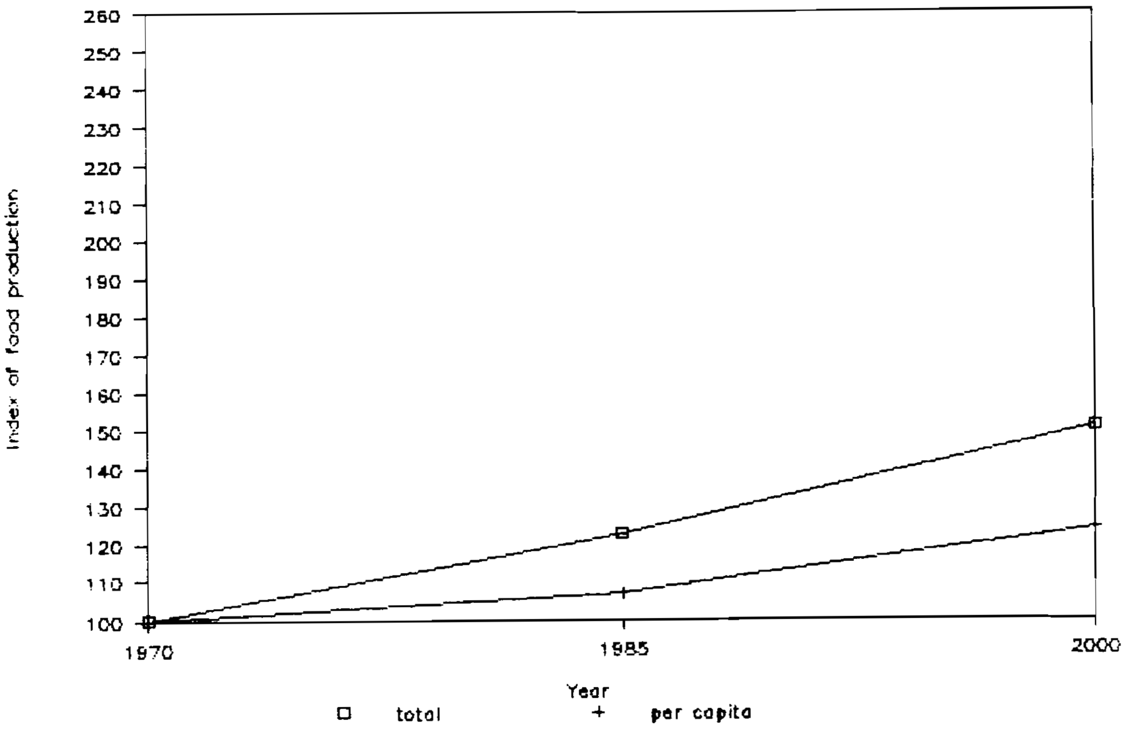


Figure 2.12 Food production in western industrialized countries
(Source: Tables 6-7, 6-8, CEQ, Vol.2:91-94)

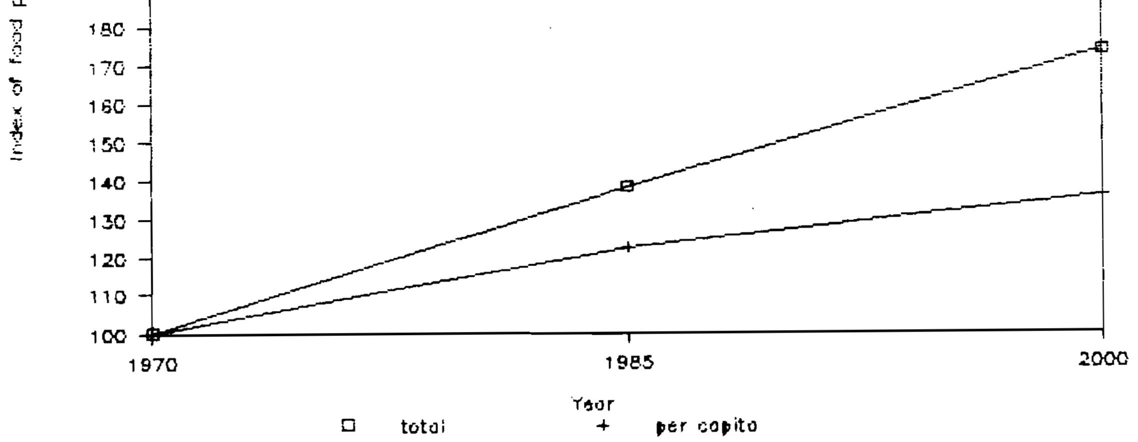


Figure 2.13 Food production in centrally planned economies
(Source: Tables 6-7, 6-8, CEQ, Vol.2:91-94)

Population growth alone will double water demand. Expanded agricultural and non-agricultural consumption will lead to regional water shortages.

Forests, mostly tropical, will be lost at the rate of 18-20 million hectares per year. This means that the LDC's will lose 40% of their present forests. Needs for fuelwood will exceed supplies by 25%, and stocks of commercial timber will decline 50% per capita. With forest clearing we will lose up to 20% of extant species.

Table 2.5 Key assumptions of the three alternative scenarios in Global 2000. (Source: CEQ, 1980:Vol.2:77)

	Scenarios			
Parameters	I:A	I:B	II	III
Population growth (%/year)	1.8	1.8	1.5	2.1
Per capita income growth (%/year)	1.5	1.5	2.4	0.7
Petroleum prices	Constant (1974-76 level)	Double by 2000	Constant	Double
Weather	Variation in yields comparable to last 25 years.		Good weather raises yield 1 S.E. above 1950-75 yield series	Bad weather minus 1 S.E.
Growth in yields	For all scenarios, the trend of the last 20 years is projected to continue, but yields are raised or lowered by weather and by the producer prices that are generated under each scenario.			

2.4.2. Evaluation

2.4.2.1. Classical sensitivity analysis

The GOL model considers four scenarios. Key assumptions of the scenarios are summarized in Table 2.5. Alternative I uses median projections for population and per capita income growth rates. Yields increase at rates consistent with the technological advances of the previous 20 years. Climate is comparable to the previous 25 years. Trade arrangements do not change. There are two versions of Alternative I. First, constant energy prices are assumed (1974-76 levels). In the second version these prices double by year 2000.

Alternative II, the optimistic run, uses lower population and higher income growth rates, favorable climatic conditions and constant energy prices. Alternative III is the pessimistic forecast. The direction of the variables is the reverse of Alternative II.

The differences between the results of the alternative scenarios are not large, that is, the model is not very sensitive to the relatively small changes in parameters of the four scenarios.

Results of the four runs are presented in tables (Tables 6-7 to 6-11, pp. 91-96 of Vol. 2). Figures 2.10 to 2.13 show the increase in food production over time for the world, LDC's, centrally-planned and western industrialized countries.

It is useful to examine the sensitivity of the model to the complete set of variables to establish upper and lower boundaries of estimates. However it is impossible to discern the sensitivity of the GOL model to variables individually.

2.4.2.2. Structural analysis

The key assumption of the study, that is no change in public policy, although useful for the study's purposes, is not realistic. In view of the large number of undesirable consequences that are forecast, policies will change. However, it is beyond the scope of the study to assess the effects of potential policy shifts.

The main structural problem is that the agency models are only weakly connected and all links are unidirectional. Projections from population and income models drive demand, which causes environmental impacts. This structural weakness causes several major problems. There is no feedback, for example, between environmental components and income growth. Also, there is no way to deal with competing demands on the same natural and economic resources. Agriculture and energy production for example are assumed to use the same fixed stock of water.

Despite attempts to achieve consistency between models, there are many discrepancies. Submodels use different patterns of regionalization with between 5 and 28 regions in the world. There are also inconsistencies in the values assigned to the same variables (OTA, 1982).

2.4.2.3. Sources of surprise

There are many ways of introducing surprises into the study. The researchers were aware of this and discuss it in a separate section along with reviewers' comments. A list of surprises is presented in Vol.2, p.715. Some surprises could be incorporated in Global 2000 by adding feedback effects on natural resources. For instance, available arable land could be assumed to decrease due to land depletion and pollution of aquifers in irrigated areas (water withdrawals for energy development would have the same effect). Another approach would be to violate the assumptions of the study where they are untenable. Given the rising disparity between rich and poor countries, crowding, scarcity of resources, and increases in the real price of food, the assumption that there would not be any major wars could easily be violated.

2.4.2.4. Relevance to long-term, large-scale environmental studies

The greatest contribution that Global 2000 can make to studies of development-environment interactions is its detailed projections of environmental impacts. More than 200 pages of the report were devoted to these issues. Limiting the study's usefulness to long-term studies are the short time horizon and the structural problems.

2.4.2.5. Ease of use

Results of the study are presented in a very useful format. The Summary volume presents a concise overview of all aspects of the study. In Volume 2, the data, both input parameters and results, are presented in tables and graphs. These are straightforward and clear.

On the negative side, the sheer bulk makes working through the study difficult; it takes time to "get to know one's way around." Compounding the problem, the index is mediocre.

Finally there is no model for a person to use. That is, there is no software. All the various agency models were used and coordinated by a large research team which has disbanded.

2.4.3. Other relevant studies

Global Models, World Futures, and Public Policy: a Critique (O.T.A. 1982: 34-39). - offers a concise review.

2.5. Food and Agricultural Program (FAP), IIASA

Parikh, K. S. 1981. Exploring national food policies in an international setting. Publication number WP-81-12. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Food and Agricultural Program. 1985. A background note for the task force meeting on economic strategies: hunger, equity and growth. Manuscript. International Institute for Applied Systems Analysis, Laxenburg, Austria.

2.5.1. Description

The Food and Agricultural Program (FAP) of the International Institute for Applied Systems Analysis (IIASA) had three broad objectives (Parikh, 1981):

(1) to evaluate the nature and dimensions of the world food situation,

(2) to identify the underlying factors, and

(3) to suggest policy alternatives at national, regional and global levels.

These objectives were supplemented with the qualification that the solutions to the problems should be consistent with paths leading to a sustainable, equitable and resilient world. In order to accomplish these objectives, two models have been developed. One is a world food policy simulation model dubbed as Basic Linked System (BLS). The second is a technological transformation (TT) model.

2.5.1.1. Approach

The BLS model consists of 18 country models, 2 country-group models (EC and CMEA) and 14 regional group models linked together in trade, aid and capital flows in a general equilibrium framework. This model shows how various economic agents adjust their behavior in response to policies in a relatively short run and what are the longer-term dynamic consequences (FAP, 1985). The policies include domestic price policies, quantity rationing, trade restrictions, strategic reserves, normative consumption and import policies, plan target realization and self-sufficiency policies as well as free market policies. The basic frameworks for national and international models are presented in Figure 2.14 and Figure 2.15, respectively. Figure 2.16 shows the computation of a domestic equilibrium. This model provides us with descriptive rather than normative future scenarios with alternative policy strategies applicable to different kinds of economies, planned as well as market, in the international space.

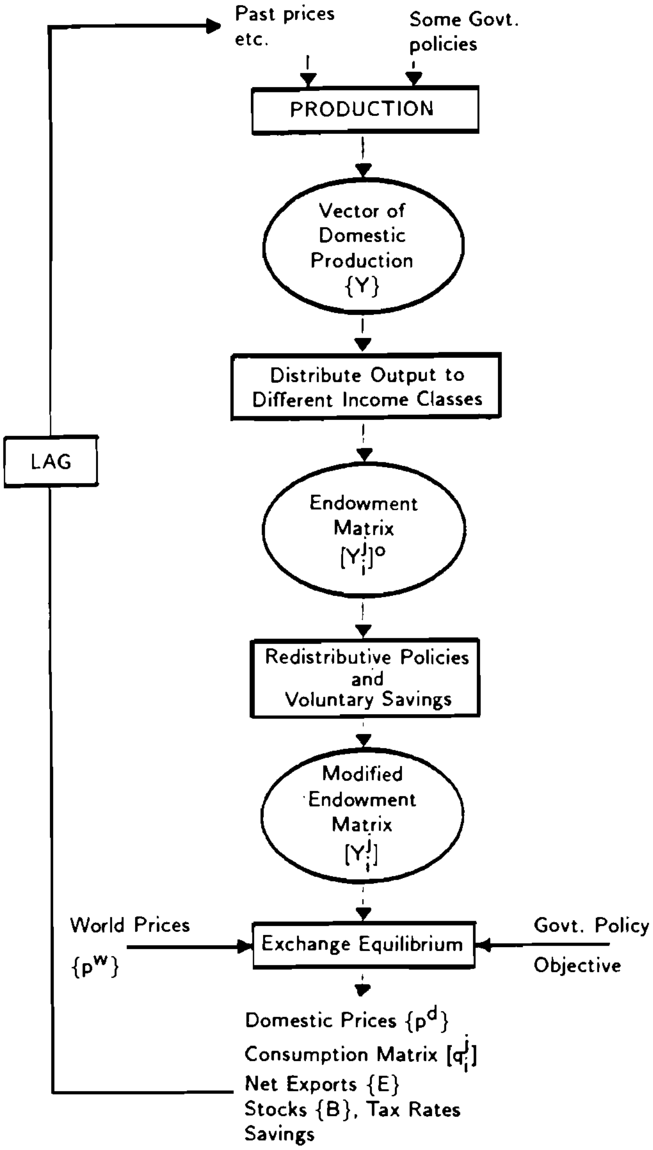


Figure 2.14 A typical national model
(Source: Parikh, 1981:22)

The TT model is a recursive linear programming model which deals with the future technological transformation of agriculture constrained by resource availabilities and serious environmental consequences. The conceptual framework is shown in Figure 2.17. Based on this framework regional case studies have been conducted in seven different countries: CSSR, USSR, U.S.A., Japan, Italy, Hungary and Bangladesh. This model is useful for short-term regional analyses rather than national or international analyses in a

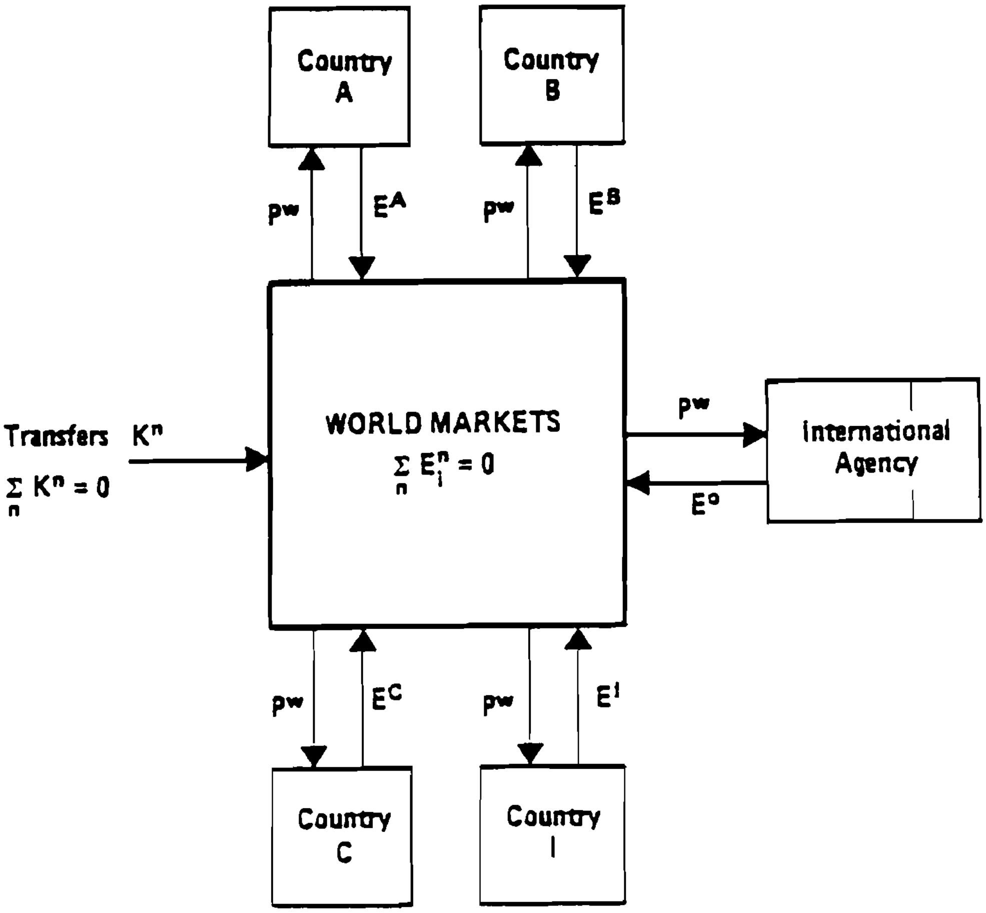


Figure 2.15 International linkage (Source: Parikh, 1981:25)

relatively long run. Some conceptual frameworks for different environmental issues have been developed through these regional studies. These cover water pollution problems in Japan and Czechoslovakia, soil erosion in Iowa, U.S.A., soil compaction and energy use in Hungary, and energy use and biomass depletion in Bangladesh.

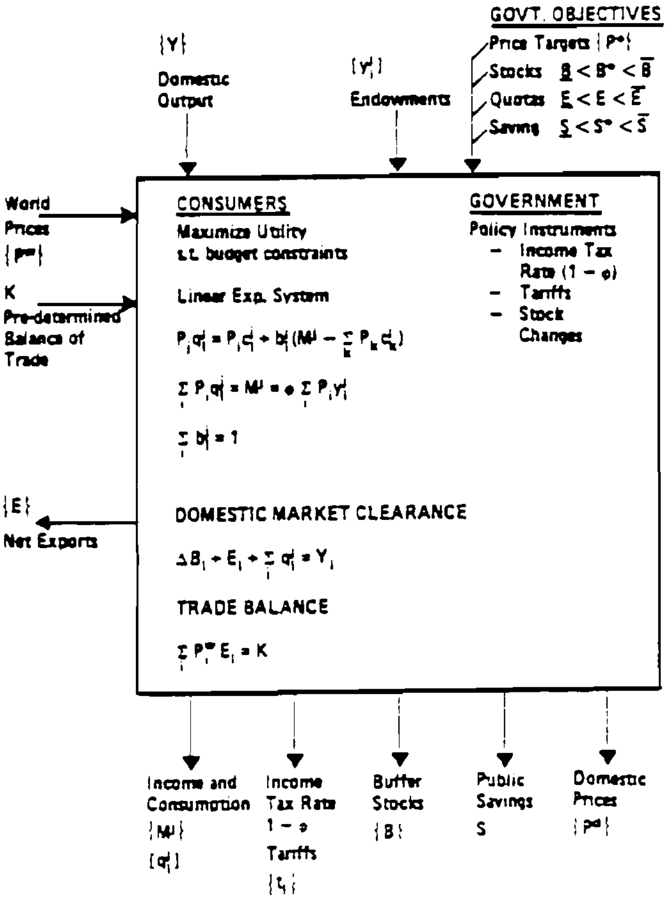
2.5.1.2. Key assumptions

The following are some assumptions of the BLS model. They are taken from the Canadian country model (Hassan and Huff, 1985) which is typical of the country models.

(1) Expected prices are based upon the current target price and lagged prices.

(2) The land input is treated as a simple time trend. Thus, the amount of available land increases in most regions over time.

(3) Labor input to agriculture is estimated by a migration function driven by the per capita income disparity between agriculture and non-agriculture. The total labor force is obtained by multiplying population by the participation rate.



Notes

Exchange Equilibrium

Given	World Prices Endowments (Note no production during exchange)
Consumers	maximize their utilities subject to their Budget constraint
Markets	are cleared as affected by Govt. actions
Govt.	try to affect the outcome Tax Rates affect Consumers Budget/Savings Tariff Rates affect Domestic Prices Quotas affect Size of Trade and hence Domestic Availability Stocks Policy affect Domestic Availability and hence Prices

Figure 2.16 Computation of domestic equilibrium
(Source: Parikh, 1981:24)

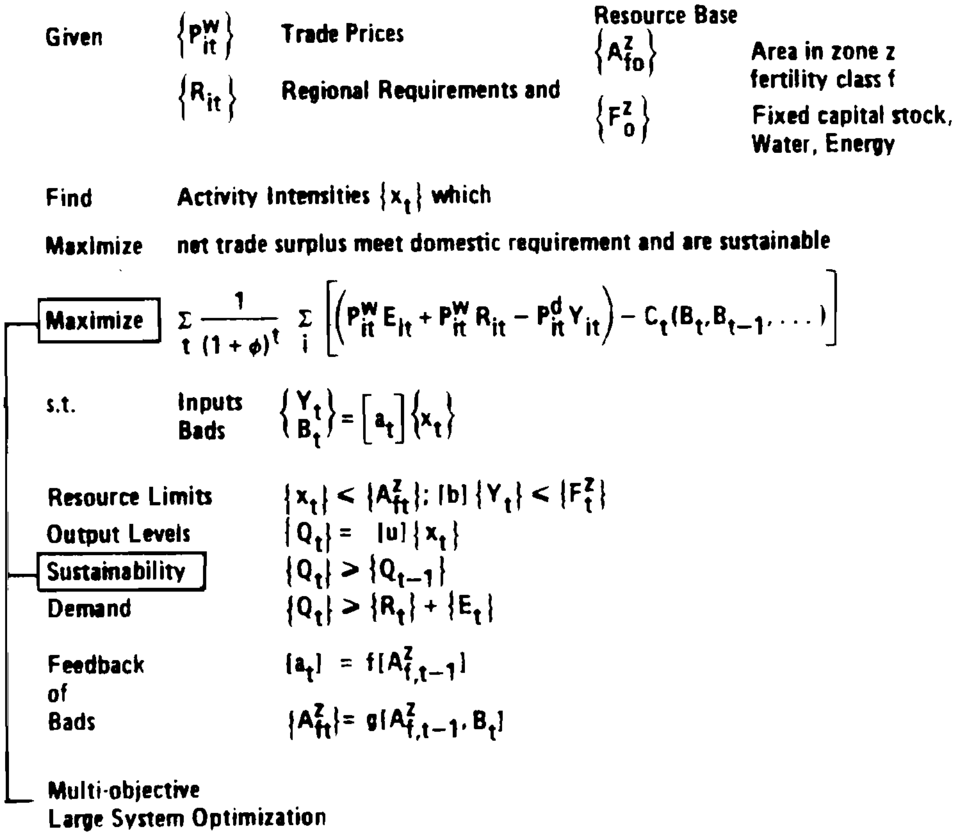


Figure 2.17 Technological transformation of agriculture: analytical framework concept (Source: Parikh, 1983:4)

(4) The level of fertilizer application is a function of expected crop prices, fertilizer price and technology.

(5) Technological progress is introduced in a mechanization function both through embodied capital stocks and by a time variable.

2.5.1.3. Results

Future production levels are the most important FAP outputs for environmental studies. Projections of world agricultural production up to the year 2000 are obtained from the BLS model based upon the assumption of no new government intervention in the world economy (see Figure 2.18 and 2.19). No substantial changes in the policies were assumed for this " reference run " scenario. Table 2.6 shows the assumptions on population and GNP used in the production estimations. Some production and calorie consumption results are presented in Table 2.7.

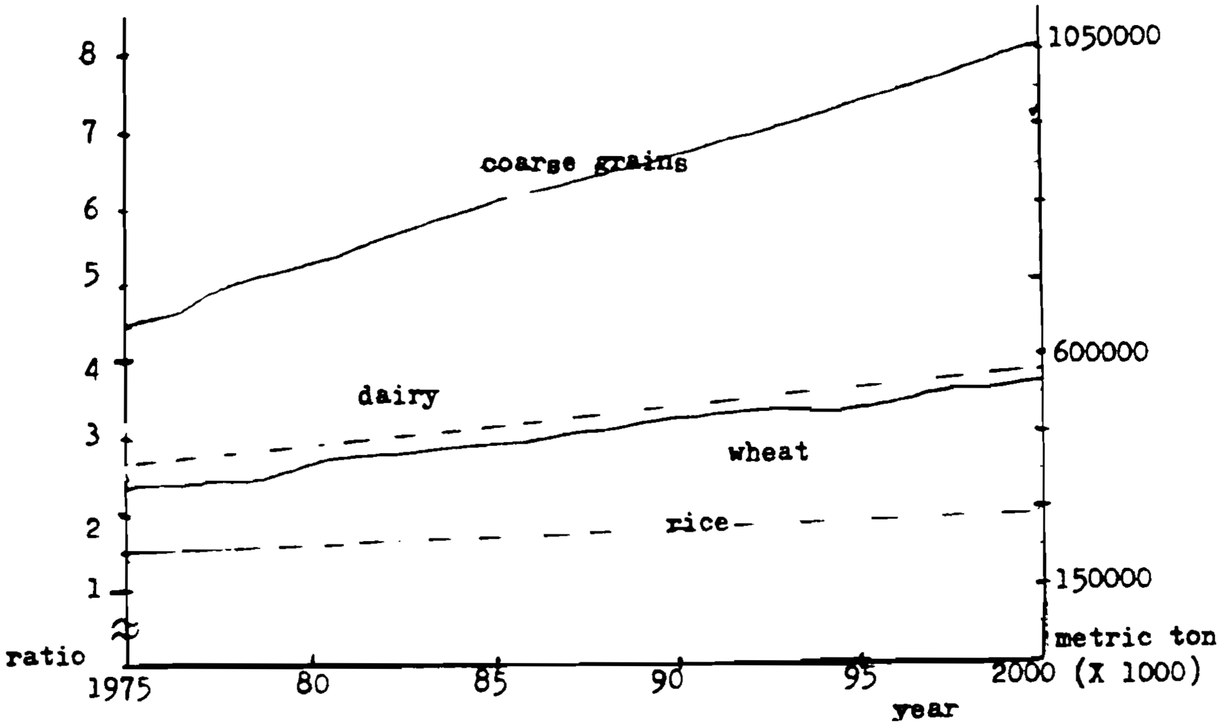


Figure 2.18 World agricultural production
(Source: Unpublished computer output, IIASA, 1985)

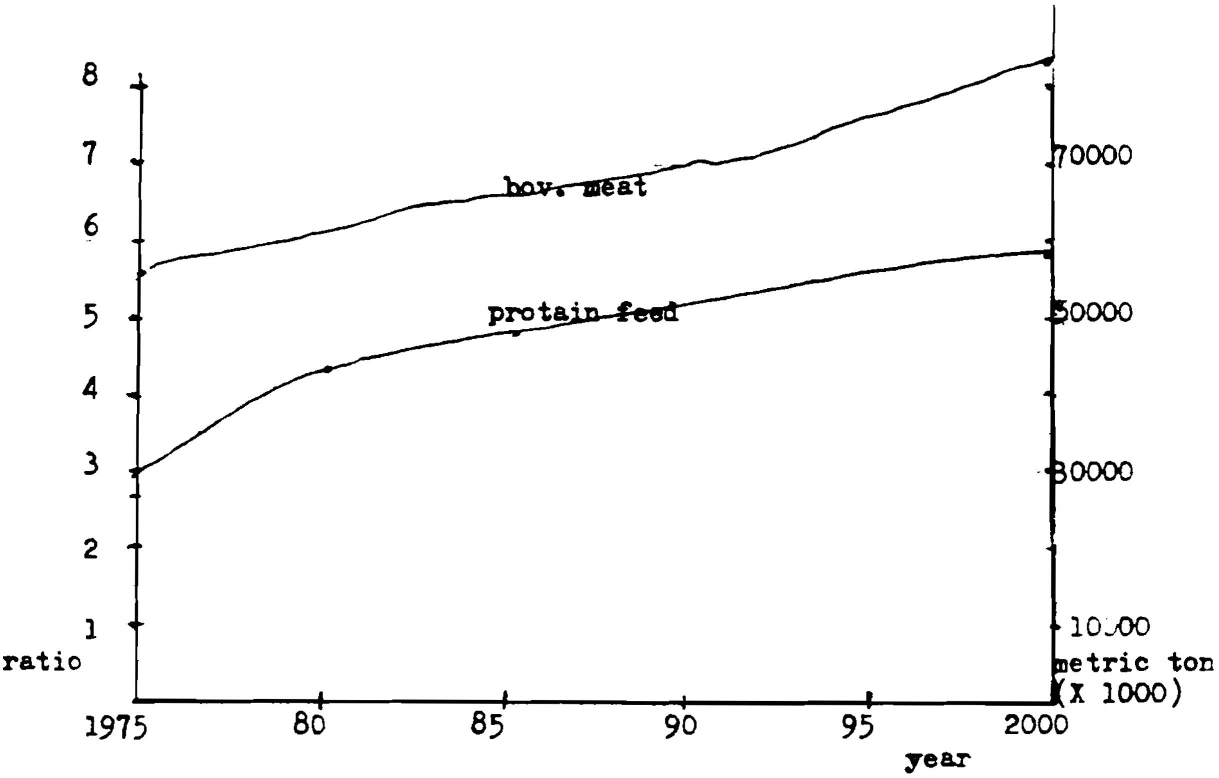


Figure 2.19 World agricultural production
(Source: Unpublished computer output, IIASA, 1985)

Table 2.6 Assumptions on population and GDP

	1980	1985	1990	1995	2000
Population					
Absolute values: (10e9)					
World	4.3	4.8	5.2	5.6	6.2
OECD	0.65	0.67	0.70	0.73	0.75
LDC(w/o China)	2.2	2.5	2.8	3.2	3.5
Factor increases: (base year 1980)					
World	1	1.12	1.21	1.30	1.44
OECD	1	1.03	1.08	1.12	1.15
LDC(w/o China)	1	1.14	1.27	1.45	1.59
GDP					
Absolute values: (10e12, US dollar 1970)					
World	5.1	6.3	7.6	9.1	11.0
OECD	2.6	3.2	3.8	4.4	5.1
LDC(w/o China)	0.61	0.78	1.0	1.4	1.8
Factor increases: (base year 1980)					
World	1	1.24	1.50	1.78	2.16
OECD	1	1.24	1.46	1.69	1.96
LDC(w/o China)	1	1.25	1.64	2.30	2.95

Source: Unpublished computer output, IIASA, September 1985

2.5.2. Evaluation

2.5.2.1. Classical sensitivity analysis

The BLS model is sensitive to future population and GDP levels (especially capital available for investments) when they are used to make projections. The population level and its sectoral allocation is an important determining factor of labor input in the production system. Population also affects the level of income per capita which is an important factor in the demand system.

GDP, together with savings and capital imports, influences the level of capital stock in production. GDP also plays a very crucial role in the demand system. Therefore, the levels of these variables have significant effects on the consequences of the study.

2.5.2.2. Structural analysis

The structure of the BLS model makes it one of the more realistic policy analysis models now available. It is a general equilibrium model which is capable of year by year simulation. Any policy change intervening in one sector of the system will not only directly affect that sector but also the rest of the system. The model is capable of measuring both effects. For example, the effect of a government policy decreasing soybean

Table 2.7 Gross agricultural production and daily calorie consumption per capita

Gross agricultural production

	1980	1985	1990	1995	2000
Absolute values:					
(10e9 US dollar 1970)					
World	390	435	485	537	593
OECD	114	125	135	142	150
LDC(w/o China)	138	161	188	221	258
Factor increases:					
(base year 1980)					
World	1	1.11	1.24	1.38	1.52
OECD	1	1.10	1.18	1.25	1.31
LDC(w/o China)	1	1.17	1.36	1.60	1.87

Daily calorie consumption per capita

	1975	1980	1985	1990	1995	2000
Absolute values:						
(Kcal/capita/day)						
OECD	3124	3184	3242	3288	3330	3369
LDC(w/o China)	2263	2336	2411	2489	2574	2664
Factor increases:						
(base year 1975)						
OECD	1	1.02	1.04	1.03	1.07	1.08
LDC(w/o China)	1	1.03	1.07	1.06	1.10	1.18

Source: Unpublished computer output, IIASA, September 1985 Note: The number for daily calorie consumption per capita in 1975 was calculated based upon the future predictions.

production in Brazil on the income of wheat producers in the U.S. can be estimated.

Another advantage of this model is that prices are considered as endogenous variables. Input substitution resulting from changing relative input prices (reflecting scarcity of the resources) can be explained. The effect is captured when future input allocations are estimated. Future scarcity of energy input might lead to the substitution of other inputs for energy. Input estimates enable us in turn to determine the future output levels. They also allow a separation of the effects of changes in relative input prices and of technical change on input substitution.

The TT model, being recursive is useful when a long-term effect is of interest. However, this model can only be used in regional analyses.

Available land is treated as a time trend function in the BLS model. This might be acceptable for a short run analysis. For a long run analysis, a future constraint on land expansion was implicitly considered. Land is also treated as a homogeneous factor. No allowance was made for differing soil types and/or climatic conditions. This is not a realistic assumption but was needed to keep the model simple.

2.5.2.3. Relevance to long-term, large-scale environmental studies

BLS mainly deals with development characteristics while TT focuses on environmental characteristics. TT was developed mainly to consider the environmental issues which cannot be captured well by BLS and thus does not examine development characteristics. The relevance of the models to the identified characteristics is examined below:

Development Characteristics

(1) Wealth: The national and sectoral (agricultural and non- agricultural) income levels can be explicitly obtained from BLS. GDP per capita can be also calculated.

(2) Equity: BLS has the capacity to calculate the sectoral distribution of food to different income classes. Education and health are not explicitly considered as indicators.

(3) Nutrition: BLS is capable of estimating the future food consumption by different income classes in calorie and commodity terms.

(4) Self sufficiency: BLS can show the level of self-sufficiency in food. Information on energy use is not explicitly available. Output stability also can be captured by BLS. TT does not deal with this kind of national level indicator.

Environmental Characteristics

(1) Water quality: BLS does not take water quality into account. However, TT is capable of estimating the quality of water used for agriculture. In the Japanese case study (Kitamura et al., 1984), the estimation of the overall material balance of nutrients, nitrogen and phosphorus, is carried out for a small region.

(2) Water availability: The amount of water supplied through irrigation systems could be calculated by using the endowment matrix for some countries e.g. India (FAP, 1985). TT could predict future water availability. An example can be found in the Japanese case study. The future water demand is also calculated in the study.

(3) Land quality: BLS does not give an explicit picture of the future land quality. However, fertilizer use and yield levels for major crops are available as indicators of future land use patterns. TT gives a better description of land quality. A simulation model developed for a case study in the USSR would be a useful vehicle for a land quality analysis of a small region (Hassan and Huff, 1985:63).

(4) Land availability: In BLS, the amount of land available for future agricultural production is calculated by using some functional forms. For example, a simple trend function is used in the Canadian model. In TT the available land is also explicitly estimated.

(5) Air quality: BLS does not take air quality into account. It implicitly assumes that a change in air quality would not be a constraint for agricultural production. In the USSR case study of TT, air temperature is included while relative humidity and wind velocity are noncontrollable factors in the model.

(6) Climate: BLS treats climate as an exogenous factor to the system. The USSR case study of TT considers climatic conditions as noncontrollable factors. No feedback is considered in either framework.

It seems that modification is necessary for BLS to take account of future resource constraints and feedback effects from the environment. This would require a large investment of money and time. With TT, regional environmental studies can be undertaken. A crucial problem would be the aggregation of the results to obtain a global scale picture of environmental change.

2.5.2.4. Ease of use and realism of scenario design

BLS can be used for scenario design if the user is interested in the relationship between economic policy alternatives and their future consequences. However, most of the indicators are related to development characteristics. Very limited attention is given to environmental characteristics. TT can be used for scenario design if one is interested in the future environmental consequences in a small region.

2.6. Resources for the Future (RFF)

Crosson, P. R. and S. Brubaker. 1982. Resource and Environmental Effects of U.S. Agriculture. Research paper from Resources for the Future. Washington, D.C.

2.6.1. Description

2.6.1.1. Scale and resolution

The Crosson and Brubaker study analyzes how agriculture will evolve in the U.S. through the year 2010. Production and environmental effects are analyzed for ten producing regions in the U.S. with attention focused on crop production. Non-U.S. production and consumption through 2010 is also analyzed to establish world demand for U.S. products.

2.6.1.2. Approach

The objective of the RFF study is to determine if long-term trends in U.S. agricultural production will put pressure on the environment and on land and water resources. A number of issues are evaluated in the stages leading up to this analysis. To assess future pressures one needs the levels of resource use and resource availabilities. However resource use depends on choices of inputs which is influenced by agricultural technology and crop yields. Quantities of inputs in turn depend upon output levels which are driven by demand for U.S. agricultural products.

Projections of resource use and environmental effects are derived without the aid of a formal model. Instead, the authors rely on trends in prices, technologies, yields and input use to approximate the evolution of resource use in agriculture. Knowledge of environmental effects based on existing and past usage is then used to estimate the environmental implications of the future use projections.

The authors present only one scenario of growth and distribution of population and income from which agricultural demand is derived. A single scenario is also advanced for agricultural supply. Parameters for this scenario are drawn in part from existing literature with adjustments described by the authors. The single scenario approach is chosen to avoid a "confusing array of projections."

2.6.1.3. Key assumptions and exogenous variables

Each stage of the study's analysis rests upon a number of key assumptions and exogenous variables. Most important for the demand analysis are assumptions about regional population, income growth and demand elasticities. Future trade patterns, exchange rates and national agricultural policies also influence the demand for each region's output. The stage analyzing future production choices relies heavily on projections of future relative prices and availabilities of inputs. For the stage of projecting resource use, assumptions regarding trends in input use and concerning future improvement in input qualities or use techniques are important. For example, fertilization patterns for crops and regions may change over time and there may be discoveries of better fertilizers or application procedures. Finally, the evaluation of future environmental degradation depends upon assumptions about linkages between resource uses and how they affect the environment.

2.6.1.4. Results

The results of the study can be divided into two categories. First are projections regarding resource use and agricultural production. The second category is projections on environmental effects.

Resource and production projections focus on four crop categories which together account for the bulk of resource use and environmental effects in the U.S. These are wheat, feedgrains, soybeans and cotton. Two chapters of the study are devoted to describing how these crops will be produced. Estimates are presented for future yield levels and for technique choices by farmers. Future relative prices of inputs are discussed as the factors determining input mix and productivity.

The study presents estimates of resource use by crop and by region. Resources and inputs are grouped in the broad categories of cropland, fertilizers, insecticides, herbicides and irrigation. Use estimates are derived by combining projections of outputs, techniques and yields with data on availability and use trends of the resources. Land projections are based mostly on demand and supply considerations whereas fertilizer and pesticide projections rely largely on marginal effectiveness of the inputs and on developments in production techniques.

Environmental effects of agriculture are traced in the study from the projected resource uses. Future fertilizer usage is discussed with respect to nitrate levels in drinking water and eutrophication of lakes and ponds. Pesticide use is evaluated in terms of threats to humans from toxins. Projections for future irrigation are linked with both salinity of surface waters and the build up of salts on croplands. Finally, cropland conversion and cropping techniques are discussed in relation to soil erosion. The environmental impacts chapter stresses the high degree of uncertainty in (i) linking resource use causally to environmental degradation, and (ii) limiting the discussion to problems currently identified.

2.6.2. Evaluation

2.6.2.1. Sensitivity analysis

Sensitivity of the results to changes in the assumptions is not directly discernable due to the discursive nature of the presentation. It is difficult for a reader to alter a set of assumptions and trace through the effects. However it is possible to describe the type of effects that would result.

Altering the population, income, income elasticity and production policy assumptions would act to scale the demand for agriculture and the study's results up or down with little effect on the interlinking stages or relationships. A change in agricultural trade patterns however may lead to a major shift in demand and move the U.S. away from export oriented crop production.

A change in assumptions regarding input prices, availabilities or qualities may have a significant effect on resource use and the environment. For example cheaper or better non-land inputs could lead to land intensive expansion of production, a reversal of the extensive mode of expansion described in the study. The resulting new input use rates and techniques would change the scale and nature of environmental effects.

Results of the study are perhaps most sensitive to assumptions regarding linkages between resource use and the environment. New assumptions introducing additional damaging effects or eliminating links could dramatically alter the results. Given the uncertainty about these interactions such new assumptions are not unrealistic. However discoveries revealing major new degradations would probably also alter the control regulations, production technologies and resource use rates.

2.6.2.2. Sources of surprise

We were also interested in the sensitivity of studies to surprises or discontinuities in trends not discernable from current trends. Crosson and Brubaker forecast trends into the future based largely on present trends and current knowledge about possible changes. No attempt is made to incorporate surprise type shocks into their study. Such shocks can be introduced at each stage of the study. On the demand end, changes in consumption habits or a reordering of trade policies and patterns could significantly alter agricultural demand. The next stage's estimates for production techniques and crop yields are extremely sensitive to breakthroughs in technological research. New crop varieties or fertilization techniques could reverse input use and yield trends. These trends also depend on input prices which are projected to increase steadily throughout the thirty year period. Unforeseen scarcities or market interventions can suddenly change these input prices. Production techniques and input use are also sensitive to major pest or disease outbreaks.

Finally, as mentioned earlier, the environmental impacts are derived in the study from currently identified damages. It is possible that present input usage is causing an undiscovered type of damage. Crosson and Brubaker mention this possibility in passing with respect to pesticide effects on soil micro- organisms.

2.6.2.3. Environmental components in the RFF study

Unlike most of the other agricultural studies described in this section the RFF study directly addresses issues of environmental degradation resulting from agricultural development. Environmental quality is approached through projections of both resource use and production technologies. For example water quality is closely related to actual quantities of fertilizers, pesticides and irrigation water used in agriculture. Equally important however is the way these inputs are used including such considerations as use rates per acre and the method and timing of application. By combining estimates of both quantities and techniques for specific crops and regions, the study draws conclusions about possible threats of eutrophication, nitrate levels, toxins, and salinity.

Land quality is addressed principally through the soil erosion issue. As with water quality, erosion possibilities are derived from estimates of both the quantity of land that is cultivated and how that land is used. Salt accumulations with irrigation and possible damages to soil micro-organisms from insecticides are also discussed.

Land and water quantities are not dealt with explicitly but are implicit in the discussion of future relative prices of inputs which in turn determine input use. Scarcities of energy and mineral resources are handled in the same way. Major loss of soil and water resources is not expected in the U.S. by 2010 given projected use rates and production techniques.

Ecosystem quality is handled in part by the water and land quality themes. Attention is drawn to the persistence of chemicals in the ecosystem and the distribution and concentrations of environmental damages.

Indicators of economic development are used as exogenous inputs to the RFF study. Income growth and national self sufficiency enter the study to project world demand and supply which are then used in estimating the demand for U.S. agricultural output. The issues of air quality, climate change, equity, and nutrition are not addressed in the Crosson and Brubaker study.

2.6.2.4. Relevance to long-term, large-scale environmental studies

The study is probably most useful for studies of development-environment interactions in defining an approach to identify agricultural activities relevant to the environment. It focuses not only on what resources are used but also on how and where they are used. This information is critical in evaluating the environmental impacts of agriculture. The interim steps leading to the environmental impact chapter identify the types of questions that must be asked in any environmental study. Of particular value are descriptions of how and why various production techniques and input mixes will be selected by farmers. The regional choices of crops, inputs and techniques are also important. This analytical procedure can be employed by others with interests in different regions or with differing initial assumptions of population, incomes or technical change.

For the immediate purpose of evaluating long-term sustainability of worldwide agricultural development the study leaves many important questions unanswered. Two key limitations are the focus on the United States only and the selection of a single development scenario. One cannot look up or extrapolate for global environmental effects or easily incorporate new scenario assumptions. Instead, the analysis must be repeated.

Also the study does not deal with longer term effects of agriculture on the environment. For instance, levels of contamination that may not pose problems in the year 2010 may accumulate to significant proportions by 2030 or 2040. This may be true for nitrification and eutrophication levels or the effects of organophosphorus pesticides.

Another uncertainty is the long run availability of resource inputs. Crosson and Brubaker find U.S. resources adequate through 2010 but what about sustainability beyond that year given water and land degradation? Also environmental problems elsewhere in the world could greatly expand demand for U.S. output. With international trade in agricultural goods the issue is one of global not regional resource availability.

2.6.3. Reviews

1) Batie, S. in Food Policy. 9,1:85. Feb 1984.

A description of the study's contents and analytical approach to the problem. Emphasizes that "the book is designed for professionals" and not recommended for a "lay reader."

2) Beattie, B. in American Journal of Agricultural Economics. 65,4:838. Nov 1983.

A description of the objectives and contents of the study. Beattie criticizes the choice of rejecting a formal modeling approach. Such an approach would clarify "the underlying cause and effect relationships and provide a more structured framework for the critical reader in assessing the validity of the results." He also comments that the single scenario approach "implies a far greater level of precision than is warranted."

3. COMPARATIVE EVALUATION OF AGRICULTURAL STUDIES

In the previous section we have described six well known studies of agricultural development. The approaches, assumptions and results of each study were discussed along with brief evaluations of each study's sensitivity to changes in assumptions. In this section we take the next step of comparing the six studies to identify common features, to show how they differ and to point out limitations of the studies with respect to their use in studies of long-term, large-scale environment-development interactions.

The six studies differ radically from one another as is clear from even a cursory reading of the previous section. These differences cause some difficulty in making a comparative evaluation. However, they also serve a purpose for environmental studies. Specifically, if the goal is to evaluate the potential interactions between agricultural development and the environment with an eye towards possible management of future conflicts. Individually, none of the studies directly addresses this topic. However, as a group, each study supplies important inputs for such an evaluation. The contribution each study can make is discussed in the first part of this section.

Section 3.2 expands on the theme of differences among the studies and summarizes the differences as well as similarities in how the six studies are focused. Key variables that the studies have in common are also identified. Even though a variety of objectives and approaches is represented in the studies, several share critical variables and assumptions.

The final part lists some of the critical omissions of the studies analyzed. Though taken as a group the studies are useful in addressing the broader questions of development-environment interactions, a number of important issues are still missing.

3.1. Contributions of Individual Studies

Four fundamental questions arise in the evaluation of future agricultural and environmental interactions:

1. What is our resource base for supporting future production?
2. What is the pattern of future production and input use?
3. Will future consumption needs be met?
4. What effect will these production and consumption patterns have on the environment?

Table 3.1 shows which studies address each of these four questions. Production potentials of the resource base are assessed in AEZ and in MOIRA. In general, AEZ provides a better basis for estimating inherent productivity than does MOIRA. This is largely due to a more complete data base and to more time being available for the study. The principal advantage offered by AEZ is its disaggregation into major crops where MOIRA only estimates grain equivalents. On the other hand MOIRA shows relative productivity of regions for the whole world while AEZ is more limited.

Agricultural production is estimated under various assumptions in AT 2000, Global 2000, MOIRA, FAP and RFF. AT 2000, Global 2000 and RFF also report agricultural input use levels. Increases in total agricultural production between 1980 and 2000 range from 1.43 (FAP) to 1.8 (MOIRA), a difference of approximately 25%. Increases in LDC production vary from 1.51 (FAP) to 2.08 (AT 2000, Scenario A), a difference of about one third.

Table 3.1 Topics addressed by individual agricultural studies

	Studies					
Topics	AEZ	AT2000	Gl2000	MOIRA	FAP	RFF
Resource base	x			x		
Agricultural production		x	x	x	x	x
Consumption & nutrition	x	x		x	x	
Environmental impacts			x			x

The adequacy of food consumption is addressed in AEZ, AT 2000, MOIRA and FAP. In general AT 2000 presents the most optimistic results in its Scenario A. This is principally due to its normative approach including assumptions of extensive aid, liberalization of trade and the absence of barriers to technology transfer and adoption. MOIRA predicts nearly three times more hunger than does AT 2000 even though its production projections are 20% higher as well. The difference stems both from the normative approach taken in AT 2000 and in the method for measuring hunger. AT 2000 simply looks at net food supply per country and world nutrition norms while MOIRA's approach is to compare effective demand by income class with country specific norms.

Environmental degradation is a feature in Global 2000 and RFF. In Global 2000 current policies and trends are extended to predict future environmental effects. In RFF, changing input prices and production practices are considered as well to evaluate future degradation.

The six studies are not only directed at differing primary issues but they approach the topics differently. For example in AT 2000 a consumption level is imposed as an exogenous constraint while in MOIRA the extent of hunger is measured after production and consumption are estimated. Also FAP is a general equilibrium model while Global 2000 and MOIRA are partial equilibrium models.

A wide variety of objectives and approaches are represented by the six studies discussed in this paper. While these differences may reduce the value of a comparative evaluation, the variety gives a broader picture of the future of agricultural development than any single study can provide.

3.2. Differences, Similarities and Critical Variables

The previous section identified how the six studies differ in terms of their contribution to environmental studies. In this section we will expand on the differences and similarities among the studies focusing on the studies themselves. The critical variables required in common for the studies will also be compared.

3.2.1. Differences and similarities

Table 3.2 shows how the studies compare for ten descriptive characteristics. The characteristics are chosen to demonstrate the variation in scope and structure of the six studies as opposed to the overall focus which was discussed in the last section. The table is largely self-explanatory though several additional model features should be pointed out.

Table 3.2 Model characteristics

	Studies					
Characteristics	AEZ	AT2000	GI2000	MOIRA	FAP	RFF
Time scale	-	2000	2000	2010	2000	2010
Space scale	LDC	LDC	Global	Global	Global	US
Demand Driven		x	x	x	x	x
Simulation model				x	x	
Normative approach		x				
Endogenous technology					x	x
Exogenous technology	3	4*	x	x		
Role for trade		x**		x	x	x
Variable prices				x	x	x
Input requirements	x	x	x		x	x
Crop disaggregation	x	x			x	x

Notes:

* AT 2000 is using a Global Technology matrix which is a discrete production function specified in terms of 4 levels: very low, low, high, very high. These are used in a linear interpolation for each land class.

** Exogenous only.

Table 3.3 Common variables in the agricultural studies

1) Production technology
2) Agricultural demand: population, income and income elasticities
3) Initial production and trends
4) Exogenous prices
5) Government policies: trade, pricing and production

First, space scale refers to the principal level of detail of the study. All of the studies have global components though several are basically regional studies with exogenous global supply or demand. Second, technology is endogenous in two studies and exogenous in the other four. Two of those four however consider three differing levels of agricultural technology. Third, all but the AEZ model assume extensive trade in agricultural commodities. However only MOIRA and FAP simulate levels of trade to compare alternative policies. Both conclude that the developed world will benefit most from trade liberalization. In the FAP model, developed countries mainly benefit from efficiency gains and the agricultural output of LDCs is also increasing compared to the reference scenario. A final note concerns the role of prices in the three economic models; MOIRA, FAP and RFF. In all three studies, variable prices affect agricultural output. In MOIRA, government intervention in markets is reflected in the model's prices. MOIRA was a direct ancestor of FAP, thus they are using a similar pricing mechanism. In both cases governments influence prices but eventually they are determined by markets. In both models prices play a key role in changing effective demand and they, of course, influence production levels and resource allocation. In the RFF study prices play the further role of influencing production technologies and thus input mix and use.

3.2.2. Common variables

Though the six studies differ significantly in objective and structure, several variables and assumptions are common to most of the studies. Five types of such variables are listed in Table 3.3. The list represents categories of variables and is not meant to indicate that the variables are identical in the models or are used in the same way. For example, technology assumptions are made in each study but in some studies technology is fixed and exogenous while in others, technology varies over space and time. In all models though, technology plays some role.

Agricultural demand is derived from assumptions concerning population growth, income growth and income elasticities of agricultural goods. Several studies go into some detail on population and income distribution as well as growth. Others are more aggregate in nature. Also depending on the study, demand is stated either in terms of totals or as output by crop, by calories or by protein. Studies assessing adequacy of consumption also include assumptions on nutritional norms.

Each study defines for itself a starting point for agricultural development in terms of initial year production which is disaggregated in some studies by region and by crop. Some also go further to identify recent production trends. These data set the stage for the central task of estimating growth in production. Estimating future output also requires attention to the resource base agriculture relies on. Each study has a section evaluating land resources with AEZ and MOIRA going into particular detail.

Table 3.4 illustrates the differences between the estimates of potential arable land that are used in three models. There are four reasons for the differences between the numbers found in the table.

First, the regions are not comparable. That is, they do not cover the same land area. Global 2000 groups contiguous countries by political affiliations (e.g. Western Europe) and level of development (e.g. African LDC's). MOIRA breaks the world down into broad soil regions. The arable land in each of these regions can be summed together for any larger regions and continents. AEZ reports figures at both the country and the continent level.

Secondly, the reports differ in their definitions of potentially arable land. MOIRA subtracts from the total land base land that is too shallow, stony, or steep, lands with poor soil, swamps, or lakes, land already used for urban and other non-agricultural purposes, and a fraction of the forested land. The remainder is classified as Potentially Arable Land (PAL). PAL is corrected for soil and water deficiencies to give IPAL, an imaginary land area that can produce at maximum rates.

To AEZ "land suitability" is a function of climate and soil. Potentially arable land is what remains when "unsuitable" land and non-agricultural land is subtracted from the total land surface.

In Global 2000, arable land is simply that land which is cultivated. From the table it can be seen that the latter definition produces estimates that are very conservative in comparison with the others. Land that is cultivated is a subset of that which could be support crops considering only climate and soil.

Third, these discrepancies reflect different underlying assumptions. Global 2000 projects that cultivated land will increase by only 4% by 2000. The authors reason that most good land is already supporting crop production. It will be more economical to intensify production on existing fields than to overcome the limitations on marginal land.

Both the AEZ and MOIRA figures are independent of time. They are static estimates of the area of land that could potentially support crops. Economics is not considered. Only the one or two environmental factors most directly associated with agriculture are considered.

Global 2000 used an econometric model. Population and income growth together create increasing demand, which stimulates production.

MOIRA uses a theoretical equation for calculating IPALI, which it uses as a land basis for estimating maximum production of grain equivalent. This is done within broad soil regions.

In all studies, except AEZ, prices enter explicitly. However their roles differ considerably between models. In AT 2000 for example prices are assumed to remain constant while the economic models (MOIRA, FAP and RFF) allow prices to vary and influence the course of agricultural development. Even in these models though, some prices (e.g. energy and fertilizer inputs) are introduced exogenously.

Government policies also enter most models explicitly. Policies generally deal with international trade, domestic pricing and production incentives or controls. In Global 2000 and RFF, policies are assumed to remain fixed over the study period while in MOIRA and FAP, several policy scenarios are analyzed. In AT 2000 the alternative scenarios reflect different assumptions about income growth and production responses.

3.3. Limitations and Omissions of the Studies

Each of the six studies has significant limitations for use in environmental studies. The limitations generally arise from omission of important linkages or variables. Table 3.5 lists six sources of such limitations.

Perhaps the most significant drawback is the failure to incorporate environmental constraints. To a greater or lesser extent all the studies share an inability to investigate the two main demands agriculture places on the environment, first as a resource supplier and secondly as a residuals sink. Accounting for resource supplies requires explicit consideration of the quantity and quality of resources such as land and water. The latter case requires explicit treatment of the feedback between environmental degradation and agricultural productivity. Both RFF and Global 2000 consider competing demands in the form of constraints on development, and note environmental degradation, but neither completes the loop by examining the implications for agricultural sustainability.

Most of the studies touch on the land input to agriculture but coverage of the total input package is grossly incomplete. When agricultural output is estimated to grow by several orders of magnitude, the adequacy of input supplies must simultaneously be assessed. Most of the estimates include significant growth in irrigation, fertilizer use and the spread of new inputs such as hybrid seeds. Yet irrigation expansion requires sizable

Table 3.4 Arable land availability (in million ha)

	MOIRA PAL	MOIRA IPALI	AEZ	GLOBAL 2000	AT 2000
Europe	399	251			
North America	546	288			
Latin America	700	391	893	165	889
Asia	1081	582			342[3]
Southeast Asia[1]	370	232	297		
Southeast Asia[2]	55	34		41	
South Asia	172	156		207	
Near East			48		
Africa	762	314	789		816[4]
North Africa and Middle East	87	22		91	95
Other African LDC's				183	
Oceania	226	77			
World	3714	1903		1539	

Notes:

1) Singapore, Vietnam, Bhutan, Sri Lanka, Bangladesh, Philippines, India, Nepal, Burma, Thailand, Dem.Kampuchea, Laos, Pakistan, Brunei, Malaysia
2) Thailand, Burma, Cambodia, Laos, South Vietnam
3) excluding China
4) Sub-Saharan Africa

capital investment along with appropriate water and land characteristics. These are accounted for in AT 2000. Maintaining the expanded role of irrigation also necessitates preserving water and land from salt contamination. Greater fertilizer use requires capital for new plants along with mineral inputs and reasonably priced energy. Finally, an extensive research and extension infrastructure must precede a major expansion of hybrid seed use.

None of the six studies explores the possibilities and the ramification of a major technological or political change on the course of agricultural development. Yet agriculture has been characterized in the last several decades by rapid technical change and political decisions have greatly influenced agricultural trade, prices and production. Though it is

Table 3.5 Limitations and omissions in the agricultural studies

(1) Environmental feedbacks (omitted)

(2) Input availability (omitted)

(3) Major technological or political change (omitted)

(4) Limited time horizon (limitation)

(5) Sectoral consistency (omitted)

(6) Homogeneous and fixed production technology (limitation)

difficult to forecast precisely the nature of such major change, it is unrealistic not to expect some significant shocks.

A fourth limitation is the relatively short time horizon of each of the studies. None goes beyond the year 2010. Long-term studies of development-environment interactions are concerned with a much longer time span to evaluate the sustainability of development, not just short run effects. This difference in timing justifies some of the above mentioned omissions of the studies. Environmental and resource constraints are not as likely to become binding in 20 or 30 years as in 100 years and the technological and political setting may remain fairly stable. However the failure to identify evolving problems and potential conflicts remains a significant omission.

Resource inputs may be unavailable due to competing sectoral demands as well as resulting from degradation or fixed supplies. As population, incomes and the non-agricultural sector grow, competition for land, water, minerals, capital, labor, energy and other inputs becomes more intense. Also input-output linkages between the agricultural and non-agricultural sectors may create bottlenecks in economic growth if sectoral growth is uneven or poorly timed. Thus the issue is not only the total availability of inputs but also local distributions of the inputs and outputs as well as locally competing demands. The studies evaluated fail to check for consistency between these competing demand and sectoral linkages with exception of capital and labor in FAP and AT 2000.

A final limitation of most of the studies is that production technologies are assumed to be fixed and homogeneous. The only exceptions are FAP which employs a time trend for technological change and RFF which allows for heterogeneous and evolving technologies. The simplifying assumption of homogeneity is not only inaccurate in representing current production but it cannot capture the types of changes necessary to meet growing food demands.

3.4. Conclusions

To summarize, the six studies evaluated here are radically different from one another. Not only do they address differing primary topics but they approach the issues differently including economic and non-economic models, simulation and non-simulation methods and global and regional scales. These differences are discussed in sections 3.1 and 3.2 above. Section 3.3 goes on to point out some of the more serious limitations of the six studies. These limitations, particularly the lack of environmental feedbacks and the 20 to 30 year time horizon appear to make the studies to a large extent inappropriate for the objectives of evaluating the long-term interactions between agriculture and the environment - although they may be very appropriate for the purposes for which they were designed. However together the studies provide an extensive framework from which to initiate such an analysis. They supply detailed information about the resources agriculture requires, the characteristics of future demand and how agriculture may grow in response to demands. This information will be an important input to future studies of long-term, large-scale interactions between socioeconomic development and the environment.

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Chapter 5

A Conventional Wisdom Scenario for Global Population, Energy, and Agriculture 1975-2075

Stefan Anderberg

1. Introduction

The aim of this chapter is to synthesize a "conventional wisdom" scenario for the global development of population, agricultural production, and energy use between 1975 and 2075. The scenario attempts to present a view of future developments that is as consistent as possible with the major studies reviewed in previous chapters. As such, it describes a surprise-free picture without any dramatic changes in the long-term trends. The scenario is based on the results of the assessments of long-term, large-scale studies and projections in population, energy and agriculture presented in Chapters 2, 3 and 4 of this report. Several basic assumptions are implicit in the conventional wisdom presented here:

- An optimistic view of the possibilities for economic development. This implies that social, political, economic, technological, as well as acute environmental problems can be overcome.
- The political and economic systems remain basically the same.
- Population growth can be controlled and the global population will level off towards a ceiling of 10 billion people.
- The growth of population and GDP are the main driving forces in energy and agricultural development.

The population figures reported here are largely based on the Keyfitz study (Keyfitz et al., 1983). The energy figures reflect the Edmonds and Reilly Base Case Scenario (Edmonds and Reilly, 1985). Since no long-term future studies are available on agriculture, our "conventional wisdom" is based on on the expert opinion of the group which prepared the critical assessment of agricultural studies (Chapter 4).

In our scenario presentation the world is divided into eight regions: North America, Latin America, Europe, Africa (including the Near East), USSR, South Asia, East Asia, and Oceania. For the list of countries belonging to the eight regions see Appendix 2 of Chapter 2.

The report is organized as follows. Section 2 summarizes the basic character of the conventional wisdom scenario for the world over the period 1975-2075. Section 3 provides a more detailed view of postulated developments in 8 regions. Finally, Section 4 contains a short evaluation of the scenario and discusses a number of critical assumptions behind it.

2. Global Development

2.1. Population and Economic Growth

The present rapid population growth in the world slows down dramatically and the population stabilizes at 10 billion people by 2075 (Figures 2.1 and 2.2). This is the result of both political actions and changes in attitudes as a consequence of particularly rising standards of living and pressures on the resource base. A retardation of population growth is already visible before the year 2000. Among the third world regions East Asia takes the lead in this development and the other regions follow. Between 2000-2025 there is a radical drop in population growth in all developing regions except in Africa, which still has an annual growth of 2%. By 2025-2050 the growth rates of East and South Asia are about at the present European level (0.5 percent/year), while Latin America and Africa are down at about 1% annual growth. By 2075 the whole world is close to stationary populations and life expectancies are almost everywhere over 70. During the whole period a combination of improving economic conditions and rigorous population control discourages large scale migration. The population of the four "developing regions" increases from 75% of the global population in 1975 to 85% in 2075.

The hundred-year period is characterized by fairly high, stable, and continuous economic expansion for the whole world. Development towards increased global economic integration, free-trade, and division of labor continues. Growth in the poor world is higher than in the rich world, but not sufficient to decrease the gap between North and South; it widens in absolute numbers even if it decreases relatively. The rich world remains as dominating as in the 20th century.

2.2. Energy

In the year 2075 the world will consume about 48 TW energy. This is almost 6 times more than in 1975 (see Figure 2.3). The per capita use is 2.4 times the 1975 level. Coal is assumed to be an unconstrained fuel during the hundred-year period and it becomes the new leading fuel. It is as dominating as oil in 1975. This demands steady technological progress in coal technology and investments in new coal fields and distribution systems. Impressive technological progress is also made in a number of other areas, e.g., synfuel conversion systems and various types of solar energy.

The market share of fossil fuels is 80% in 2075, compared with 90% in 1975 (see Figure 2.4). The share of conventional oil is very small. The use of synfuels, mainly derived from coal and shale oil, is important (10.8 TW, 22% of the global energy use). Gas use (2.8 TW, 6%) reached its highest point around 2025 and is decreasing. The forecasts of huge supplies of accessible deep gas are not born out.

Nuclear and solar power are also viewed as unconstrained, but will be too expensive to reach more than marginal importance. Nuclear energy (3 TW, 6%) has, after rapid growth before the year 2000, a more hesitant development and then growing market shares towards 2075. Breeders and fusion are of no importance. Hydro and solar energy (6.8 TW, 14%) expands more than 11 times.

Commercial biomass energy (0.9 TW, 1.8%) is locally important, but achieves a low and thereafter relatively unchanged market share early in the hundred-year period. The use of biomass for energy is constrained by the demands for food and forestry products.

Overall, the world's energy demand and supply patterns in 2075 require an effective system of international trade. The interregional trade picture changes some during the hundred years (see Table 2.1). By 2075 the main exporters are East Asia, USSR, and Africa, and the big importers are Europe, Latin America, and North America. Oceania is a minor exporter and South Asia is a minor importer. Half of the interregionally traded energy is coal.

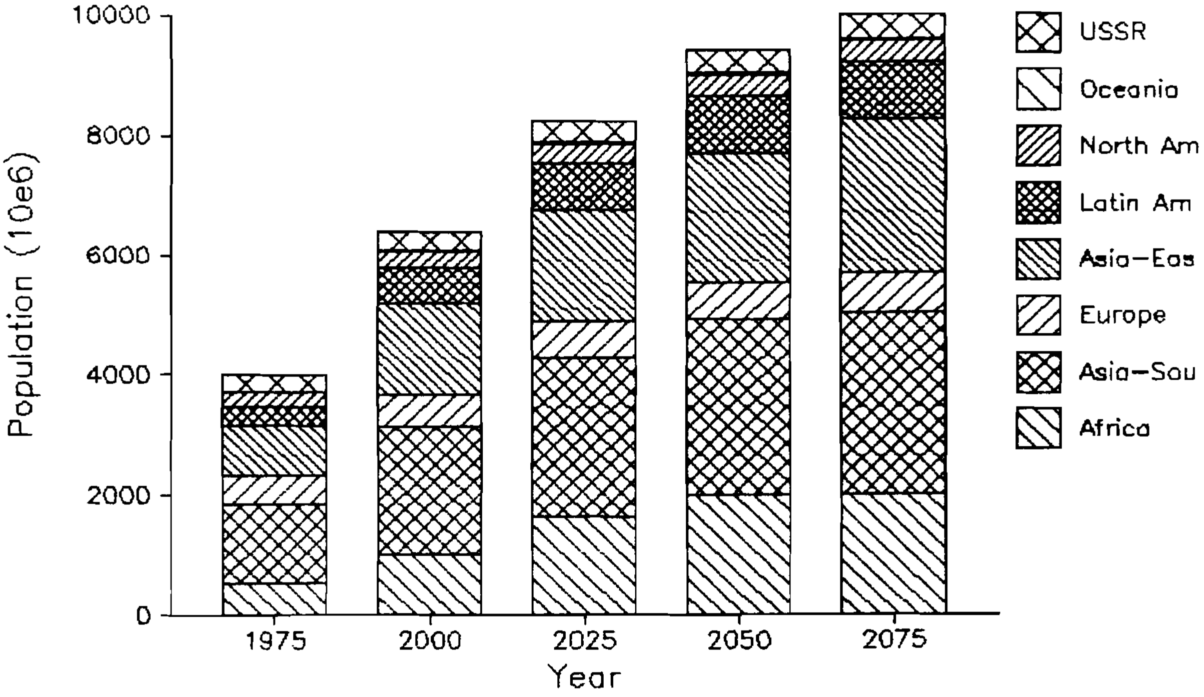

Figure 2.1 World population

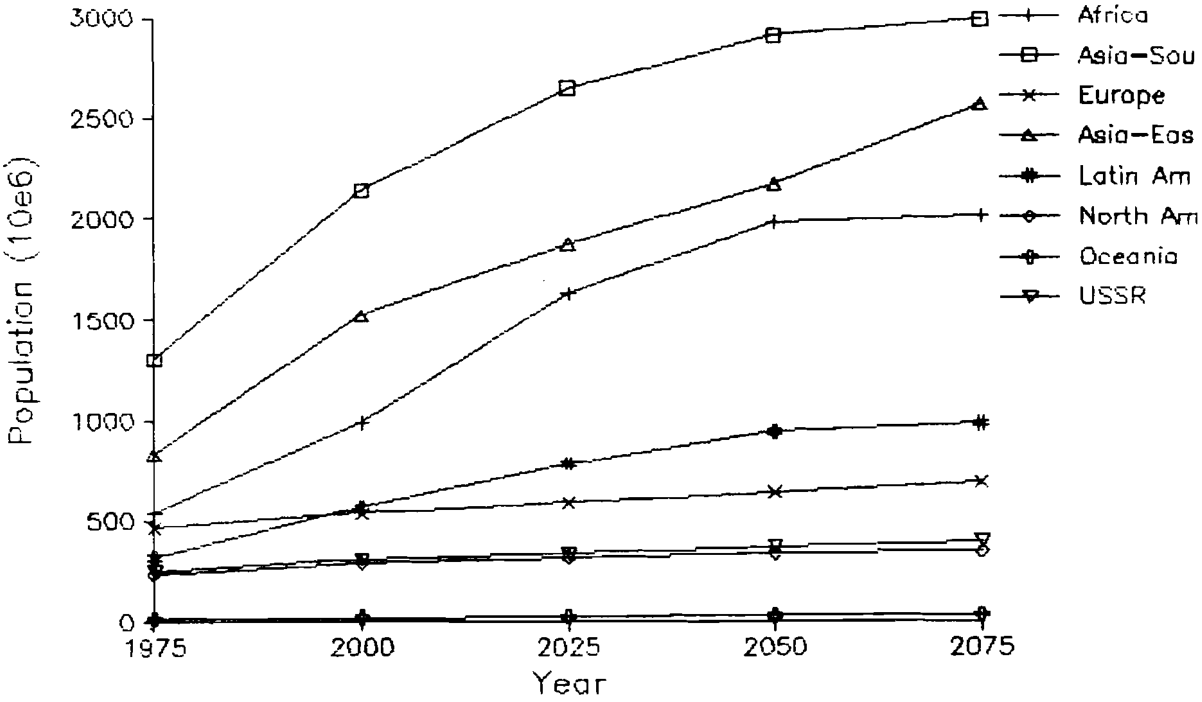

Figure 2.2 World population by regions

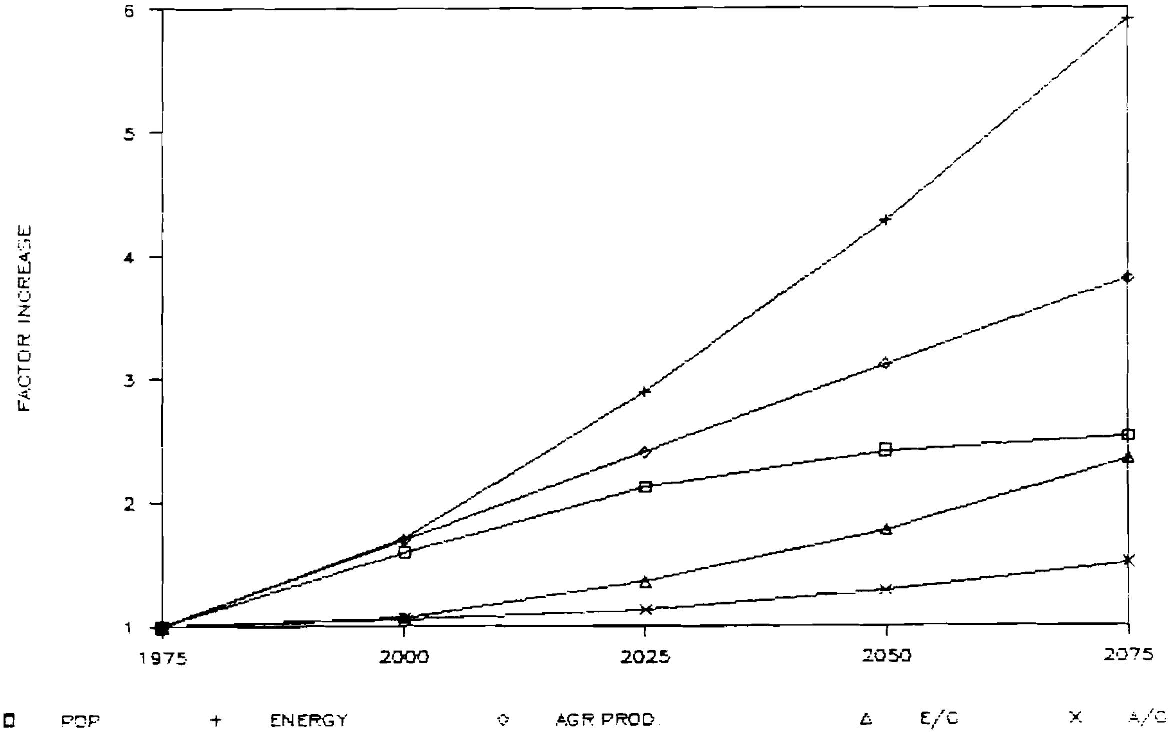

Figure 2.3 Global development
(*Note:* E/C: energy consumption per capita, A/C: agricultural production per capita)

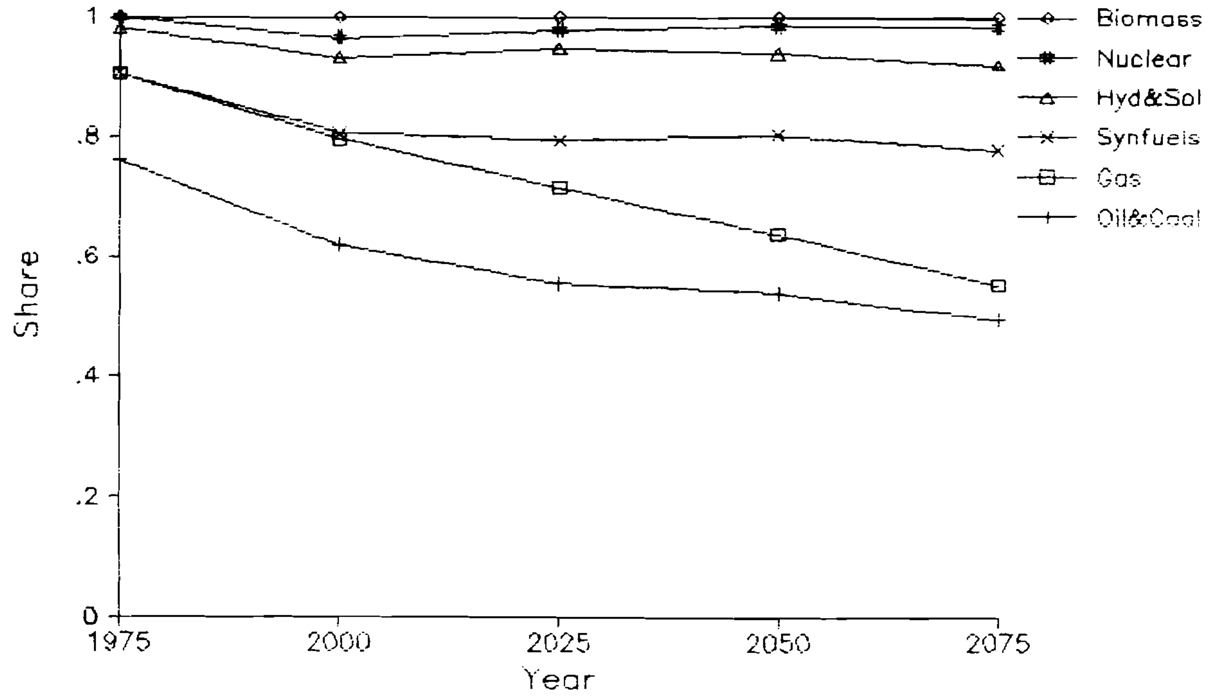

Figure 2.4 World fuel mix

Table 2.1 Interregional energy trade - net imports (TW)

	1975				2075			
	Oil	Gas	Coal	Total	Oil	Gas	Coal	Total
North America	0.4	0.13	-0.09	0.44	1.05	0.35	-0.65	0.75
Latin America	-0.2	-0.03	0.01	-0.22	0.54	0.06	0.48	1.08
Europe	1	-0.16	0.08	0.92	-0.17	0.4	1.83	2.06
Africa	-1.4	-0.09	0.01	-1.48	-0.24	-0.55	-0.31	-1.1
USSR	-0.02	0.1	-0.01	0.07	-0.48	-0.43	-0.64	-1.55
South Asia	0.04	0	0	0.04	0.08	-0.07	0.24	0.25
East Asia	0.15	0.05	0.01	0.21	-0.94	0.19	-0.79	-1.54
Oceania	0.03	0	-0.01	0.02	0.06	0.05	-0.16	-0.05
TOTAL TRADE	1.62	0.28	0.11	2.01	1.84	1.05	2.55	5.44

The third world regions increase their share of total energy consumption, but since they have higher population growth the inequity of energy use remains. Per capita consumption (Figure 2.5) is highest in North America, which with 28.5 kW per person (3 times the 1975 level) becomes an extremely energy intensive society. Oceania has 21.3 kW per capita (five-fold increase) and Europe 16.5 (three-fold increase). USSR has more than doubled energy use per capita and is on the 1975 North America level. The poorer regions have three to four times their 1975 per capita use. Latin America and East Asia are on the 1975 Oceania level (about 4kW). Africa uses 2.5 kW per person and South Asia is with 0.8 kW per capita still on the East Asia/Africa level of 1975.

2.3. Agriculture

Agricultural production per capita increases by 50%, reflecting improved nutrition in the poorer countries. This indicates an almost fourfold increase in total production. The main sources (Table 2.1) of this increase are:

- The area of arable land is increased by 18%.
- Yield levels are increased by a factor of 3.3 as a result of higher yielding varieties, improved pest management, improved and increased fertilizer use and irrigation, an increase in cropping intensities (harvests per year) by a factor of 1.25.
- Post harvest losses are reduced by 50%, increasing the total supply by a factor of 1.07.

The increase of cropland area is mostly at the expense of the forested areas (Figure 2.6). In Africa and Latin America the increase is approximately 50% and the forested areas decrease by about 30%. On the global level grazing lands are reduced by 6% and forests by 16%. The "other lands", which cannot be used for agricultural production, grow by 13% primarily as a consequence of desertification, erosion, and urbanization.

Table 2.2 Development of major production factors in agriculture

Region	Area of cropland (million ha) 1975	Area of cropland (million ha) 2075	Area of cropland (million ha) Ratio	Yield (MT/ha) 1975	Yield (MT/ha) 2075	Yield (MT/ha) Ratio	Cropping intensity (number of harvests/year) 1975	Cropping intensity (number of harvests/year) 2075	Cropping intensity (number of harvests/year) Ratio	Factor for reduced crop loss
North America	232	220	0.95	3.4	7.5	2.2	0.90	1.15	1.3	1.04
Latin America	157	242	1.54	1.7	4.5	2.6	0.61	0.80	1.3	1.07
Europe	142	128	0.90	3.3	7.0	2.1	1.05	1.26	1.2	1.04
Africa	245	365	1.49	1	3.3	3.3	0.56	0.78	1.4	1.08
USSR	232	267	1.15	1.5	5.0	3.3	0.85	1.05	1.2	1.06
South Asia	211	220	1.04	1.3	4.0	3.1	1.07	1.34	1.3	1.07
East Asia	170	204	1.20	2.2	5.5	2.5	1.07	1.34	1.3	1.07
Oceania	44	48	1.10	1	2.5	2.5	0.80	1.00	1.3	1.04
TOTAL	1433	1694	1.18	2	4.9	2.5				

Table 2.3 Irrigation and fertilizer use

	Irrigation						Fertilizer use					
	million ha			% of cropland			kg/ha arable land			total use (mio MT)		
	1975	2075	Ratio	1975	2075	Ratio	1975	2075	Ratio	1975	2075	Ratio
North America	17	17	1.00	7	8	1.14	95	145	1.53	22	32	1.45
Latin America	12	20	1.67	8	5	0.63	29	110	3.79	5	27	5.40
Europe	12	15	1.25	8	11	1.38	201	402	2.00	29	52	1.79
Africa	23	34	1.48	9	9	1.00	17	80	4.71	4	29	7.25
USSR	14	19	1.36	6	7	1.17	74	145	1.96	17	39	2.29
South Asia	47	70	1.49	22	32	1.45	16	105	6.56	3	23	7.67
East Asia	57	85	1.49	34	42	1.24	67	155	2.31	11	32	2.91
Oceania	2	2	1.00	5	4	0.80	29	70	2.41	1	3	3.00
TOTAL	184	262	1.42	13	15	1.15	46	140	3.04	92	237	2.58

Table 2.4 Development of agricultural production

	Production (million MT)			Production per capita (MT per capita)		
	1975	2075	Ratio	1975	2075	Ratio
North America	709	1975	2.8	3	5.6	1.9
Latin America	163	933	5.7	0.5	0.95	1.9
Europe	492	1148	2.3	1.03	1.66	1.6
Africa	137	1014	7.4	0.25	0.5	2.0
USSR	296	1488	5.0	1.2	3.7	3.1
South Asia	294	1227	4.2	0.35	0.5	1.4
East Asia	399	1601	4.0	0.3	0.5	1.7
Oceania	44	125	2.8	2.6	4.15	1.6
TOTAL	2534	9511	3.75	0.64	0.95	1.48

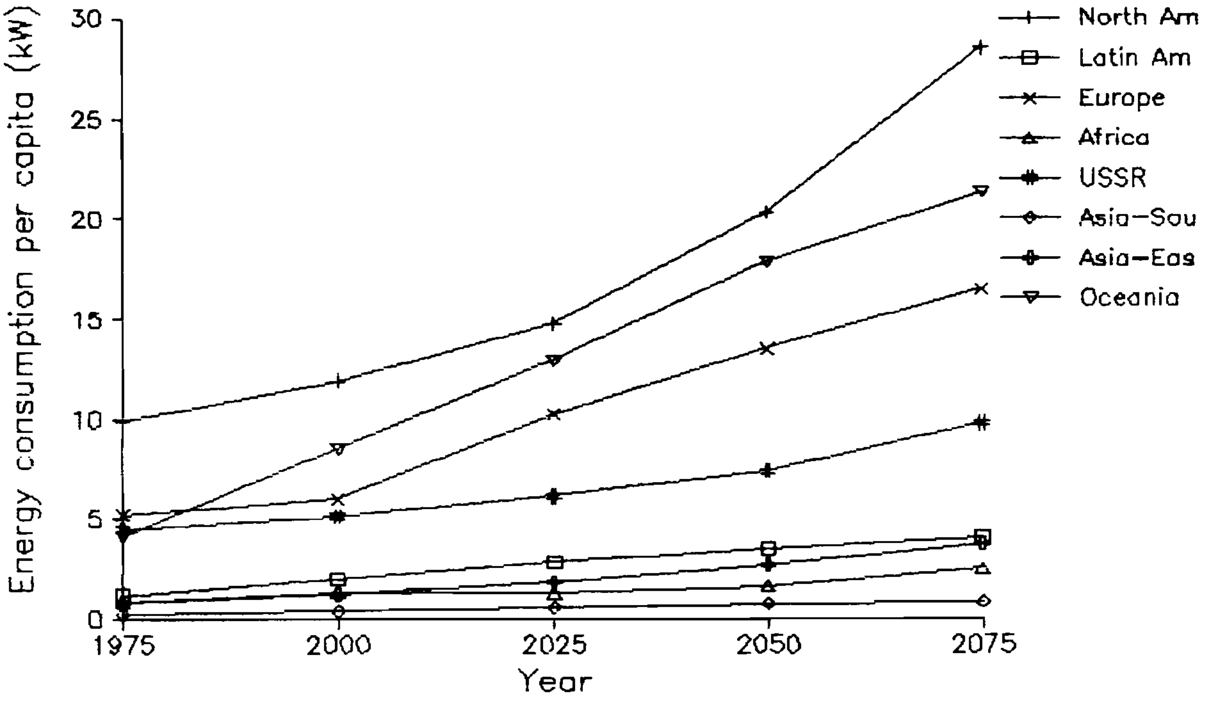

Figure 2.5 Energy consumption per capita

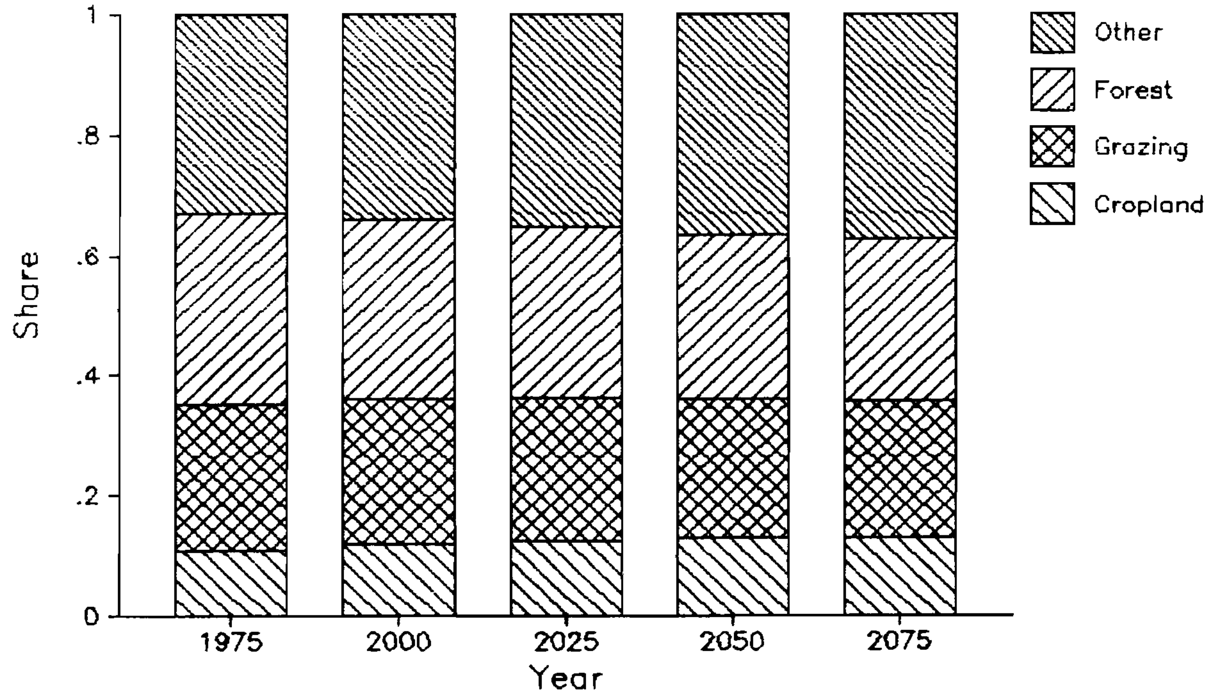

Figure 2.6 Global land use change

No revolutionary new technologies are developed during the hundred-year period. However, research produces a continuous stream of incrementally improved technologies suited to diverse environmental and economic conditions. Biotechnology plays a role in this, but its effect is to stave off diminishing returns to technologies already in use, rather than to bring about a quantum jump in output. Because of increasing competition for land, these technologies tend to be land-saving with variation around the world reflecting differences in the land/population ratio. Accordingly, crop and animal yields rise, reflecting genetic improvements, greater use of fertilizer, and more intensive use of land made possible by increased irrigation and development of crop varieties with shorter growing season. Cropping intensities increase to over 1 in all regions except Africa and Latin America (Table 2.1). Irrigated land increases globally by 42% and the use of fertilizers and biocides grow 2.8 and 2.5 times respectively (Table 2.2). The average amount of fertilizer per hectare is higher in 2075 than the 1975 North American use (which is only half of the European). Agriculture does not experience any serious energy problems because it is of high priority and the most expanding regions, with the exception of South Asia, are energy surplus regions. In 2075 agriculture still consumes only about 5% of the total energy production.

The number of people depending directly on agriculture for their family income increases from 2.0 to 3.6 billions, but this means a decrease from 49 to 36% of the global population.

Increments in total production vary widely in the different regions; from 30% in Europe and 90% in Oceania to 470% in Latin America and 640% in Africa. Production per capita grows in all the regions, in Africa and Latin America by 100% and in the USSR by 220%. The per capita figures show, however, that the regional differences have not decreased by 2075. An increasing tendency of nation states to treat adequate food as a right of their citizens, liberalized trade policies and increased purchasing power mitigate but do not eliminate the large scale distributional problems.

3. Development of the Regions

3.1. Europe

European population growth is relatively slow (Figure 2.2 and Figure 3.1). Population grows from 472 to 690 million (0.4%/year). Agricultural production increases by 130%, per capita output by 60%, particularly due to more irrigated land and higher yielding crop varieties (Tables 2.2-2.4). Fertilizer use is doubled and irrigated land increases by 25%. The increase in fertilizer use is less than expected because research reveals new ways of using fertilizer more efficiently and also increases the nitrogen fixing capacity of cereal crops. The cropland area decreases by 10% and grazing lands by 35% (Figure 3.2). Contrary to other regions, the forested area grows by 11%. "Other lands" increase by 31% primarily due to urbanization.

Total energy use grows from 2.5 to 11.4 TW or, from 5.2 to 16.5 kW per person (Figure 2.5). Europe is the leading innovator region in the energy sector; all changes or new trends, like the transition from oil to coal, can be noted here first. By 2075 Europe remains the most important energy importer, but is not as dominating as hundred years before. More domestic fuels are used, primarily coal. Non-fossil fuels have a market share of 25%, of which nuclear power accounts for 40% (Figure 3.3).

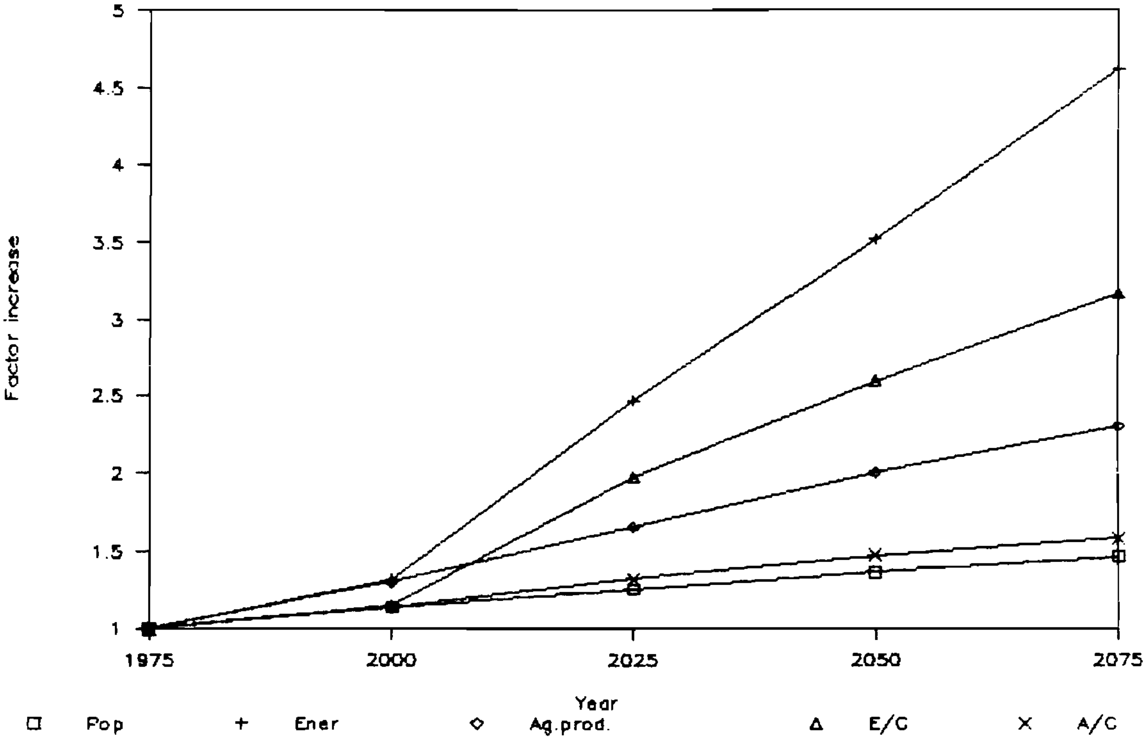

Figure 3.1 General development - Europe

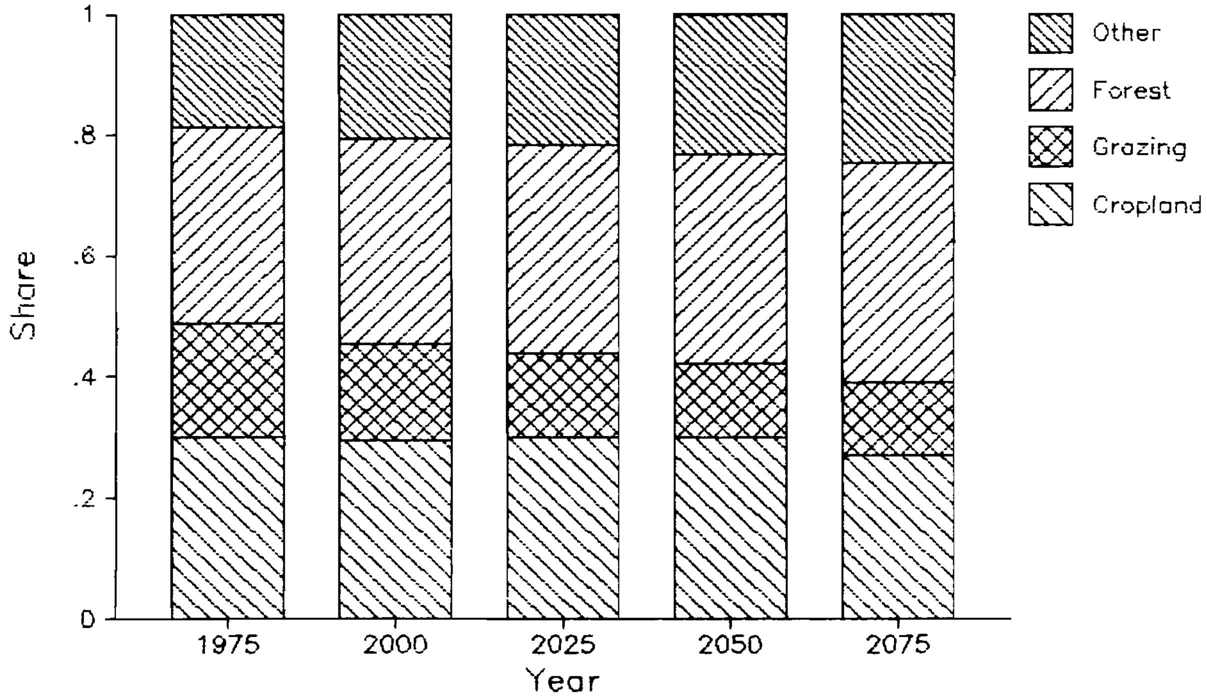

Figure 3.2 Land use change - Europe

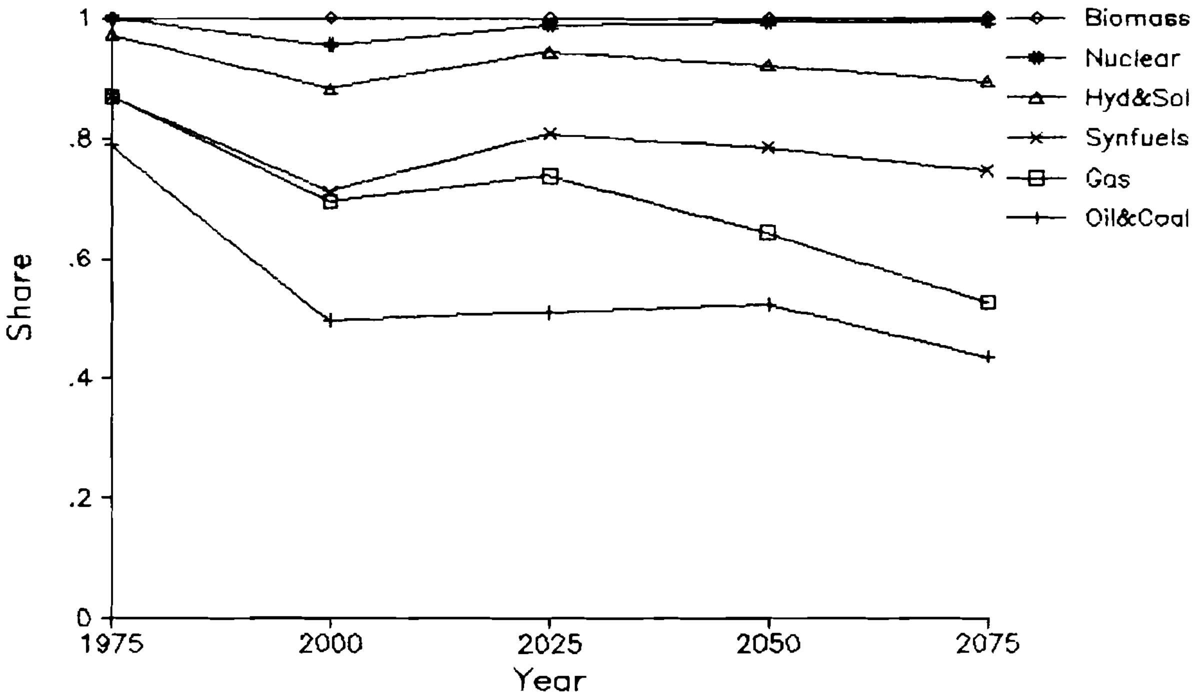

Figure 3.3 Fuel mix - Europe

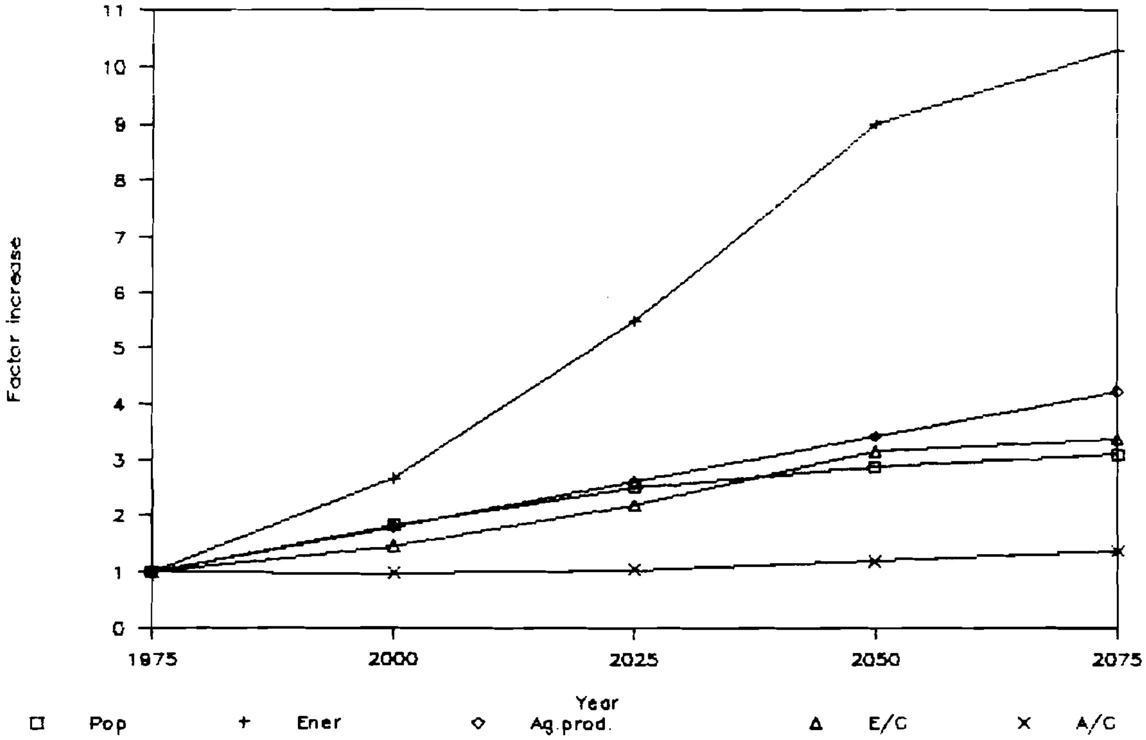

Figure 3.4 General development - South Asia

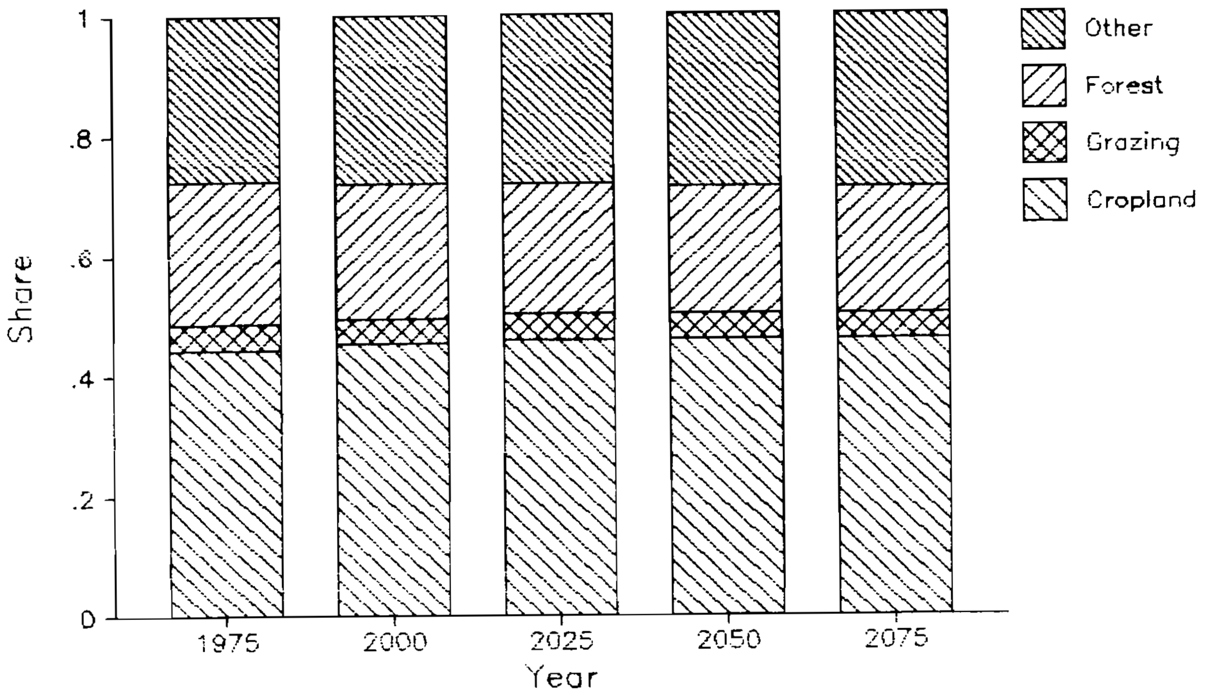

Figure 3.5 Land use change - South Asia

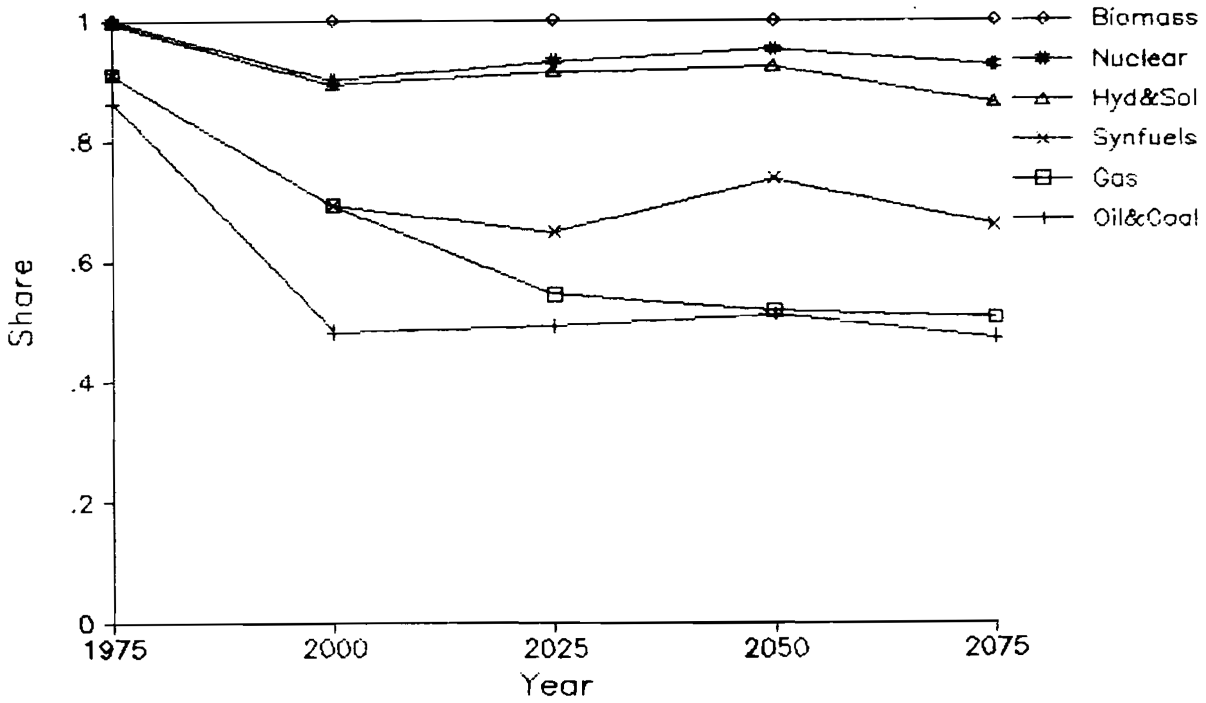

Figure 3.6 Fuel mix - South Asia

3.2. South Asia

South Asia is a region that is poorer and has more limited resources than the others. But in some ways, e.g., R&D and technological know-how, it has resources and capabilities far above most countries in the Third World. The reason why South Asia has so much lower consumption (and production) than the other regions is that it is the only homogeneously poor region.

Population grows from 832 million in 1975 to 2091 million in 2025 and 2560 million in 2075 (Figure 2.2 and Figure 3.4). Agricultural production grows by 320%, per capita output by 40%. Virtually all the increase comes from increased yields of crops. This is made possible by introduction of higher-yielding, pest-resistant crop varieties and by more intensive use of land. Irrigated land, already high in India in 1975, expands by 50% and fertilizer use per hectare increases by a factor of 6.3 (Tables 2.2-2.4). There are not any greater land use changes (Figure 3.5). The cropland area is in 2075 46% (44% in 1975). The fraction of arable land does not exceed 13% in any other region except Europe and South Asia.

Energy consumption grows from 0.2 to 2.2 TW in total and from 0.3 to 0.8 kW per person (Figure 2.5). The non-fossil fuel market share is almost 35%, higher than in all other regions with the exception of Latin America (Figure 3.6). Notable is that the use of biomass for energy, despite lack of forests, is higher in absolute numbers than in Europe and North America.

3.3. North America

Population grows from 237 million in 1975 to 324 in 2025 and 350 by 2075 (see Figure 2.2 and Figure 3.7). Agricultural production increases 2.8 times. This is a result of intensification; e.g. higher inputs like 50% more fertilizer per hectare and higher yielding crops, not by increasing the cropland area (Tables 2.2 - 2.4). In fact the area of cropland declines by some 5% (Figure 3.8). Grazing lands and forests decrease somewhat, too, while other lands increase due to urbanization and degradation by pollution and desertification.

Total energy use increases from 2.3 TW in 1975 to 10.0 in 2075 or from 9.9 to 28.5 kW per person (Figure 2.5). The energy/GDP ratio is higher only in the USSR. The use of fossils and particularly oil is important during the whole period (the lowest value is 84% in 2000) (Figure 3.9). The transition from oil takes place much later than in Europe, and the development of alternative energy sources is not as fast. All the non-fossils are relatively undeveloped by 2075. In spite of large coal exports the region is a major energy importer (Table 2.1).

3.4. Latin America

At the beginning of the hundred-year period the population grows fast from 322 million in 1975 to 785 by 2025, but growth slows down from 2.8%/year before 2000 to 1.3%/year between 2000 and 2025 (Figure 2.2 and Figure 3.10). The continent has abundant resources with possibilities for extensive expansion of economic activities. The economy is also expanding rapidly. Agricultural land is extended dramatically and new energy sources, like hydro power in the Amazon area, and new oil, gas and coal fields are exploited. Latin America is one of the leading energy exporters by 2000.

During the second half of the hundred-year period the resources become scarce and there seems to be a crisis between 2025 and 2050 when population growth is still important and the economy has to change from extensive (new resources taken into production) to intensive (given resources used more efficiently) expansion. The region becomes a net energy importer (Table 2.1). By 2075 the population stabilized at approximately 1 billion

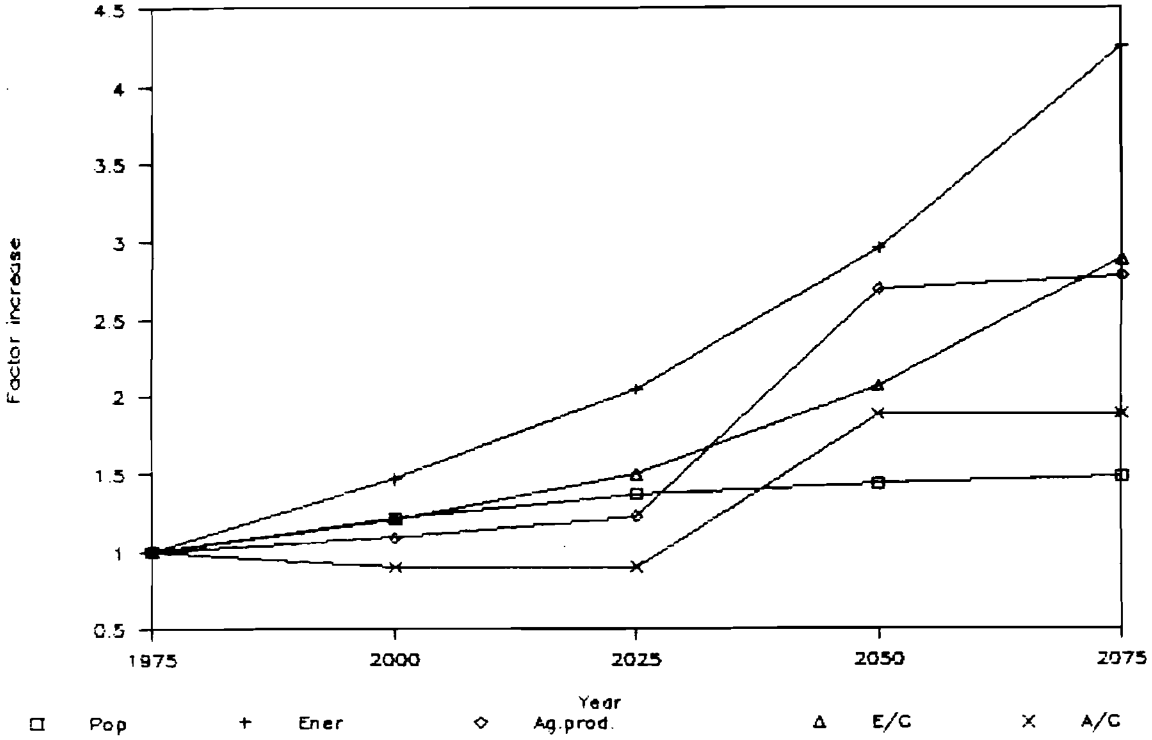

Figure 3.7 General development - North America

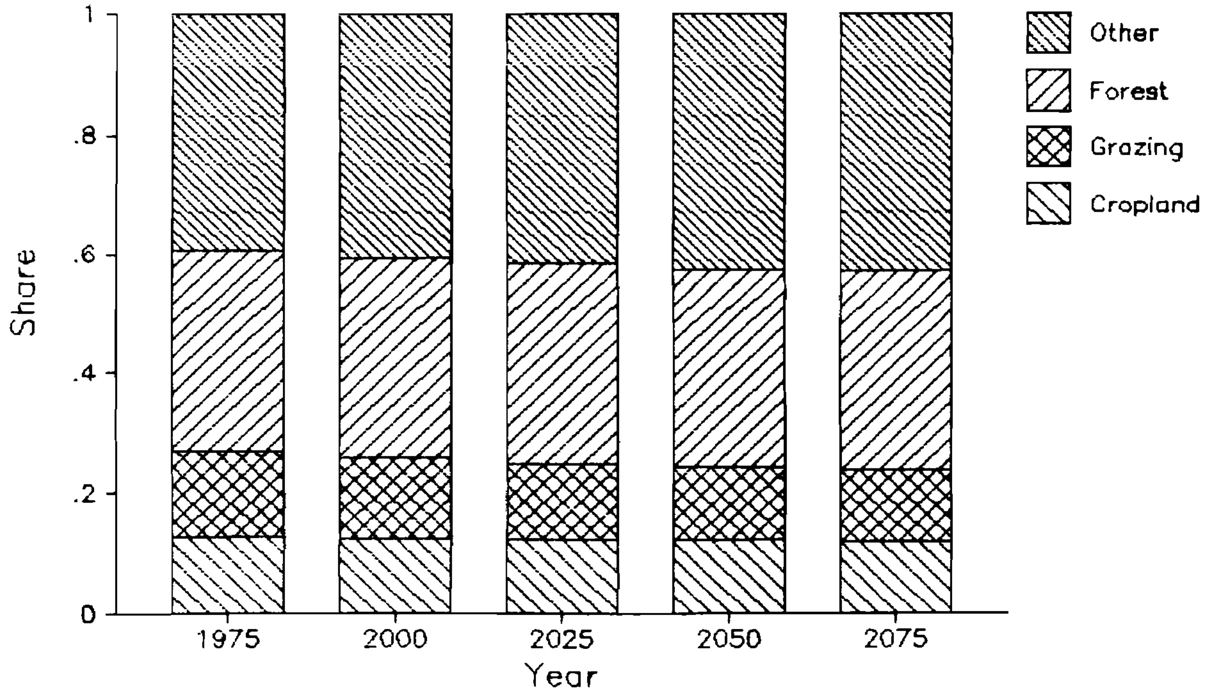

Figure 3.8 Land use change - North America

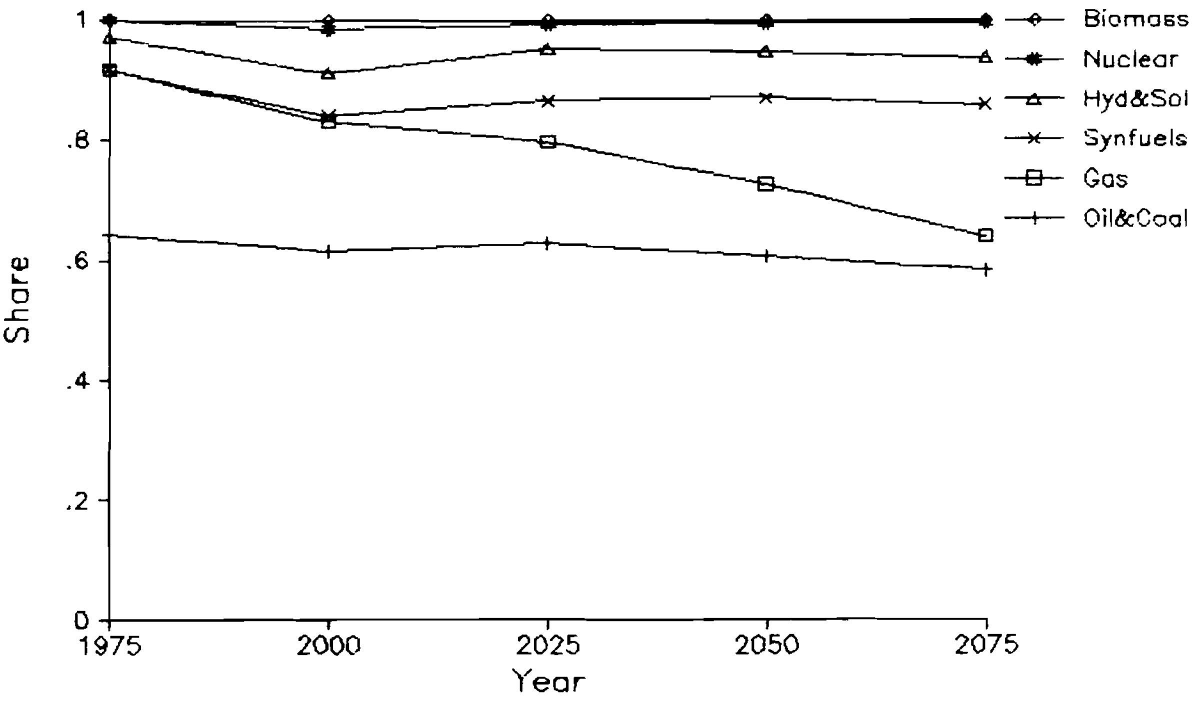

Figure 3.9 Fuel mix - North America

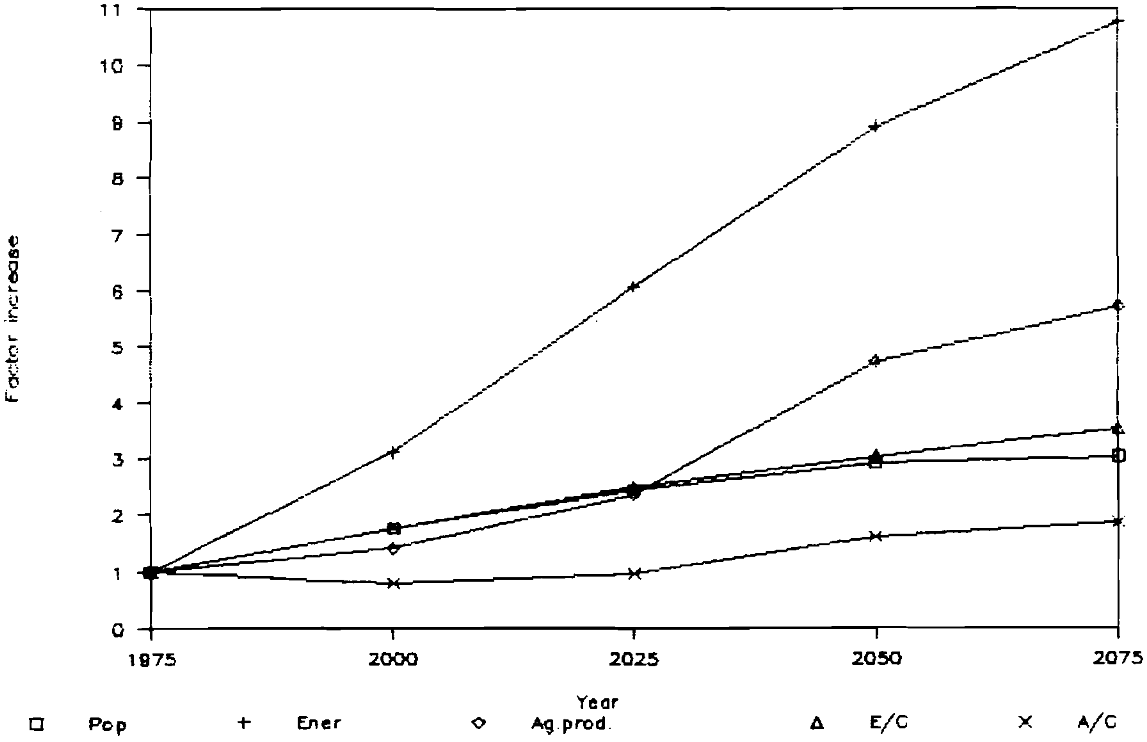

Figure 3.10 General development - Latin America

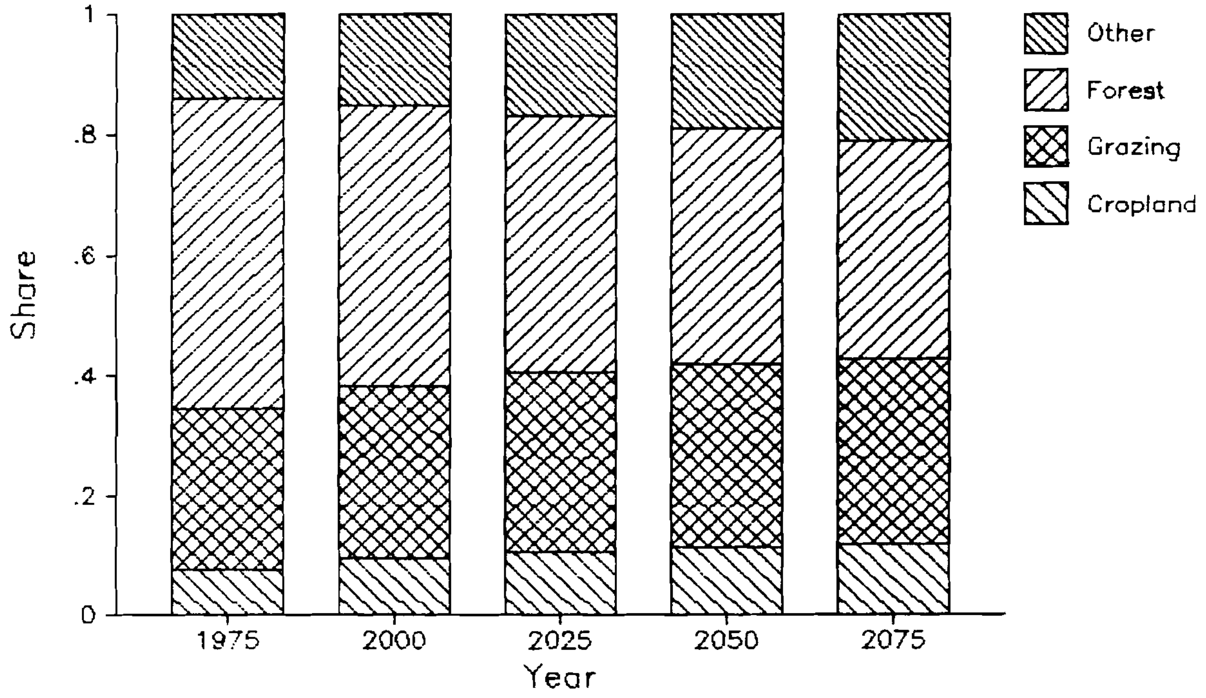

Figure 3.11 Land use change - Latin America

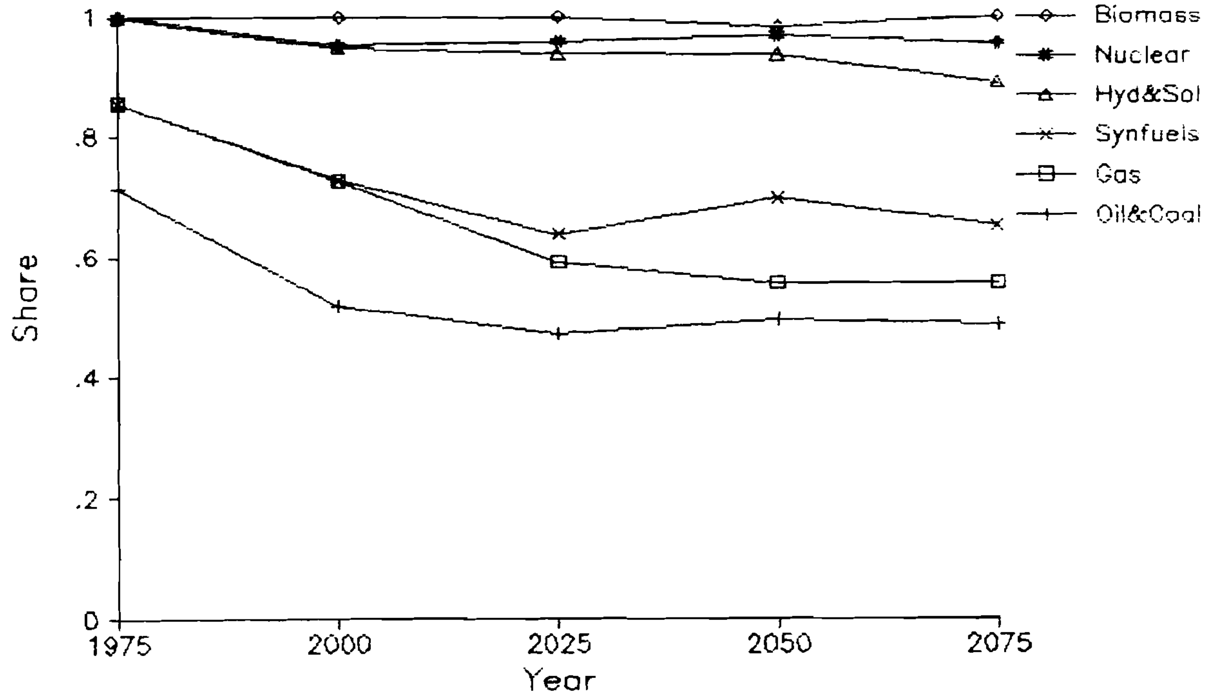

Figure 3.12 Fuel mix - Latin America

(980 million).

The general development of Latin America is well characterized by the agricultural sector. The production between 1975 and 2075 is increased by 470% or 90% per capita (Table 2.4). The arable land is increased by 54% (Figure 3.11). Grazing lands expand by 16% primarily due to the fact that after deforestation the lands are initially used as grazing lands before being converted into cropland. 30% of the forests disappear. In this sensitive process much land is degraded, with "other lands" increasing by 49%. Intensification is even more important for the growth of production. Both irrigation and fertilizer use increase significantly (Table 2.3).

Total energy use grows from 0.4 to 4 TW or from 1.2 to 4.1 kW per person (Figure 2.5). The use of non-fossil fuels is more important than in other regions reaching 35% in 2075 (Figure 3.12). The production of hydro energy shows decreasing market shares towards 2075. Latin America, once a major energy exporter is by 2075 one of the leading interregional importers (Table 2.1).

3.5. Africa

Africa consists of two sub-regions, the Near East and 'Black Africa', which have totally different initial conditions in terms of population, resources and economic wealth. Both have high economic growth, but the growth in GDP per capita is higher in the northern part because of lower population growth and rich capital and natural resources. The region as a whole shows a development pattern similar to that of Latin America, except for the fact that Africa has even more abundant resource-base, e.g. for energy (Figure 3.13).

Population grows from 541 million in 1975 to 1631 in 2025 (2.2%/year) and 2010 million by 2075 (0.4%/year between 2025 and 2075) (Figure 2.2). Though this indicates a radical decrease in population growth during the decades around 2025, it takes place later than in other regions and thus Africa has the highest relative population growth.

Agricultural production is increased by 640% (Table 2.4). There are substantial increments in all factors that are important to production growth (Table 2.2). The cropland area is increased by 49% (Figure 3.14), mainly derived from grazing lands, which decrease by 20%. Animal husbandry is intensified and moved into other areas. Land, presently unsuitable for grazing (e.g. lands infected by the Tse-tse fly), are opened up by control measures. Forests diminish by 28% and "other lands" grow by 17%.

Energy consumption grows from 0.5 to 5.0 TW in total and from 0.8 to 2.5 kW per person (Figure 2.5). Until 2050 Africa is the dominating interregional exporter. About half of the production is exported to other regions. Most of the expansion takes place south of the Sahara. During the last 25-year period the resources become scarcer. Exports are cut by 2/3 (Table 2.1). The production of non-fossil energy (particularly hydro and solar) is expanded and from a very stable fossil share of 80%, Africa is down at 68% by 2075 (Figure 3.15).

3.6. USSR

The USSR has a relatively slow growth. The population grows from 255 to 400 million (0.5%/year) (Figure 2.2 and Figure 3.16). There is, however, a breakthrough for Soviet agriculture (Tables 2.1 - 2.3). Production is multiplied 5 times (3.2 time per capita). This is mainly a consequence of higher inputs. The cropland area is expanded by 15%, particularly by transformation of forests and swamps. The 8% increase of "other lands" is a result of problems caused by extremely high inputs in agriculture, e.g., salinization and pollution of soils (Figure 3.17).

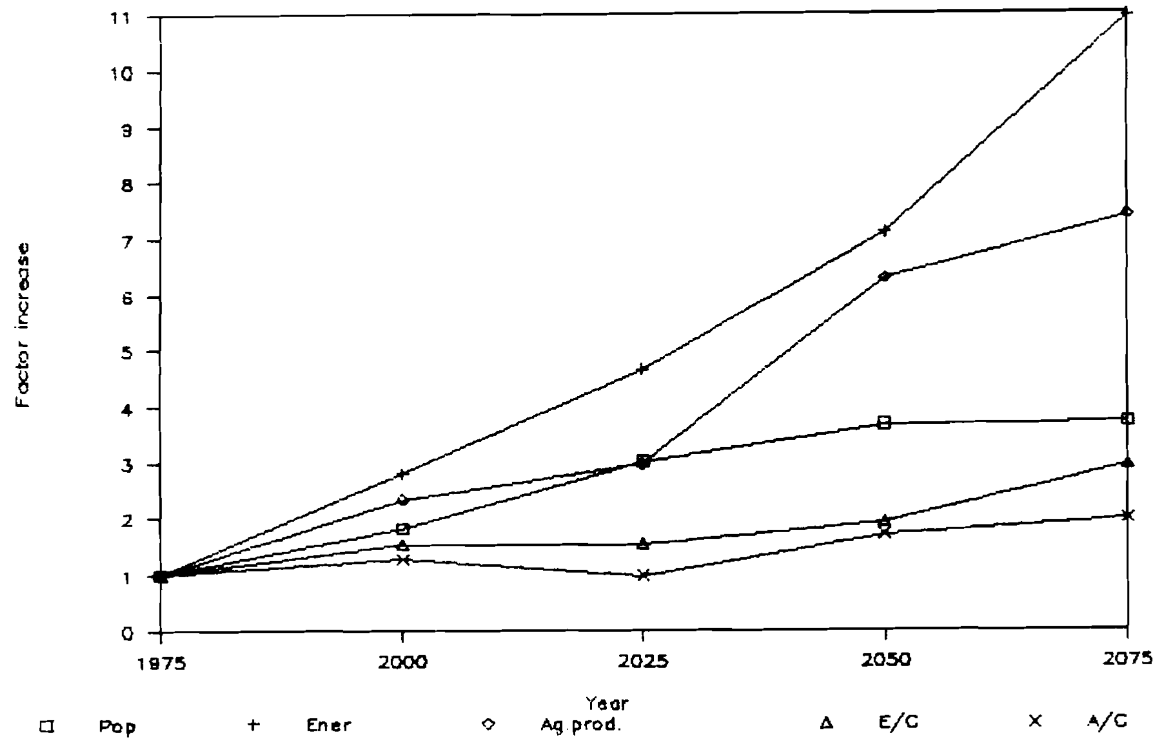

Figure 3.13 General development - Africa

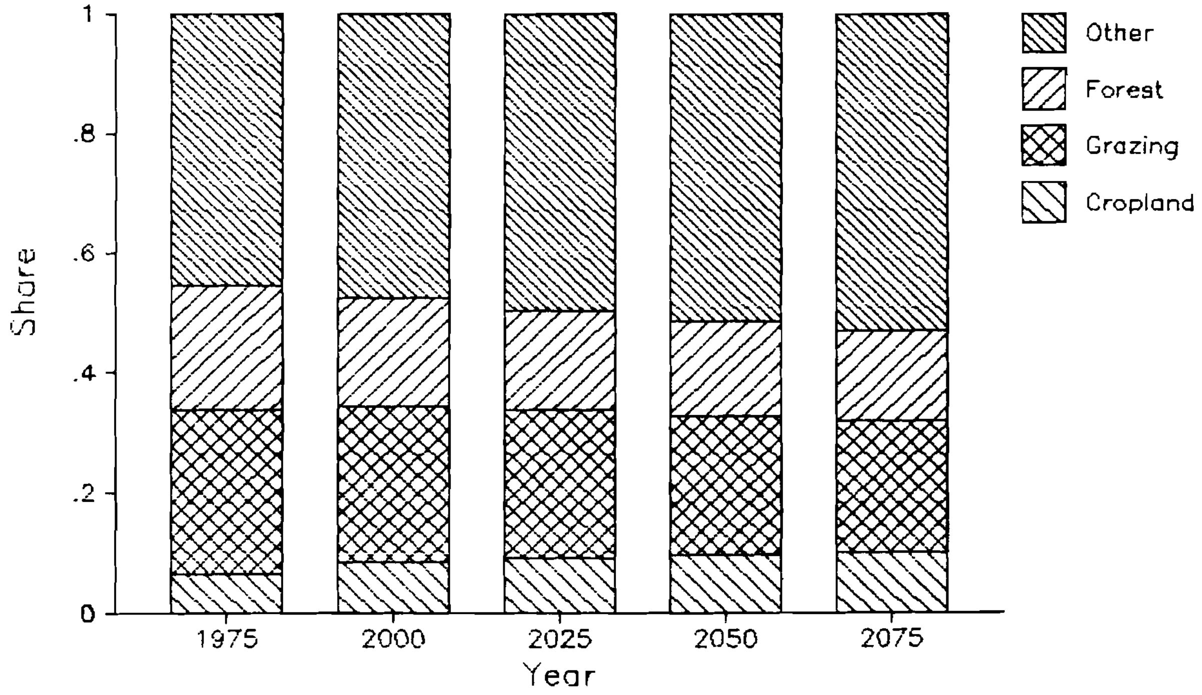

Figure 3.14 Land use change - Africa

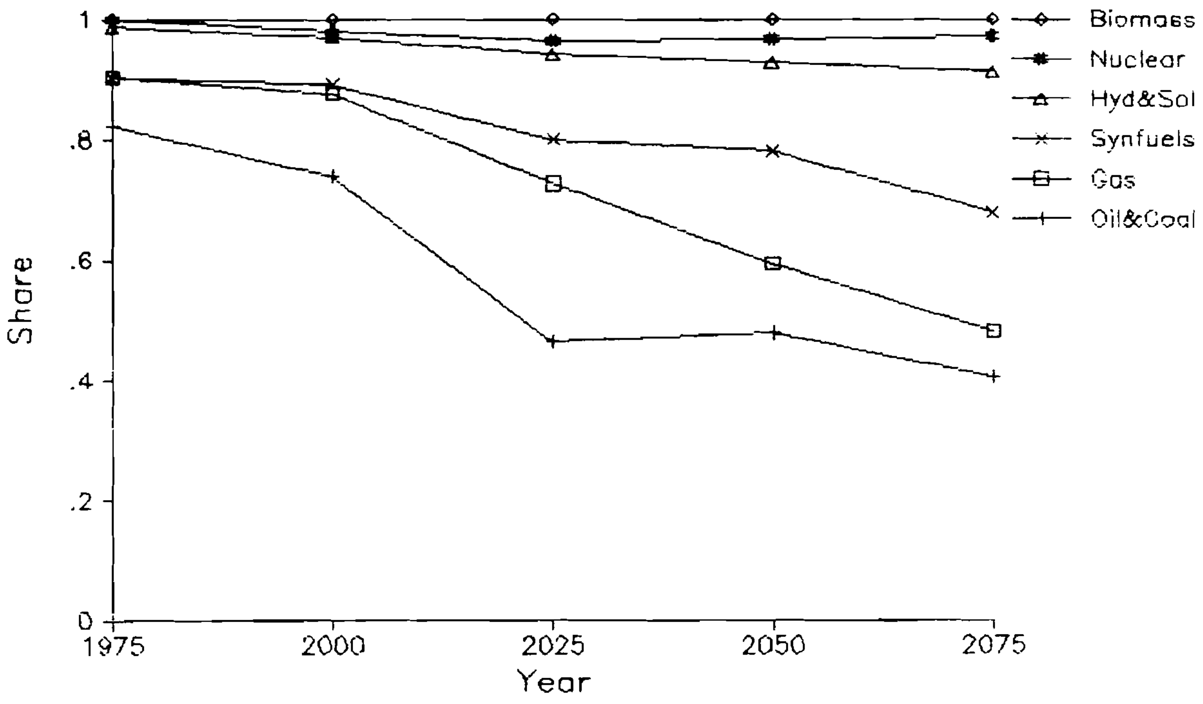

Figure 3.15 Fuel mix - Africa

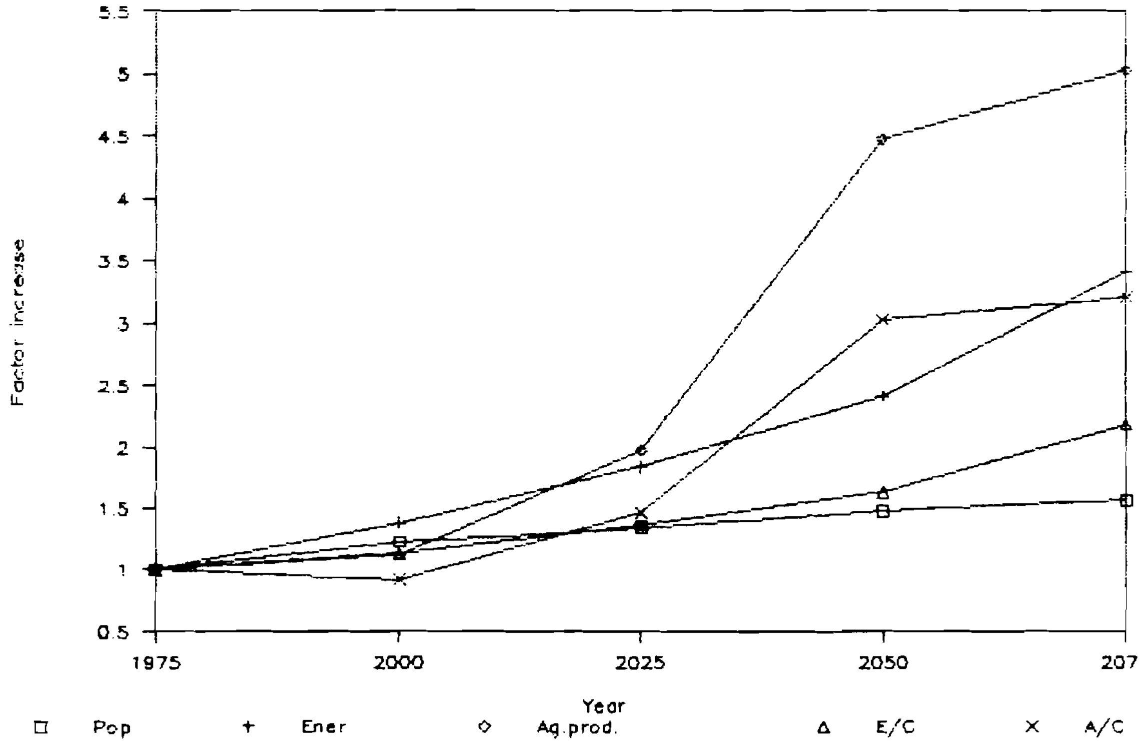

Figure 3.16 General development - USSR

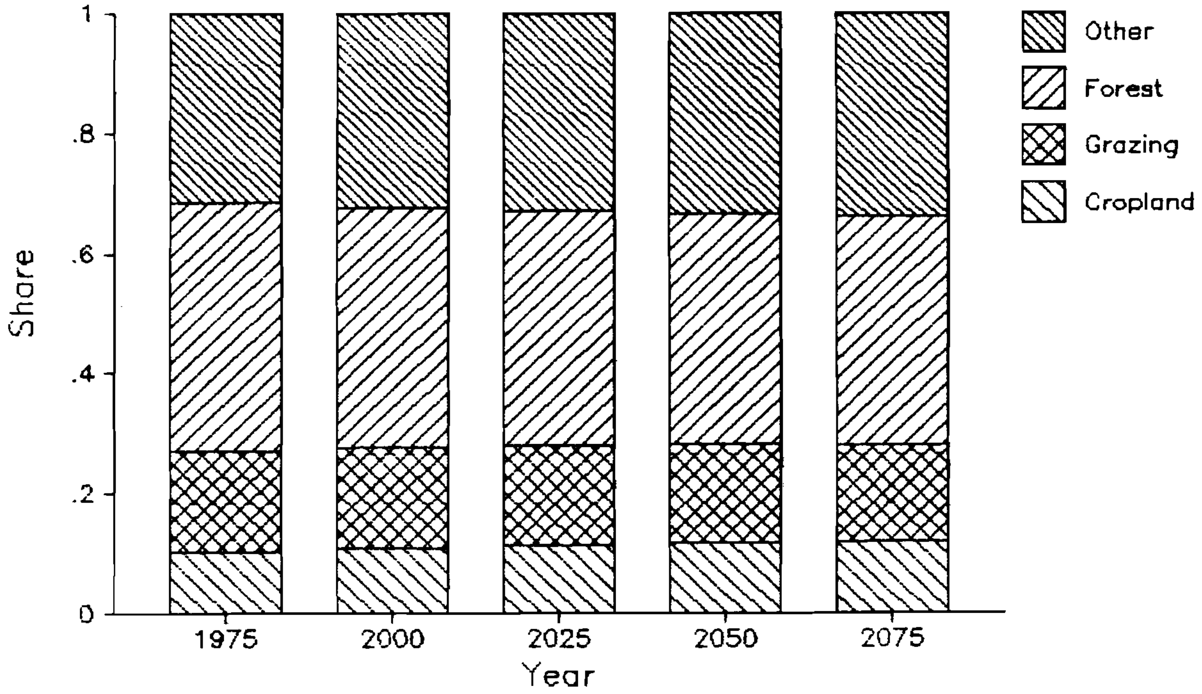

Figure 3.17 Land use change - USSR

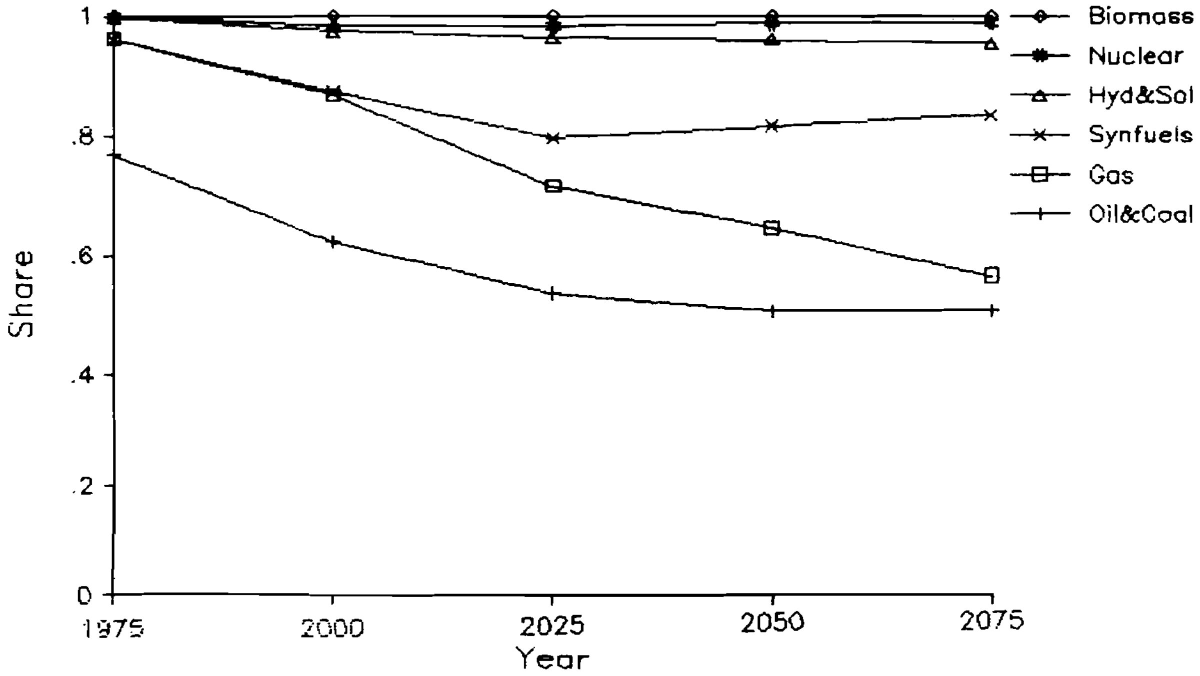

Figure 3.18 Fuel mix - USSR

Energy consumption grows from 1.2 to 3.9 TW in total and from 4.5 to 9.8 kW per person (Figure 2.5). Energy efficiency progresses, production grows faster than consumption and the USSR becomes one of the leading exporters. The use of fossils is very important, 83%. Nuclear power use is moderate (Figure 3.18).

3.7. East Asia

This is probably the most heterogeneous region. Japan is a highly developed country at the same level as Oceania. With 3-5% of the region's population it consumes 34-35% of the energy. It is the most densely populated region with 3 billion people in 2075 (Figure 2.2 and Figure 3.19). Population growth is a bit slower, 0.8%/year, than in the other dominantly developing regions.

Agricultural production is augmented by 300%, 70% per capita (Table 2.4). In 2075, after a 20% increase in the cropland area, practically all potentially arable land is used in production. This is possible due to the introduction of crops adapted to salt affected soils. 34% of the cropland is irrigated in 2075 (Table 2.3). "Other lands" grow by 6%, mainly caused by salinization. The forests loose 14% of their area while grazing lands are unchanged (Figure 3.20).

Energy consumption grows from 1.1 to 11.2 TW in total and from 0.9 to 3.8 kW per person (Figure 2.5). The region becomes a leading energy exporter primarily because of increased exploitation of the rich fossil sources of China (Table 2.1). The fossil fuel use is dominant, with 82% of the market in 2075. The share of synfuels is important, 28% (Figure 3.21).

3.8. Oceania

Oceania has a relatively small population (e.g. only about 1% of the East Asian). Population grows from 17 million to 30 million (0.6%/year) (Figure 2.2 and Figure 3.22).

Agricultural production increases by 180% (Table 2.4). There are only minor changes in land use (Figure 3.23). Some dry areas are made productive by the use of more drought resistant crops. The "other lands" increase by 12%, mainly due to desertification. The use of fertilizer is lower than in any other region despite a significant increase from 29 to 70 kg/ha (Table 2.3).

Energy consumption grows from 0.07 to 0.64 TW in total and from 4.1 to 21.3 kW per person (Figure 2.5). The energy sector is dominated by the fossil fuels which have a market share of 84%. The coal and gas resources are rich. Solar energy is rather undeveloped but rapidly expanding by 2075 (Figure 3.24).

4. Commentary

Every scenario must, if it is to be used critically, be anchored in the experiences of the past and present. In this section, the assumptions and questionable points of the scenarios will be brought into light. I will try to discuss, clarify, and, if possible, justify them.

4.1. Some major problematic points in this scenario are:

Agriculture

The intention behind the agricultural scenario was explicitly to portray a possible, but very optimistic development. There are, of course, many objections to raise against its credibility, which we acknowledge. Among the most severe problems to solve are the

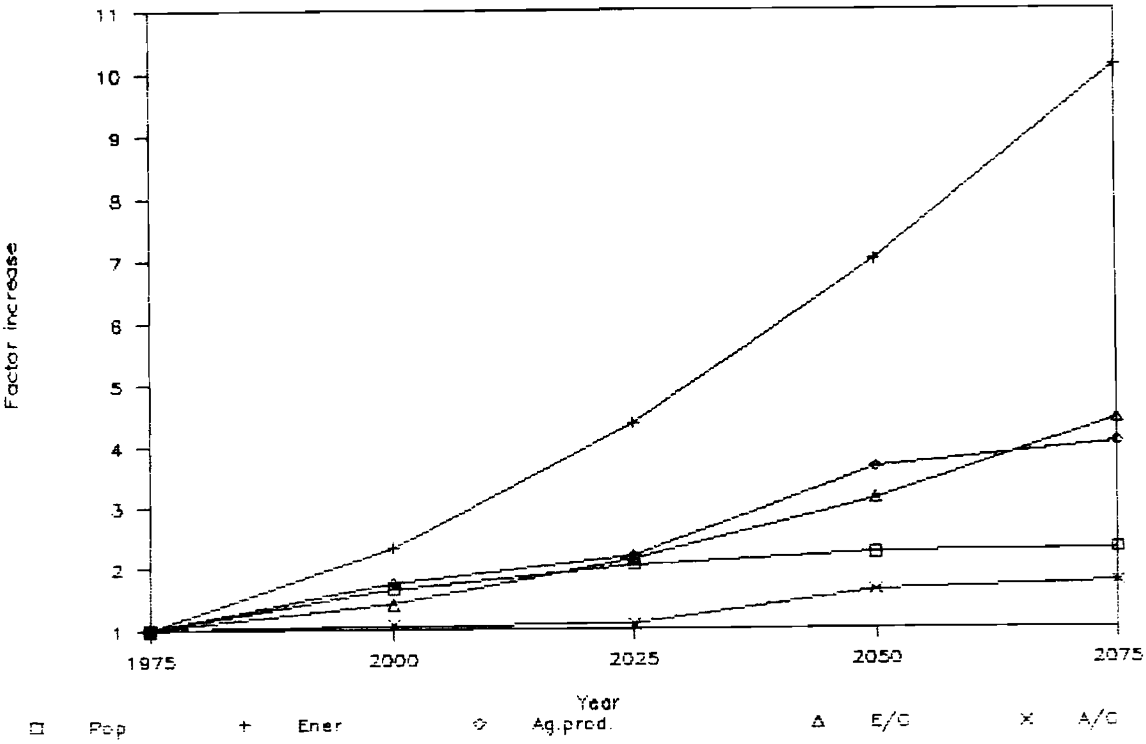

Figure 3.19 General development - East Asia

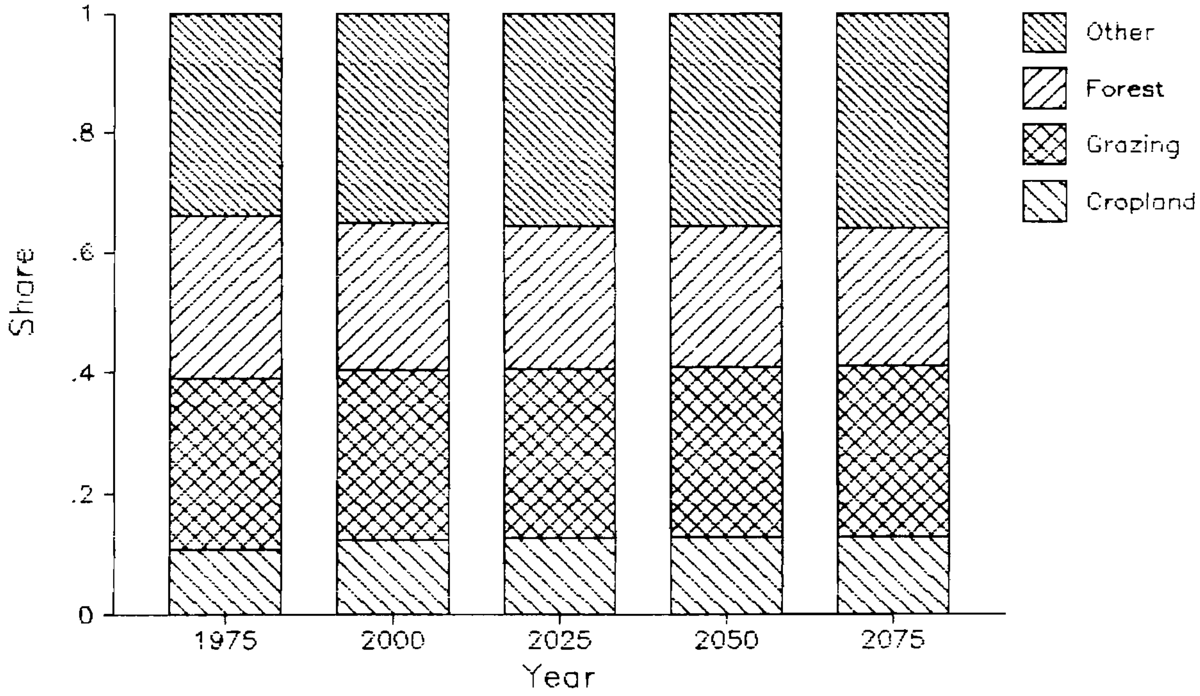

Figure 3.20 Land use change - East Asia

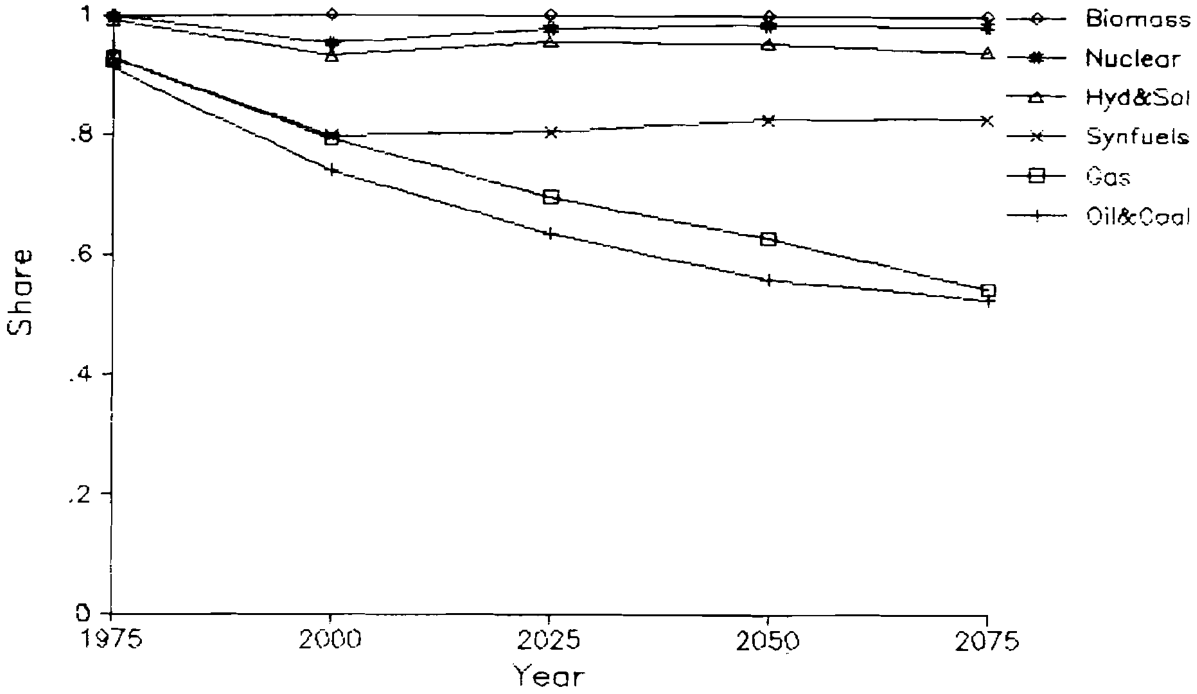

Figure 3.21 Fuel mix - East Asia

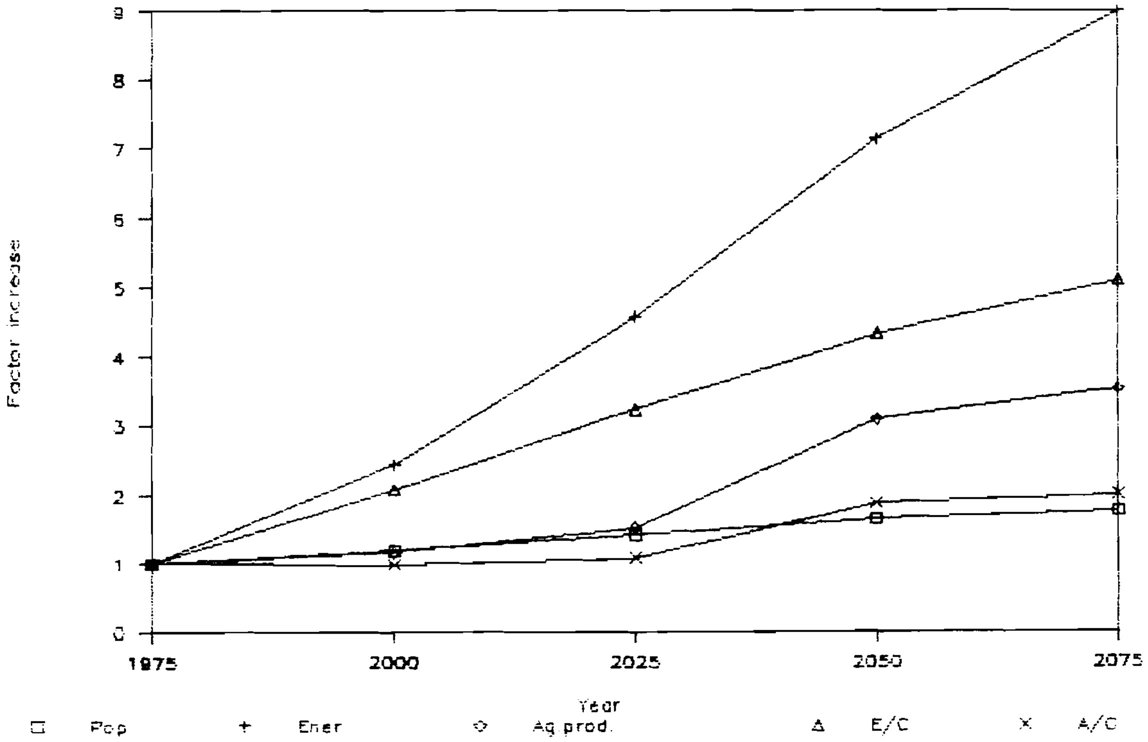

Figure 3.22 General development - Oceania

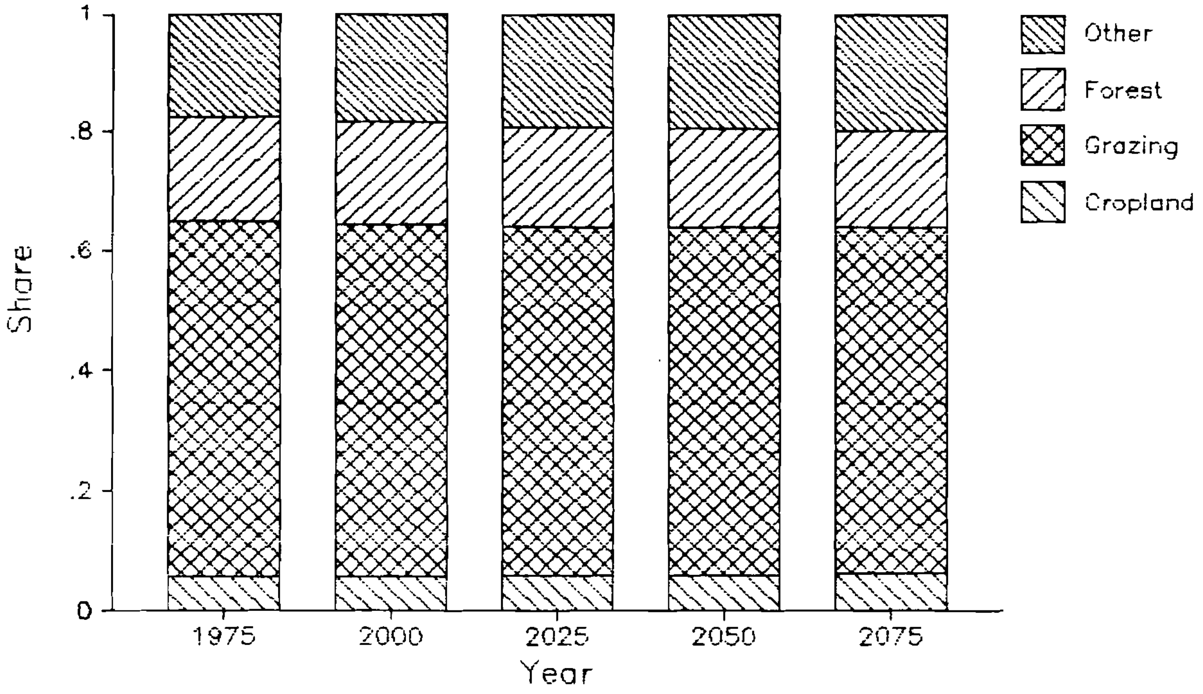

Figure 3.23 Land use change - Oceania

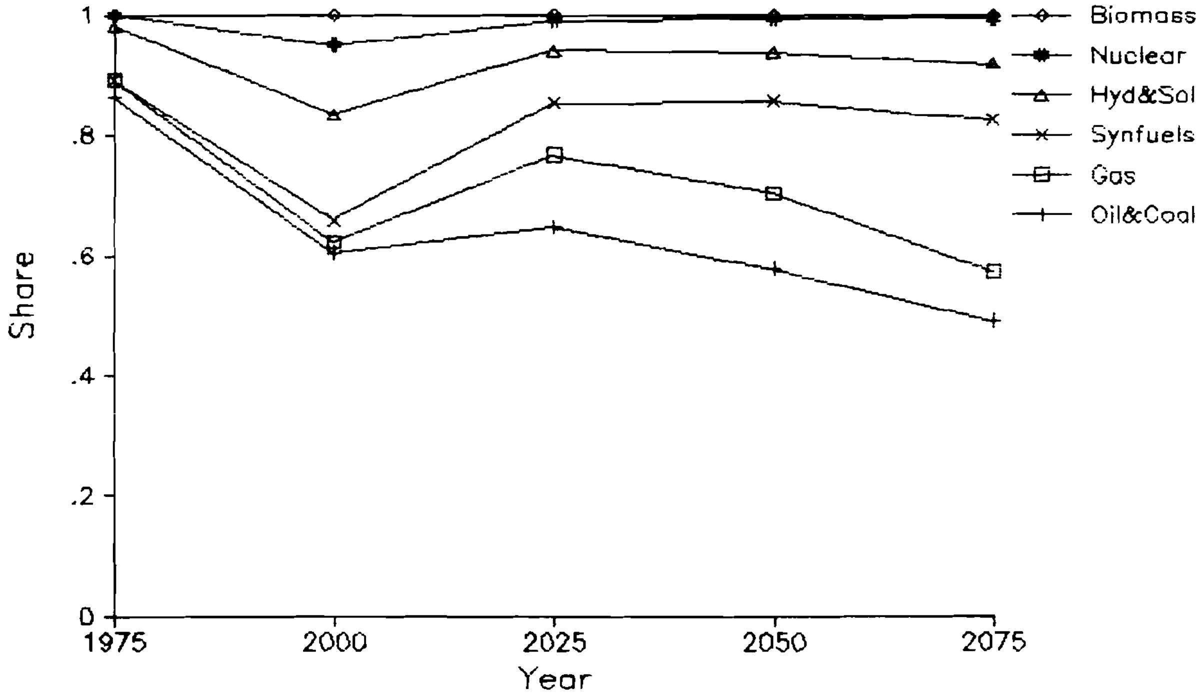

Figure 3.24 Fuel mix - Oceania

lack of water and fertilizer (especially phosphates) resources. This scenario demands radical improvement in water management, large scale desalinization and recycling of nutrients.

The distribution of growth between North and South

We would like to see a more balanced development between North and South. However, if we look at present trends, there are no signs of such development taking place. To decrease the gap would probably presuppose a different global economic system and a conscious policy among countries with this goal in mind. We cannot yet discern any important steps in this direction.

Is there an upper limit to growth in the industrialized world?

It is of course very hard to imagine a society that consumes 3-4 times more energy than North America today, but such a scenario would have been considered as a low forecast only a few years ago.

The fuel mix: continued dominance of fossil fuels.

Coal is assumed to be unlimited during the next hundred years and the only constraint is the capacity of production increase that is assumed to be 2.9% per annum. The coal supply assumption is among the most sensitive variables in the Edmonds and Reilly model. This means that even small changes in fuel prices would change the fuel mix significantly. Further objections could also be raised against this assumption:

- Producing these amounts of coal would perhaps be more expensive than is expected in terms of energy losses as well as in terms of investment and environmental costs.
- Alternative technologies might develop more rapidly than expected and be better able to compete.

But the fact that today coal is the only fuel that can replace oil and gas is a strong argument for radical increases in coal use in the future.

Feed-backs from the environment are missing

An important objection to this scenario is the lack of feed-backs such as severe environmental problems, which could demand actions that would radically alter economic development. These are left out primarily because the intention behind these scenarios is to sketch alternative socioeconomic developments and their environmental implications are the task for the studies in which they will be used. But it is not easy to include such feed-backs in any model. This is, for example, because:

- We do not yet know enough about long-term environmental impacts. We cannot tell what the impacts will be, for example, of increasing concentrations of greenhouse gases or where, when and how they will be felt. Therefore it would not be plausible to define actions that could be taken to meet such problems.
- History does not provide examples of international actions which have been taken to solve environmental problems, and which have radically changed or restrained economic development.

4.2. Some environmental implications of this scenario

To sum up, there is no doubt that this scenario is an optimistic one as far as economic development is concerned. Whether it is an over- or underestimation of the actual course is not important as long as it can be believed possible. It is more interesting to investigate possible environmental consequences of a scenario of economic development. Such an exercise is likely to lead to a better assessment of the range of environmental implications of alternative future paths of economic development.

If development were to take place as described in this scenario, then what would be the impacts on the natural environment in the future? What would be the major environmental problems?

Concentrations of population are associated with severe environmental stresses. Densely populated parts of the world coincide with high energy use and often with intensive agriculture. The most critical areas are likely to be the city agglomerations in the Third World which will grow rapidly over the next 50 years. These areas are also likely to be the focus of problematic competition for land between urban and non-urban activities.

In connection with agriculture the most severe problems would probably then be:

- Soil degradation, by e.g. desertification, erosion, salinization, and pollution, often caused by severe pressure on soil resources and inappropriate agricultural methods. These problems are likely to be most severe in Latin America, Africa, and Oceania.
- The use of biocides and fertilizers. Agricultural development in this scenario is based on radical increases in inputs such as biocides and fertilizers. The consequences of these would be a diffusion of problems such as increased rates of non-biodegradable chemical substances in the environment, eutrophication of lakes and seas, etc.
- Competition for scarce resources, in particular for land and water.

The stresses sketched out above would probably evolve from strictly local problems into regional ones. In such a way, localized eutrophication of lakes and coastal waters has evolved into a regional problem of environmental disruptions of whole marine ecosystems such as the Baltic and the North Seas.

The environmental cost of the sixfold increase in energy use can be expected to be fairly high and to a large extent connected to the high use of fossil fuels. The burning of fossil fuels would increase five times and the fuels used, mostly coal and shale oil, are likely to be far more polluting throughout their cycle of use than the fuels used today. Even if coal burning technology is vastly improved, there are still likely to be serious environmental problems connected to such expansion. At the local level many new coal fields would have to be developed, particularly in Siberia, China, Africa, Australia, and North America. These would utilize vast amounts of land and water resources which are already scarce in many parts of the world. At the regional level acidification of land and water is already an alarming problem in developed regions and is beginning to appear in developing regions. Globally the most important environmental impact is likely to result from the increasing concentration of greenhouse gases (CO_2, NO_x, etc.). These are predicted to more than double over the next hundred years. It is possible that severe effects of some climate change will have been experienced by 2075. The environmental impacts of other fuels are likely to be less extensive, but not necessarily less important. Very few rivers are likely to escape hydro-electric expansion and twenty times more nuclear power would bring increased risks for accidents and proliferation of nuclear arms.

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APPENDIX

Supporting tables for the Conventional Wisdom scenario

Table A1. Conventional wisdom scenario for population

	Population (10e6)					Factor increase (1975=1)				Growth rate			
Regions	1975	2000	2025	2050	2075	2000	2025	2050	2075	2000	2025	2050	2075
North America	237	288	324	340	350	1.2	1.4	1.4	1.5	1.22	1.13	1.05	1.03
Latin America	322	569	785	942	980	1.8	2.4	2.9	3	1.77	1.38	1.20	1.04
Europe	472	538	592	641	690	1.1	1.3	1.4	1.5	1.14	1.10	1.08	1.08
Africa	541	987	1631	1983	2010	1.8	3	3.6	3.7	1.82	1.65	1.22	1.01
USSR	255	312	343	377	400	1.2	1.3	1.5	1.6	1.22	1.10	1.10	1.06
South Asia	832	1521	1873	2170	2560	1.8	2.3	2.6	3.1	1.83	1.23	1.16	1.18
East Asia	1300	2139	2644	2904	2980	1.6	2	2.2	2.3	1.65	1.24	1.10	1.03
Oceania	17	20	24	28	30	1.2	1.4	1.6	1.8	1.18	1.20	1.17	1.07
World	3976	6374	8216	9385	10000	1.6	2.1	2.4	2.5	1.60	1.29	1.14	1.07

Table A2. Energy consumption per capita (kW)

Regions	1975	2000	2025	2050	2075
North America	9.87	11.91	14.75	20.32	28.51
Latin America	1.18	1.99	2.85	3.50	4.08
Europe	5.21	6.00	10.22	13.53	16.49
Africa	.83	1.33	1.31	1.64	2.51
USSR	4.51	5.10	6.15	7.37	9.80
Asia-South	.25	.37	.54	.79	.84
Asia-East	.85	1.21	1.83	2.67	3.76
Oceania	4.12	8.50	12.92	17.86	21.33
World	2.05	2.20	2.79	3.65	4.83

Table A3a. Energy consumption

	North Am	Latin Am	Europe	Africa	USSR	Asia-Sou	Asia-Eas	Oceania	World
1975									
Population mio	237	322	472	541	255	832	1300	17	3976
Energy/cap kW	9.87	1.17	5.21	0.83	4.52	0.26	0.86	4.07	2.057092
Oil&Coal TW	1.5	0.27	1.94	0.37	0.89	0.18	1.01	0.06	6.22
Gas TW	0.64	0.05	0.2	0.04	0.22	0.01	0.02	0.002	1.182
Synfuels TW	0	0	0	0	0	0	0	0	0
Hydro&Solar TW	0.13	0.05	0.25	0.04	0.04	0.02	0.07	0.01	0.61
Nuclear TW	0.07	0.001	0.07	0.01	0.004	0.001	0.01	0.001	0.167
Biomass TW	0	0	0	0	0	0	0	0	0
Total TW	2.34	0.371	2.46	0.46	1.154	0.211	1.11	0.073	8.179
2000									
Population	288	569	538	987	312	1521	2139	20	6374
Energy/cap kW	11.9	1.98	6.01	1.33	5.11	0.37	1.21	8.35	2.20
Oil&Coal TW	2.1	0.59	1.6	0.97	0.99	0.27	1.91	0.1	8.53
Gas TW	0.74	0.23	0.65	0.18	0.39	0.12	0.14	0.003	2.45
Synfuels TW	0.03	0.002	0.06	0.02	0.009	0	0.02	0.006	0.15
Hydro&Solar TW	0.25	0.25	0.55	0.09	0.16	0.11	0.35	0.03	1.79
Nuclear TW	0.25	0.006	0.24	0.01	0.01	0.003	0.05	0.02	0.59
Biomass TW	0.06	0.07	0.14	0.02	0.03	0.06	0.11	0.008	0.50
Total TW	3.43	1.15	3.24	1.29	1.59	0.56	2.58	0.17	14.01
2025									
Population	324	785	592	1631	343	2091	2644	24	8434
Energy/cap kW	14.76	2.85	10.23	1.3	6.14	0.54	1.82	12.96	2.79
Oil&Coal TW	3	1.06	3.08	0.99	1.13	0.55	3.06	0.2	13.07
Gas TW	0.82	0.27	1.38	0.56	0.38	0.06	0.29	0.04	3.80
Synfuels TW	0.32	0.11	0.42	0.16	0.17	0.12	0.52	0.03	1.85
Hydro&Solar TW	0.42	0.67	0.82	0.3	0.35	0.3	0.73	0.03	3.62
Nuclear TW	0.19	0.05	0.27	0.05	0.04	0.02	0.11	0.02	0.75
Biomass TW	0.04	0.08	0.08	0.08	0.04	0.08	0.11	0.003	0.51
Total TW	4.79	2.24	6.05	2.14	2.11	1.13	4.82	0.32	23.57
2050									
Population	340	942	641	1983	377	2386	2904	28	9601
Energy/cap kW	20.33	3.5	13.53	1.64	7.38	0.79	2.67	17.75	3.65
Oil&Coal TW	4.2	1.63	4.53	1.56	1.4	0.96	4.33	0.29	18.90
Gas TW	0.82	0.2	1.05	0.38	0.39	0.01	0.53	0.06	3.44
Synfuels TW	1	0.47	1.23	0.6	0.47	0.42	1.53	0.08	5.80
Hydro&Solar TW	0.54	0.79	1.18	0.48	0.4	0.35	0.99	0.04	4.77
Nuclear TW	0.33	0.11	0.61	0.13	0.07	0.05	0.24	0.03	1.57
Biomass TW	0.04	0.1	0.06	0.11	0.04	0.09	0.13	0.003	0.57
Total TW	6.93	3.30	8.66	3.26	2.77	1.88	7.75	0.50	35.05
2075									
Population	350	980	690	2010	400	2560	2980	30	10000
Energy/cap kW	28.51	4.08	16.49	2.51	9.79	0.84	3.76	21.29	4.83
Oil&Coal TW	5.81	1.95	4.93	2.05	1.98	1.02	5.88	0.31	23.93
Gas TW	0.57	0.27	1.05	0.39	0.23	0.07	0.2	0.05	2.83
Synfuels TW	2.18	0.38	2.51	0.99	1.06	0.33	3.18	0.16	10.79
Hydro&Solar TW	0.78	0.95	1.68	1.18	0.47	0.44	1.26	0.06	6.82
Nuclear TW	0.57	0.26	1.11	0.29	0.13	0.14	0.49	0.05	3.04
Biomass TW	0.05	0.18	0.09	0.14	0.05	0.16	0.19	0.004	0.86
Total TW	9.96	3.99	11.37	5.04	3.92	2.16	11.20	0.63	48.27

Table A3b. Fuel mix (%)

	North Am	Latin Am	Europe	Africa	USSR	Asia-Sou	Asia-Eas	Oceania	World
	1975								
Oil&Coal	64.1	71.4	78.9	82.1	76.9	86.3	91.0	86.2	76.0
Gas	27.4	14.1	8.1	8.1	19.2	4.7	1.8	3.0	14.5
Synfuels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro&Solar	5.6	14.2	10.2	8.4	3.5	8.6	6.3	8.9	7.5
Nuclear	3.0	0.3	2.8	1.3	0.4	0.4	0.9	1.9	2.0
Biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	99.9	100.0	100.0	100.0	100.0	100.0
	2000								
Oil&Coal	61.2	51.4	49.4	75.2	62.3	48.0	74.0	59.9	60.9
Gas	21.6	20.0	20.1	14.0	24.5	21.3	5.4	1.8	17.5
Synfuels	0.9	0.2	1.9	1.6	0.6	0.0	0.8	3.6	1.0
Hydro&Solar	7.3	21.8	17.0	7.0	10.1	19.5	13.6	18.0	12.8
Nuclear	7.3	0.5	7.4	0.8	0.6	0.5	1.9	12.0	4.2
Biomass	1.7	6.1	4.3	1.6	1.9	10.7	4.3	4.8	3.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	2025								
Oil&Coal	62.6	47.3	50.9	46.3	53.6	48.7	63.5	64.8	55.5
Gas	17.1	12.1	22.8	26.2	18.0	5.3	6.0	12.0	16.1
Synfuels	6.7	4.9	6.9	7.5	8.1	10.4	10.8	8.6	7.8
Hydro&Solar	8.8	29.9	13.6	14.0	16.6	26.6	15.1	8.8	15.4
Nuclear	4.0	2.0	4.5	2.3	1.9	1.8	2.3	5.0	3.2
Biomass	0.8	3.6	1.3	3.7	1.9	6.8	2.3	0.9	2.2
Total	100.0	99.8	100.0	100.0	100.0	99.6	100.0	100.1	100.1
	2050								
Oil&Coal	60.6	49.4	52.3	47.9	50.5	51.1	55.9	57.7	53.9
Gas	11.8	6.1	12.1	11.7	14.1	0.5	6.8	11.9	9.8
Synfuels	14.4	14.2	14.2	18.4	17.0	22.3	19.7	15.9	16.5
Hydro&Solar	7.8	23.9	13.6	14.7	14.4	18.6	12.8	8.0	13.6
Nuclear	4.8	3.3	7.0	4.0	2.5	2.7	3.1	6.0	4.5
Biomass	0.6	3.0	0.7	3.4	1.4	4.8	1.7	0.6	1.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	2075								
Oil&Coal	58.3	48.9	43.4	40.7	50.5	47.2	52.5	48.9	49.6
Gas	5.7	6.8	9.2	7.7	5.9	3.2	1.8	7.9	5.9
Synfuels	21.9	9.5	22.1	19.6	27.0	15.3	28.4	25.2	22.4
Hydro&Solar	7.8	23.8	14.8	23.4	12.0	20.4	11.3	9.5	14.1
Nuclear	5.7	6.5	9.8	5.8	3.3	6.5	4.4	7.9	6.3
Biomass	0.5	4.5	0.8	2.8	1.3	7.4	1.7	0.6	1.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A4. Land use change

(million ha)		Area of cropland			Grazing lands			Forest			Other lands		
	Total land area	1975	2075	Ratio	1975	2075	Ratio	1975	2075	Ratio	1975	2075	Ratio
North America	1835	232	220	0.95	265	220	0.83	617	606	0.98	721	789	1.09
Latin America	2020	157	242	1.54	539	626	1.16	1040	727	0.70	284	424	1.49
Europe	473	142	128	0.90	88	57	0.65	154	171	1.11	90	118	1.31
Africa	3648	245	365	1.49	985	803	0.82	761	547	0.72	1656	1933	1.17
USSR	2227	232	267	1.15	374	356	0.95	920	846	0.92	701	757	1.08
South Asia	479	211	220	1.04	21	19	0.90	114	101	0.89	134	139	1.04
East Asia	1561	170	204	1.20	441	437	0.99	419	359	0.86	530	560	1.06
Oceania	798	44	48	1.09	472	463	0.98	140	128	0.91	143	160	1.12
TOTAL	13041	1433	1694	1.18	3185	2981	0.94	4165	3485	0.84	4259	4880	1.15
(percent)													
North America		12.6	12.0		14.4	12.0		33.6	33.0		39.3	43.0	
Latin America		7.8	12.0		26.7	31.0		51.5	36.0		14.1	21.0	
Europe		30.0	27.1		18.6	12.1		32.6	36.2		19.0	24.9	
Africa		6.7	10.0		27.0	22.0		20.9	15.0		45.4	53.0	
USSR		10.4	12.0		16.8	16.0		41.3	38.0		31.5	34.0	
South Asia		44.1	45.9		4.4	4.0		23.8	21.1		28.0	29.0	
East Asia		10.9	13.1		28.3	28.0		26.8	23.0		34.0	35.9	
Oceania		5.5	6.0		59.1	58.0		17.5	16.0		17.9	20.1	
TOTAL		11.0	13.0		24.4	22.9		31.9	26.7		32.7	37.4	

Chapter 6

Surprise-Rich Scenarios for Global Population, Energy, and Agriculture 1975-2075

Stefan Anderberg

1. INTRODUCTION

A surprising future development - what would that be?

The answer to this question depends of course on *who* answers it. In this report, three scenarios for global socioeconomic development over 1975-2075 are presented. They are deliberately intended to describe somewhat surprising or unconventional paths into the future and therefore be useful as alternatives to standard "conventional wisdom" projections for the study of possible future developments. These scenarios are the result of efforts within IIASA's project on "Ecologically Sustainable Development of the Biosphere" and are based on the output of an international workshop that was held in Sweden, January 1986 (Svedin and Aniansson, 1987).

1.1. Aims of the Report

The major aims of this report are:

(1) To present three consistent, well elaborated, but highly unconventional scenarios, that describe somewhat speculative or surprising futures, and which can be used in different studies of long-term, large-scale interactions between socioeconomic development and the environment As a background and frame of reference to these developmental paths, a "Conventional Wisdom Scenario" (see Chapter 5 in this volume), has been used.

(2) To present a discussion on the whole procedure of creating these scenarios: the basic ideas, theories and attitudes towards historical change and development and possible "surprises", major problems in the different scenario frameworks, possible variants, and numerical representations. Thus this report makes an effort to contribute to a more general discussion on the construction, presentation and use of scenarios.

1.2. Structure of the Report

Section 2 entitled "Background" contains a short review of future history genres in the past, some modern definitions of the term "scenario", an introduction to basic terminology, and some examples of different types of scenarios in modern futures research.

In Section 3, "The scenario construction", the aims of scenarios in general and within development-environment studies in particular are focused upon and a background of the presented scenarios is given.

The three scenarios are then presented in Section 4 with summaries and numerical representations of the various developments. Then, some further explanations are given for the basic assumptions, views and rationale that guided the scenario writing and the numerical elaborations.

The "Summarizing Final Discussion" contains a discussion on the whole scenario construction process, methods, styles of presentation, and the value of the whole exercise.

2. BACKGROUND: SCENARIOS FOR THE FUTURE

2.1. Future Histories in the Literature

Writing about the future is a literary form with old traditions. We can trace it back to Sir Thomas More in the 16th century, if not even further; Plato's "The Republic" from the 4th century B.C. or some parts in the Bible could serve as good examples. This literature is of course quite varied. The Swedish historian of ideas Tore Frangsmyr (1980) discerns eight main genres of futuristic literature:

1) Critiques of the present: the major aim of the authors is to criticize their own society or certain tendencies in their present by painting a picture of a future state of society. In this group we can find, for example, More, Huxley and Orwell.
2) Plays with thought: technological wonders, travels in space or to the inner parts of the earth. This category comprises most of the science fiction literature.
3) Religious prophecies: this is an extensive group of religious and mystical forms of predictions.
4) Interpretations of signs in nature: refers primarily to astrology and "traditional practical life wisdom" (e.g. weather forecasting). But here Frangsmyr poses the question of whether modern warnings of environmental degradation could not also be sorted into this category. If so, "signs of nature" have, thus, changed from superstition to science.
5) Political ideologies: these almost always refer to the future. One could perhaps break out ideologically based utopias as a subgroup.
6) Historical analogies: the future is predicted by pointing out similarities between the present and some historical situation. This branch is not as strong as it used to be, but remains influential.
7) Theoretical constructions for making predictions: this means all efforts through the ages to find an exact method to predict the future. It started with Raimundus Lucullus in the 13th century and has continued with a long string of mystics and mathematicians among whom the most well-known are Leibniz, who tried to find such a mathematical language; Swedenborg; Christian Wolff, who tried with conventional language; and Comte, who with his positivistic system aimed not only to predict, but to govern development. Computer models can be perceived as part of this tradition, at least as it has been used in some modern studies.
8) Empirical efforts to describe future development through prognoses and calculations. These are closely related with the former group. The difference is that they do not pretend to be able to predict the future.

This categorization of futuristic literature is of course not indisputable. Some of the groups are questionable and many books and studies fall between the categories. The reason to present this short review here is, however, to get a valuable historical perspective on modern future history writing. This perspective makes it clear that it is not only in our time that thinking about the future has been in vogue and it might help us to question what we are doing and to clarify intentions, thoughts and procedures and perhaps unveil some of our time-bound and cultural biases. It is also possible that, since this literature is a part of our culture, we are quite influenced by it. We might also have things to learn from this rich array of literature on entertaining ways of presentation, imagination and the view of the possible during various historical epochs. These points will be interesting to return to later.

It is important to note that the that best future studies can do is to explore alternative possible future developments. By such exercises we can hope to bring a useful perspective on the present situation and the problems we are facing today and perhaps the problems of tomorrow. But we can never predict the future.

2.2. What is a Scenario ? - Some Alternative Definitions

Scenario is a term that has become increasingly popular. In future studies Herman Kahn was perhaps the first to introduce it (Wilson, 1976). He has defined scenario as "a hypothetical sequence constructed for the purpose of focusing attention on causal processes and decision points" (Kahn and Wiener, 1967). That scenarios are always hypothetical seems not be a point of controversy, but is still important to emphasize.

Through frequent use, the meaning of scenario seems to have become increasingly broad and vague. Wilson (1978) first describes scenarios as "essentially stories", then defines a scenario as "an exploration of alternative futures" or "an outline of one conceivable state of affairs given certain assumptions" (Wilson, 1978:225). That scenarios basically are stories about the future and explorations of alternative developments are some points to remember, even if, as can be seen further down, they are not guidelines for all scenario construction. The third statement emphasizes, however, a future state instead of a future path. This is a view that seems to be common particularly in the gaming literature (e.g., see DeLeon, 1975) and is one of two points of confusion that seem to be frequent in connection with scenarios in modern future studies. How is the time dimension to be treated ? Is a scenario a path into the future or is it a future state of the world? Another point of great variation between different studies is the one of content - how detailed should a future development be described to be called a scenario?

The scenario concept came into futures research via military strategic and gaming, but originated from theater (Becker, 1983). In theater it refers to the screenplay with such components as action, catchwords, stage properties, decor, light, and sound. It has at least five components: actors, actions, materials, positions in space, and a set of points in time. Asplund (1979) takes this as a starting-point for a general definition of a scenario:

> "A scenario coordinates these five components in such a way that for each point in time is stated: (i) in which positions the actors are; (ii) in which positions the materials are; (iii) what actions the actors make." (Asplund, 1979:92)

This is suggested to be taken as a general form for scenarios. It is for the researcher to define relevant actors, actions and materials (which may in fact be anything in the world). An important trait of scenarios is, according to this definition, that without a sequence of actions and events in time, it cannot be a scenario. There should also be a certain demand on the content that it at least should allow for a "tolerable performance" of the future in the way that is described in the scenario. This should mean that the reader can easily follow the sequence of events and imagine such a development and get some feel for the assumptions and logic behind it. If this demand is not met, then it should not be called a scenario, but a "synopsis" for the future.

Other demands on a scenario that are put forward in the literature are primarily those of simplicity, intelligibility (comprehensibility), reliability, logical consistency, and explanations of simplified assumptions. Gershuny (1976) suggests that it seems almost impossible to combine them all, but they should be kept in mind. Perhaps the two most important are intelligibility and logical consistency. An intelligible scenario must be consistent, but the inverse is not true, because to be intelligible, a scenario must among other things be psychologically plausible and socially acceptable, and these vary with time and culture while logical consistency does not (Asplund, 1979). To make a scenario intelligible, the central trends and assumptions must be explained, argued for, anchored in the recent past, and related to historical experience. It is important to remember that "the future is a continuation of the past" and that "historical trends, properly understood, set close limits to the possibilities of human action" (Hall, 1977:6 and 10).

2.3. Various Forms of Scenarios

Instead of looking at various alternative ways of defining what a scenario is, what it should be, and what demands one should put on scenario writing, one can look at what "scenarios" have meant in practice in modern futures research. Before starting such a review, a few basic concepts need to be introduced. A useful taxonomy of scenarios is presented in "La methode des scenarios" (France:Datar, 1975; Hall, 1977) in which two basic types of approaches are advanced:

1) Exploratory scenarios, where one starts in the present and tries to project various trends into the future. These can be either tendential, i.e. they concentrate on the consequences of certain trends if they should continue, or framework, in which the field of possible futures is delimited.
2) Anticipatory scenarios, where one starts with painting a picture of a future situation and then asks: how do we get there? This category is most often either normative, i.e., how do we reach a desirable future, or contrasted, e.g. a solar or uranium future society. Crisis scenarios, which are so common in war gaming (e.g. DeLeon, 1975, De Weerd, 1974) could also be added into this category.

Another useful dichotomy is methodological and informal scenario writing (Asplund, 1979). The methodological approach is where a certain method or model is used to assure that it does not matter who constructs the scenario. The same input assumptions should lead to the same output. The informal scenario writing procedure differs from situation to situation and from author to author. This does not mean that an informal scenario is unstructured or lacks logical consistency. It should be possible to define criteria of quality for both informal and methodological scenario writing.

Two forms are predominantly used for making the difference between alternative scenarios; alternative developmental trends in key factors like population, energy use and GDP, and alternative developmental constructs i.e. differing assumptions about the dynamics of the future world (Makridakis and Wheelwright, 1978).

2.3.1. Exploratory scenarios

Among studies that use an exploratory approach, a great variety of studies can be found, for example:

1. Methodological without developmental constructs (the dynamic structures of the world remain unchanged)

Most computer model studies use different assumptions on key factors like population and economic growth as primary scenario characteristics. The developmental constructs, if there are any, are built into the model. But an often hidden assumption is that many of the basic structures like the political, ideological, economic and environmental systems and often also technology, if they are not particularly focused in the study, remain relatively unchanged or, sometimes, have a linear development. These studies are most often sectoral or sometimes multi-sectoral, because it is hard to model more than one sector. Here we can find global energy studies like Haefele et al. (1981) or Edmonds and Reilly (1985), natural resource studies like "Limits to growth" (Meadows et al., 1972) and multi-sectoral studies like Leontief (1976) or Global 2000 (CEQ, 1980). Their approach is definitely methodological (the scenario construction, but not necessarily the model building) and the output is dominantly quantitative. The scenarios constructed with such models are usually presented primarily with numbers and graphs and are seldom very attractive reading. This means here that they do not tell an entertaining story, but they can of course, if treated right, present a valuable discussion on future problems. But in general, computer model runs are too meager to be called more than "a synopsis", a sketch of the future.

2. Methodological scenarios with developmental constructs

One representative for exploratory scenario studies where a set of alternative developmental constructs was used to characterize the scenarios is Interfutures (Lesourne, 1979). In this study the scenarios are defined with the help of assumptions about 4 dimensions:

- relations between developed countries,
- internal dynamics in developed countries,
- North-South relations,
- internal dynamics in developing countries.

With varying combinations of assumptions about these dimensions, six alternative scenarios are sketched in the study. The approach is both methodological, with computer model runs, and informal, with a discussion on the possible consequences of the various assumptions made. But no real stories are told in this study. The "scenarios", mostly in quantitative form, mainly have the function of setting a framework for discussion. They are compared and discussed immediately and never presented like alternative "future histories".

3. Informal exploratory scenarios

Herman Kahn was certainly a very informal futuristic writer. He chose what he considered the most important trends to focus on, extrapolate and discuss. His style has been described as subjective, pointillistic, improvised and kaleidoscopical. His most important assumption is that future development will resemble the past (Agel, 1973; Cole, 1977; Asplund, 1979). Most often he extrapolates what he considers to be the central trends into the future. For example, in "The next 200 years" (Kahn et al., 1976) only one scenario is presented and discussed. What is presented is basically the most likely future and the most likely solutions to future problems, according to Herman Kahn and the Hudson Institute. No alternatives are given; these are left to readers and critics to imagine. Even if Kahn's style is informal, the presentations and discussions are dominated by numbers and graphs, the traditional scientific language.

Another type of scenario is presented in "Sverige i varlden" (Sweden in the world) (Huldt et al., 1979). The aim of this study was to examine how alternative developments of the international system may affect Sweden. Four, clearly distinctive, alternative developmental lines are explored here. They are chosen from a four-field model with two pair of opposites on the axes: internationalization vs. disinternationalization and conflict vs. cooperation, on the axes. This gives the following scenarios:

- "Towards a new order" (internationalization + cooperation)
- "The society of the developed nations" (internationalization + conflict)
- "Liberum veto", i.e. an anarchic system of small nations (disinternationalization + conflict)
- "The world of small units", i.e. a happy, peaceful cooperating world, based on small independent units (disinternationalization + cooperation)

These scenarios are only presented verbally. They have the form of four separate future histories and each tries to anchor the characteristic trends in the recent past and discuss or present possible consequences of the sketched developments for Sweden .

A similar approach is used in "Europe 2000" (Hall, 1977), where six alternative futures are sketched for Europe:

- "Europe suppressed, or survival of the two blocs".
- "One Europe, or Europe united by challenge"
- "A Europe of nations"
- "A Europe of regions, or the revolt of the regional periphery"
- "Explosive change in Eastern Europe"
- "A Chinese arrival on the European scene"

These scenarios are never fully developed like stories in the above study. Their main function is to sketch a field for discussion, showing a broad framework of possible, and varying, futures.

2.3.2. Anticipatory scenarios

1. Normative approaches

The history of futuristic literature is full of normative, informal, "utopian" scenarios, where more or less detailed, ideal future societies are described and ways of getting there are pointed out. The most influential and well-known writings in this field are probably those of the 19th century. Among these we can find socialistic utopias like the ones of Fournier, Owen, Bellamy ("Looking Backward 2000-1887") and Marx and Engels ("The Communist Manifesto"), anarchistic utopias like the ones of Proudhon and Kropotkin, or more environmentally oriented pieces like William Morris: "News from Nowhere". They have a long row of followers, but in our century very few utopias have had any lasting attention. One of the exceptions is Skinner's "Walden Two". (See Kumar (1987) for a modern review of Utopias from different times.)

Hazan Ozbekhan has developed a more methodological approach for constructing normative anticipatory scenarios. This method consists of several steps which include critical analysis of the present system, definition of a framework of possible futures and of objectives, elaboration of a preferred future state, and construction of a way to get there (France:Datar, 1975). It is interesting to note that exploratory scenarios are also used for the preliminary analysis.

2. Contrasted anticipatory approaches.

Contrasted anticipatory scenarios often seek the extremes. The titles of contrasted future scenarios for France, made by SESAM (France:Datar, 1975) exemplify this tendency:

- "La France de cent millions" (France with a very high population)
- "La France cotiere" (France dominated by the coastal regions)

A typical contrasting scenario study is the Swedish energy future study "Sun or Uranium" (Loennroth et al., 1978), where two contrasting energy futures for Sweden are sketched: Uranium- Sweden where 80 % of the energy in 2015 is provided by nuclear power, and Solar-Sweden where only renewable fuels are used. In both cases the same amount of energy is used in 2015. The main part of the scenario construction here is a quantitative exercise, e.g. how much investment or how much land will be needed for energy production and what will a possible fuel mix look like in these contrasting futures.

2.4. Conclusions

There is no established doctrine on how to create, present or use scenarios. In the studies mentioned above we have seen a plethora of differing methods.

The exploratory studies build on different trend assumptions. Most common is perhaps extrapolation of current trends as perceived from recent experience. This kind of study can be said to form today's conventional wisdom. More sophisticated is the framework approach where varying isolated trends extrapolated into the future define the limits of the possible future and form a base for discussion about problems in alternative futures (e.g. Hall, 1977; Lesourne, 1979; Huldt et al., 1979). Anticipatory studies hypothesize future situations that can be desirable (based on certain goals), undesirable (e.g. a future crisis situation) or contrasted (painting some alternative futures to be compared), and try to find reasonable ways to get to these future states.

Many studies use a combination of approaches and within these categories a great diversity of methods can be found. They can be based on a formal methodology e.g. the use of computer models or some sort of tree or box model, or the approach can be more informal. In any case there are several demands that should be placed on a "good" scenario. These include:

(1) Provision of adequate information and explanations of the central assumptions that the scenario is built upon. Questionable, weak or controversial points have to be brought to light, not to be hidden.

(2) A logical contiguity of events and continuity of actions during the progression of the scenario through time, and some consideration of historical experience. These are important to make the scenarios as intelligible as possible.

(3) Sufficient detail to allow for a tolerable "performance" of the scenario. The detail requirement and the focus have of course to be adjusted according to the purpose of the scenario project. A balanced and consequent use of detail should also be called for, but this must not prevent the scenario writer from feeling free to make the presentation more interesting and vivid by introducing some variation in detail.

In all these points an adaptation to the specific goals of a scenario project is implicit and this should be a major demand; a "good" scenario is one that fills its defined function. This is also emphasized by Brown (1968): "The function, form and content are determined by the specific research task at hand. Different levels of analysis have differing requirements for detail and scenario credibility."

3. THE SCENARIO CONSTRUCTION

3.1. Why Scenarios ?

In Section 2 different scenario approaches, uses and demands on a scenario were presented. The main conclusion was that a "good" scenario is adapted to achieve the goals that are defined within the project where the scenario technique is used. The examples show that the uses differ between various projects, but there are also similarities. But why has scenario building been used? What are the advantages and purposes of this technique?

There are two particularly advantageous qualities of scenarios that are emphasized in the studies mentioned in the previous section:

1) The scenario serves as a tool to force imagination, stimulate discussion and focus attention at specific points of interest (France:Datar, 1975).

A scenario is a perfect tool to force policy-makers to "think big" (Pratt, 1974). This can mean to think globally, take longer time-scales into consideration, be more imaginative than in every-day thinking, etc.; in short, they open wider perspectives in thinking and discussion. An essential quality of a scenario is that it makes the future more concrete, touchable and opens the field for a constructive discussion about it. In Loennroth et al. (1978:97-98) it is stated that:

> "It is important to try to present a consistent whole, and the hope is that Uranium- and Solar-Sweden can serve as a base for discussion on what people desire will be possible in the future, especially since both Uranium- and Solar-Sweden can be viewed as representatives of different values and opinions that are current in the society" (author translation)

It is also commonly emphasized that scenarios make it possible to explore consequences of the adoption of various strategic policies, given differing trends that dominate the development of the surrounding world (Lesourne, 1979). This is often a central objective for scenario writing in the context of gaming and policy exercises. Here, for example, it is important that a scenario is written in such a way that:

> "(a) it stimulates users to formulate strategies in relation to it; and (b) it assists users in the identification of the benefits and pitfalls of alternative strategies." (Ygdrassil et al., 1986:15).

2) The scenario provides a coherent framework for analysis on how various issues or sectoral developments impinge on one another and interact (e.g. Lesourne, 1979). This is important if multi-sectoral studies are to bring new knowledge. Wilson (1978:227) points out:

> "history is a 'booming, buzzing confusion' of events, trends and discontinuities,..... Scenarios have a special ability to represent this multifaceted, interacting flow-process, combining (when appropriate) demographic changes, social trends, political events, economic variables and technological developments."

For environmental projects which focus on the large-scale, long-term interactions between development and environment, scenarios are indispensable tools. Both of the qualities mentioned above are essential. In the policy exercises, scenarios are needed to stimulate discussion, force imagination and focus attention on the long-term, large scale problems that few policy-makers are disposed to consider. For long-term studies and assessments, scenarios can serve as frameworks for combining the various sectoral fields.

3.2. The Aims of the Scenarios

One of the areas of particular attention for long-term, large scale environmental studies concerned with "scenarios of socioeconomic development". The goals of these efforts are manyfold (see, e.g., Clark, 1986). Primarily, the intention is to characterize possible paths of human development for the world over the next century. The scenarios presented in this report are aimed to be used as inputs in various parts of future environmental projects:

- the environmental assessments,
- the regional case studies,
- the Policy Exercise.

To fulfill this task, they need among other things to:

- describe alternative coherent future developments which are possible to use as frameworks in the different studies;

- present some essential input numbers for population, energy and agricultural development;
- be sufficiently interesting and entertaining to stimulate attention, imagination and discussion; and
- be flexible enough to adapt to differing contexts and change according to the demands of various users. There must be room for further development of a scenario and it should never be regarded as completed. A scenario should stimulate discussion and criticism and be open to improvements. In this way it can be used as a research tool to bring forth certain kinds of knowledge about, e.g., the mechanisms of development and change.

Secondarily, it is important for the users to gather experience of scenario writing, construction and presentation.

Thirdly, the users should devote particular attention to exploration of discontinuities and surprise, and to constructing surprise-rich alternatives to the smooth "conventional wisdom" standard projections.

3.3. Why Surprise Scenarios ?

Most modern future studies have been based on "an evolutionary paradigm - the gradual, incremental unfolding of the world manner that can be described by surprise-free models, with parameters derived from a combination of time-series and cross-sectional analyses of the existing system" (Brooks, 1986:326).

They usually assume that the dynamics of the present system, as perceived from studies of the recent past, will remain basically the same. In most studies the global economic, political and social structures are implicitly similar to the present. Technology, economy and environment, if focused, develop in a highly linear pattern. This approach can elucidate long-term trends and broad-scale pattern. These studies are necessary but insufficient, particularly, if we want to improve management of long-term interactions between development and environment. This is, for example, because: "....change can also occur in abrupt, discontinuous bursts" (Holling, 1986).

> "By leaving out the external shocks, non-linear responses, and discontinuous behavior so typical of social and natural systems, surprise-free analysis leaves us unprepared to interpret a host of not improbable eventualities" (Clark, 1986:31).

Clark (1986) discerns these weaknesses of the dominating futures research and the lack of methods to deal with discontinuities in future development when he states that:

> "A central challenge of our Biosphere Project is to see how far we can go in developing the methods, models and concepts necessary to move beyond surprise-free analyses to a more realistic treatment of the interactions between development and environment." (Clark, 1986:32)

3.4. The "Surprise-Rich" Scenarios

The three scenarios that are presented in this report should be viewed in the context of analyzing surprise-rich development paths. They are efforts to characterize some possible, even if highly surprising, futures. They are based on the output of a workshop that was held in January 1986 to construct "surprise-rich" developments to complement "surprise-free" conventional wisdom. This activity was jointly hosted by IIASA and the Swedish Council for Planning and Coordination of Research (FRN) and led by Professors Torsten Hagerstrand of University of Lund, Sweden, and Robert Kates of Brown University, USA. Twenty scholars with backgrounds ranging from history to technology assessment and ecology were brought together for a week at Friibergh Manor outside of Stockholm. After a briefing on the "conventional wisdom" scenario, the participants jointly defined a set of 3 surprising or unconventional states of the world for the year 2075. The participants then broke into three groups, each of which attempted to write three consistent "future histories" describing paths that the world could take from its present state to the surprising end-points of 2075, while invoking as few miracles as possible. The three tasks that the groups tried to solve were:

1. The Big Shift

The center of the world economy moves eastwards to East and South Asia. The Western World stagnates in both population and economic activity.

2. The Big Load

A world with 20 billion people, much higher than any demographer today would expect, but with relatively high standards of living in terms of energy use and agricultural production.

3. The Big ?

Here the groups were allowed to construct their own surprising futures.

These future histories focussed particularly on the development of Europe and South Asia. On the last day of the workshop, the groups compared their independent solutions to the "future history" problems and revised their treatments accordingly. The results have been published by FRN under the title "Surprising Futures - Notes from an International Workshop on Long-term World Development" (Svedin and Aniansson, 1987), which here is also called the "Friibergh Book". The three "surprise-rich" scenarios that are presented in my report result from efforts to combine and further elaborate these future histories, complement them with numerical paths and to present them in a more organized, summarized manner.

4. THE SCENARIOS

4.1. Introduction to the Scenario Presentations

In this chapter three surprise-rich futures for the world 1975-2075 are sketched. The scenarios are based on the future histories that were produced at the Friibergh workshop. Together with versions of "The Big Shift" and "The Big Load", "The Rurban Arcadian Drift", which describes a small-unit, small-scale future development derived from the three "Big ?" future histories (presented in the Friibergh book under "Hope Regained" and "History Lost"), is presented. The three scenarios are in short as follows:

1. The Big Shift

South and East Asia become the center of the world. Europe and the rest of the Western World undergo a "noble decline" with economic and social crises. The gap in wealth between North (North America, Europe, USSR and Oceania) and South (Latin America, Africa and the rest of Asia) decreases considerably. World population stabilizes at about 8 billion. Global energy use and agricultural production per capita increase similarly to the conventional wisdom scenario, but their distributions are entirely different.

2. The Big Load

Population does not stabilize and reaches 20 billion by the year 2075. Energy use is 12 times higher and agricultural production 7.5 times higher than in 1975. This is possible due to radical changes in social and political systems and population distribution, and to revolutionary technological innovations. By 2075 more than half of the used energy is consumed in Northern regions, which have approximately the same share (25%) of the global population as a hundred years earlier.

3. Rurban Arcadian Drift

Major catastrophes result in a reduction of population, disruption of the process of increased global integration and a total reconstruction of the global system. The South develops rapidly and in the North small village societies with a high degree of self-reliance, low energy-use, but also a very narrow-minded, local orientation, are established. In this world science stagnates and nobody really cares about global problems. Population is by 2075 only 6.8 billion. Energy use increases 3.7 times and agricultural production 4 times. Some 80-85% of the energy use takes place in the southern regions.

These scenarios focus, as did the workshop, particularly on Europe and South Asia. For each scenario the presentations below consist of an introduction, a chronological summary (where the sequence of events, actions and development is presented), a part where the development of population, energy and agriculture is described more explicitly by numbers and graphs, a commentary on the numerical representation, and a final part where the essential ideas in the scenario are discussed.

For more details, further explanation and information about the scenarios and the logics behind the development sketched in them than is presented here, see Svedin and Aniansson (1987). The Big Shift version is a combination of all four Big Shift sequences. The Big Load version has used "Big Load: History Sequence 2" as base, but borrowed integrable ideas from the other sequences as well. The Rurban Arcadian Drift uses the framework of "Hope Regained 1: The Rurban Arcadian Example" including some traits from "Hope Regained 2" and "History Lost". The chronologies are here sometimes slightly changed to match the 25-year periods, but the main source of events should be clearly recognizable.

The main guideline of the efforts to give the surprise-rich scenarios numerical representations has been to keep growth rates, quantities of migration, the use of various fuels and penetration rates and influence of new technologies in the scenarios within the limits of what may reasonably be considered as possible, according to recent studies and present "expert opinion" (or "conventional wisdom"). Everything that is close to or beyond these limits of the perceived possible has to be specially illuminated in connection with the scenarios. This means that the scenarios either designate ways to get around these, for example, by new inventions or socioeconomic, institutional and ideological changes, or that the assumptions are explicitly stated and left open for discussion. Note here that miracles are minimized in the scenarios and only a few revolutionary inventions are implemented, none of which are any "final solutions".

Population, energy use and agricultural production have been chosen as key factors in the numerical representations of the scenarios since they probably are the most important indicators of impact on the environment. From them it should be possible to deduce consistent levels of other activities of importance such as industrial activity.

The procedure of constructing these numerical paths can be best described as an interactive process between the scenarios, the numbers and conventional wisdom, and also between construction efforts and criticism. The numbers of the Conventional Wisdom Scenario were used as a starting-point. The subsequent problems were: What do the scenarios imply for the development of population, energy and agriculture? How should we adapt the numerical paths of The Conventional Wisdom Scenario to this? Conventional wisdom is based upon the assumption that the basic structures of the world will be similar to the present. The driving forces are largely economic. Here the problem is how changes in the political, institutional, ideological and social structures would influence these key factors. Once the development for these indicators was sketched, the next questions were: Is this really reasonable, taking recent studies into account? Is there enough support for this in the scenario? Changes were often necessary in both the numbers and the scenarios. This procedure was repeated several times. Development of the basic indicators and the scenarios have then been worked through, been criticized and complemented with fuel mixes and key factors during a workshop with invited specialists and presumed users.

This process is intended to be on-going, both with further elaboration of particular fields of interest for the users and, if called for, adaptations as "new" knowledge is brought into consideration. Since a scenario is only hypothetical and constructed for the purposes of a certain project, it should be open for possible changes. Changes in the overall structure are of course more difficult to allow since they are complicated to introduce and might affect large parts of the whole construction. Such changes therefore require strong arguments.

Comparisons of the distributions of population, energy use and agricultural production between North and South, the present industrialized and developing regions, have in general been calculated with the development of Europe and South Asia and the Conventional Wisdom Scenario as guide-marks for the development of other regions in North and South. In the Big Shift the growth of South Asia is higher than in other developing regions, and the growth of Europe lower than in the other industrialized regions. In the other scenarios the corresponding regions follow the development of the two regions more closely.

The division into 25-year periods is done for practical reasons, but also with an eye on using the scenarios in Policy Exercises (Toth, 1988a, 1988b) with 25-year steps. Between each step, the participants could speculate about the coming development and design some policies. Used in this context, the scenarios should be somewhat more flexible than those presented here, but the hope is that in this form they could serve as some kind of base for a Control Team, which could elaborate alternative developments, and trend breaks.

4.2. The Big Shift

The center of world economy shifts to the East. South and East Asia, with more than half of the global population, become dominating in economic, political and scientific matters and also exert great cultural influence on other regions. Behind this development is primarily an enormous internal development with radical political actions and important institutional and social innovations, but also the changed international situation with a weakening of the Developed World.

In the former industrialized world, capitalist as well as socialist countries turn introvert, occupied by social and economic problems. The East-West conflict fades away. The present superpowers are preoccupied with internal problems. The Third World has, like Asia, high economic growth under influence of the Asian examples, and the gap between North and South decreases importantly.

Europe is unable to handle the arising problems and to adapt to the new international situation. Population stagnates, and a lack of cooperation between different countries and social groups leads to chronic social and political instability and economic decline.

During this period India is a very dynamic and expansive society, successful in solving most upcoming problems. This is a consequence of both an advantageous international situation and some radical political actions and social innovations. A new social ideology, a kind of synthesis between new modernist ideas and traditional religious and social values, proves successful in guiding development, mobilizing the masses and keeping social tensions below the boiling point.

By 2075 the world has a relatively stable population of about 8 billion people. Five times more energy is consumed and the agricultural output has increased 2.5 times over the hundred-year period, while the population has only doubled. The inequalities of wealth are less significant than a century earlier.

4.2.1. Chronology

The most important events in this scenario are summarized in Table 4.1. Factor increases of population, energy use and agricultural development for the World, Europe and South-Asia are presented in Figures 4.1, 4.2 and 4.3, respectively.

1975-2000

Economic instability and recession is hitting the developing countries hard. Several bankruptcies of major countries occur. Thoughts of self-reliance and threats of breaking with the world market become widely spread. The expected reduction of population growth does not take place. The crises culminate just before the turn of the century with problems for the banks, chaos on the stock-market, threatening collapse of the global monetary system and chronic famines in large regions of the Third World.

Europe has relatively slow growth compared with the preceding 25-year period. Rising social costs, exacerbated by an increasing percentage of retired and unproductive population, result in slower productivity growth and increasing social tension. A large part of the population is chronically unemployed. This group becomes the hearth of growing social discontent and unrest. A series of disastrous nuclear accidents, of which the Phoenix catastrophe in France is the worst, puts an end to the once impressive nuclear programs in Europe and the rest of the world with the exception of South Asia and USSR.

In India Rajiv Gandhi introduces a very ambitious and radical modernization program, which involves administration and taxation reforms, greater market orientation, massive R&D investments, agricultural and educational programs and social reforms particularly directed to groups important for economic development. In contrast to most other countries, India actively develops its own nuclear reactors, which require less capital and over time become less prone to catastrophic failure. Furthermore, the ambitious family planning programs result in reduced population growth.

2000-2025

Demands for a New Economic Order unify most developing countries against Europe (not including the USSR) and USA. China, Japan and USSR support these demands. In 2001 a treaty is signed on a New Global Economic Order, including a long-term plan for the development of the Third World. In exchange for improved terms of trade, the developing countries promise to take drastic actions to control population growth. The movement of industrial production accelerates southwards. Multinational corporations support widespread and ambitious programs for education and agricultural development. In the 2010s signs of a slow-down of global population growth can be observed. There is an increase of innovational activities in the South, particularly in Asia. In the North there is increased exchange and convergence between Eastern and Western countries.

The reform programs of India turn out to be extremely successful. Some very important innovations such as high-yielding millet and small electric tractors have Indian origin and come to be mass produced with surprising speed. The nuclear industry begins to export reactors to other parts of Asia. India is also becoming an important military power and establishes its sphere of influence with increased control of its neighbors. Rajiv Gandhi dies in 2014. After a couple of years, Mahatma Singh establishes a new regime that very successfully reconciliates the various religious groups and combines Indian sacred traditions with continued progressive modernization programs.

Table 4.1 Chronological summary of the Big Shift scenario

	WORLD	EUROPE	SOUTH ASIA
2075	The new order with Asia as center of the world established	Development of tourist industry Agricultural exports	
2050	Multinationals moving eastwards	Large scale biomass plantations Decline Population and energy use stagnates High-tech emigration	Suburbanization Asia leading in science Stable population Fast and stable growth
2025	Radical reduction of population growth Industrial production moves southwards Accelerated energy use growth Education/birth control program New Economic Order	Internal interstate conflicts Stagnation	Mahatma Singh "tradmod" synthesis Exports of nuclear technology Successes for Indian R&D Military expansion
2000	Economic crisis Continued population growth and economic recession	Increased social instability Phoenix nuclear catastrophy Chronic unemployment	Nuclear energy investments R&D investments Social reforms Rajiv's new deal
1975			

Europe has enormous problems to adapt to the new situation. Economic progress is slow and there is continuous conflict with increasing violence between various age, ethnic and social groups within the states and also increasing tensions between the states. This social disruption leads to gradual migration of economic activities to Asia and particularly to India, whose British traditions, stable government and location in a flourishing Asia make an attractive alternative to the economically stagnating West.

2025-2050

Population development is sensational. Already in the 2030's some countries of the former Third World are down to zero-growth. The Western World seems to have lost the leading position in science to Asia, where India, China and Japan also have become important military powers. The former superpowers USA and USSR have lost their global ambitions and concentrate on their internal development. In 2030 a treaty of nuclear disarmament is signed by USA, USSR and the European countries. This removes the last remnants of superpower influence in Europe and gives the Soviet Union the possibility to concentrate on the Chinese border. Multinational corporations base their activities to an increasing degree in the East and South.

The economy of South Asia flourishes and Indian agriculture is revolutionized by introduction of new crops. A large, reasonably well-educated middle class is developing, which, though not as well off as its counterparts in some other regions of the world, provides a stabilizing element in the Indian society. One aspect of this development is the increased suburbanization of Indian cities. Population densities in these suburbs are still higher than in the suburbs of non-Asian cities, but the severe urban problems have subsided before the turn of the century. Suburbanization is one factor contributing to a slow decrease in agricultural land. Indian influence is growing considerably in Africa, where the "Indian way" becomes the new alternative.

In Europe the crises and conflicts culminate. The stagnation turns into a slow decline in population as well as of standards of living.

2050-2075

Towards the end of the hundred-year period South and East Asia can be viewed as the more dominating core area of the world. They are not only the dominating regions in economic terms, but also in political and cultural terms. USA, USSR and Europe are stagnating, but still wealthy compared with other regions. Europe turns more and more into a museum. Population and energy use are decreasing and tourism is becoming a major industry in both Western and Central Europe. The numerous Chinese and Indian middle classes have sufficient disposable income for tourism abroad to become popular. Their children often attend university in Europe. Biomass plantations with various kinds of fast-growing species have become a typical trait of the European landscape.

South Asia has become a rather wealthy, modern, well-organized society, but some signs of the "European disease" with relative economic stagnation, high public expenditure (e.g. for armament) and growing social unrest (because of large social and economic inequalities) can be observed.

4.2.2. Population

Global population growth levels off faster than anyone expected and the world has by 2075 a stable population of about 8 billion people, 7/8 living in the four former Third World regions. The population of South Asia already stabilizes in the 2030s at approximately 2 billion (2.4 times the 1975 population). After 2040 Europe has a declining population and by 2075 its numbers are down to the same level as a century earlier.

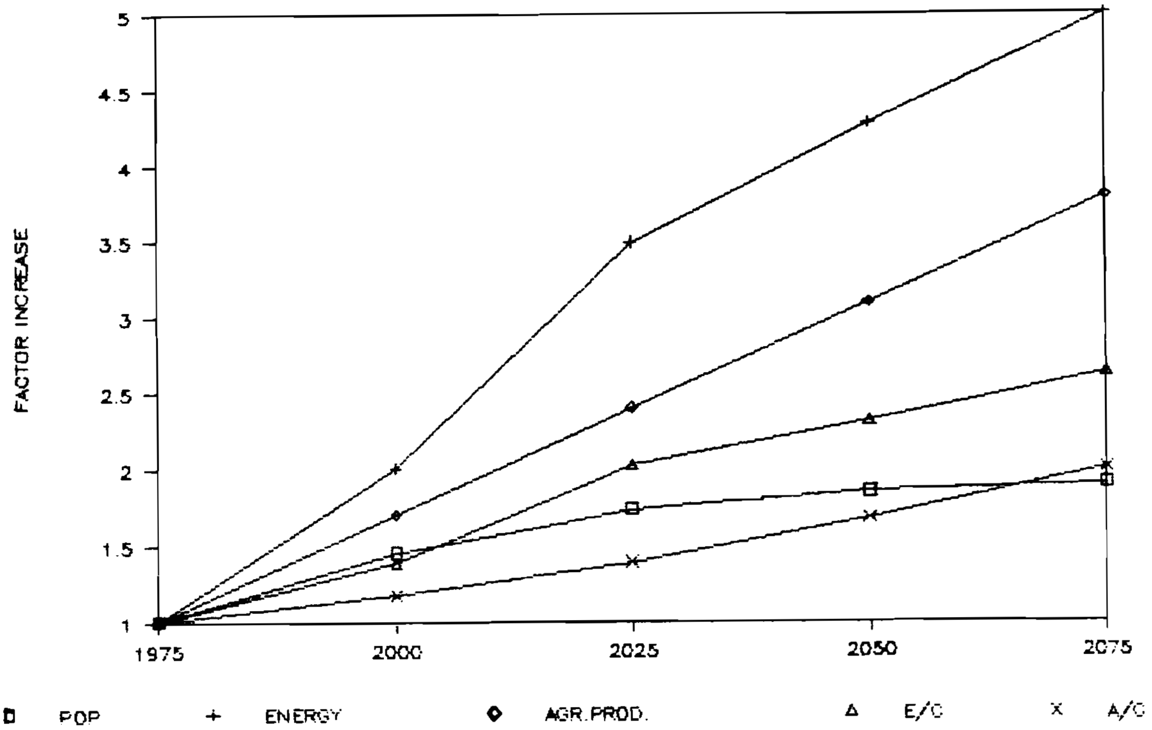

Figure 4.1 Big Shift scenario: factor increases of population, energy use and agricultural production for the World
(Note: E/C = ener.use per capita, A/C = agr.prod. per capita)

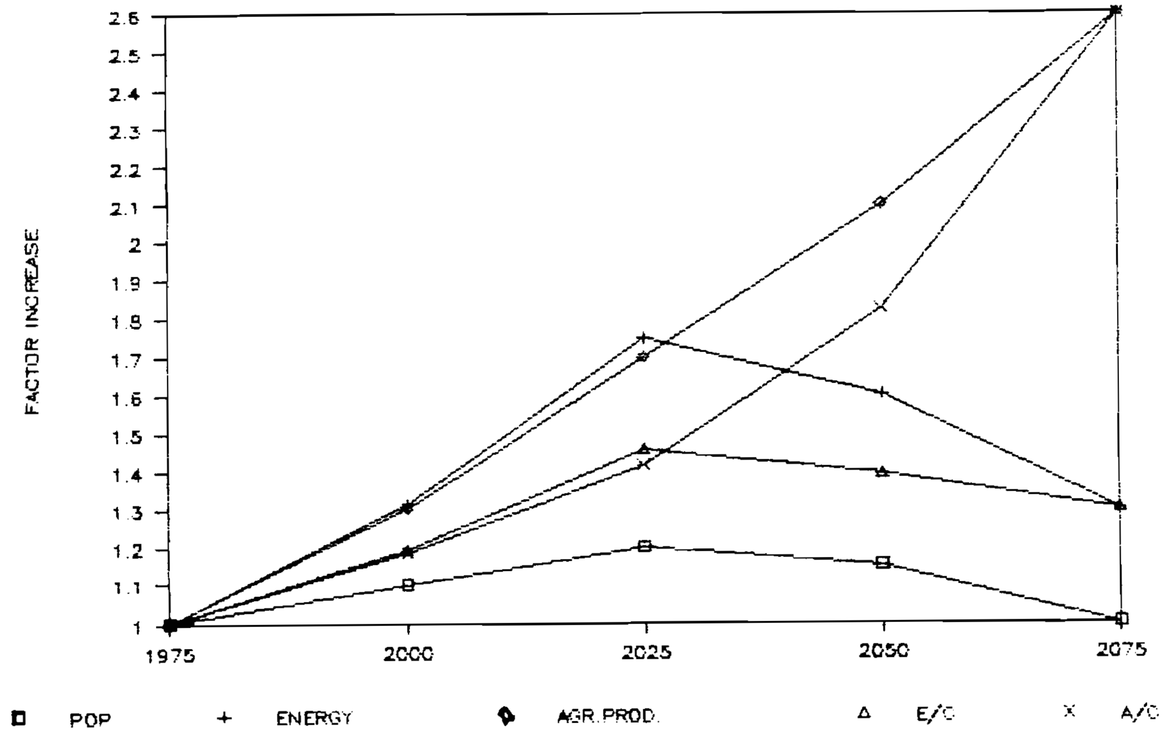

Figure 4.2 Big Shift scenario: factor increases of population, energy use and agricultural production for Europe

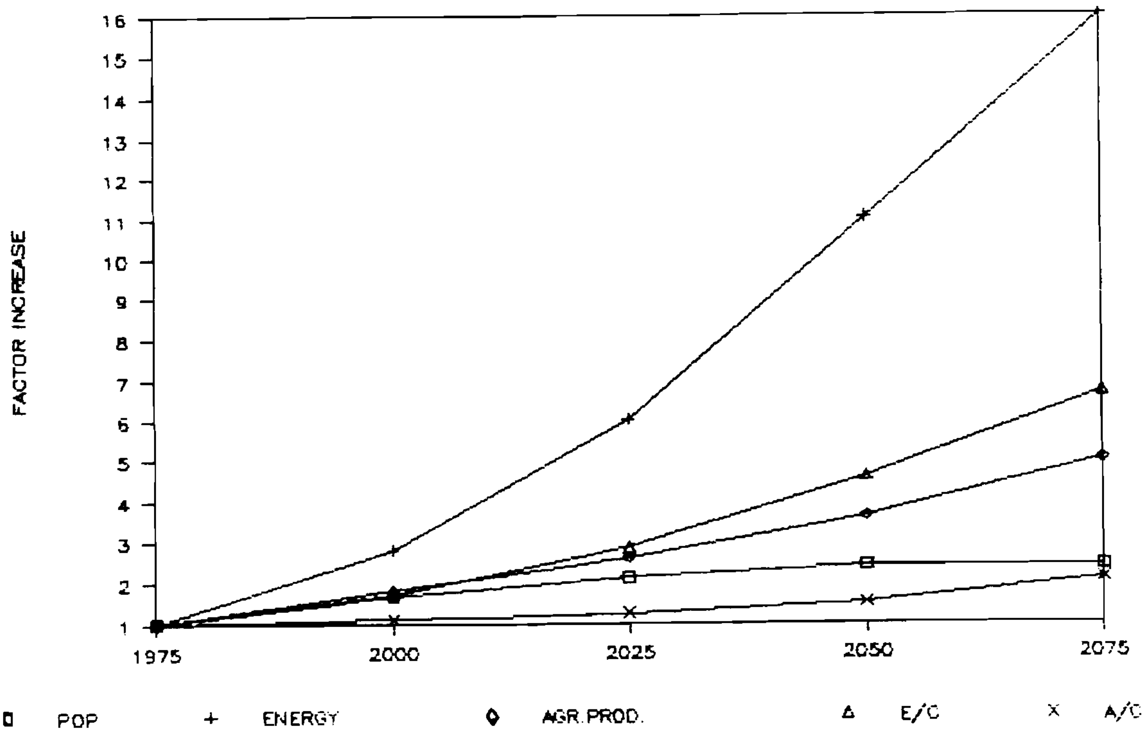

Figure 4.3 Big Shift scenario: factor increases of population, energy use and agricultural production for South Asia

4.2.3. Energy

Global energy use increases five times over the hundred-year period. Energy consumption per capita is 5 kW in 2075. This is the same figure as in the conventional wisdom scenario (CWS), but the distribution of use is much more even: 2/3 is used in the southern regions (compared with about 40% in the CWS, where the distribution of population between North and South is roughly the same). The profound economic and geopolitical transformations of the world society give rise to unprecedented patterns of energy production and use. For example, the Phoenix accident totally removes (even if for a very long transition period) nuclear power as a contending energy source in the Western World and forces a commitment to development of renewable sources. By contrast, India's nuclear development flourishes, while biomass and solar energy, which might have been expected to prosper on Indian latitudes and rural conditions, play only a modest role, even if solar energy begins to compete successfully with nuclear energy as the century progresses.

After stable increase for centuries, energy use in Europe reaches a maximum in the 2020s and declines then as a result of the severe crisis and by 2075 it is at a level 30% above that of a century earlier. Despite languishing population growth, this signifies a per capita consumption above the 1975 level by a similar margin and does not point to any long-term deterioration in living standards, it nevertheless does suggest a downward slide from per capita income levels, which prevail in the early 21st century. Fossil fuels dominate the market totally, particularly after the close-down of nuclear power, but the weakening economy and unreliable supplies encourage introduction of large biomass and solar programs.

In South Asia energy use increases 16 times during the hundred-year period. All sources of energy are expanding radically. Nuclear power becomes the most important energy source, especially for production of electricity, but fossil fuels still constitute almost half of the energy supply in 2075. The typical trait for the Indian society is, however, its low energy profile. India is still in 2075 using less than 10% of the global energy use.

4.2.4. Agriculture

Global agricultural production increases 2.5 times between 1975 and 2075 (per capita 1.3 times). This increase is primarily the result of a relatively successful modernization of the agricultural sector in the Developing World, which is supported by improved terms of trade, fewer trade barriers, and ambitious programs for agricultural development implemented by governments, international agencies and multinational corporations. The increase comes both from an extension of cropland, which increases by 20%, and from intensification. Which of these is more important differs from region to region, depending on available land and technological level. Fertilizer use increases by a factor of 2.5 and irrigated land by 30%. No revolutionary new technologies are introduced, but research and development establishments produce a continuous stream of improved technologies and genetic improvements suited to the special environmental and economic conditions of farmers around the world. Some of the more important of these have Asian origin.

South Asian agriculture experiences a minor revolution during the hundred-year period. Total production increases five times and per capita production more than doubles. Behind this development there are amongst other things some highly successful government programs, which include:

- educational programs to raise the skill level of farmers;
- social welfare and economic programs to ameliorate the conditions of small farmers and make it possible for them to invest;
- R&D-generated innovations that are readily adopted by Indian farmers, e.g. small electric tractors, new fast-growing bamboo;
- an active program to increase the amount of irrigated land;
- a program to increase fertilizer use by stabilizing prices and providing subsidies.

By 2075, fertilizer use per hectare has increased eightfold and land under irrigation by 80%. Fertilizer use increases in part due to intensification of land use i.e. two or more crops are grown on the same land each year. The increase in irrigated land occurs despite a 5% decrease in total agricultural land (including pasturage) due to land pressures by the growing suburban population of India.

Total agricultural production in Europe grows by a factor of 2.6. Because a large part of this is devoted to relatively low value biomass for energy production, and because of low population growth, agricultural technology develops along a more land-extensive path than during the 20th century; the amount of agricultural land increases by 30%, the amount of irrigated land remains unchanged, and the growth of fertilizer use per hectare slows down drastically compared with the preceding 50-year period (despite a factor increase of 1.9). As in the world generally, yield growth decreases through the hundred-year period.

4.2.5. Commentary

4.2.5.1. Numerical representations

The curve of global population is fashioned after a very low Keyfitz-path (Keyfitz et al., 1983). What makes this development possible is primarily the surprising Asian development. The path for South Asia is a stretched version of the global curve with a shorter distance in time to a stable population. This development would certainly be a surprise, but could in fact be supported by some recent "optimistic" forecasts which point towards possibilities for even more radical decreases of birth rates in India. The population of Europe increases as described in the conventional wisdom scenario and then declines by 16% during the second half of the hundred-year period.

Global energy use increases during the first half of the hundred-year period faster than in the "conventional wisdom". This is primarily due to the radical economic expansion in the developing countries. After 2050 global growth slows down because of the stagnation in the North. In Europe energy use reaches a peak in the middle of the hundred-year period and decreases then by about a 1/3 until 2075. The energy consumption in South Asia follows a higher path than in any of the other scenarios with relatively constant growth until the final 25-year period when the growth slows down a bit as the economy is maturing.

The fossil fuels are still the most important energy sources, but not as dominating as in the conventional wisdom (60% vs 80% of the market), while renewables play a more important role (24% vs 18%). Nuclear energy is important in Asia, having a market share of almost 40% in South Asia, but is abolished in most other parts of the world. None of the global energy figures in this scenario are very radical according to present "expert opinion", but the geographical distribution of energy use is surprising.

Global agricultural production per capita follows about the same developmental path as in the "conventional wisdom" (even a little bit higher for the first fifty years) until 2050, but then levels off in comparison. The increase comes also primarily from introduction of land-saving technologies, including higher yielding crops, crops with shorter growing seasons, mechanization, and increased irrigation and fertilizer use. This development is most evident in the developing world. The role of biotechnology is restrained. The average annual increase in yields, 1.7%, is less than in the second half of the 20th century.

In Europe, agricultural production grows considerably more than in the reference scenario. A large part of this increase is biomass for energy production, but European agriculture is also thought to become more export-oriented as the purchasing power of the urban populations in the developing regions grow. The technology develops along a more land-extensive path. The amount of land in agricultural production grows significantly. The rate of increase of fertilizer use per hectare is far less than in most parts of the world, especially compared with the rates of growth in the 20th century. In part this slower growth reflects the already high levels of fertilizer use in Europe, but it also indicates low returns to additional amounts. Added to this are the rising costs of natural gas, the main feedstock of modern nitrogen fertilizer production.

The South Asian agricultural development is totally dependent on the success of the land-saving technologies. The 80% expansion of irrigated lands demands that virtually all the remaining potentially irrigatable land in the region are taken up. The salinity problems associated with such a high level are assumed to be kept under reasonably satisfactory control. The radical 7.6 factor increase of fertilizer use is also problematic because of the great problems of environmental concern that are likely to occur in connection with such a development; the nitrogen carried away in runoff in a monsoon climate is much higher than in a European climate.

4.2.5.2. Basic ideas

The big surprise in this scenario is the changing relationships between West and East. There will not be an increasing gap, but rather the reverse; Asia is going to take over the core role in the world economy.

How would such a shift be possible?

The thought inspiring this scenario has been called "peripheral theory" (see e.g. Senghaas, 1985), expressing the great future prospects of China (but never India) in a future where richness in population means great strength and opportunity, providing man-power and an ever increasing demand. India is, however, like China, not a typical developing country and should not be compared with countries in Africa and Latin America. The most obvious difference is of course the size. India is also an old high culture with a rich tradition in science as well as in commerce and social organization. Enormous contrasts are perhaps the most characteristic trait of the Indian society. Everything can be found there from the most efficient industrial farming, nuclear power stations, first class research etc., to the most primitive subsistence farming, from affluence to the millions of starving people in the big cities. There are not only contrasts, but also contradictions. It is, for example, strange that India, the country in the world with the largest number of starving people, is also one of the biggest food exporters. Such sad contrasts and contradictory facts are what suggest a great potential of future prospects for India.

The major assumptions in this scenario are:

1) The main driving force in this "Big Shift" consists of the internal markets of India and China, but there is also a considerable increase in their participation in world trade.

   The expansion of the domestic markets of these huge and populous countries will create savings and increasingly replace foreign capital, that, however, along with some foreign technology, plays an important role during a period of transition.

2) The expansion of market forces is triggered by relaxation of government control over free enterprise, which will release enormous entrepreneurial energy.

   In both India and China, there is an entrepreneurial tradition and at least an embryo of a capitalist class, which is not the case in most developing countries. A basic assumption is, thus, that the only possible way for Asia is some kind of market capitalism. But this is not thought to be comparable with the western 19th century liberalism. India and China have an entirely different history and different social systems and traditions. The market forces will to a large extent be controlled and encouraged by political and social forces. Tendencies in this direction are already visible by the gradual abandonment of centralist and paternalist policies during the regimes of Deng Xiao-ping and Rajiv Gandhi.

3) The specific cultural traditions and religious institutions, which have been seen as reactionary forces and hindrances to all kinds of progress, will prove to be very valuable in both mobilizing the masses, encouraging innovation and initiatives, and in balancing the enormous stresses which rapid development poses on society.

   In Europe religion seems to have played an important role during the breakthrough of capitalism (see e.g. Weber, 1968). The new ideas of the Reformation encouraged individualism, hard work, saving and economic success. Could anything similar happen in India? This is really a hazardous field. It would of course be a surprise. From a Westerner's perspective, hinduism is often perceived as one of the major religions of the world with the least positive attitude towards life and interest for the problems of this world (Aspelin, 1977). But, despite this, would it be totally unreasonable that this religion could adapt to give some support to a new, more progress-oriented societal ideology? We have for example experienced how Mahatma Gandhi used traditional values and religion for mobilization of the masses. The argument could in fact be made that most successful regimes and long-lasting efforts of progressive transformation of societies, at least to some extent, have had to adapt to the specific traditional values and institutions of their particular society. This has meant both using religion and tradition in some sort of new interpretation as a force to unite the people (e.g. Khomeiny in Iran or Quadaffi in Libya), seeking some connection and support of religion (e.g. like Nasser in Egypt or the Sandinists in Nicaragua) or at least to some extent build on old institutions, values and traditions. To this last category relatively secularized societies like Japan and the USSR can be counted today. The Japanese example is perhaps the most obvious case. In the case of the Soviet Union, I refer to the rich literature that describes the similarities between present Soviet institutions and those during the ancient Tzarist regime and the important use of Church Slavic (the old liturgian language of the Russian-Orthodox church, comparable with Latin in the catholic West) in politics since the days of Josef Stalin (Gerner, 1980). Ronald Reagan's success with demagogic use of traditional American values is another example.

The assumption is that each society has to some extent to build on its own traditions and history. Politicians have to adapt to values, morals and myths. Failure to adapt to social structures, values and morals can for example be found in connection with the implementation of Western development strategies in developing countries and the fall of regimes perceived by the West as successful, e.g. the Shah regime in Iran. If India is going to realize its potential, it must find its own way.

4) To make the Asian upswing possible, a certain relaxation of Western penetration and dominance is needed.

For the economic upswing of Japan, World War I, which isolated Britain from the Asian market, was a triggering factor. In this scenario, the Northern economic collapse, the New Global Economic Order (not to be overestimated), the gradually increasing difficulties of managing internal problems in the West, and the improvement of domestic investment opportunities all strengthen the position of India in negotiating relations with multi-national corporations for joint ventures and opening up new markets in Asia and Africa for Indian products.

5) A very important and perhaps controversial assumption is that growth in the developing world is possible even if the Western World stagnates and participates to a lesser degree in world trade.

As has already been stressed, the primary forces are the internal markets of India and China with their immense latent demand. This is supported by historical examples of most populous Western countries (France, Austria-Hungary, Germany and even the USA) which during their take-off stages applied protectionist policies and had relatively limited foreign trade (though of course some technology import). As well, their domestic markets were the main driving force in their often rapid and successful industrialization process. They were less dependent on international trade and had a much less fluctuating industrialization than small export-oriented countries. (Senghaas, 1985). In this scenario, the whole Third World will experience important and relatively stable growth. Even if trade will not be as important compared with our century, it will still play a great role. When East and South Asia a couple of decades into the 21st century will be able to compete on the growing markets of Africa and Latin America, then they will get an extra push forward, while the Western World will face another problem.

Can Europe really stagnate? What are the forces behind such a development? Even if none of us believe that this could happen, tendencies can be perceived that could prove to be the critical factors for Europe:

a) The aging population. If population stagnates, which it tends to, the next relatively small generation will have an enormous amount of elderly people to support. This will of course also happen in the Third World, but not until the end of the hundred-year period and it may be presumed that countries there will have less costly methods to take care of elderly people.

b) Old industrial sectors in Europe, as well as in North America, have failed to remain competitive. What will happen if the present "future industries" get overwhelmed by foreign competition? If industry in Europe fails to remain competitive, where will investments take place? If export of capital takes place, the economic recession will only be aggravated.

c) Under circumstances of low growth rates, social stresses and competition and disagreement between different social groups increase enormously, as has been noted in the 1970s and early 1980s. Various ethnic, age and professional groups all see themselves as maltreated. Ethnic strife and terrorism are more likely to occur. The political system is put under constant pressure from interest groups and there is definitely a risk that the political system, built on representative democracy, will be put out of order and be replaced by some kind of negotiation system, where the strength of various interest groups decides what advantages they can get. Some tendencies in this direction have already been discerned during recent years.

d) Another important assumption is that the highly developed social infrastructure in Europe, with large bureaucracies, will inhibit innovation and raise political barriers to enhanced competitiveness. This tendency can be aggravated by the increasing problems of distribution. The internal problems in various countries will also create more international conflicts between countries in Europe.

4.3. The Big Load

Population growth does not slow down as expected and the global population reaches 20 billion people by 2075. However, in terms of agricultural production (7.5 times the 1975 production) and energy use (12 times the 1975 energy use), it is a rather wealthy world. This imposes tremendous stress on social and environmental systems. The world is held together by a political and social system based on a high degree of ethnic autonomy at the local level and a "New World Order" at the global level, providing strong international control in key areas of economic relations and environment. Much of the most dynamic leadership comes from churches and multinational business consortiums. Nation-states have become increasingly preoccupied with internal affairs and are reduced to increasingly symbolic functions. Vigorous technological advances and innovations have made continuous economic expansion possible. Important migrations have taken place, partly encouraged by climatic change and some revolutionary innovations, which have opened up new areas, primarily in Central Asia, Africa and Oceania for agriculture.

Europe is characterized by social instability and strong fluctuations in both economic, population and energy use development. But Europe, like the rest of the Northern regions, keeps its position, far ahead of the developing world. With exception for the period just after the turn of the century, the economic growth is low compared with the 20th century.

South Asia has considerable and relatively stable economic growth during the whole hundred-year period. Despite substantial emigration, it is not until major innovations in agriculture and solar energy are spread after 2050 that there is room for radical improvement of the standards of living for the majority.

4.3.1. Chronology

The most important events in this scenario are summarized in Table 4.2. Factor increases of population, energy use and agricultural development for the World, Europe and South-Asia are presented in Figures 4.4, 4.5 and 4.6, respectively.

1975-2000

This is a period with marked economic recession and relatively slow economic growth in most parts of the world. Population growth is slowing down and is not considered an important problem. Some dramatic events occur: in the early 90s the Afrikaner regime in South Africa falls and the Iranians take over Iraq, showing that a large population can be a military asset. Energy conservation develops rapidly as an important high priority goal.

In Western Europe unemployment is in the 1990s constant at 15-20%. People defer having children, South-North migration continues. There are signs of interethnic terrorism. Governments do not find ways to handle the problems and lose much prestige and credibility. Tax revolts arise. Massive aid programs are successful in raising health standards and decreasing mortality in the Third World. With the exception of Asia, the developing countries have severe economic problems.

2000-2025

Population growth does not level off as expected. The scandal in the 2010s when a male oral contraceptive, which has been sold in some countries in Africa and Asia for more than ten years, proves to have permanent rather than temporary effects in the heat of the tropics, makes it impossible to continue family planning in any form in the Developing World. In Europe a wave of "neofertility" arises as a response to increased ethnic competition and to an economic upswing beginning around 1995. Uncontrolled expansion of population from 2015 and onwards with absolute increases rising above any historical numbers. During this period many governments lose their authority and become increasingly preoccupied with bureaucratic functions. Ethnic groups in many countries take over many former governmental responsibilities, such as health care and elderly care. Frequent food shortages involving greater and greater areas is a growing problem. Water is in many parts of the world a limiting factor both for agriculture and settlement.

2025-2050

This period is characterized by an intensification of migrations into formerly not so densely populated areas like Canada, Siberia, Africa and Australia. From the end of the 2020s there is enormous population growth in these areas. Energy and food production have increasing difficulties keeping the pace of population growth. Ethnic strife, often in direct connection with competition for limited resources, are part of everyday life in most regions. In the newly settled areas with turbulent uncontrolled settlement, a relatively anarchic situation develops with open conflict between various groups of settlers. These local but widespread interethnic conflicts culminate at a scale that is to be called the Seven Years' War (2043-2050).

The War culminates with widespread release of poison into water supply systems around the world, which stuns the world and halts the hostilities. After this "cease-fire" the basic problem is still unsolved: how to cope with the continuing increase and simultaneously contain the conflicts of interest?

2050-2075

Table 4.2 Chronological summary of the Big Load scenario

	WORLD	EUROPE	SOUTH ASIA
2075			
	Birth control program		
	Revolutionary innovations		Breakthrough of green cropping
	Treaty of Ahmedabad		
2050	Seven Years War		
	Widespread ethnic conflicts		
	Squatter movements	Migration to Siberia, Australia, Canada, Sahara	
	Governments less important		
2025	High, stable economic growth		
	Increased population growth	Neofertility wave	
	Contraceptive scandal	Tax revolts	
	Government authority questioned		Important emigration
2000	Large scale migrations South North	Rise of widespread interethnic terrorism	
	Iran defeats Iraq		Relatively stable growth
	The white regime in South Africa falls	High, chronic unemployment	
	Economic recession		
1975			

The period after the Seven Years' War is among the most dynamic in global history, with fortunate circumstances leading to rapid development of all sectors and regions. The Peace of Ahmedabad is signed in 2051 by the leaders of ethnic societies, churches and multinational companies as well as residual nation-states. It constitutes a New World Order based on rights and duties of ethnic communities, and guarantees for a high degree of local ethnic autonomy. A World Government that is powerful inside a well-defined limited sphere of what is defined to be of global concern begins to develop. A global taxation system based on a model used in India since the beginning of the century is introduced. The community is the primary taxpaying unit and responsible for its members. Tax money is redistributed between communities to reward pacific societies and penalize transgressive ones. Development during the 2050s and 60s is very rapid and based on widespread introduction of new technologies. Photovoltaic energy is a new important energy innovation and also the food market is radically changed by green crop treatment. Green produce, i.e. grain harvested before ripening, becomes the main staple diet in large parts of the World. The New World Order is, however, not without problems and crises. Ethnic conflicts still occur, but at relatively tolerable levels.

Family planning programs are implemented by the World Government. Some signs of reduction of population growth rates can be noticed by 2075, but competition between ethnic groups, though now latent, makes changes in attitudes slow.

4.3.2. Population

Major improvements in health standards in the Developing World, the collapse of family planning, the opening up of new areas, and the wave of neofertility in the North entail that the expected slowdown of global population growth does not occur. The growth rates are slowly decreasing, but the absolute increase is relatively stable. The distribution of people between rich and poor regions stays the same (1 to 3) as in 1975.

The population of Europe is tripled. Immigration is important for most of the hundred-year period and a rise of fertility sweeps across Europe after the year 2000.

In South Asia the growth rate is relatively stable (1.5%/year), but somewhat lower than in the 20th century (2%/year). Despite important emigration to Europe, Siberian, Australian and North American populations increase 4.5 times.

4.3.3. Energy

Global energy use increases 12 times during the hundred-year period and is close to 100 TW by 2075. Energy use per capita is 2.4 times the 1975 level by 2075. This translates into an average global growth trend of 2.5%/year and about 1%/year in per capita terms. All energy sources are intensively exploited. Fossil fuels dominate the fuel mix with 70% of the market. Several energy sources which were statistically insignificant in 1975 contribute major shares in 2075: synfuels 23%, biomass 4% and solar 14%. The 41% share accounted for by these three items corresponds in 2075 to almost the proportion which oil (now down at 9%) enjoyed in 1975. Nuclear power is also intensively used in all regions (8% of the world market). Biomass and solar energy production consume large amounts of land. A radical development in photovoltaic technology gives an important contribution after 2050. Energy use is distributed more fairly than in 1975, but the four richest regions still consume more than 50% of the energy with only 25% of the population. USSR, East Asia and Africa are the dominating energy exporters, while Europe is still the most important importer region.

Energy use in Europe is, despite slower growth than prior to 1975, seven times higher in 2075. Per capita use is more than doubled. The fossil fuels still account for 2/3 of total energy use. At the end of the 20th century slow population growth coupled with energy conservation, retards energy consumption growth. In time, with rising population

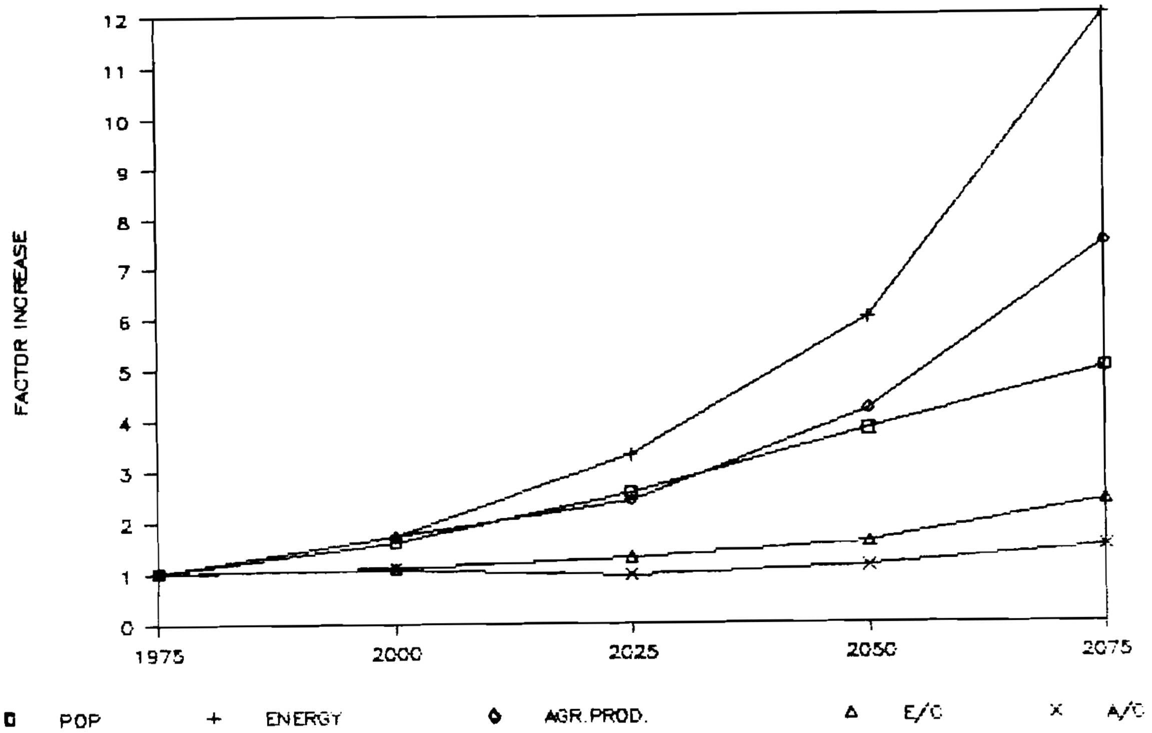

Figure 4.4 Big Load scenario: factor increases of population, energy use and agricultural production for the World

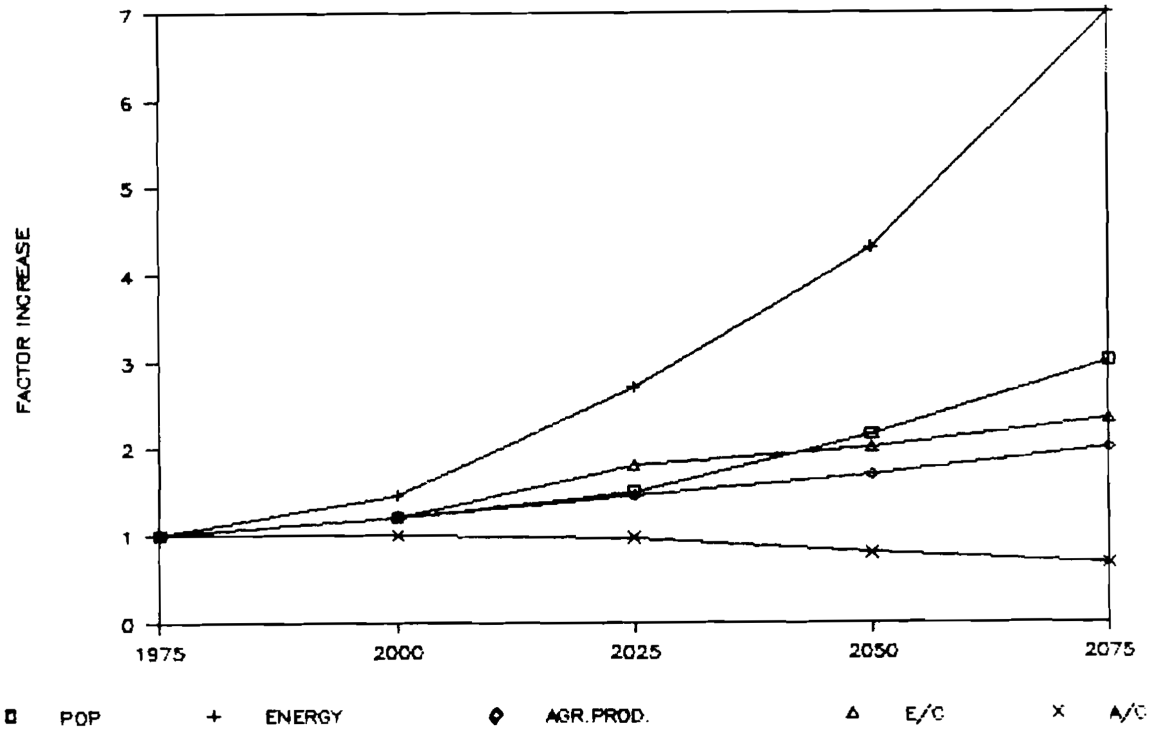

Figure 4.5 Big Load scenario: factor increases of population, energy use and agricultural production for Europe

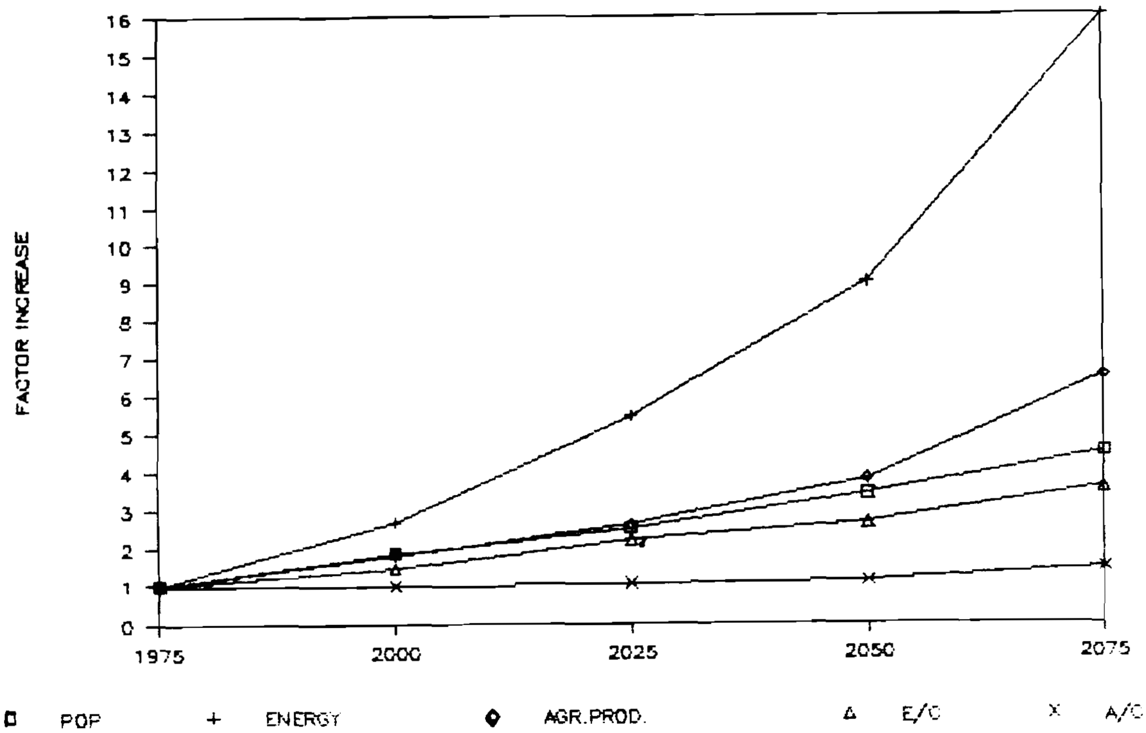

Figure 4.6 Big Load scenario: factor increases of population, energy use and agricultural production for South Asia

growth and emerging new technologies, the pace of growth in energy use once again accelerates. After 2025, biomass-oriented location of industries becomes increasingly popular.

In South Asia, energy use increases 16 times after rapid growth throughout the hundred-year period. Per capita consumption increases by only 3.5 and in 2075 is still very low by international standards. The energy sector is dominated by fossil fuels and solar power towards the end of the hundred-year period. Biomass and nuclear power increase in importance. However, population pressures preclude further significant increases in agricultural land devoted to biomass fuel production.

4.3.4. Agriculture

Global agricultural production increases 7.5 times (1.5 times per capita). Agricultural development is rapid during the whole hundred-year period, with new methods and crops being developed and diffused. In dry areas carrying capacities are revolutionized. But still the hunger problem long persists and per capita production does not rise until near the end of the hundred-year period. With world population continuing to increase at a rapid rate, land for agriculture becomes increasingly scarce. Competition for land between food and biomass production is also a growing problem from 2050. Consequently, higher crop and animal yields account for most of the increase in production. Land in agriculture increases by 50% and yields rise by 400%. The yield increase results from a combination of high investment in development of new technologies and policies which give farmers incentives to adopt them. Land in irrigation worldwide increases by 180% and fertilizer use rises by 450%. Most of these increases are in the developing countries. The introduction of green crop harvesting is one response to the scarcity of land and changes the food market radically; this procedure is spread relatively fast, particularly in southern regions.

Per capita food production in Europe declines markedly as a consequence of an opening of the region's agriculture to outside competition. The region is by 2075 a major importer of food, with the USSR region as the main supplier. The area of cropland decreases by 30%, so the doubling of output (most of it biomass for fuel) is achieved by a 190% increase in yield. Per hectare fertilizer use rises by only 40%. Yields increase far less than this primarily because of a 45% expansion of irrigated land and managerial improvements which increase the efficiency of fertilizer use. The green crop harvesting does not experience a breakthrough here before 2075. The Europeans still prefer traditional harvesting.

On the Indian Subcontinent an intensive program of agricultural R&D results in a continuing stream of new, higher yielding, pest-resistant crop varieties. Combined with a more than doubling of the irrigated area and an ever more massive 900% increase in fertilizer use, the improved varieties give a yield increase of 510% over the hundred years. Agriculture is recognized to be the highest priority so that the total land in agriculture, despite other land pressures, stays stable and indeed increases slightly (5%). It is not until after 2050, when "green crops" and other innovations are introduced, that production can really grow faster than population. By 2075, total production has risen to 6.5 times the 1975 level, which translates to a 40% increase in per capita production.

4.3.5. Commentary

4.3.5.1. Numerical representation

The Big Load is definitively the scenario where the upper limits are most obviously challenged. The population curve is here chosen as a relatively straight line, allowing for decrease in geometrical growth, but showing relatively constant arithmetic growth after 2000. This gives about the same growth rate in 2000-2075 as in the conventional wisdom scenario 2000-2025. Europe has higher growth in 2000-2050 than before 2000, while South Asia follows the global curve.

In this scenario the growth rate of energy use is held rather constant both globally and regionally. The average annual growth trend of 2.5% in total energy use and about 1% in per capita terms are rates of change which, if they did not, in their dimensions, imply such massive environmental and social problems, would not be so seriously out of line with the experience of our century. There are of course fluctuations due to the turbulent socio-political development, but these do not have considerable influence on the relatively stable long-term trends. It should however be emphasized that the socio-political restructuring is one major pre-requisite for making this development possible.

The fossil fuels bear the main burden of this expansion and still account for 70% of the market in 2075, but the contributions from solar and nuclear energy have become more important towards the end of the hundred-year period. The use of all fuels are stretched towards maximum limits. This means that especially the use of fossil fuels is probably not sustainable i.e. possible to keep at such a level very much longer than to 2075. The oil, the coal and the gas supplies will soon be exhausted. Oil shales and tar sands are likely to last longer. Biomass energy use is probably also beyond a sustainable level and already seriously competing with food production in large parts of the world. Notable is that despite the radical improvements in solar energy technology, the market share of renewable energy is not higher than in the Big Shift, though the use is of course much higher in absolute terms.

Until 2050 the agricultural sector has, despite high steady growth, problems to keep pace with population growth. With the breakthrough of green cropping and new energy technologies, agriculture experiences a kind of "momentum jump". The development sketched in this scenario involves some highly problematic points:

- The increases of the amounts of agricultural land (50%) and irrigated land (180%) are far above what most analysts think possible.

- The radical increase of fertilizer use and irrigation, that mostly take place in developing countries, are also touching the limits of the perceived possibilities because of severe environmental impacts (e.g. eutrophication and salinization) that are likely to be connected to them.

It is interesting to note that under the circumstance of continued population growth, although lower than at present, the limits of the perceived possible will already be seriously challenged by the intensification needed to keep the present production per capita. The increase in per capita production comes in this scenario almost entirely from the revolutionary innovations that are diffused in the middle of next century.

The problems mentioned above are likely to be first and probably most severely experienced in Asia, where potential arable land is already scarce, and thus virtually all of the continuously high increases in this scenario must come from intensification. The annual rate of yield increase in South Asia is 1.8%, unprecedented in history over a long period. The 130% increase in irrigated land and the 900% increase in fertilizer use demand tremendously successful technological development and management. Even if this level of irrigation would be possible to reach, it cannot be expected to be sustainable over long periods due to the erosive characteristics of the soils in the region. The development of fertilizer use demands large sacrifices of environmental quality for the needs of food production for the continuously growing population. These problems with conventional intensification is what suggests that the green cropping technique reaches its widest adoption in Asia.

The major problems of European agricultural development in "The Big Load" are quite different: why is the increase not higher compared with the revolutionary development in other regions, and how will there be sufficient supply in other regions to cover continuously the European need of imports? What makes this development possible is primarily continued economic strength based on industry and knowledge, that assure the purchasing power of the Europeans and fewer trade-barriers for agricultural products.

4.3.5.2. Basic ideas

Most modern population studies describe paths to a stable world population. This "ceiling" can be found at various levels (about 8-15 billion in the studies reviewed for the "conventional wisdom") and most often it is reached by the end of the study period, no matter what its length. But what will happen if the global population does not stabilize? Would continued population growth be possible despite improving standards of living?

To reach 20 billion people by 2075 allows, however, a considerable decrease in global population growth (from about 2.0 to 1.2%/year). But still a rather strong argument seems to be needed to make this development convincing, particularly when population growth by 2075 does not show any sign of levelling off. The mechanisms suggested here are an important redistribution of population, with for example considerable migration into new areas of settlement (note that these do not have to be based on agriculture), a collapse of family planning, and ideological changes towards higher value in having children, which are encouraged by the increased competition between ethnic groups. These will at least partly countervail the birth reduction expected with increased wealth.

The second difficulty in this scenario is to provide a reasonably stable global structure compatible with such high energy use and agricultural production. The strengthening of global central power, balanced by an increase of local power with a strong division of responsibilities, is perhaps not a sensational solution. Within nation-states numerous examples can be found of a parallel strengthening of central and local power, diminishing the power of intermediate institutions. In centralized countries like Sweden, France and some socialist states like Libya, quite strong local institutions are surprisingly abundant. In a world with faster communications it would not be totally unreasonable to suggest that the nation-states could lose their present position as the most powerful and influential level, particularly in a future with a strong increase of internal conflicts. The thought is that the world government has strong power in the most essential fields to ensure circulation of people and goods. The system could be compared with the present federal republics, with small but strong states.

This rise of local power will be both a consequence of and a solution to the problems with increased ethnic strife all over the world. Mass migration is of course a pre-requisite for this development. That ethnicity will play an important role in the future is an assumption based on the experience of the recent past with a renaissance of ethnic conscience and a surge of manifest ethnic conflicts all over the world.

On the global level, multinational corporations play an important role as mediators. They will be the propagators for an increased global economic and political integration and cooperation. Also of great importance is their function as networks for fast and widespread diffusion of innovations.

Since World War 2, the corporations have grown to become very important and also very powerful global networks that are difficult for individual governments to control and upon which they usually are very dependent. They have even been able to cross borderlines and establish linkages to an extent that nobody would perhaps have expected a few decades ago. I refer here primarily to their linkages to China and the SEV countries. They definitely play an important role of diffusing products and perhaps also technology, lifestyles and values connected with these products. These economic linkages bring power and influence. Through their contact networks they already today have unique possibilities to act as intermediaries (e.g., sometimes it can peep forth in the newspapers that some American business executives seem to have very close contact with leaders in Kremlin), and there are few signs that their influence will decrease in the future.

That multinationals could have great prospects of playing an important role is not a new idea (Pearson, 1985). It has even been suggested that they might help to create a more equal and peaceful world. Even if some directors have shown strong interests in philanthropical activities, there are few signs that the activities of these companies would help to balance the world. And this is not argued for here. What is suggested is only that the multinational corporations could appear as some kind of legitimate insurance and guarantee for transnational arrangements and their incentive for playing this role would largely be economic. A stable, integrated, high-growth world with large volumes of trade is the base for their existence.

The energy and agricultural futures that are sketched in this scenario, are really on the rim of what can be viewed as possible. This also includes close to maximum rates of use of some energy fuels and penetration rates for innovations. These will not be possible to reach without very smoothly working economic and information systems.

Implicit in this scenario, contrary to the "Big Shift", is the fact that population growth drives development. This is similar to the developmental theory, proposed by Ester Boserup (1981), which argues that poverty or lack of resources causes intensification of production and brings new resources and new innovations into use. This theory supports the prospects for high economic growth in this scenario, with high population causing an enormous pressure on the resource base.

4.4. Rurban Arcadian Drift

In the end of the 20th century some interrelated global catastrophes - the Greatpox epidemic, social chaos in many regions, collapse of the global economic system and global trade, famines - result in dramatic decreases in population, particularly in the North, and cause total restructuring of the global society. The greatest transformations take place in Western Europe and to a lesser extent in Eastern Europe and North America. In these areas, rural and small-town societies with a high degree of self-reliance emerge. These rurban societies depend almost totally on local resources, use small-scale technologies, have very few contacts outside the local region and are characterized by strong social linkages, a sense of belonging to the local community, but also by widespread suspicion towards the "outer world". International trade declines to a pre-industrial level in the North. The South is put into a favorable position with less population pressure and less competition for energy and other natural resources. This makes accelerated growth possible. The gap between North and South diminishes. The rurban ideals also become very widely diffused in the South.

However, very narrow-minded, utilitarian view-points, which focus primarily on the local situation, dominate in most parts of the World. As well, nobody cares about global problems, and many fields of science stagnate. In the North, science degenerates into literary criticism, astrology and the study of magic. Towards the end of the hundred-year period there are, however, signs of adolescent uneasiness in many localities, and a certain "renaissance" for science occurs.

By 2075 there are 6.8 billion people on Earth. Energy use and agricultural production are four times higher than a century earlier. Energy use is more evenly distributed than in the most recent centuries.

4.4.1. Chronology

The most important events in this scenario are summarized in Table 4.3. Factor increases of population, energy use and agricultural development for the World, Europe and South-Asia are presented in Figures 4.7, 4.8 and 4.9, respectively.

1975-2000

The end of the 20th century is a period of increasing problems of economic as well as social, political and environmental nature. The economic recession continues and unemployment rates are higher than ever in the industrialized world. Social tensions and terrorist activities increase. Tougher control of citizens is introduced in many countries. The Third World suffers even worse from economic problems and total chaos threatens. There is an alarming rise in death rates from AIDS in all parts of the world.

In 1993 there is a nuclear confrontation in the Near East, which is by great effort kept from expanding into a global war.

But it is not until the Greatpox shock in 1997, that the vulnerability of modern society is made apparent through brutal experience. Greatpox originates from a mutated virus that has been developed in laboratories and is contagious and mortal to an unprecented extent. It is diffused with enormous rapidity to all major cities in the world. Total chaos burst out; people flee the big cities and leave their jobs, most activities get disrupted, international trade ceases, industrial activity decreases, and the monetary system collapses. Exchange trade is reintroduced, but the provisional linkages have been destroyed even for the most necessary items. The industrialized countries with the most complex and complicated economic systems are hit most severely by this development. The advanced farming systems cannot function without the usual essential inputs like petrol, which no longer can be obtained because of the collapse of the distribution systems. Widespread famines occur, particularly in the city areas, 1998 and onwards.

Table 4.3 Chronological summary of the Rurban Arcadia scenario

	WORLD	EUROPE	SOUTH ASIA
2075			
		Openings towards "the outer world" ?	South is not any longer very far behind North in economic terms
2050		Energy use/cap and agr.prod./cap stabilized	
	Stabilization of the New Order	Libraries close Astrology flourishes	Radically improved standards of living
		Falling birthrates	Reduced population growth
2025	Nation-states loose their importance	Cities disappear Science declines	Accelerated growth Utilitarian orientation
	Local self-reliance in the North	Rurban, small-scale reconstruction Critique of civilisation	Technological advancement
	Economic collapse	Total chaos, famines	
2000	Trade disrupted		
	GREATPOX	30% deceased	15% deceased
	Nuclear confrontation Near East	Increased terrorism	
	Economic recession	Social tensions	
1975			

The Third World societies prove less vulnerable; people are more experienced to cope with disasters. By the year 2000 the world seems to have lost 1 billion people, almost 20% of the population three years earlier. Energy use and agricultural production have had dramatic falls in Europe. In South Asia, society is not that shaken. Many people have died but this has not caused the Indians to leave their homes or the social system to collapse.

2000-2025

After a few years, the first Greatpox epidemic is over but Greatpox is to reappear twice during the next two decades. Population increases between the epidemics at a relatively high rate. In the industrialized world it is a period of reconstruction, but also of reflection and self-examination. Why has this disaster happened? How may a repetition in the future be avoided? Ruthless civilization critique flourishes in this period. The fundaments of the whole western civilization have proved to be insufficient. People do not return to the cities. Instead, the depopulation of the cities continues. New small-town societies, based on small-scale farming and industry, are created. Local self-reliance, small-scale, simplicity, low energy use, and decreased consumerism are the new guidelines and ideals.

Science is not well regarded. It is connected with the urban way of life and the origin of Greatpox. Most universities and scientific institutions are closed down. The only really accepted research area is technology for basic production, in small-scale.

The local communities fight hard for their autonomy and the nation-states do not regain their former power and importance.

Inspiration for the building of the new rurban societies comes from southern models, which have proved less vulnerable to the shock. The Third World benefits from lower prices for energy and other natural resources, less influence of the industrialized world, and less population pressure; in large areas a very dynamic development takes place. R&D expands, important progress is made, but as in the North it has a very utilitarian orientation. The traditional western way of development is rejected everywhere.

2025-2050

Radical restructuring in the North continues and economic growth in the South is very fast. Population growth decreases, in southern regions primarily due to higher standards of living, in northern regions due to stringent family size regulations in the now dominating rurban communities, which see a stable population as an ideal.

Energy use and agricultural production per capita have stabilized in Europe. International trade is still at a relatively low level: all basic products are provided locally. This has resulted in increased heterogeneity, for example, in types of energy, building materials, techniques, customs, and traditions. The rurban philosophy, however, is not an enemy of high technology; computers and computer models are often used both in agriculture and industry.

Intellectual life in Europe and other northern regions is rather poor. The technological level is viewed to be adequate, when all perceived problems have been solved. Reading has gone out of fashion. Libraries are closed down because of book deterioration. The study of astrology, magic forces and literary criticism dominate the few remaining research and educational institutions. In the strongly developing South a very technologically oriented culture has developed.

2050-2075

Towards the end of the hundred-year period a new world system is well-established. Population in Europe has stagnated and so has energy use and agricultural production. In Asia, Africa and Latin America, industrial and agricultural growth continues on a high steady level.

The pioneer spirit in the rurban communities fades away. The young generation that has not experienced the building of the new society resist with increasing power the heavy restrictions on consumption, travel and the discontinuity perceived between the self-fulfilling but also small universe of the Rurban world and the more dynamic world in southern regions.

New social institutions are spread through Europe, linking the small communities. These institutions are concerned with intellectual and cultural activities, which have long been dormant. They have an interest in gathering information on different techniques and lifestyles and want the various societies to learn from each other. They also start to study history. In the southern regions environmental problems are just being discovered, but it is not a high priority issue. Environmental degradation has so far been considered to be the price one has to pay for the enormous economic development, which has lifted most societies up from the 20th century poverty. That the local industrial activity would importantly influence the global environment is seen as just incredible and of no concern to their society.

4.4.2. Population

By 2075 the world population has risen to only 6.4 billion. Almost 90% live in the former Third World. Significant redistributions have occurred and great urban concentrations have disappeared.

The population of Europe has decreased by 20%. The Greatpox epidemic hit Europe severely and since then population growth has been kept down by strict measures of family planning within the urban societies. In South Asia the population has more than doubled, but population growth is, because of increased standards of living, down at levels that were common in so-called industrialized countries at the end of the 20th century.

4.4.3. Energy

Global energy use has increased 3.7 times. Energy use has declined in the Northern hemisphere, but has presently increased in the South, where now 5/6 of all energy is consumed. Since primarily local and regional resources are used, variation in the fuel mix is enormous. In many regions there has been an upswing in alternative renewable fuels, especially various forms of biomass and solar energy. Fossil fuels are still important, particularly in the southern regions, but their use is more concentrated than ever.

In Europe the small-town societies have achieved low consumption of energy and consumer products. Energy saving and durability are highly valued goals. Energy use per capita is 25% lower than in 1975. In Central Europe fossil fuels are still used, but in Scandinavia wood and biomass are the most important resources for not only energy but also chemical and even food production.

In South Asia rapid strides have been taken in catching up with the former world leaders. Despite a 14-fold increase in total use, per capita consumption is only half of Europe's. During the first half of the hundred-year period, India benefited from the low international prices for oil. Later improvements in solar and biomass technologies, for example, have played an important role.

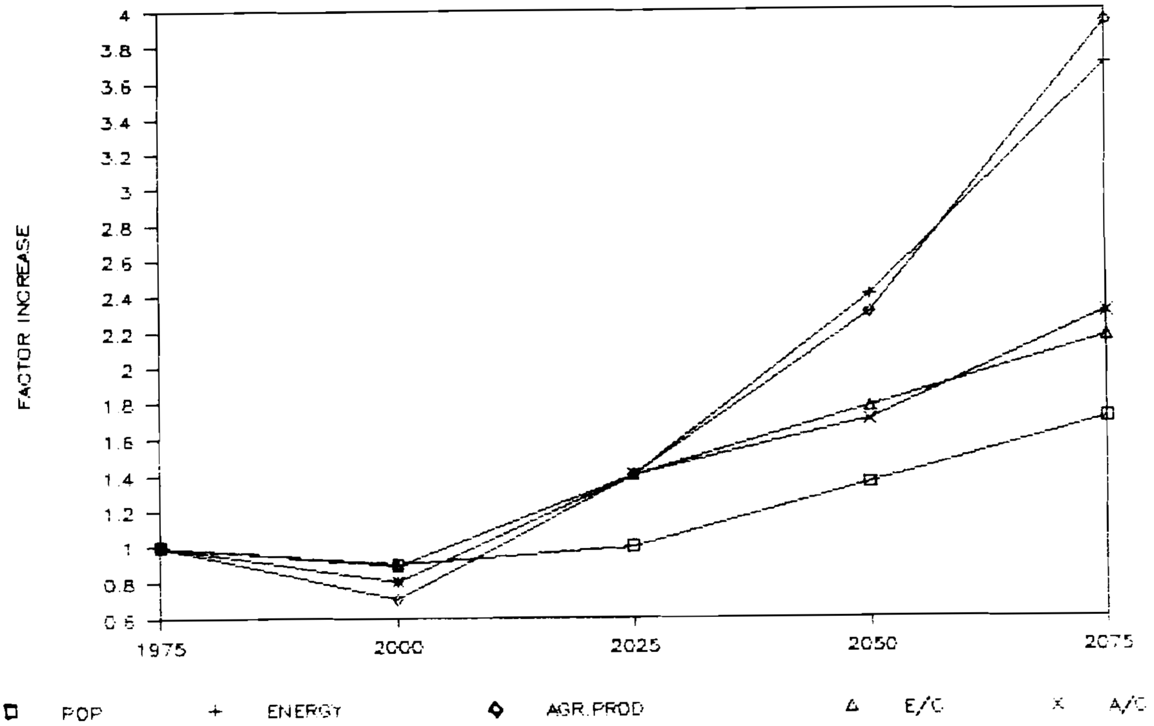

Figure 4.7 Rurban Arcadia scenario: factor increases of population, energy use and agricultural production for the World

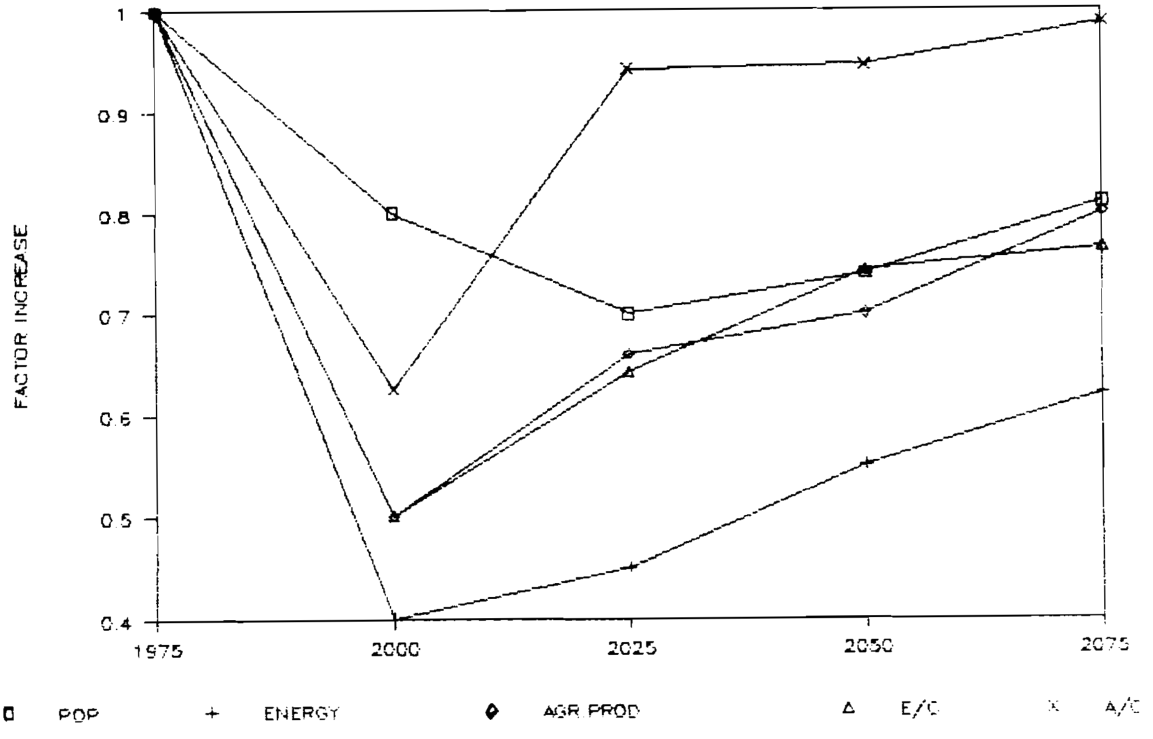

Figure 4.8 Rurban Arcadia scenario: factor increases of population, energy use and agricultural production for Europe

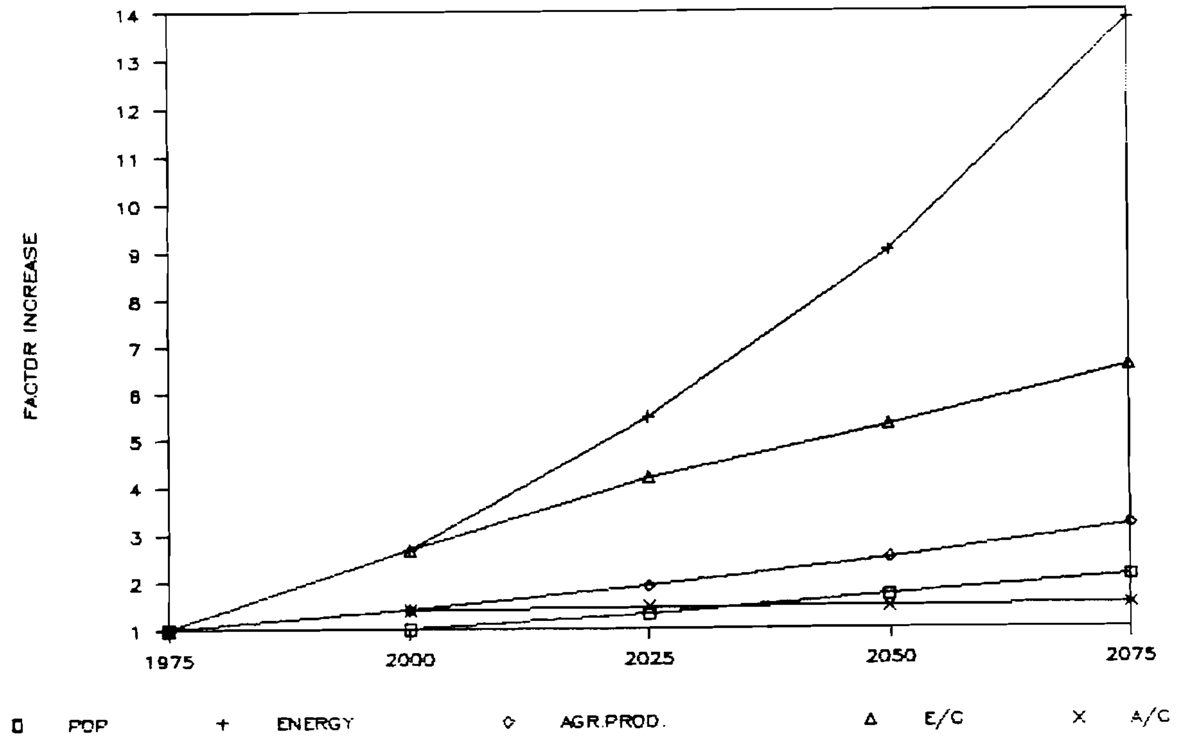

Figure 4.9 Rurban Arcadia scenario: factor increases of population, energy use and agricultural production for South Asia

4.4.4. Agriculture

Global agricultural production per capita has increased by 130%. The world is considerably better fed, but there are areas of exception, where the local resources are too scarce to give the population a sufficient diet regularly and these areas do not receive much support from outside.

In Europe agriculture is based on small production units and relatively high labor inputs. Production per capita is almost the same as in 1975. A worldwide problem has been provision of fertilizers, a problem with various local solutions. An overall change is that of sewage systems; no society can any longer afford to waste its nutrient capital by releasing it into lakes and seas.

In developing countries a general trend has been that more emphasis has been put on rural areas and rural development. The urban centers have lost their former economic and political power and cultural dynamism.

4.4.5. Commentary

4.4.5.1. Numerical representation

Because of great diversity and the very imaginative development, this scenario is very difficult to catch in numbers, at least on the global scale and for Europe. The 20% population decrease in the first Greatpox epidemic is in fact not so important compared with the worst plagues in history, but is nevertheless sensational. The growth rates are subsequently relatively low, about the present in Europe and much lower than present in South Asia, because of birth control in the North and higher standards of living in the

South.

In Europe both energy use and agricultural production increase slowly after the shock, but stay at modest levels. South Asia energy use follows a high growth path with almost as high growth as in the Big Shift, and agricultural development is about the same as in the Conventional Wisdom Scenario in absolute terms, but considerably higher in per capita terms. For this scenario, no fuel mixes or agricultural key factors have been developed.

4.4.5.2. Basic ideas

The "Rurban Arcadia" scenario is definitely the most problematic of these future histories to justify and make seem possible. My guess is that this story is far beyond the perception of the possible for most people, but to find a surprising future one must definitely move close to and sometimes beyond the limits of the possible. Even if none of us believe this story possible to perform, it might be an interesting exercise to think about this eventuality - we might learn something from it. To make it more acceptable and interesting, some further explanations and information on the construction process are needed.

This version of "Rurban Arcadia" is an effort to combine elements from the three future histories of Friibergh Task 3, where the various groups were allowed to write whatever surprising future story they chose to. Two groups painted a picture of their desired ideal world of 2075, including a lot of traditional traits of "utopias": the world would be more democratic, peaceful, equal and efficient. People would be healthier, better fed, have more social security and live in small-scale societies with a strong sense of community. Both groups agreed that for this new and better world, an optimal population would be about 6 billion people, a relatively well-established figure in modern "dreams" about the future (see e.g. Hughes, 1985). Then came the big problem: how to get there?

Both groups agreed, independent of each other, that such a low population figure cannot be reached without introducing a number of terrible disasters, eliminating a large share of the global population, so they had to implement such disasters as epidemics, and nuclear wars. These had to be more disastrous than anything the world had ever experienced in order to counteract the rise in fertility which follows upon catastrophes and function as an alarm for the world, resulting in the creation of a new and better world from the ruins of the old.

But both these seemingly utopian efforts contained some, even if minor, unsolved problems or dark clouds on the horizon. These traits inspired this version of "Rurban Arcadian Drift - a utopia with troubles". To enrich the problematic side, elements from a third scenario, including a future decline of science and literacy were added. In that future history, science turns into magic and people in the Western World spend most of their time in front of big TV-screens, chewing qat.

This scenario is to a much higher degree than the others a "play with thought". It is based on the view that an unproblematic future utopia, where everything is perfectly arranged, is not really a very interesting future to study, nor a very possible one. The major and perhaps most surprising or controversial ingredients in the story are:

- the global disaster (the Greatpox epidemic) a definite turning point in history;
- the development of a small-scale Arcadian world in the North;
- the back-side of this development is that these societies turn into monolithic and narrow-minded social formations with a high degree of uniformity within the societies and of diversity and pluralism between them. On the whole there is a radical decline of science and philosophy and also of interest in the global situation and the "outer world" in general.

Why have these elements been introduced? Are they interesting speculations? Have they any probability at all?

The big disaster

Every society that is not aware of and not very interested in finding out about its vulnerable sides, is probably very vulnerable and open to all kinds of negative surprises. The modern western large-scale society can, in fact, be much more vulnerable than is perceived, very much due to its reliance upon a few very big, sophisticated, complicated systems that are hard to control or even to get a clear view of. Examples include the global economic system, the market economy in general, and energy distribution. These complicated systems are based on division of labor and responsibility and dependent upon all people involved accomplishing their small tasks to contribute to the well-working machinery we all are dependent upon. As long as these systems function we are hardly aware of them; or, we are fascinated by their smooth way of working, giving us income, food, goods, services, electricity, and information, and we just have to bother about our small contributions. If this system would collapse, e.g. by too many people not performing their tasks, destruction of the energy distribution systems, lack of spare-parts to essential machinery or anything that the overall system is totally dependent on, triggered by, for example, a world-wide catastrophe of the Greatpox type, many would be left totally helpless. That modern society is more vulnerable than we perhaps believe is something which should be discussed more often. The centralized electricity systems would probably be the best target for a terrorist group wanting to paralyze a modern state. To fill this function in the scenario, the Greatpox epidemic is introduced. It is of course a product of pure imagination, but is it totally impossible? And would it not be worth discussing the vulnerabilities of modern society to more or less unexpected, but not impossible, events? A more resilient society could also be put forward as an important future goal.

The rise of the New Order and the decline of science

If the primary consequences of the Greatpox are large numbers of dead and a collapse of urban large-scale society, the secondary consequences are the rise of strong criticism of modern urban civilization, doubts about the blessings of the "Big Society", and the appearance of the new rurban ideology as a dominating dogma and ideological factor. Science is regarded with suspicion, because of its close connection to the Greatpox and large-scale society.

That some sort of revolutionary change or interruption is needed for a radical restructuring of society is most often an explicit basic assumption in utopian scenarios. Here the Greatpox fills this function. The environmentalist ideology, manifest in the anti-nuclear and "green" movements in Europe, shows a strong tendency towards abolishment of essential parts of the advanced large-scale technology, closely linked to most scientific research today. But to see suspicion against all kinds of science and philosophy as inherent in this ideology is of course to go a step too far. It does not, however, seem totally unreasonable to argue that the position of science may fall drastically due to the epidemic and its consequences. Neither is it impossible that during a "rurban" revolution, when only practical sides will be stressed, there will not be surplus resources available to science. Or, that in the established rurban societies there will not be very much demand for the fruits of science. Only sciences and technologies with direct links to practice will be called for.

Why was this decline of science included in the scenario? If the disaster was partly included as a sort of recommendation for societies and politicians to be more concerned with weaknesses and vulnerable points in societies, this part is included partly as an appeal for more self-criticism within the scientific community. Both within science and society there seems to be a great need for more careful consideration of the various forms of applying scientific research from human, societal, ethical and moral aspects. There must be some reason for the increasing criticism of science and doubts about the blessings of science and technology. Scientists should not try to escape from these problems, but rather listen and reflect. Better communication between scientists and the public is necessary.

Uniformity within and plurality among the rurban communities

It is beyond all doubt that there would develop great differences between societies in a world consisting of small units with low interaction, and where each unit depends mainly on its own resources and stresses its own local traditions and characteristics. But whether introvertness, narrow-mindedness, disinterest for the surrounding world and aspirations towards uniformity would flourish within such societies is more disputable. Of course, we have for example the expression "small-town mentality" including such tendencies, pointing in this direction, but it is hardly sufficiently convincing. Stronger arguments offer the recent wave of literature on "creative milieus" (e.g. Andersson, 1985), inspired by "Wittgenstein's Vienna" (Janik and Toulmin, 1979). These books praise the big cities for their potential role as creative centers, because of their possibility of creating opportunities for frequent and perhaps fertile exchange between different people, ideas and activities. Big cities and also big nations seem to have the possibility of developing a more diversified and advanced range of art and intellectual activities. Accordingly, a world of small units and with low interaction among them would definitely be a less creative world and intellectual life would be empoverished. Historical examples supporting these assumptions are the Middle Ages of Europe and traditional conservative uniform agrarian societies.

This scenario and the utopian traditions

This scenario can also be seen as a kind of critique of small-scale, small-town utopias, pointing out some critical points in many of them. For example:

- We can never isolate totally from the rest of the world. Even in an "arcadian" future there will be global problems which require some sort of common attention and action. If a certain exchange of goods is not made possible, enormous inequalities of living standards will evolve, creating huge problems in the long run.
- What role do cities play as innovation centers? Are they needed to allow or maintain pluralism within a society? Are narrow-mindedness and limited views and interests a characteristic of the small unit? If so, how may these be counter acted?
- Even more important perhaps is the question of how to reach a small-scale society without disasters and dogmatic repression (e.g. Cambodia during the 1970s).

In short, there are a number of problematic points in Arcadian futures that should be considered further. These last arguments and questions are, of course, not put forward to justify the scenario from a possibility perspective, but to show that it might enrich the "garden utopian" tradition.

4.5. Summary - Comparison of the Scenarios

The scenarios presented above differ in many respects. In relation to the conventional wisdom scenario, they can be perceived as some kind of extremes:

1) one ending with extremely high numbers in population, energy use and agricultural production (THE BIG LOAD);
2) one with extremely low end points (THE RURBAN ARCADIAN DRIFT);
3) one with relatively similar (a little lower) numbers as the conventional wisdom at the global level, but the regional distribution of wealth is radically different (THE BIG SHIFT).

It is thus not only the global end points that can be surprising, but also the distribution of population, production and consumption. Summary data of the four scenarios are presented in Table 4.4.

4.5.1. The global development

The global population curves (Figure 4.10) are perhaps for most of the scenarios their main characteristics since population is always regarded as an important driving factor, even if not a necessary condition, for production growth. The various end-points vary from 6.8 billion (1.7 times the 1975 population) in Rurban Arcadia, over 7.7 billion in the Big Shift and 10 billion in the Conventional Wisdom to 20 billion in the Big Load. The population numbers in both the Big Shift and Rurban Arcadia are surprisingly low, while that of the Big Load is extremely high compared with today's expert opinion. The Big Shift shows, similar to the conventional wisdom, a rather normal curve, even if it is extremely low because of the surprising development of Asia. In the Big Load, population shows a rather stable increase with only slowly decreasing growth rates, while in the Rurban Arcadian case the population, after a radical decline around the turn of the century, grows fairly steadily at a rate of about 1% per year, a rate that is slowly decreasing towards 2075.

The distributions of population (Figure 4.11) vary importantly in the different scenarios. In 1975, 25% of the global population lived in the Rich World (the North), which here consists of North America, Europe, the USSR and Australia. The only scenario that keeps this distribution is the Big Load, while the others allocate around 15% of the population in the North by 2075. What makes this surprising development possible in the high growth scenario are primarily the increased fertility in the Northern regions and large migrations from South to North.

The energy use end-points are fairly similar in terms of per capita use. The per capita use numbers of 2075 only vary from 2.16 in Rurban Arcadia to 2.63 in the Big Shift. Their paths to get there vary, however (Figure 4.12 and Table 4.4). The Rurban Arcadian development is closely linked to the population development and so is that of the Big Load, until the last 25-year period, when energy use takes a jump in per capita terms. The energy development curves of the Big Shift and the Conventional Wisdom are more loosely linked to population. The Big Shift curve takes a higher path in the beginning and it is not until the after 2050 that the Conventional Wisdom passes the Big Shift in terms of total use.

The distributions of energy use (Figure 4.13) divide the scenarios into two groups:

1) The more "Third World development oriented" Big Shift and Rurban Arcadia, where the Southern regions consume 2/3 or more of the energy used in 2075. The gap in per capita terms between North and South is decreased, at least in relative numbers.
2) The more "status quo oriented" Big Load and Conventional Wisdom, in which the rich regions still consume more than half of the energy used in 2075. As a consequence the difference in energy use per capita between Northern and Southern regions is widened, both in relative and absolute terms.

Fuel mix data for 1975 (actual) and 2075 (Conventional Wisdom, Big Shift and Big Load scenarios) are summarized in Table 4.5. Fuel mix data are presented for Europe, South Asia and world total.

Agricultural production (Figure 4.14) is usually linked to the development of population. In general it grows faster than population and in some periods a lot faster. Examples of "quantum jumps" can be observed towards the end in the Conventional Wisdom as well as in the Big Load and the Rurban Arcadia scenarios.

Table 4.4 Summary of factor increases of key variables in different scenarios

Year	CONVENTIONAL WISDOM					BIG SHIFT					BIG LOAD					RURBAN ARCADIA				
	EUROPE					EUROPE					EUROPE					EUROPE				
	POP	ENERGY	AGRO	E/C	A/C	POP	ENERGY	AGRO	E/C	A/C	POP	ENERGY	AGRO	E/C	A/C	POP	ENERGY	AGRO	E/C	A/C
1975	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2000	1.14	1.31	1.30	1.15	1.14	1.10	1.31	1.30	1.19	1.18	1.20	1.45	1.20	1.21	1.00	0.80	0.40	0.50	0.50	0.63
2025	1.25	2.46	1.65	1.97	1.32	1.20	1.75	1.70	1.46	1.42	1.50	2.70	1.45	1.80	0.97	0.70	0.45	0.66	0.64	0.94
2050	1.36	3.52	2.00	2.59	1.47	1.15	1.60	2.10	1.39	1.83	2.15	4.30	1.70	2.00	0.79	0.74	0.55	0.70	0.74	0.95
2075	1.46	4.62	2.30	3.16	1.58	1.00	1.30	2.60	1.30	2.60	3.00	7.00	2.00	2.33	0.67	0.81	0.62	0.80	0.77	0.99
	SOUTH ASIA					SOUTH ASIA					SOUTH ASIA					SOUTH ASIA				
	POP	ENERGY	AGRO	E/C	A/C	POP	ENERGY	AGRO	E/C	A/C	POP	ENERGY	AGRO	E/C	A/C	POP	ENERGY	AGRO	E/C	A/C
1975	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2000	1.83	2.67	1.80	1.46	0.98	1.65	2.67	1.80	1.62	1.09	1.83	2.67	1.80	1.46	0.98	1.00	2.00	1.40	2.00	1.40
2025	2.50	5.46	2.60	2.18	1.04	2.10	5.46	2.60	2.60	1.24	2.50	5.46	2.60	2.18	1.04	1.30	5.40	1.90	4.15	1.46
2050	2.87	9.00	3.40	3.14	1.18	2.40	11.00	3.60	4.58	1.50	3.40	9.00	3.80	2.65	1.12	1.70	9.00	2.50	5.29	1.47
2075	3.08	10.30	4.20	3.34	1.36	2.40	16.00	5.00	6.67	2.08	4.50	16.00	6.50	3.56	1.44	2.12	14.00	3.20	6.60	1.51
	WORLD					WORLD					WORLD					WORLD				
	POP	ENERGY	AGRO	E/C	A/C	POP	ENERGY	AGRO	E/C	A/C	POP	ENERGY	AGRO	E/C	A/C	POP	ENERGY	AGRO	E/C	A/C
1975	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2000	1.60	1.71	1.70	1.07	1.06	1.45	2.00	1.70	1.38	1.17	1.60	1.71	1.70	1.07	1.06	0.90	0.80	0.70	0.89	0.80
2025	2.12	2.88	2.40	1.36	1.13	1.73	3.50	2.40	2.02	1.39	2.56	3.30	2.40	1.29	0.94	1.00	1.40	1.40	1.40	1.40
2050	2.41	4.28	3.10	1.78	1.29	1.85	4.28	3.10	2.31	1.68	3.80	6.00	4.20	1.58	1.11	1.35	2.40	2.30	1.78	1.70
2075	2.52	5.91	3.80	2.35	1.51	1.90	5.00	3.80	2.63	2.00	5.00	12.00	7.50	2.40	1.50	1.71	3.70	3.93	2.16	2.30

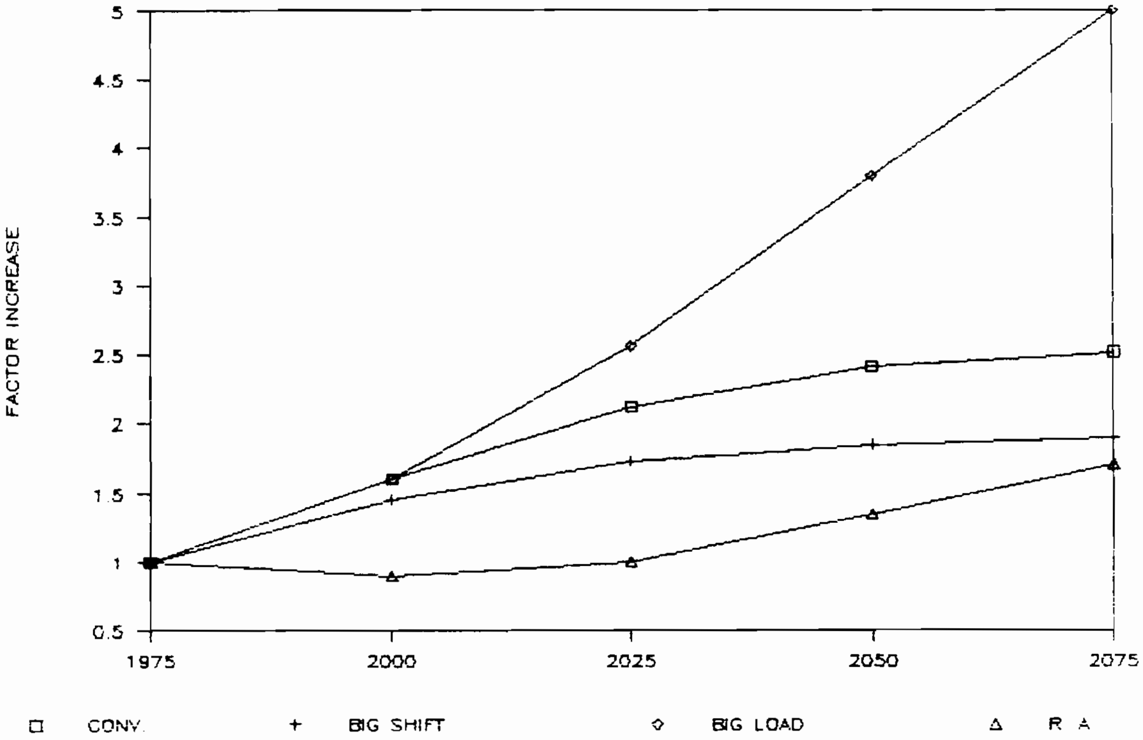

Figure 4.10 Global population trends in different scenarios

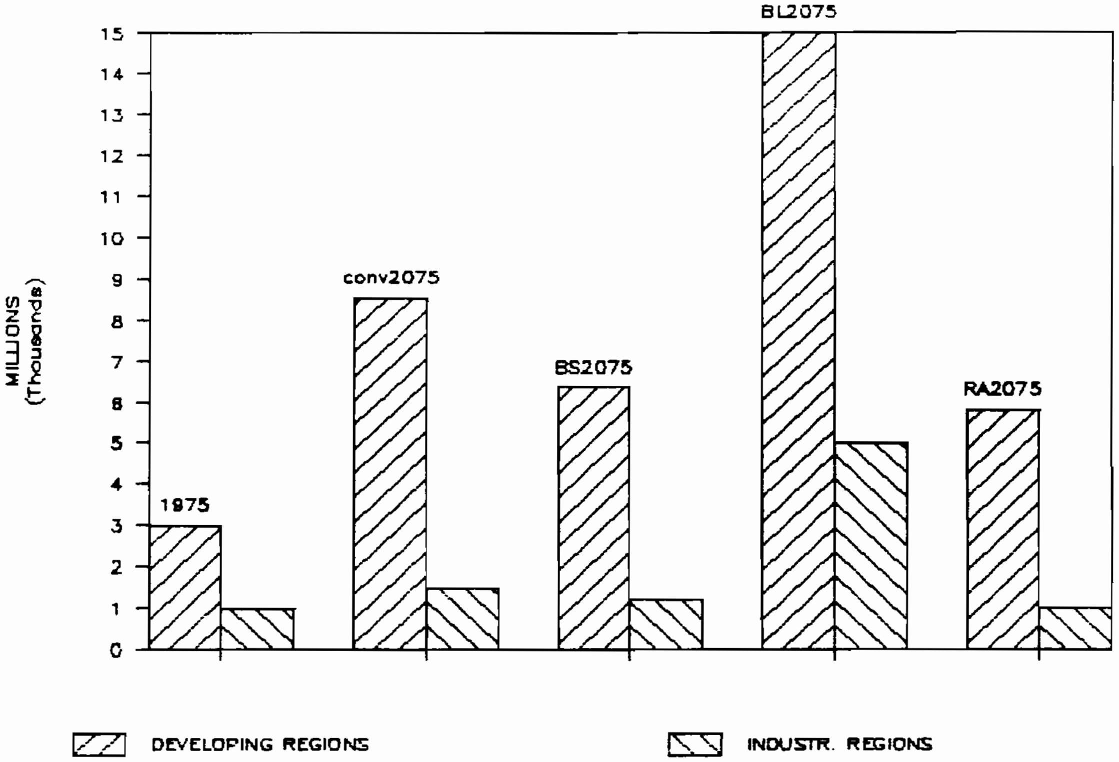

Figure 4.11 Distribution of global population in different scenarios

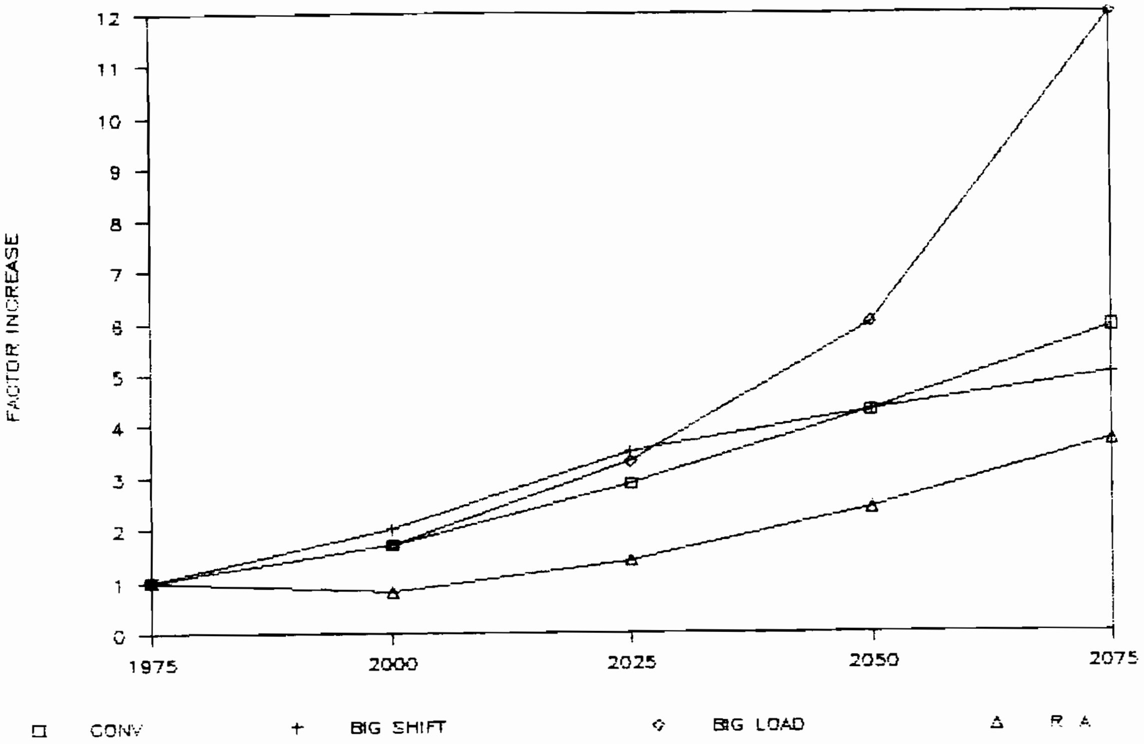

Figure 4.12 Global energy use in different scenarios

Figure 4.13 Distribution of energy use in different scenarios

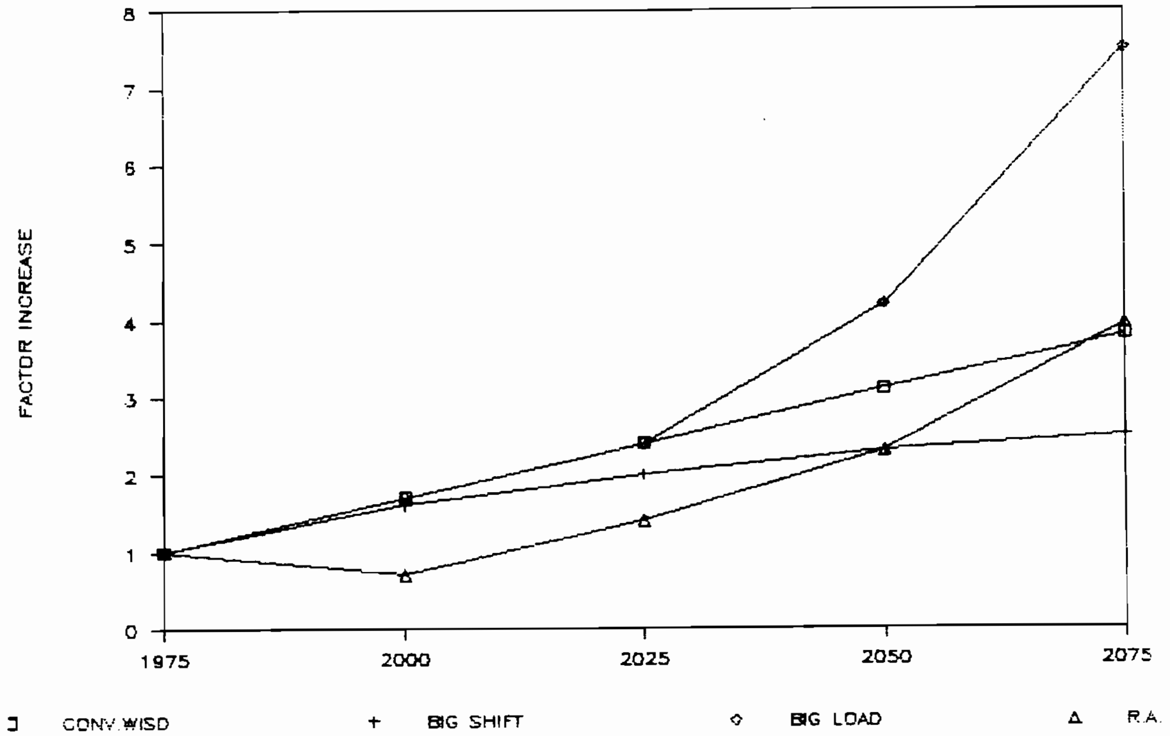

Figure 4.14 Global agricultural production in different scenarios

4.5.2. The regional development - Europe and South Asia

The differences between the outcomes of the various scenarios are much more important for the particularly focussed regions (Europe and South Asia) than at the global level.

In Europe, the population (Table 4.4) of 2075 in the Big Load is almost 4 times as large as in Rurban Arcadia, 3 times that of the Big Shift and more than twice the outcome of the Conventional Wisdom. All the three surprise scenarios give for Europe a much lower energy consumption per capita than the Conventional Wisdom, perhaps reflecting a pessimistic view of European development prospects. The Big Shift is a future where agricultural production in Europe, which experiences a 160% growth, plays an important role both for the European economy and the global supply.

In South Asia the variation is less important in relative terms. The 2075 population in the different scenarios varies from 2.1 times the 1975 population in Rurban Arcadia up to an increase factor of 4.5. In relative numbers the increases of both total energy use (10-16 times) and total agricultural production (3.2-6.5 times) differ considerably less. Per capita energy use divides the scenarios into two very distinct groups: the high-growth Rurban Arcadia and Big Shift with almost 7 times growth, and the low-growth Big Load and Conventional Wisdom with about half of that. Agricultural production per capita increases by a factor of 1.4-1.6 in all the scenarios with the exception of Rurban Arcadia where it is doubled. The surprise scenarios all tend to be more optimistic than Conventional Wisdom about the prospects for South Asian development.

Table 4.5 Energy fuel mix data for 1975 and for 2075 in three scenarios (TW)

	World				Europe				South Asia			
	1975	2075			1975	2075			1975	2075		
Fuel type		CW	BS	BL		CW	BS	BL		CW	BS	BL
Oil	3.7	8	4	9	1.5	1.63	0.2	1.4	0.11	0.34	0.2	0.4
Coal	2.4	15	12	34	0.44	3.3	1	6.1	0.07	0.68	0.8	1
Gas	1.4	3	2	4	0.2	1.05	0.15	0.9	0.01	0.07	0.1	0.1
Synfuels	0	11	8	23	0	2.51	0.5	3	0	0.33	0.5	0.6
Hydro&Solar	0.6	7	8	18	0.25	1.68	1	3.4	0.02	0.44	0.4	0.8
Nuclear	0.2	3	6	8	0.07	1.1	0	1.9	0.001	0.14	1.2	0.3
Biomass	0	1	2	4	0	0.09	0.45	0.5	0	0.15	0.2	0.2
Total	8.3	48	42	100	2.46	11.36	3.3	17.2	0.211	2.15	3.4	3.4

Table 4.6 Summary factor increases between 1975 and 2075 in three scenarios

	Conventional Wisdom			Big Shift			Big Load		
	World	Europe	S-Asia	World	Europe	S-Asia	World	Europe	S-Asia
Population	250	150	310	190	100	240	500	300	450
Agr.prod.	380	230	420	250	260	500	750	200	650
Energy use	580	460	1000	500	130	1600	1200	700	1600
Fertilizer	300	200	660	250	250	790	550	100	1000
Irrigation	140	125	150	130	100	180	280	145	230
Cropland	120	90	105	120	130	95	150	70	105
Yield	250	210	310				330	240	340
Intensity	130	120	130				150	120	180
Yield*Intensity	325	250	400	210	200	530	500	290	610

5. SUMMARIZING FINAL DISCUSSION

In the final chapter, this effort of scenario construction will be further reflected upon and discussed. Do some of the experiences from this work have a more general value which might provide help to other projects of scenario building?

5.1. The Method

The method that was used in this scenario construction can be summarized as follows:

1) Construction of a standard projection.
   This was made through studies of recent projections of future development that experts in various fields find probable today. This so-called "conventional wisdom" guided the construction of a standard projection.
2) Definition of some alternative surprising numerical end-points.
   The "conventional wisdom" scenario was used as a frame of reference by the participants in the workshop at Friibergh to define some surprising future states.
3) Writing of future histories
   The main task for each working group at Friibergh was to write three interesting stories to describe paths to reach the defined end-points.
4) Construction of three scenarios with numerical paths.
   The nine future histories were then used to make three further elaborated scenarios with numerical representations. The aim of consistency with scenario frameworks and with present knowledge guided this work. These scenarios were then criticized, further elaborated and complemented with more details for energy and agricultural development.

Following the terminology that was introduced in Section 2.3 above, this method could perhaps be described as a kind of informal anticipatory scenario-writing with strong numerical consciousness. This methodology does not imply that the results will become the same no matter who is involved, as was the definition of methodological scenario-writing, but guides development to take "conventional wisdom" about such factors as possible growth rates, penetration rates, and definite resource limitations into account. The numbers have played an important role through the whole process, as a guideline and constraint for the Friibergh-stories and as a consistency check. The reason is that these numbers are supposed to be very important inputs for the users. Through continuous reference during the whole process, the key numeric values are very well anchored in the scenarios.

5.2. The Value of the Scenario Themes

These "surprise-rich" scenarios have varying themes. The first two show relatively stable developments with strong basic trends: one towards a changed center of the world and the other towards a very high population and level of economic activity. The third scenario sketches a more complicated future with dramatic disastrous events leading to a sensational development: a small-scale society North and a rapidly modernizing South. They all share, however, a common feature in that they seek solutions to the problem of how problematic, surprising futures may plausibly be reached.

Is this an interesting combination of themes? If the answer is "yes", it is not because there are no other collections of interesting futures to explore, but because these futures are inspiring challenges to thought, imagination and discussion and perhaps can serve as an inspiring framework for research efforts within a wider range of futures. A basic thought is, thus, that explorations of such extreme futures can be a valuable source of knowledge and understanding of long-term, large-scale processes. They might also provide valuable help in planning for greater resilience to unexpected, surprising future developments and improved preparedness for action to meet such developments. Another important purpose is to sort out particularly urgent research areas. If these scenarios can serve as inspiring tools for such efforts and inspire construction of interesting scenarios, then they have achieved their purpose.

The scenarios have yet another interesting dimension. They reveal how a group of Western scientists today think about the future: What is a surprising future? Which are the solutions one finds to get there? What kind of events could radically influence global and regional development? In which fields are sources for the surprising developments looked for? Which restructurings of the global society and political and economic systems are considered possible?

In short, the scenarios tell us something about how the dynamics of the world are perceived from the present view-point by a group of highly qualified scientists. In the workshop at Friibergh, it was interesting to note a number of similarities between the stories of the different groups. Some of these are basic traits in the presented scenarios: problems with ethnic conflicts, bureaucracies and economic collapses, some release of the market mechanisms as a pre-requisite for the Big Shift, the adoption of a relatively strong world government for the Big Load. Some of these ingredients are probably very much bound to a Western perspective and to our time, but this should not necessarily be viewed as a deficiency of the scenarios, for a certain adaptation to time and culture is necessary in order to make them intelligible and interesting to a Western audience (see Section 2.2). A different group of people would surely have brought in other ideas, but for radically contrasting stories to occur, a group from a radically different culture, the Third World or perhaps Eastern Europe, would probably be needed.

Why was a group of scientists chosen for this exercise? Wouldn't it have been interesting with other groups of people, e.g. politicians, planners or business executives?

An important problem in this kind of scenario-writing effort is how to be able to make such surprising developments intelligible, for example, to find some way to connect as far as possible the future history to our time and past experience. If such a connection is not made, the stories will fail to attract the attention and imagination of readers and users. The group that was selected for this exercise represents important knowledge in a broad scale of academic disciplines and experience in thinking about future problems. Such qualified scientists should have not only broad interests and views, imagination and creativeness, but also possess a strong sense for logical consistency and self-criticism, which seemed very valuable in these contexts. Imagination and speculation were central in this task, but great efforts were made to make the surprising developments as plausible and logical as possible. How successful these efforts were is for the readers to judge.

Another important thing is that Western scholars, at least of the class that participated in the workshop, are relatively unbound, have a certain distance to societal power centers, and can allow themselves to feel unconstrained in speculating about societal development.

A scenario project, particularly concerning informal scenarios, should certainly select participants for a writing or construction exercise with great care. To travest one of the guidelines for scenario building recount above: the participants should be adapted to the aims of the scenario project.

5.3. Projected Use and Styles of Presentation

It was concluded early in the paper that a scenario should be adapted to its uses. It is therefore inappropriate to discuss, for example, the style or form of presentation of a scenario without considering its projected use. Form of presentation is definitely very essential. In Section 3 it was emphasized that one of the main tasks of a scenario is to force the imagination of the readers and thus be a stimulating base for opening discussion on certain future problems defined within the scenario project. To achieve this, the scenario needs to be sufficiently entertaining to catch attention, but at the same time maintain its highly informative content. If the information is overly detailed, the scenario soon becomes boring and unreadable. Important is also that it can serve as an heuristic tool, and be open to and stimulate further imagination, speculation and discussion.

The ideal scenario is perhaps an unattainable goal. But it is possible that one could come closer to the goal by using different forms of presentation. In connection to this project there are, for example:

- The more subjective impressionistic "future history", in which in the examples from Friibergh (see Svedin and Aniansson, 1987), it is most often stated that the development or future situation is seen through an individual's eyes and limited perspective.
- The more neutral, impersonal, concentrated, all-seeing, numeric summaries, which mainly focus on hard facts and central events and trends from a global point of view.

These two forms definitely have a potential to be complementary; the former can serve as an entertaining introduction, that stimulates attention and imagination and provides details from different perspectives, the latter brings order to the scenario by presenting a framework, primarily focused on hard data pertaining to large-scale development. They have also partly different aims in connection to various uses. The summaries in this report are more directed towards being useful frameworks for regional studies, while the "future histories" are to give stimulating contributions to the construction of scenarios for ventures like Policy Exercises. They may also be viewed as efforts to suit different mentalities; it is quite possible that readers may have strong distastes or predilections for one form or the other, and then they will have the two forms to choose between. In any case, being based on different perspectives, they deliver together a richer amount of information than each one could alone.

The difference between these two styles is perhaps not so great as one may think. If we take a look at ordinary history writing, we should be aware that no matter what its form - scientific or literary, theoretical or impressionistic, focused on persons, political decisions or long-term development - it is always an expression of an individual's efforts, with his limited views and available information, to present some more or less consistent logical pattern or story. There are definitely similarities between history writing and future history writing, even if there is, of course, a big difference in that the latter does not have any empirical basis The various forms used in connection with this project, in the Friibergh book and in this report, could be viewed as examples of different but realistic ways to give an historical presentation, depending on mentality, view-point and aims.

A narrow, subjective view-point can be very valuable in a scenario. It might bring more realism and stimulate interest and imagination. The experiences from everyday life are lost while moving into the future. Most information we are exposed to consists of subjectively selected fragments without any relation to some kind of bird's eye perspective. This enormous stream of fragmented information is one of the main causes of complicated decision making situations. In a totally logical world, with perfect and relevant information, decision-making would not be that complicated. This should be something worthwhile to consider in the Policy Exercises. A simulation of a total information flow is of course impossible, but to allow some difference in perspectives and some superfluity of information would not be inappropriate. Some forms of presentation that would be interesting to develop further to enrich scenarios follow.

- Letters are one way of introducing very subjective perspectives. For an example of experiment to present a scenario by letters, see Chapter IVc in Svedin and Aniansson (1987).
- Images can definitely bring more concreteness to imaginative future states. An example of this approach is Emmelin and Brusewitz (1982). The pictorial dimension should, however, be treated with great care, since it is a very powerful tool. Images make very strong impressions and can easily serve as propagandistic instruments to form the attitudes of people.
- A front page or a whole newspaper would be a perfect way to combine different approaches and reconstruct something of an information field with somewhat disparate information for the reader to construct his own view of the future world. That can be an interesting challenge.

In any case, the difficulty of moving into the future must not be underestimated. We are all much more bound to our time than we might think. The importance of a search for imaginative and varied ways to present information to somewhat decrease this timeboundness cannot be overemphasized in most scenario projects.

5.4. Surprises and the Value of this Scenario Building Effort

5.4.1. The term "surprise" and surprise-rich scenarios

"Surprise" is a central term in this report. The use of it here might have been perceived as casual, since no effort has been made to penetrate or define the concept. The word "surprise" is certainly a very hazardous term to use, mainly because it is so closely related to a subject; a surprise needs to be a surprise to somebody. But who is then this somebody? An expert in some scientific field, a politician, or the public? What is surprising to some is perhaps not surprising to others. In order to avoid this problem at least to some extent, the concepts of "surprise", "surprise-rich", and "surprising future" are here predominantly related to surprise-free models or generally accepted "conventional wisdom" futures. They are deliberately speculative and imaginative about future development in an attempt to find and explore surprising, but not totally unrealistic, alternatives to the standard projections. To find these alternative paths it was necessary to implement somewhat surprising developments or trend-breaks in a number of areas, both structural changes and some new sensational inventions. No matter if they are surprising or not to the reader or writer, could be these called "surprises" in relation to the surprise-free projections that do not speculate about such eventualities. But it is important to emphasize that it would not have become a very interesting outcome of this exercise if the writers did not constrain the amount of surprise within the bounds of the feasible.

To sum up - the primary value of these scenarios is that they show one example of how to create alternatives to standard projections. Such alternatives are important since the world does not behave as logical as is assumed in standard projections. These scenarios show paths towards future development, where more dynamism is allowed for and the logics of these developments are more open to discussion, than those determining the results in a computer model. Important here is also the intention to minimize surprise: this allows us to contend, maybe as a challenge, that this is the minimum amount of surprise, according to present knowledge as represented by the Friibergh Group, that can bring us from here to these future states. It is for the readers and users to react to and discuss the assumptions and logic behind the surprises of the scenarios, perhaps change them, but primarily use the scenarios as unconventional, broader frameworks for further explorations of possible developments. Questions like "What would the environmental responses be like?" or simply "How can we avoid this or that future state?" might inspire and reveal new insights and knowledge.

5.4.2. The study of surprise and discontinuity

This effort could also be viewed as a contribution to the study of surprise and discontinuity. The scenarios contain different kinds of surprises and also speculation about their possible consequences for global and regional development. Even if it shows an interesting approach to this area, this effort is of course far too limited to catch more than one glimpse of the whole problem with surprise and discontinuity. One limitation is that most environmental surprises are excluded.

The study of surprise and discontinuity is yet only in its early childhood. Many talk about the importance of taking these "strange unexpected phenomena" into account, but few have so far done anything substantial to build some sort of conceptual framework for the study of surprise. Among these few exceptions are Brooks (1986), Holling (1986) and Timmermann (1986). Harvey Brooks has among them perhaps the broadest approach to surprise; the others are mostly concerned with surprises in connection to the natural environment. Brooks discerns three kinds of surprises arising from technology, institutions and development:

1) "Unexpected (more or less dramatic) discrete events" such as oil shocks, reactor accidents, major national accidents, and political coups.
2) "Discontinuities in long-term trends" such as the stagflation phenomenon or the decline in energy use growth/GNP growth ratio in the OECD countries during the 1970s.
3) "The sudden emergence into political consciousness of new information" such as various environmental alarms (e.g. the ozone depletion, forest decline, asbestos).

Notable here is that the first two categories are richly examplified in the surprise-rich scenarios, while the third is deliberately excluded from these scenarios of socioeconomic development.

This is only one example of a possible typology of surprise. I am quite convinced that many would think primarily on revolutionary technological inventions, which are not explicitly considered in this scheme. Another possible dichotomy would also be:

- "Real" surprises: something that is genuinely new and unexpected to everybody.
- "Pseudo" surprises: something about which knowledge was available but not mobilized. This is the case for most environmental alarms; they are known or suspected by some long before reaching political consciousness.

In order to find "pseudo surprises" I imagine that some "intelligence" work would be very rewarding. There must be plenty of interesting examples of surprise from the past and of suspicions about or fear of surprises in the future within various scientific disciplines (even if these are not thought of as surprises by those who are aware of them). Such an inventory could perhaps bring valuable insights into the nature of surprise. One cause of "pseudo" surprises is definitely that some areas are not sufficiently focused upon by research (Anderberg 1986).

Most important here is of course that continued efforts are being made and that awareness of the need for research into the phenomenon of surprise is kept alive. There are surely many different approaches to try, and it is definitely too early to present some sort of overview of alternative methods.

Surprise-rich scenarios are here suggested as one way of approaching these problems and bringing "surprises" and unexpected events into discussion and awareness. They might, if properly designed and used, be a tool to bear new knowledge about possible dynamics of the global system and an aid in creating incentives to orient action towards establishing a society that is better prepared for surprise.

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